MECHANICAL SILVICULTURE

by

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A Doctoral Thesis

Submitted in partial fulfilment of the requirements of the award of
Ph.D of the Loughborough University of Technology

August 25, 1991

Thesis Title: MECHANICAL SILVICULTURE

ABSTRACT

Problem: How to mechanise tree planting in North American logged sites? Trees are presently hand planted.

Preliminary exploration identified the following collection of sub-problems.

Vehicle: How to carry tools reliably and cost effectively over rough obstacle strewn ground?

Results: U.S.A. - patent granted
European Patent Office - patent granted
Canada - patent granted
The patents cover the main form and mode of operation of a simple but unconventional vehicle.

Silvicultural/mechanical:
How to mechanise the handling and placement of trees?

Results: Two International Patents allowed. They cover a magazine/feed mechanism and a placement mechanism. They form a planting tool.

One man guides the vehicle/tool system. An array of planting tools is carried. Two problems arise from the need to make guidance manageable and the planting rate fast enough.

Spacing: How to cause the members of a collection of simultaneously operating tools to space themselves appropriately the spacing being driven by machine perceived cues?

Choice: How to cause a tool to move to and halt over a plantable spot, tool action being driven by machine perceived cues?

Results: One International Patent allowed.

Spacing: A conceptual solution is described.

Choice: A semi-automatic solution is described. It involves a system of tool guidance and a system of tool set-up, both light guided. Two methods for the detection of light signals in the presence of sunlight have been investigated. Choice-automatic; two solutions have been explored. One uses standard data processing, the other "parallel" processing. Here an idealised device is described which will compare for likeness two two-dimensional patterns.

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Chapter I.
INTRODUCTION

This thesis is concerned with the problem of mechanising the planting of seedling trees. It is centrally concerned with finding a device (it may be a system of devices) which will operate in the difficult ground conditions encountered in North America. Here sites are planted where natural forest has been logged. The ground is littered with obstacles so that standard agricultural planting methods cannot be used (Riley, 1983).

There is a clearly articulated demand for a device to machine plant in these conditions ("Forest Regeneration", American Society of Agricultural Engineers, 1981: Riley, 1983). It is as yet unmet. In the absence of a machine planter tree planting on logged sites is done by hand.

The underlying needs which give rise to the demand are for means of increasing the rate of planting, means of improving the quality of planting and for means of lowering the cost of planting. These needs are expressed as a demand in two different ways. The majority demand (judged by the comparative number of research projects in progress {Appendix 1} and by the emphasis in the literature) is for a mechanical device which is pulled or carried by a tracked logging tractor or by a wheeled logging tractor. The minority demand is for a hand-held device which will enhance the ability of the hand planter.

Our concern is with the majority demand. It was judged that the chances of getting a suitable hand-held tool, one handier than either the planting shovel or the mattock and one where the effort involved in its design is likely to yield a reasonable financial return are negligible. It is argued later that a solution in terms of a device carried by a logging tractor of one of the types presently in use will not be viable either functionally, economically or logistically. It was judged that there is considerable commercial potential for a solution in terms of a vehicle suited to silvicultural work on North American logged sites which carries tools for planting and other silvicultural tasks.

After an initial exploration of the problem in those terms a choice was made to seek a solution in the form of a comparatively light and small vehicle of initially unknown form which is able to carry tools for planting seedling trees and also tools for other silvicultural tasks. The design of the carrier and of the planting tools (also of unknown type at this point) were to be concentrated on. The needs of other silvicultural tasks were to be kept in mind.

Four main problem areas needed to be dealt with. They are described in order of crucial importance.

There is a financial/strategical sub-area. There is a vehicle problem. There is a collection of problems (silvicultural/mechanical) having to do with the storage and handling of seedling trees. There is a collection of problems, "spacing and choice", having to do with causing a tool to choose planting spots amid a chaos of ground obstacles and having to do with the automatic spacing of the members of an array of simultaneously operating tools.

The problem that has been dealt with in the financial/strategical area is that of problem definition - describing a solution type which promises to occupy a reasonable seeming commercial niche. The procedure has been a circular one. Putative solutions and sub-solutions have been assumed and the commercial implications of these assumptions explored. The conceptual solutions which are chosen affect the commercial possibilities and the commercial constraints limit the conceptual choices. In addition, the technical possibilities, the methods by which concepts are to be embodied in a given financial/technical environment affect the concepts which are likely to be usable, and thus the type of solution which can be aimed at. It has been necessary to cycle through these three, far from independent, areas - commercial, conceptual (conceptual design at a general level) and technical (looking for feasible target implementations or for the parts with which to effect an implementation) until a seemingly workable combination emerged. What is described here is a combination that was finally found and some of the rationale for it.

An important part of the strategical work has been that of limiting and ordering the work which has to be done. The whole problem is a large one for one person to undertake. Possible solutions and sub-solutions have been explored until a workable collection of attributes has been found. An attempt has then been made to isolate one or two pivotal problems and to use their having been treated to a patentable level as a cut-off point for the work for thesis purposes.

Without a vehicle to carry it a planting device would be of no use. It has been necessary to explore for alternatives to logging tractors as the carriers of planting and other silvicultural machinery. Presently existing tracked and wheeled tractors are not suitable for this purpose.

The vehicle problem is a crucial part of the planting problem. Both the financial plan and the technical design have been found to hinge upon it. The attributes which are called for by planting (and by stand work) are not satisfied by existing tractors, neither did they look to be satisfiable by an orthodox ground vehicle. An exploration has been made at the conceptual level for a suitable vehicle.

There are other silvicultural tasks, juvenile stand thinning, plantation tending and forest surveying whose further mechanization demands a solution to a vehicle problem (Holtman, 1981). The demands on the solution are those of planting with some additional dimensional constraints. The demands of planting, tending and thinning, together with the dimensional constraints, the logistical constraint, the economic aspects and the practical problems met with on the sites, point to a need for a vehicle more specifically fitted to silvicultural work. There would be other uses for a suitable vehicle type including military ones.

The silvicultural/mechanical sub-area contains a collection of problems to do with the storage, handling and placement in the ground of seedling trees.

There are three main families of commonly used seedling trees:

(1) Bare rooted seedlings;

(2) Packaged root seedlings derived from the bare root type;

(3) Packaged root seedlings which are grown as such;

(Appendix 2).

A major difficulty in mechanising the planting of seedling trees is that there is a variety of bare root seedling sizes, there is a variety of package root types and there is a variety of package root seedling sizes (Appendix 2). There is also the possibility of new types being developed. In North America more than two thousand million seedlings are produced for planting each year (Appendix 2: Brace, 1982: B.C. Forests and Lands, 1987: USDA, 1983). The tree seedling producing industry is a large one with established techniques. It was judged that as many as possible of the widely used seedlings types needed to be able to be dealt with by a planting mechanism. An unspecialized device has therefore been sought, one which will store, retrieve from storage, transfer to the ground and places into the ground the full range of commonly used bare-root and packaged root seedlings. No preparation of the seedlings (such as re-packaging) is to be necessary. It was considered possible that a range of "calibres" as the same basic mechanism might have to be used.

There is no existing mechanism with this range of abilities.

At the present time there is no automatic mechanical storage and handling system for bare-root transplants. The mechanical placement devices for bare-root seedlings are all hand loaded; they work in farm-field conditions.

There exist experimental automatic handling and planting devices for package root trees (Appendix 1). Each of these devices is able to handle a limited number of package types (commonly only one type and in a narrow range of sizes). The handling which is performed involves either the loose dropping or the blowing of a tree into an excavation.

There is at present no automatically operating storage handling and placement device which will handle both bare root seedlings and package root seedlings. There is at present no automatically operating storage and handling mechanism which does not use loose dropping (or blowing) as a transfer device. We have attempted to design a device which stores, handles and places both bare-root and packaged root seedlings with loose transfer from the store to the ground being avoided. (Loose transfer is an unsuitable method for the placement of bare-root transplants). It is an obvious potential point of malfunction.

A central target of the present work has been that of using simple perceptual/motor schemes to make possible either operator controlled mechanical planting of seedling trees at a required rate or to make the automatic planting of trees possible. It has been necessary to provide an overall design context for this work, the context provided by the work on the vehicle and handling work, to be able to undertake design work in this area (spacing and choice).

The underlying problem needing to be solved is that of minimizing the amount of ground preparation which must be done to be able to machine plant in logged ground, that is, ground littered with forest and logging debris and with the stumps and root systems of the felled trees still in place. Clearing is not an economical choice; any ground preparation is expensive (Province of B.C. 1989). The use of hand planters in effect minimizes the ground preparation which needs to be done. A human planter can space himself by eye from already planted trees, pick out suitable spots amid a chaos of ground obstacles, perform light soil preparation and then place a tree in the ground. It is necessary to attempt to match this avoidance of the need for extensive ground preparation. It is necessary to attempt to exceed the rate of hand planting and quality of hand planting in order to obtain an acceptable rate of return on the use of a machine.

Semi-automatic and fully automatic tool operation have been explored.

Chapter II.
DEMAND

There is at the present time no operational mechanical planting device for unimproved logged ground ("logging cutover"). There are devices which are under development; the competitive situation is described in Appendix 1. To obtain a conceptual design for a suitable device was likely to involve considerable design effort. The development of this design to a working stage and then its marketing was likely to be a costly and financially risky undertaking. It was necessary to be clear at the outset about the demand - its form, its size, its value, its possible longevity. It was necessary to understand the nature of the financial environment for machine development and in relation to the availability of funds the nature and reasonable low risk production environment. These factors control the type of design which can be undertaken.

The personal financial risk stemming from undertaking design work needed to be kept low. The rate of return which was potentially realizable from the design needed to be as high as possible in order to attract the capital needed for its full development.

Is a mechanism for planting trees in fact needed? If it is then what kind of mechanism would meet the need whilst at the same time occupying a reasonable commercial niche?

There are basic needs to increase the rate of planting, to increase the quality of planting and to lower the cost of planting. These needs are known to the writer from his having worked in silviculture in Canada. Independent evidence for their existence is to be found in the literature of silviculture (e.g. Riley, 1983: Forest Regeneration ASAE, 1981). Evidence is also to be found in the design effort which is being put into mechanical planting in the U.S.A., Canada, Sweden and Finland (Appendix 1).

In the major forestry countries in the West the extractive side of log production is highly mechanized. The replacement side is primitive. In North

America replacement is not keeping up with the annual cut. There is an immense and growing backlog (Riley, 1983: FERIC, 1988). There is growing concern about the life-time costs of plantations, about the inadequate care of plantations, about the survival rates of planted trees and about the cost of the needed treatment of plantations to ensure adequate regeneration. There is at present no alternative to the use of hand labour for planting and for early plantation tending. There is a need for a system of mechanical silviculture which can do such work as tree planting, plantation tending, the tending of juvenile naturally regenerated stands and if possible have use in such additional tasks as forest fire fighting and prevention.

That mechanical tree planting is taken seriously is evident from the commercially funded and governmentally funded research effort being put into the problem. Nonetheless arguments are put forward that mechanical planting is tied to present day logging practices, that change of practice is necessary and will come about and that this change will get rid of the need for mechanical planting (B.C. Forest Service, personal communication).

There are two versions of the argument known to the writer. One relates to large-scale extraction, the other relates to small-scale extraction. The supposed consequences of each argument is that mechanization is not needed. It may be said immediately that whether logging practices change or not will not remove the need to plant trees neither will it get rid of the backlog of sites needing to be treated nor would such changes alleviate the costs of planting and managing plantations. A change of practice would affect the type of solution to mechanical planting which was suitable.

At the moment large sites are commonly clearcut, all standing trees are felled and the merchantable timber removed. An alternative is to selectively log, that is, cull the merchantable timber from a stand leaving smaller trees to develop to merchantable size. In British Columbia there has been a small-scale move towards allowing individuals to manage, under supervision of the Forest Service, comparatively small areas (e.g. one thousand acres) of forestland, selectively logging parts, clear-cutting other parts as is judged to be appropriate. Trees still have to be planted on these units.

If large-scale commercial practices in North America changed to selective logging or a mixture of selective logging and clear-cutting then trees would still have to be planted.

The argument is put forward that a change in extraction practices will come about. As part of the new practice smaller scale units will be logged (whether by clear-cutting or by selective logging we are not sure) and that this practice will do away with the need for mechanical planting. The practice which is suggested seems like that used for the individually managed small areas already mentioned. However, in the Interior of British Columbia the writer has listened to managers of small Crown Land tracts complain about the chore of tree planting, the cost of tree planting and the difficulty of being able to hire labour to do the job. The potential is there for a machine owner/operator to do contract planting on a small scale. This arrangement, the hire of a machine with its owner/operator, is already typical in North America in such endeavours as mechanical excavation, log hauling, skidding, bulldozing, gravel hauling and haying.

If Canadian practices changed to the use of smaller units whether selectively logged or clearcut the demands on a planting device would become close to those already needed if a device is to be able to operate in the south-eastern states or the U.S.A. where, because of the land tenure pattern, smaller units are dealt with. This region is the most important silvicultural region on the continent. Its requirements will in any case have to be met by any design.

In addition, the possibility that machine planting might have to be done on selectively logged sites moves the demands on the tool carrier towards those needed for plantation tending and for juvenile stand tending. This move definitely puts the machine requirements, particularly those of the carrier, beyond those met by any system of which we have knowledge. Logging tractors are at present the only vehicles having a performance that in any way approaches that needed by a silvicultural vehicle.

In every region in North America where large scale commercial logging is practiced the planting of trees is a most important component of a re-afforestation and it is one that is likely to remain so. It is necessary to be prepared for the introduction of better methods but it should be understood that the growing of trees is a slow process (e.g. forty years to merchantable size on the cost of British Columbia, eighty years in the Central Interior). The development of silvicultural methods to a point of commercial application is not a short-term undertaking. Even if new methods become available the size of the tree growing business, the capital involved and the existing organization geared to tree planting will create considerable resistance to the acceptance of new methods. The need to replace the forests is a long term one. The need to plant seedling trees is likely to persist.

It is concluded that the demand for a mechanical tree planter can be taken seriously. Care must be taken to meet the particular demands of the American south-east, the demands of the Canadian and American large scale silvicultural contractors and the potential demands of the smaller scale silvicultural contractor (who could emerge from a change of management practice). A machine which was designed with these needs in mind would be likely to find market acceptance and survive change. It would do so more especially if the device had multiple uses.

There are two other important factors needing to be considered, the potential Luddite reaction and the business cycle.

The British Columbian economy has slowed down. Parts of the U.S.A., particularly the mid-western farming regions and those states dependent on oil, are experiencing a recession. There is, in North America at least, a feeling among financial analysts that there is a good chance of a more general recession occurring within the next five years (Nesbitt-Thompson, personal communication). Hand tree-planting has played a role as a commercial enterprise, a means of employing the unemployed and as a source of seasonal employment of casual labourers. There is research being done on mechanised planting in Canada, the U.S.A., Sweden and Finland. Commercial and governmental funds are being used for projects. Nonetheless, whether a machine planter would be acceptable politically during a recession is an open question; both governmental and commercial organizations are sensitive to political pressure. The threat of recession and the possibility of a Luddite reaction need to be guarded against. These threats can be reduced by having a wide range of applications for the design and the design sub-parts and by seeking solutions having wide potential for development.

It has been said that two forms of demand for mechanization can be recognized. The minority demand (judged by the views of foresters, commercial contractors and by the emphasis in the professional literature) is for a hand-held tool, possibly "gun" like, which will augment the performance of the hand planter. At the present time hand planting (with shovel, mattock and dibble) is the only operational way of re-planting typical logging cutover. The majority demand is for a logging tractor pulled or carried mechanical system (Appendix 1).

It was judged that to design a hand carried tool which is handier than the mattock and shovel is not an easy task. With these tools trees of all types and sizes can be planted in the full range of conditions met with. The commercial potential of the hypothetical replacement tool is questionable. A hand held tool which would, for example, double the rate of hand planting is hard to imagine. This means that the upper boundary for the retail price for the tool could not be much in excess of the price of a good planting shovel. To design a tool which had a decided advantage over these tools and which would sell (retail) for a price in the region of $100 looks like a difficult task. Good shovels and other hand tools are inexpensive. They last many seasons. They are light, handy, reliable and easily transported. They require a minimum of maintenance. They can be used for light ground preparation. To improve on these simple but adequate hand-tools and in a commercially significant way was judged not to be a feasible undertaking.

Is a ground vehicle plus mechanical tool solution type worth exploring?

It will be argued in the section on the vehicle design that logging tractors have the following inadequacies:

(1) They are too expensive to run if a reasonable bid price range (ie: price for planting a tree) is to be used (Province of British Columbia, 1989);

(2) They are logistically unsuitable;

(3) They are functionally unsuitable;

(4) They are dimensionally unsuitable.

Here these things will be assumed to be the case. Given these assumptions good commercial potential looks to reside in a solution having the form of a very-rough-terrain tool carrier of as yet unknown type which is capable of being used for a range of silvicultural tasks including tree planting. It should have in addition the potential for wider, non-silvicultural, use.

Using the collection of assumptions discussed in Chapter 2, an estimate can be obtained of a basic market for a device to perform only planting (a more flexible device will have a larger market) in the region of four thousand units (vehicle/tool) each of which has a retail price in the region of $100,000 to $150,000 Canadian. (The exchange rate of £1 = $2 {Canadian} can be used as a rough guide. The rate of exchange has varied since this study began between £1 = $1.25 and £1 = $2.25). If planting and site preparation are performed by the vehicle plus tools then a basic demand for eight thousand units in the same price range exists in North America.

This retail price range points to a possible lower boundary for a cost of production as being in the region of $50,000 to $75,000 Canadian and an upper boundary in the region of $66,000 to $100,000 Canadian.

These rough figures, which are based upon conservative assumptions and with either a single use predicated (planting only) or with wider use (preparation and planting) suggest that further exploration is worth undertaking. There is financial "room" for a design.

The selling price range which has been considered is well within the range of logging equipment. In principle, as long as the rate of return on the cost of ownership and/or use of a piece of equipment is adequate, it does not matter how much the equipment costs. In practice, the equipment selling, buying and using community and those who finance and insure equipment are used to a particular range of prices. A price within the established range will be treated as unexceptional. In this range the equipment will be affordable and financeable given adequacy of the rate of return generated by its use.

The financing of development needs to be taken into account in the formulation of a design strategy. For ease of discussion four research and development phases are distinguished - Phases I, II, III and IV; the reality is more complex.

Phase I begins with a demand and no concept and if successful ends with a clear developable concept with pivotal parts covered by patents if patenting is appropriate.

Phase II begins with a developable concept and ends with a primitive working system or with a collection of primitive working sub-systems.

Phase III begins with a primitive working system and ends with a production model.

Phase IV is production and further development.

The problem of financing is treated here from the perspective of the writer. Commercial financial support for Phase I will not usually be obtainable. Neither will it be possible to obtain governmental support. It is possible in Canada though not easy to obtain development funds for Phase II. It would be necessary to have brought the work of Phase I to patenting stage or an equivalent stage if patenting is not in question.

After Phase I and having covered the pivotal parts of a design with patents it is possible but not easy to sell licenses. It is more common for some development to have to be done with preferably a rough working system having been obtained. It is also possible that commercial funds might be obtained at the end of Phase II.

This discussion summarizes the experience of the writer in dealing with patent agents and from having approached both governmental and commercial sources of financial support in Canada and the United Kingdom. The likelihood is of having to finance Phases I and II without help. That this will be the case has been adopted as an assumption for this study. A leading implication of this assumption is that the commercial potential of the design undertaken (if any) should be as wide as possible; this will lower the risk of a complete loss of capital put into the design. If multiple use is sought a fragility would be removed from the design: in the single use (only planting) everything hinges upon solving planting tool problem in a commercially viable way.

A most important generator of commercial potential is the vehicle. The vehicle is also functionally pivotal. Without a suitable carrier the design of planting tools would be premature.

North American sites are particularly difficult with the Province of British Columbia having conditions of more than usual difficulty due to its ruggedness and its large size (about 1.5 times the area of France). The work sites are typically logged natural forestland - no standing trees, rough, obstacle strewn, possibly soft, possibly steep and gullied, possibly trackless and with the stumps of the old forest still in place. It is not economically feasible to clear the sites. Continent wide more than two thousand million trees are planted annually. As an aid to the imagination this number represents an area of more than 4,000 square miles. This area may be conceived of as strip 100 miles long and 40 miles wide stretching between Loughborough and London. (Appendix 7; Brace, 1982; B.C. Forests and Lands, 1987; USDA, 1983)

A vehicle which could operate in trackless cutover, whilst at the same time meeting economic and logistical demands of planting would have other uses. With suitable dimensions it might be used as a carrier of tools for tree plantation tending, the tending of naturally regenerated stands of juvenile trees, as a carrier of tools for forest fire fighting/prevention, as a carrier of tools for site preparation, as a carrier of ground survey personnel. The demands of these tasks will be taken into account. By extending the variety of uses and the seasonal use of an important part of a planting system (i.e. the vehicle), the demands on the performance of the planting system itself are lowered. The return demanded from the whole system would then be spread over the other tasks.

The vehicle (and its brethren) would have uses outside silviculture including military uses.

The following collection of uses suggest themselves.

A military vehicle or family of vehicles for extremely difficult terrain (i.e. trackless, steep, soft, obstacle strewn or in situations where there is a primitive road or trail system and where there is seasonal destruction of roads, etc.) - troop carrier, supplies carrier, command post, artillary carrier, missile carrier, radar carrier, mobile ambulance, siege vehicle or anti-riot vehicle able to negotiate rubble filled streets and building debris (a silvicultural vehicle must be able to negotiate ground obstacles).

A drill carrier. A rough country carrier of construction tools, blasting equipment, etc. Pipeline inspection. A vehicle for remote frontier and police duty (e.g. Afghanistan). A vehicle for operating in natural disaster areas where the road system has been disrupted. An automatically guided factory vehicle able to negotiate obstacles, climb slopes and stairs. A mobile "space" toy.

More distantly, as a development basis for a family of vehicles for ground logging which do not require to work from roads or trails. The building of harvesting roads and trails on the work sites would be avoided. Cutting down the amount of road building having to be done would considerably reduce logging costs. It would reduce the amount of land which is being withdrawn from tree production. It would also reduce soil erosion.

A decision was made to explore for a solution to the planting problem having the form of a vehicle of as yet unknown type, able to negotiate very difficult obstacle strewn ground, which carries tools for planting seedling trees, these tools being also of unknown type. The vehicle is to be able to carry tools for other silvicultural tasks; its design is to reflect the need to perform these tasks.

The plan was adopted of pursuing the definition of the whole design problem to a point where a clear, well-balanced solution form could be seen. An attempt would then be made to solve conceptually the main design sub-problems which revealed themselves to a level of detail which satisfy the International Patent Examiners. Patents were to be sought if possible for pivotal concepts in the solution. Patenting secures the legal title to content having potential commercial value. In addition the demands of the patent examiners provide a meaningful level of detail to aim for one likely to be achievable by a person working alone in an area so little developed.

An attempt has therefore been made to complete Phase I of the research and development sequence.

Chapter III.
FURTHER PROBLEM DEFINITION

In this chapter an attempt is made to get clear the main form of a reasonable hypothesis for a vehicle plus planting tool solution. A collection of attributes for a balanced seeming solution is exposed, a solution hypothesis. In subsequent chapters an attempt is made to construct a solution which satisfies it. The hypothesis guides the work but it is not rigidly held to. If serious difficulty is encountered with it further on or if previously unconsidered choices become apparent there is no objection to re-thinking it. The problems giving rise to a reconsideration of the hypothesis should however be sufficiently grave; nothing is gained by changing the direction of exploration without good reason.

A comprehensive collection of attribute variables has been gathered (Appendix 4). More will appear as the work progresses. There is no attempt to meet the majority of them or even to consider them further at the earliest stages of conceptual design. They provide useful conceptual signposts. They are things which are kept in mind. They are likely to have to be considered in detail later on but may turn out to have significance at an early design stage.

A key attribute (or factor) is the rate of return on the capital invested in the use and/or ownership of the planting device. Factors which influence this one are the bid price range for contract tree planting (the price per tree for planting), the hours of seasonal use, the rate of planting per hour and the number of human operators needed to run the device.

The seasonal use is influenced by the portability of the device (its ease of freighting), its ability to get to the work sites, the diversity of uses for the different sub-parts of the device and for the device as a whole.

The range of site types on which the device is useful, its "flexibility", depends on its slope climbing ability, its ability to overate on soft ground and on its ability to negotiate obstacles. The more flexible the device is the greater its seasonal use and other potential use.

Portability is influenced by the size and weight of the device plus the ease with which it can be loaded and off-loaded if trailered.

The rate of planting is influenced by the rate of travel of the carrier over the ground, by its maneuverability, by the rate of planting of the planting tool (or of a collection of planting tools), the rate of feeding of the trees to the tool, the rate at which the tool can be guided to a suitable planting spot, the rate at which the correct spacing (therefore tree spacing) can be achieved from already planted trees and with trees being planted if more than one tool works simultaneously, the rate at which correct spacing can be achieved from other significant objects (e.g. naturally regenerated commercial species).

The logistical needs of the most demanding end user, the silvicultural contractor, need to be met. Attention must be given also to the logistical needs of the potential users in the American south-eastern states. These states together form the most important silvicultural area on the continent with six hundred million trees being planted in the region in 1983. This amount is more than one quarter of the total number of trees planted in North America in 1983, the year in which statistics were gathered for this study. Since that time the number of trees planted has increased (from 113 million trees in British Columbia to 130 million trees: we do not have detail for the U.S.A.).

Whatever system of planting is chosen its rate of operation will be limited by the speed at which the tools can be carried over the ground. Wheeled logging tractors operating off-trail over logging cutover are limited to speeds below 1.5 m.p.h. (Sutherland, 1981). Tracked tractors operate at roughly the same speeds. At higher speeds the operators experiences an uncomfortable bumpy ride; there is a danger of tipping. Let us assume vehicle speeds of up to 1.5 m.p.h. for exploratory purposes.

From among these influencing factors and with some additions two important sub-collections can be distinguished.

One collection bears more directly on the economics of a solution. The other collection bears more directly on the concrete form of a solution.

Collection 1:

(1) Season length

(2) Number of operators

(3) Rate of return generated by use

(4) System rate of planting

(5) Alternative use

(6) Development potential

Collection 2:

(1) Vehicle speed (assumed to be in the range 0 - 1.5 m.p.h.)

(2) Number tools planting simultaneously

(3) Individual tool planting rate

(4) Slope climbing ability

(5) Obstacle heights able to be negotiated.

The two sub-collections are, of course, interconnected. The factors within each sub-collection are themselves interconnected.

The following "economic" hypothesis was adopted:

(1) The bid price range is to be 12 to 16¢ Canadian. This is about 9 to 12¢ U.S. Hand planting bid prices are in the range of 20 to 25¢ Canadian.

(2) 600 hours of seasonal use maximum. The maximum season length in the S.E. of the U.S.A. is about 120 days. Contractors in British Columbia can work a season as long as this or longer by starting on the coast and going inland and north with the thaw. This is commonly done. (McKenzie, 1981)

(3) The system planting rate is 1,000 trees/hour. This is a guess. This rate is being aimed at by the group working on machine planting at the University of North Carolina.

(4) One operator will guide the vehicle/tool system.

Our plan was to put a collection together and then examine it for economic reasonableness. If this was obtained then an attempt was to be made to put together a hypothesis for a technical solution, one having also the ring of reasonableness.

The factors "Alternative use", Collection 1, (5), and "Development potential", Collection 1, (6), are important. The potential of the vehicle has been discussed. This has already led to a choice of a vehicle plus tool solution form being sought. Nothing further can be done with these two factors until conceptual design work is entered upon.

Example 1. A rough estimate based upon the economic hypothesis:

(1) 400 hours of seasonal use (Hatfield, 1981)

(2) Single use - planting only

(3) 12¢ bid price

(4) System planting rate 1,000 trees/hour

(5) One operator

(6) Expenses arising from the actual field operation - 2/3 of gross earning from any given contract (a working figure based upon the writer's experience in silvicultural contracting).

(7) The net return (before tax) is 18.5% of the capital invested to acquire the machine (400 hours work). The 18.5 figure was taken from the highest rate of interest reached by Canada Bonds in 1981. This level of interest stifled investment in forest industry business. It was concluded from this that this figure is competitive with the rates of return earned by business investment.

Under these assumptions:

(1) A machine would earn in one season,

$$\frac{(400 \text{ hours} \times 1{,}000 \text{ trees/hour} \times 12¢\text{/tree})}{100¢/\$1} = \$48{,}000 \text{ (gross)}$$

(2) The net return would be, $\frac{\$48{,}000}{3} = \$16{,}000$

(3) The machine retail cost would be,

$$\frac{16{,}000}{18.5} \times 100 = \$86{,}500$$

(4) A possible range of costs of production might be,

$43,000 - $58,000 (i.e. 1/2 - 1/3) retail.

(~~ASAE, 1988:~~ Gabor, 1977: Statistics Canada 1986: ICMC/IProdE, 1978: Dean, 1969: Hill, 1979) (The problem of getting to a retail price range and then that of breaking this price estimate proportionately into the standard categories - profit, labour, overheads, materials, sales - were extensively explored. Little of practical use was found.)

This rough estimate suggests that even with a single use, with a short season being worked and a considerable reduction of the bid price from the prevailing hand rates and with, in addition, a high rate of return being demanded, a machine could be profitable. Its retail price would be in the lower half of the price range for logging equipment. Its cost price (for a production version) provides for considerable design effort. The estimate is a conservative one. In particular, the season length is only one third of that which a contractor might work. The potential for profitability in a short season and with an 18.5% return on the cost of purchase per season suggests that a local owner/operator would in a reasonable mortgage rate climate be able to borrow money to purchase the machine. He would at the present time (January, 1989) more than break even. He would probably have to raise his bid prices above those of the large contractor but he could take on smaller jobs than the large contractor. With more than one use for the device the small operator would be able to earn a living.

Let us now pick out and explore a basic collection of "technical" attributes. No concrete technical solution is known at this point. The assumptions listed are not independent of each other.

(1) Vehicle speed - up to 1.5 mph on the worksites;

(2) The vehicle operation will be a stop and start one. When planting is taking place the vehicle will be stationary;

(3) The individual tool planting rate is to be in the range of 20 to 30 seconds per tree;

(4) The planting tool will spot plant (Appendices 1 and 3);

(5) A minimum of eight tools are to work simultaneously;

(6) The system rate of planting is to be 1,000 trees per hour;

(7) Slopes of up to 45° are to be climbable and crossable;

(8) When the vehicle is standing on level ground there is to be at least 1 m. clearance between the underside of the vehicle and the ground.

The last two factors, slope climbing ability and ground clearance are put aside for later consideration. They are in the section which deals with the vehicle. They are important but at this point nothing more can be done with them whereas the other factors have immediate implications.

An attempt is to be made to obtain a balanced design solution, one in which no excessive demand is placed on any one sub-system. In the absence of an operational system, what is or is not a reasonable collection of design choices is a matter of judgment. One makes choices and then sees what comes out of them. If a hand can plant a tree in 20 to 30 seconds, it does not seem unreasonable to expect a machine to do the same. If a skidder or a tracked tractor can travel over cutover, ground conditions on which they are not primarily designed to operate, at a safe maximum speed somewhere in the region of 1 to 1.5 mph, then it seems not unreasonable to expect a device specifically designed to traverse this ground to be able to move at the same speed. A solution which demanded that a tree be spot planted every second from a vehicle moving continuously at a speed of 15 mph has a ring of unreasonableness. It might turn out to be possible. It seems wiser to choose design parameters and values for these parameters which make what seem to be unexceptional demands on each sub-system.

If it is assumed that the average speed of the vehicle is 0.75 mph and that the inter-tree spacing is 8 feet then,

$$\frac{1760 \times 0.75 \times 3}{8} + 1 = 496$$

is the number of tree spots arranged in a single row which are passed in one hour. To obtain coverage of 1,000 planting spots in the same time, either the speed of the vehicle must be increased or the number of rows planted in one pass must be increased or both factors must be increased. Our preference would be to choose to increase the number of rows which are planted simultaneously unless the demands on tool organization and guidance seemed to be becoming extreme.

In general, by using an array of simultaneously working tools the demands are lessened on vehicle speed and on the planting rate of each individual tool in the array. Because of the clutter of ground obstacles which the vehicle has to negotiate when working on logged ground it was judged to be wise to seek a solution which demanded a low range of vehicle speed; great maneuverability is called for, considerable ground clearance and good slope negotiating ability. For the same reason (ground clutter) a solution demanding what seemed to be a low individual rate of tool operation was also sought. It was possible that a suitable overall planting rate might be obtained from the combined output of an array of simultaneously operating tools.

The use of an array of tools lowers both the needed individual tool rate and the needed vehicle speed. But it gives rise to the need to unload the operator of the vehicle/tool system of the task of fully guiding the operation of each tool, that is the tool motion and the handling and placement of trees. There is too much for the operator to do.

Ignoring for the moment the problem of guiding the vehicle, if the operator is guiding an array of 8 tools and if the minimum planting rate per tool is one tree every 30 seconds then the operator has a maximum of 3.75 seconds to deal with each tool. This has an air of unreasonableness. Assuming that he has moved the vehicle from the last planting position, the operator will have to align the array with already planted trees, make sure that the tools are correctly spaced from these trees, make sure that the tools in the array are correctly spaced from each other (there is a more full discussion in the section on spacing and choice), choose a planting spot for each tool in turn, guide each tool to the spot and activate the loading of each tool (hand loading each tool is out of the question). He must then, finally, activate the planting of each tool (again, hand activation is out of the question).

It has been said that a hand planter on average walks from an already planted tree and plants a new tree in 20 to 30 seconds (British Columbia, Ministry of Forests, 1984). If moving is assumed to take half the time (distances of 2 to 3 meters may be involved, so that moving will be faster than this) then there are 15 seconds left for choice, minor site preparation and tree placement. There will usually be more time than this. It does not seem likely that the operation on one tool in a mechanised system could be done within an average time interval of four seconds.

One can go either to fully automatic tool operation or to a semi-automatic operation where the operator is unloaded to a point where he can function. The need for him to move from the driving position in order to guide the tools is to be avoided because of the time involved in his doing this and for reasons of safety.

The following tasks have to be done:

(1) Drive the vehicle to an array planting position or having planted an array, move the vehicle to a new planting position;

(2) Align the array with already planted trees;

(3) Space the tools from already planted trees and other significant objects;

(4) Space the tools from each other;

(5) Make vertical each tool (groups of tools might be levelled together);

(6) Choose a planting spot. Site preparation is ignored until later;

(7) Guide each tool to its chosen spot;

(8) Cause each tool to load with a tree;

(9) Cause each tool to place the tree into the ground. The trees must be vertical and the excavation into which they are placed must allow for the roots to be fully extended. No air spaces must be left around the roots or the root pack;

(10) Prepare the tool array for carriage to the next planting position (this includes the raising of each tool from the ground);

(11) Move the vehicle/tool system.

The following plan was adopted:

(1) The vehicle problem is to be investigated;

(2) Mechanical planting is to be investigated;

(3) One operator is to guide the vehicle/tool system on the worksites;

(4) An array of tools is to be carried. They are to operate simultaneously;

(5) Tree handling and placement are to be automatic;

(6) Spacing within an array (inter-tool spacing) is to be automatic with some initial hand setting being allowable;

(7) Alignment of an array to be planted with already planted trees is to be under the guidance of the human operator;

(8) The operator is to be able to halt the operation of any tool in the array. This is needed to deal with the need to avoid significant objects which may affect the planting pattern and which may not be easily machine recognizable. (It is possible for road and cut-block boundaries and naturally regenerated commercial species to occur within the array area.)

(9) The vehicle is to be stationary when planting is taking place;

(10) The planting tools are to spot plant (Appendix 3);

(11) Light site preparation is to be performed;

(12) Levelling of each planting tool is to be automatic;

(13) Individual planting spots are to be chosen:

a) Semi-automatic choice is to be investigated. (The operator makes the choice and directs a tool to a chosen spot. The difficulty is the speed of direction);

b) Automatic choice is to be investigated. (The planting tool chooses its own spot and is automatically directed to the spot);

c) Perceptual guidance is to be investigated.

(14) The main form of an integrated design is to be sought. This is to include:

a) Tool array position on the vehicle;

b) General array lay-out;

c) General system of tool manipulation;

d) Tool/tool communication, if necessary, for spacing;

e) Operator/tool communication - for halting tools, starting tools, for semi-automatic operation, etc.;

f) Data processing method to be used.

g) Communication between tools and their data processors;

h) Sensory system.

Comments on this plan.

The semi-automatic solution (operator choice, etc.) and the fully automatic solution can be identical up to the mechanism of choice and possibly in some details of the methods of tool direction.

In the semi-automatic case the operator has no time in which to actually direct each tool to its planting spot, that is, actually direct the detailed motion of the tool. Three sub-tasks can be identified. They are:

(1) Find spot;

(2) Mark spot;

(3) Call (or direct) tool to spot.

The human operator can find a good planting spot at a glance. It would be useful if he could then "mark" the spot with a machine recognizable mark. He could then leave the tool to automatically find the mark, move to it and place a tree at the mark. Whilst a particular tool was doing this the operator could deal with another tool. The difference between automatic and semi-automatic solutions would then be that in the automatic solution the tool itself makes the choice - recognizes a naturally occurring mark.

Planting in cutover cannot be mechanised by the use of furrowing techniques (Riley, 1983). A satisfactory solution, one avoiding the need for clearing, is that of having a machine perform "true" spot planting. This requires that correctly spaced individual spots suitable for the placement of a tree be chosen and then worked. Spot planting unless it is performed at high speed does not lend itself to being performed from a continuously moving vehicle. It seems more reasonable, given the nature of the ground, to use stop and start vehicle operation with planting taking place whilst the vehicle is stationary. This choice simplifies everything - spacing, guidance, levelling, alignment with already planted trees. A high rate of planting can be obtained with what looks like a low individual tool operating rate and a low vehicle speed from the use of an array of simultaneously operating tools. This solution choice gives rise to the need to space the tools of the array appropriately.

The minimum array size was chosen on "arithmetical" grounds. A 1,000 trees/hour system rate of planting was to be explored. If eight trees are planted every 30 seconds (worst case) then 16 trees are planted every minute. Hence 60 x 16 trees, 960 trees, are planted in one hour.

To work in aisles of trees (plantation tending and juvenile stand tending) with 2.5 m. (= 8 feet) spacing assumed the vehicle should either be permanently within or contract to be within a $(2.5 \text{ m})^2$ envelope. For road carriage without special license the vehicle when in a freighting configuration should have a width of 8 feet or less. It is assumed that the height and length specifications for haulage without a special license will be easily met. For long distance haulage it is assumed that the vehicle will be carried on a standard trailer which is to be pulled by a standardly available, full-sized, North American pick-up truck. The vehicle should be as light as possible. Axle weight restrictions are imposed on roads in the Interior of British Columbia during the spring thaw and the autumn "freeze-up". The planting season begins with the thaw. Some planting is done in the autumn but will finish before the onset of freezing weather. Stand work may be done until well into the winter. Unfrozen forest roads and even paved highways will not stand up to heavy haulage during the thaw. It may be necessary to dismantle the silvicultural vehicle for carriage.

Assuming that the vehicle provides a longitudinal base of 2.5m, an array of eight tools can be placed on two separate bases, four to a base, and these bases attached parallel to the vehicle long axis (figure 1).

Example 1. 30 second planting rate, 8 tool array, 2.5m spacing.

To plant a sequence of arrays the vehicle halts for a maximum of 30 seconds whilst planting takes place. It must then move 5m (figure 2) to the next array position. To plant 1,000 trees 125 arrays must be planted. To plant this number of arrays will (according to hypothesis) take 125 x 30 seconds or 62.5 minutes. This rate leaves no time for moving from one array position to the next array position.

To deal with this difficulty the array size can be increased or the planting rate or both. The vehicle speed is assumed for the moment to be held steady. If the array size is increased it is advantageous to increase its width as much as is reasonable, rather than its length. Increasing the width is equivalent to an increase of the number of rows which are planted simultaneously. It is found that the vehicle speed required can be kept low (in the region of 1 mph) by increasing array width (Examples 3 and 4).

Example 2. Planting rate 20 seconds, array size 8 tools, 2.5m spacing assumed.

(a) 125 arrays to be planted at 20 seconds per array;

(b) Approximately 42 minutes for planting;

(c) 125, 5m spaces to be travelled in 18 minutes (figure 2);

(d) Speed required;

$$\frac{124 \times 5}{1600} \quad \times \quad \frac{60}{18} \quad \text{mph} \quad = \quad 1.3 \text{ mph}$$

(simultaneous acceleration assumed).

Example 3. Planting rate 30 seconds, array size 16 tools, 2.5m (figure 3).

(a) Number of arrays, (1000/16) = 62.5 = 63

(b) Number of moves 62

(c) Size of move 10m

(d) Time for planting (63 x 30) seconds = 31.5 minutes

(e) Time for moving 28.5 minutes

(f) Speed required

$$62 \times \frac{10}{1600} \quad \times \quad \frac{60}{28.5} \quad \text{mph} \quad = \quad 0.8 \text{ mph}$$

Example 4. Planting rate 20 seconds, array size 16 tools, 2.5m spacing assumed.

(a) Number of arrays, (1000/16) = 62.5 = 63

(b) Number of moves 62

(c) Size of move 10m

(d) Time for planting (63 x 20) seconds = 21 minutes

(e) Time for moving 39 minutes (instantaneous acceleration)

(f) Speed required

$$62 \times \frac{10}{1600} \quad \times \quad \frac{60}{39} \quad \text{mph} \quad = \quad 0.6 \text{ mph}$$

It is concluded that to plant 1,000 trees an hour with an 8 - 16 tool array and at an individual tool rate of 20 to 30 seconds per tree will require a vehicle speed within the range of 0.5 to 1.5 mph. In the last example a speed of 0.6 mph was indicated. This is the average speed which is required. No account has been taken of the rates of acceleration and deceleration of the vehicle. Time will have to be spent aligning the array with already planted arrays. In example 4 an increase of the average speed to 1.2 mph would halve the time needed for moving (38 seconds to 19 seconds) and allow 19 seconds for aligning the array. Whether these figures are reasonable is not known at this stage; the vehicle speed range has been chosen to match the speeds of existing vehicles. It does seem that this speed range is compatible with the individual tool rates being considered (20 - 30 seconds) and with the range of array sizes which have been examined (8 - 16). The required system planting rate (1,000 trees/hour) can be obtained with combinations of speeds and individual rates of planting chosen from these ranges.

It is intended now that a system be explored which consists of an array of tools in the range 8 - 16 tools which are carried by a vehicle which travels at a speed in the range of 0.5 to 1.5 mph, the individual tool planting rate being in the range of 20 to 30 seconds.

In this section the topic of "perceptual" guidance for tools is introduced. General considerations. It should be possible to reduce the amount of computation needed to guide automatically operating tools and to reduce the needed accuracy of placement of the objects which are to be worked on by the tools by using perceptual cues; perceptual cues are functionally like tool endstops. Exactly how much freedom of workpiece placement there is will depend on the circumstances of an individual task. In a system that automatically spot-welds road vehicle doors, by using perceptual cues, the degree of accuracy of the placement of the door to be worked on can be reduced (with a subsequent saving of money on the door handling and placement mechanism). An extreme case is one where the "work-pieces" are randomly scattered. Talking figuratively, here the tool has no choice but to find the work pieces and align itself with them where it finds them. The task of spot-planting trees in logging cutover is an example where the work-pieces (i.e. the ground patches needing to be worked on) are randomly placed. The use in a fully automatic solution of perceptual cues for guiding the tools seems for the task of planting not only a natural direction in which to look for a solution but the only solution save that of clearing the sites when the need for choice of planting spots would disappear. Clearing is not economically feasible.

An alternative to fully automatic guidance by perceptual cues for the particular problem of planting, is to revert to fully manual control by a human operator. However, as has already been discussed, it is doubtful whether full manual control would enable the required planting rate to be achieved with one operator being used.

Some sub-problems such as the spacing of the tools lend themselves to an automatic solution inasmuch as such a solution can be made to hinge on the machine recognition of a contrived mark; this machine recognition problem looks to be solvable. Automatic levelling should also be solvable. Other problems such as those of the alignment of the array with already planted trees, and the spacing from naturally regenerated commercial species ("residuals") and from other significant objects are best dealt with using the judgment of the human operator. They appear to contain difficult machine recognition problems. The judgments which are involved are ones which a human operator can make at a glance.

It is reasonable to distribute the tasks needing to be done in planting carefully between the operator and the machine. A human operator has no difficulty choosing a planting spot so that a semi-automatic solution based on operator choice appears to be worth exploring. It is at the same time worth exploring machine choice. There is commercial potential for a solution (Prudential Bache, 1983).

There are two collections of problems which have been put aside. The problems of machine site preparation and machine planting spot preparation need to be taken into account. They have been put aside until their treatment becomes unavoidable. (Discussion of them occurs in the sections dealing with semi-automatic and automatic choice and in the Conclusion.)

The collection of problems needing to be dealt with fall into four major sub-collections. They are:

(1) Vehicle - the carriage of tools over difficult terrain.

(2) Silvicultural/mechanical - the automatic mechanical handling and placement of seedling trees.

(3) Spacing - the automatic spacing of a collection of simultaneously operating tools.

(4) Choice - choice of planting spot:
   (a) Semi-automatic - the operator makes the choice and marks it, the tool then operates automatically to find the spot and place a tree at the mark.

   (b) Automatic choice - machine choice of a spot by the recognition of naturally occurring "marks".

The major problem areas are listed in their order of crucial importance. They are treated in that order in the chapters which follow.

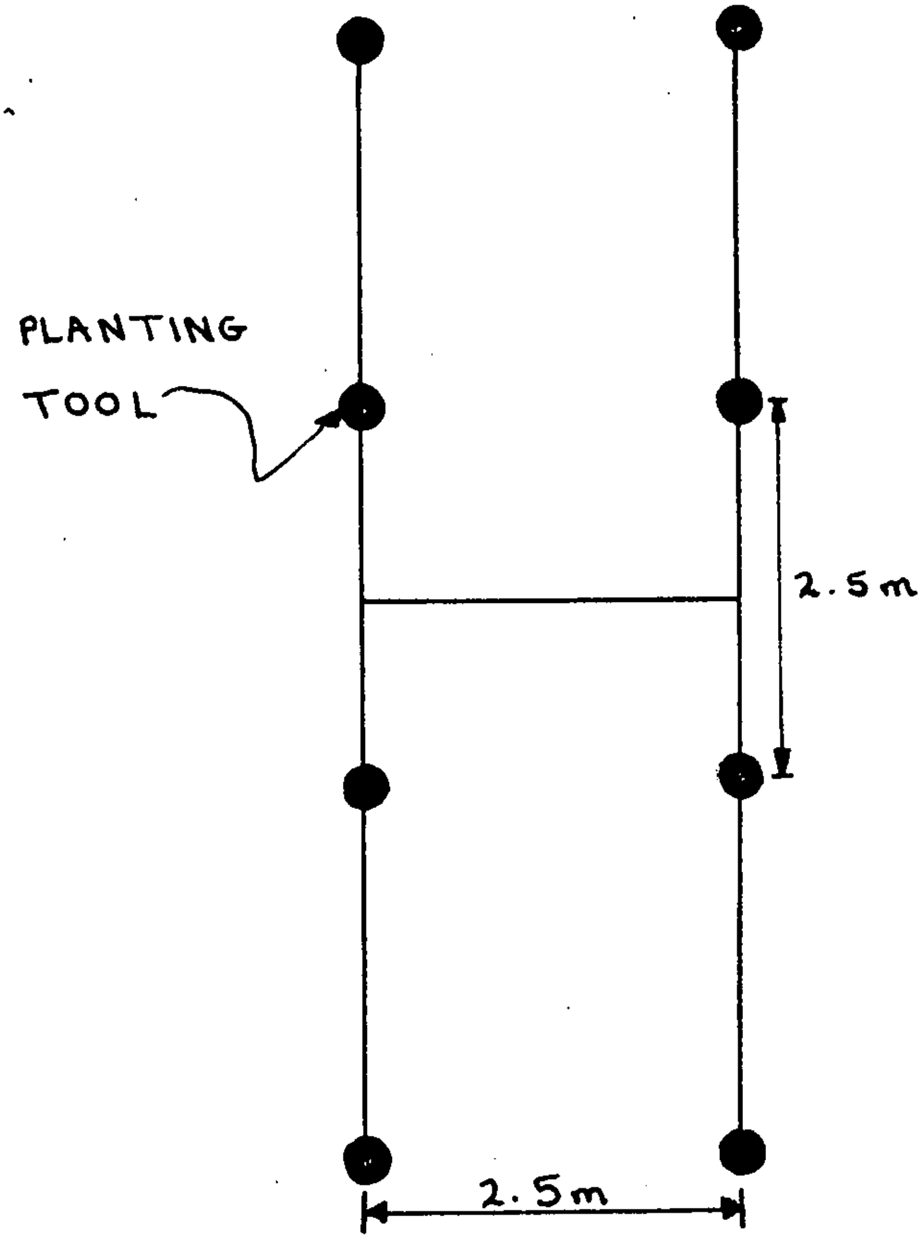


DIAGRAM 1.

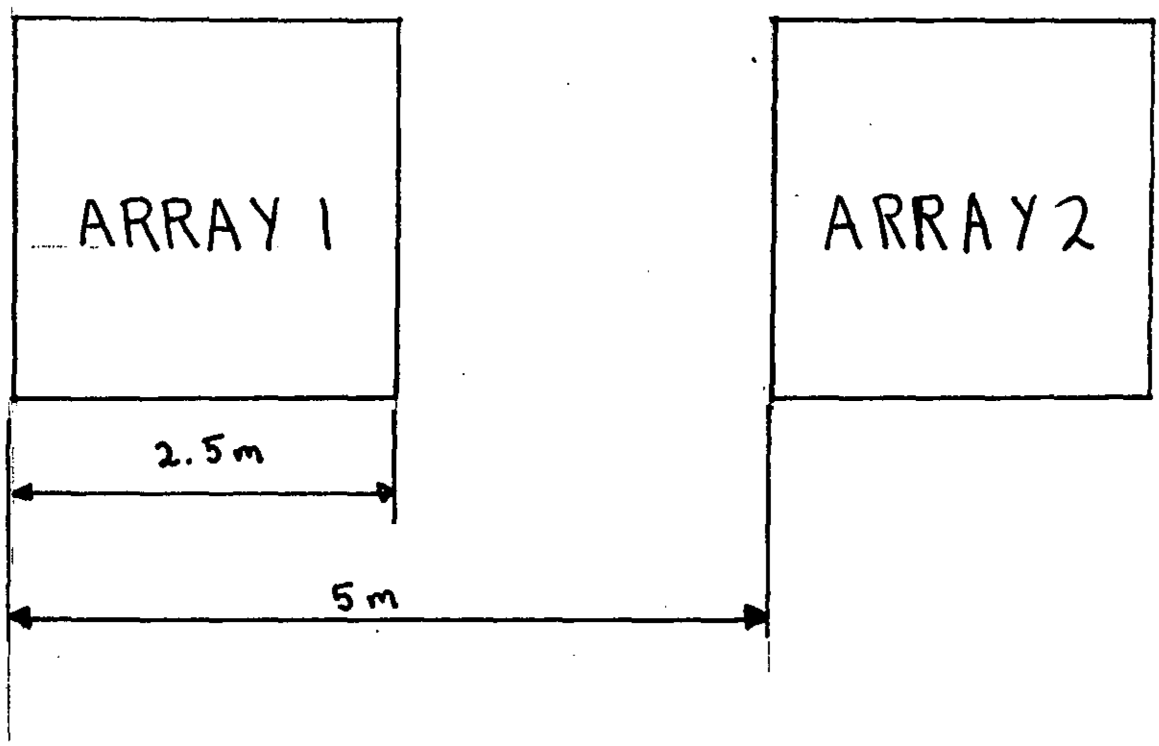


DIAGRAM 2.

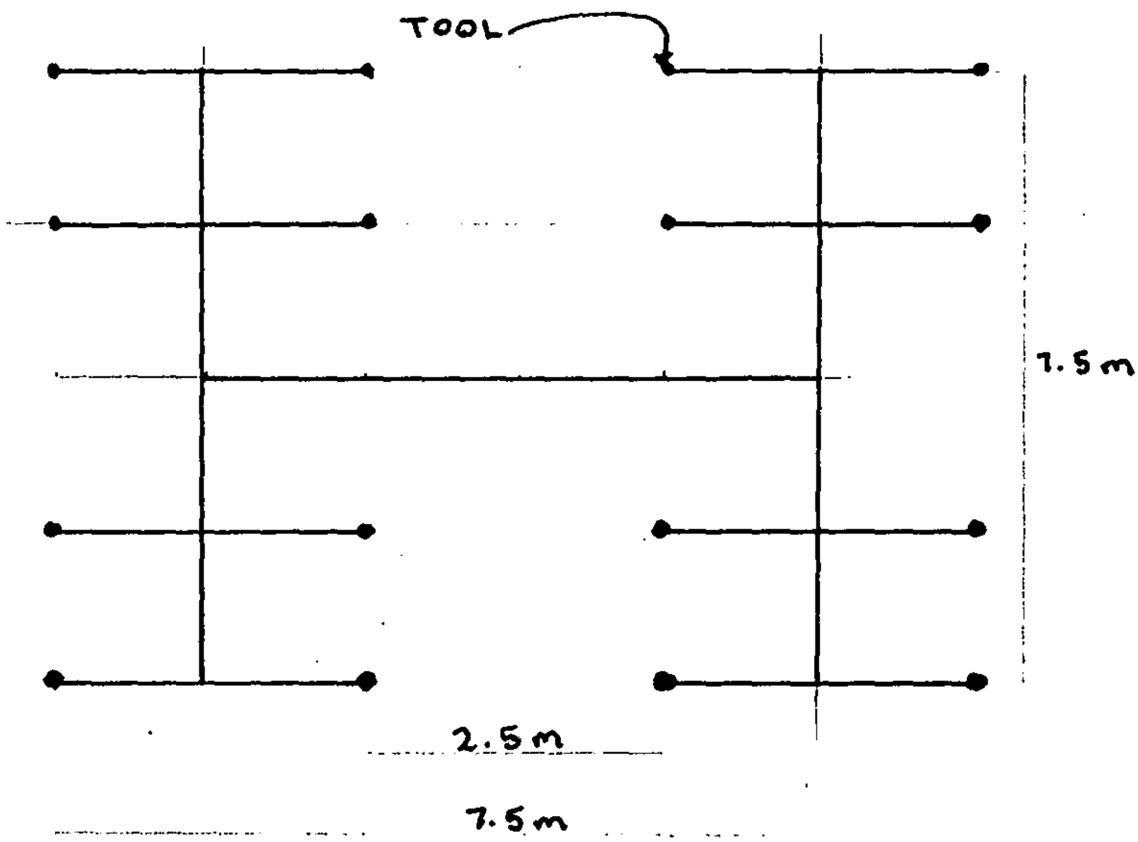


DIAGRAM 3.

Chapter IV.

VEHICLE

It is assumed that the silvicultural tool carrier will be a ground vehicle. There is no existing airborne carrier. It was judged that an airborne vehicle design was not worth pursuing.

There are four distinct tool transportation problems.

(1) Long distance haulage from job to job (hundreds of miles).

(2) Carriage of tools from worksite to worksite in the same vicinity over driveable forest roads or public roads (tens of miles, frequent loading and off-loading).

(3) Movement to worksites from a point of access reachable by a road vehicle or otherwise accessible (e.g. by water) (up to ten miles).

In some cases it is possible to drive to the worksites. In other cases tools can be carried to the vicinity of a worksite. They must then be carried over ground which is unsuitable for normal road vehicle (soft, blocked {e.g. blown down trees, road washed out} flooded, snow filled {e.g. shaded portions of a trail in early spring}). It may be possible in some cases to get to a site in a four-wheel drive vehicle. It may not be possible to pull a trailer into the same site or to take in a heavier load carrying vehicle.

(4) Movement on the worksites - on logged sites in both the U.S.A. and Canada trackless obstacle cluttered ground will have to be negotiated. For stand work cramped trackless and obstacle strewn conditions will be met with.

No vehicle exists which "solves" the fourth problem. It is assumed at this point that an attempt will have to be made to design one. Logging tractors are designed to operate from trails. Where logging using ground vehicles is performed, bulldozers push trails from which both they and wheeled logging tractors extract felled trees. The trees are felled to the trails. Neither wheeled nor tracked logging tractors are designed to operate freely on logged sites (Holtman, 1981). They are functionally unsuitable.

For stand work and plantation work wheeled and tracked tractors are too large and unwieldy to be able to manoeuvre in aisles of closely spaced trees (CAT Handbook 1984). They are dimensionally and functionally unsuitable.

Both bulldozers and skidders require heavy haulage equipment. For the American south-east the need for specialized haulage equipment to move a device would rule out its use. The work sites are commonly small (less than 100 acres). It is too expensive to have the hauler sitting idle with his equipment waiting to move planting equipment. Scheduling for numerous moves on public roads from small site to small site is awkward. Implementing such a schedule would be expensive.

It has already been said that in Canada during the thaw forest roads will not stand up to heavy haulage. Long distance haulage of heavy equipment is expensive. If a hauler carries equipment several hundred miles from his "home" operating area he will not without charge wait to move the equipment again. He will either need to have arranged for another load to haul back or have return expenses defrayed. A silvicultural contractor is unlikely to be able to afford to own heavy haulage equipment. Nor is he likely to want to own logging tractors, nor wish to haul them over long distances.

The possibility exists of hiring a local heavy equipment operator. At the thaw heavy equipment may be left in the bush; at a logging camp for example. Assuming that the equipment can be got from where it is parked to the worksites the cost of operation will be too high (Province of British Columbia, 1989). The cost per hour for the hire of a reliable piece of equipment will not be covered by the gross return earned from tools planting at a rate of 1,000 trees/hour and with the bid price range being aimed at being used. In fact the <u>gross</u> return from the use of the hand planting bid price range would just be covered.

It is concluded that logging tractors are neither logistically nor economically suitable. There is no other vehicle which approaches functional adequacy.

It is now assumed that the first three carriage problems must be solved for what will be called the "silvicultural tractor", that is the solution to the fourth carriage problem. The carriage problems must be solved for both the tools and the silvicultural tractor.

The first problem can be solved by carriage on a normal road vehicle. This could be with a flat-decked truck or a flat-decked trailer. Whichever one is used it should be of a standardly available type. No special carrier for road haulage is to be required. No special road haulage licenses are to be required. Our preference is to use a flat-decked trailer pulled by a standardly available full-sized North American pick-up truck, possibly of a four wheel drive type. These vehicles are ubiquitous in the country regions of North America. With the owner/operator in mind and also conditions in the American south-east it is preferred that the road vehicle can be of an unspecialized type. With British Columbian conditions in mind the vehicle should be smaller rather than larger. The planting equipment may have to stay on a particular worksite for periods of days. It may have to remain in one work area going from site to site for periods of weeks. It is preferred not to have a specialized carrier tied to the equipment. With a trailer and pick-up, the trailer can be left as close to the vicinity of the worksite as is possible. The pick-up, detached from the trailer can be used to get the operator home, to a logging camp or to a source of supplies. It can be used to carry these supplies as also could be the trailer if necessary. The contractor whether large-scale or small will certainly own at least one, usually four wheel drive, pick-up.

The second problem can be solved also by the use of a pick-up truck pulling a flat-decked trailer. The silvicultural tractor is to self-load and self-unload. Loading and unloading should be operations capable of being performed by one man.

The third problem can be solved by a combination of the means used to solve the first two problems and the fourth problem.

It is possible that the silvicultural tractor may have to get to the worksites under its own power over trails unsuitable for normal travel; distances in miles may be involved. Speeds in the range of 0 to 1.5 mph are to be aimed for on the worksites. It would be useful if higher speeds than this were available for travelling trails where conditions permit higher speeds. Let us guess at a 5 mph maximum on trails. It would be satisfactory if equipment could be reliably got to a worksite at this order of magnitude of speed. Preliminary hypothesis:

(1) Operating speed range on the worksites of 0 to 1.5 mph.

(2) Speeds of up to 5 mph on trails.

(3) 1m clearance between the vehicle underbody and ground when the vehicle is standing on flat, level ground. (The British Columbia Forest Service grades sites for difficulty - Figure 1). The most difficult ground obstacle classification is that having "Frequent logs grouped and crossed more than 1m (3 feet) high".

(4) The vehicle is to have a width of less than 8 feet when fully retracted; the vehicle may have variable width. (Metric units are official in Canada. These units are used or both metric and Imperial units are used in government publications. In general Imperial units are used in parallel to metric units. In the U.S.A. non-metric units are commonly used but there is increasing use of metric units. For preliminary work both metric and non-metric units are used. This is unavoidable - spacing prescriptions in British Columbian Forest Service literature are given in hectares and meters - U.S. road haulage regulations use feet; U.S. planting prescriptions use feet and so on. A choice as to units can be delayed until later.

(5) The vehicle length may be less than or equal to 8 feet (2.5m) when fully retracted. Length may be variable.

(6) For stand work (plantation tending and juvenile stand tending) a compact device is needed in order for it to be able to move handily in aisles of trees. In very young plantations the vehicle body will be above the trees. An envelope of 2.5m^2 should encompass the fully retracted vehicle.

(7) For planting, the vehicle should have the ability to manoeuvre easily amongst considerable ground clutter. The need for awkward to and fro movement in order to change direction is best avoided.

(8) The vehicle is to operate on slopes of up to 45° from the horizontal (Figure 1 B.C. Forest Service form). It is to be able to operate across such slopes and up and down them.

Considerable effort was made to get slope data. A rough idea of the distribution of slopes found on worksites could have been obtained from an examination of a sample of the British Columbia Forest Service assessment forms. It turned out that they are not regularly kept. It is to be remembered that these slope assessments are the "feel" of the assessor (using some measurement). A site having a reasonable seeming slope assessment could still have gullies where more severe slopes are met.

The 45° boundary was chosen as being severe enough to include all reasonable conditions. The most severe condition on the assessment form is sites having slopes above 65% (30°). If this requirement cannot be met by a balanced design it will be retreated from.

(9) Gross vehicle weight of up to 5,000 kg. This is a guess. A reasonable load carrying capacity was aimed at. The carrying capacity needed for the carriage of a days trees is light (500 to 1,000 lbs.). The carrying capacity needed for the carriage of liquid for such purposes as fire-fighting should be as high as is reasonable. (See Appendix 2 for tree weights) See Figure 2 for estimates of the power requirements for the vehicle. The weight boundary was derived in a somewhat circular fashion from the speed requirements and the slope climbing requirement.

(10) Power requirement comments. At this point there is no knowledge of a device which can solve the on site carriage problem. Hence there is no knowledge of its efficiency. The rough estimates do however indicate that one is probably dealing with power requirements that are in an unexceptional range.

A 3 H.P. air compressor (22 cfm at 125 psi) will provide power for running power tools which are suitable for work on small steel craft (e.g. up to 79 feet on deck) (Colvin, 1985). It will drive tools for work such as that of grinding steel and drilling steel. The work requiring to be done in tree planting is not as heavy nor as continuous as that required for steel boat building. Tree planting is capable of being performed by a man with a small shovel. For order of magnitude estimation purposes let us use the 3 H.P. of the compressor as an upper power requirement for one planting tool. Thus, sixteen tools working simultaneously and continuously would require 48 H.P.

When the tools are working the vehicle is stationary. The tools of the tool array have imposed upon them an order of precedence (see Chapters 7, 8 and 9). The work to be done is of short duration (maximum of 30 seconds per tool). There are intervals where no tool is working during which time the vehicle is moving. The vehicle will not always be on 45° slopes and if it is on such slopes it may be going less than 0.5 mph. Some proportion of the power output of the vehicle power source can when the vehicle is moving drive the compressor. The output of the compressor can be stored at these time in a reservoir; a higher compression reservoir could be used as a back-up during peak usage if this were necessary but in any case power tools will not usually use as much as 3 H.P. Again we seem to be dealing with modest requirements which can be serviced by a power source within a 50 to 100 H.P. range.

A conceptual solution to the fourth problem, that of the carriage of tools across trackless logged ground, will now be described. It promises to satisfy the demands of the task and promises also to have wide application and good developmental potential.

The demands of comparatively small size, low weight and power combined with the ability to operate on steep slopes and over obstacles of up to 1m in height pointed to the use of an alternative means of locomotion to those of wheels or tracks. The device needed was one which could slot easily into existing work patterns and did not need a team of men to set up. One man was to operate the device. It was judged that it should be of such nature that one man was needed also to haul the device to the worksites, off-load it, operate it and, when the time came to move it, on-load it. The operational sequence associated with a small piece of equipment such as a back-hoe suggested itself; a trailer hauled ground vehicle.

The logistical needs point to a comparatively light small handily moveable, very maneuverable vehicle. Financial constraints, pointing to the use of standard materials and standard fabrication techniques and the use of a simple workshop, point also to the need for comparative simplicity of construction (see Appendix 4).

The demand for considerable ground combined with small size and low power suggested the use of a small ground vehicle which was raised on struts. The problem then arises of how to cause a strut mounted vehicle to move.

True walking was to be avoided. It was aimed rather to have the load carried on the functional equivalent of a raised self-advancing "track" or "rail" which could form if not a level path then at least an unobstructed one for the load to travel on above all but the highest ground obstacles. True walking was to be avoided because leg coordination looked like being difficult to achieve in an obstacle strewn environment. Very large sums of money have been spent on mechanical walking (T.J. Todd, 1985). Our judgment was both that an approach via walking to this particular problem was not a good choice and that the effort and money needed for a walking solution was beyond our capability. A solution to the problem of moving a strut mounted vehicle has been sought in another direction.

A summary of the difference between the device which was discovered (silvicultural tractor) and the prior art is given here. This is followed by a discussion containing sufficient detail for the principle of locomotion to be understood. No further detail is given in this thesis. Following this discussion it is assumed that a suitable carrier will be available.

A partial classification of the silvicultural tractor.

(1) The silvicultural tractor is a member of a family of devices which are known in the patent literature as "stepping" or "stepper" mechanisms. These mechanisms are commonly employed in self-advancing mining devices. Figure 4 shows the principle of motion.

(2) The mining devices usually cannot of themselves chance direction other than to reverse the direction in which they are currently travelling.

(3) The silvicultural tractor is a member of the sub-group of stepping devices, "strut mounted stepping mechanisms". In this group there are devices which are able to change direction more generally; they form the relevant prior art. It is to be noted that the standard locomotory principle employed by this group, with the exception of the silvicultural tractor, is identical to that employed by the larger group which includes the mining devices.

(4) The silvicultural tractor is distinguished from the strut mounted stepping mechanisms because:

   (a) It can produce, with what is claimed to be a development of the stepping mechanism, continuous motion (see further discussion). All other steppers mining or strutted produce a stop and start motion.

   (b) The silvicultural tractor can produce motion with all its struts on the ground. This property is essential to its being able to produce continuous motion. It is useful also in situations where more traction and power are needed (steep slopes, slippery conditions, heavy loads).

   In all steppers two sets of supports can be distinguished. All steppers except the silvicultural tractor must in order to perform translatory motion alternately lift from the ground first one set of supports and then the other. They are unable to translate with all struts on the ground.

A sequence of steps explain the leading ideas in the silvicultural tractor. One form is shown.

Diagrams 1 and 2 show a structure consisting of a hollow sectioned beam, A, into which telescope two sub-beams, A1 and A2. (The second diagram suggests an alternative). Attached to A1 is a cross beam A5. Attached to A2 is a cross beam A6. Attached to each cross beam are two struts, A3(1), and A3(2) attached to A1 and A4(1) and A4(2) attached to A2. The struts (A3(1), A3(2), A4(1), A4(2)) are extendable and retractable, their being made up of sub-beams, let us say for exploratory purposes, with the lower beam telescoping into the upper beam. (This arrangement could be reversed. One beam could slide externally on the other. The strut could fold, etc.) In addition to their being extendable and retractable the struts may also be rotated so that each one becomes parallel to its supporting sub-beam. (Diagram 4)

In Diagram 1 imagine that the structure shown is suspended above the ground so that translatory motion of the beam AO is prevented. If whilst the structure is suspended in this way, A1 is extended and A2 is retracted, then, no translatory motion of A is brought about. The horizontal position of each pair of struts relative to the ground is changed. This is "Step 1".

Step 2. Diagram 3 shows the same structure as that illustrated in diagram 1 placed on the ground with the struts firmly placed upon the ground (friction, spikes, etc.). If now A1 is extended and A2 is retracted, then AO (the central beam) is caused to move to the right relative to the ground. The struts remain where they were before the motion was begun.

Step 3. If this motion could be continued a simple means of moving a strut mounted vehicle would be obtained (and in turn of carrying a load in conditions where considerable ground clearance is needed).

To obtain continued translation steps 1 and 2 are combined. Diagrams 4, 5 and 6 show two identical structures (like those of diagram 1) one mounted above the other and connected by the structure "P" so that the beams AO and BO are translationally rigid relative to each other (and hence to "P"). The whole structure is resting on the "B" - struts. The A-struts are retracted. Let B1 extend and B2 retract. This motion causes the complete central structure (BO, P and AO) and also the upper sub-beams and their struts to translate to the right.

Assume that whilst this translation is occurring, A1 retracts and A2 extends (Diagram 4. This is the same situation as that shown in Diagram 1 where the structure is suspended above the ground). Now when the lower structure sub-beams (B1 and B2) complete their motion, the upper structure sub-beams (A1, A2) are positioned so as to produce a further translatory motion in the same direction of the central structure (AO, BO and P). The A-struts are placed down. The B-struts are retracted. A motion identical to that already described now takes place but with the roles of the A - sub-beams (A1 and A2) and the B-sub-beams (B1 and B2) reversed.

The A-struts carry the load. Extension of A1 and retraction of A2 move the central structure to the right. The B-sub-assembly is now suspended above the ground. The B-sub-beams now prepare for a subsequent carrying cycle, B1 retracting and B2 extending. When the A-carrying cycle ends, the B-sub-beams are in position to continue the translatory motion. And so on. A sequence of these cycles will move the whole structure to the right.

Reversal of motion. If the diagrams where drawn upon transparent paper then by turning the paper over a sequence of motion would have been shown which moves the whole structure to the left. The means for producing the motion already exists. The transition from movement in one direction to movement in the reverse direction needs to be explained.

Suppose that the A-structure is bearing the load (it could be the B-structure) and that the A-sub-beams have completed the movement which causes the central structure to move to the right; A1 is extended and A2 is retracted. At the same time B1 is retracted and B2 is extended. Now if instead of transferring the load to the B-structure, the load is maintained on the A-structure and A1 is retracted and A2 is extended, the vehicle moves to the left. If at the same time as this motion is occurring the sub-beam B1 extends and the sub-beam B2 retracts, the B-structure will be ready to continue the leftward translatory motion.

More general change of direction. By making the P-structure a pivot, a means by which the direction of motion can be changed more generally is provided.

To change direction (A-structure assumed carried) AO is rotated until it points in the desired direction of travel. This change of direction of the A-sub-assembly (or the B-sub-assembly) is obtained with the carrying struts motionless, a useful property when working in obstacle cluttered ground. If the A struts are now placed down, the B-struts may then be retracted and the B-sub-assembly rotated to a position which is parallel to that of the A-sub-assembly.

As has been said, this change of direction can occur with the vehicle being translationally motionless. Awkward to and fro movement such as that needed to turn a wheeled or a tracked vehicle in confined conditions and in the presence of obstacles is avoided.

There is a possibility of the struts of one sub-assembly interfering with the struts or other structure of the other sub-assembly. This is particularly the case when the lower structure is being swung towards a stationary upper structure. The problems can be avoided in this case by such means as those of retracting sufficiently the A struts for the initial rotation of the A sub-assembly and then, when the B sub-assembly is being carried, by retracting sufficiently the B-struts and retracting sufficiently the B-sub-beams.

Although very low speeds are being dealt with the control and coordination of the alternate taking up of the load by the two sets of struts, especially as this will be taking place on uneven ground, will need to be carefully considered. Ergonomic and other problems arise. No detail is entered into here. There is a further note on these things in the section on spacing and choice.

Motion with all struts load carrying. In extreme conditions all eight struts can be placed upon the ground and the central structure (AO, BO and P) translated by, for example, simultaneous retraction of A1 and B1 and simultaneous extension of A2 and B2. These movements will move the vehicle to the right. Continuation of this cycle is obtained by a sequence which is a variant of that already described.

Thus, with the vehicle stationary the load is carried by one of the sets of struts (say the A-struts). The B-struts prepare for a new carrying cycle and then take the load, the vehicle remaining stationary. The A struts retract and the A sub-beams prepare for a new carrying cycle, the vehicle remaining stationary. Both the upper and the lower sub-assemblies are now prepared for a carrying cycle in the same direction. They can produce this carrying cycle simultaneously, come to a halt, prepare again for a new carrying cycle and then repeat the motion. And so on.

Continuous motion. Continuous motion of the central structure (AO, BO and P) can be obtained using the movement sequences already described and with an appropriate coordination of the loading/unloading cycle of the struts.

Suppose that the A-struts have begun a carrying cycle, the B-struts have retracted. Now the A-struts and their sub-beams are carrying the load. Suppose that the sub-beams are moved by means of hydraulic cylinders. The same pressure applied to the A-cylinders as is applied to the B-cylinders will move the B-sub-beams more quickly than the A-sub-beams (which are loaded). The B-sub-beams will thus get to the condition of preparedness for their carrying cycle before the full motion (or the required motion) of the A-sub-beams has been completed. If just before the completion of the A sub-beam carrying cycle the B-sub-beams begin their motion, the B struts are placed onto the ground with the A struts still in contact with the ground then both sets of struts will be carrying the load, the central structure will remain in motion. If now the A-struts are retracted from the ground the central structure will continue to be kept in motion.

A repetition of this sequence will keep the central structure (AO, BO and P) in continuous motion.

The coordination of the loading and unloading of the sets of struts will need care. It would be possible to achieve it via the use of a mechanism of perception with a microprocessor acting as a mediator between perception and action (see the section on spacing and choice).

Stepping combined with wheels or tracks. For military purposes it may be useful to have a vehicle having a reasonable road speed combined with an ability to negotiate rough ground. There already exist standard structures such as those used for the cranes on self-loading logging trucks and for the attachment of the crane to the frame of the truck which could be adapted to build a dual purpose vehicle.

The standard stepper mechanism.

In diagram 7 AO is a structure, a tool, which is attached to the structure BO, a rail, in such a way that horizontal translation of AO relative to BO, or BO relative to AO. AO and BO are so attached that raising AO from the ground will raise with it BO.

Sl, S2, S3, S4 are extendable struts.

Movement of the device. Assume that BO is on the ground. AO in this position slides upon BO left or right doing work. To advance the work area or to move the whole device away from the present area, AO is brought to the centre of BO. The struts, S1, extend lifting BO from the ground. By a means not shown BO is then moved to the right or to the left. This movement can be repeated. When BO is placed down again onto the ground AO moving on BO can reach new work areas.

The strutted stepper mechanism and the strutted mechanisms which are able to change direction more generally than from forward to reverse or from reverse to forward all use this mechanism in order to move.

In the standard mechanism two structures AO and BO are always present with either one being able to translate relative to the other. Where a pivot is used to obtain general change of motion this translates with either the upper or the lower structure. In the silvicultural tractor structures homologous to AO and BO of the standard mechanism are attached to each other so to be translationally rigid. The translational motion of the silvicultural tractor is obtained from structures for which there is no homology in the standard structure. Without the rigid attachment of the structures AO and BO, the movement obtained by the coordinated extension and retraction of the sub-beams of the silvicultural tractor cannot be obtained. Neither can the "double" motion be performed which is obtained by duplicating the A-sub-assembly and attaching the duplication to the A-sub-assembly.

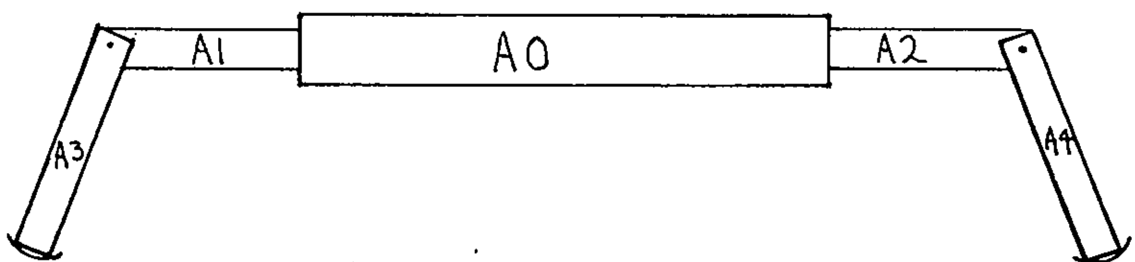


DIAGRAM 1.

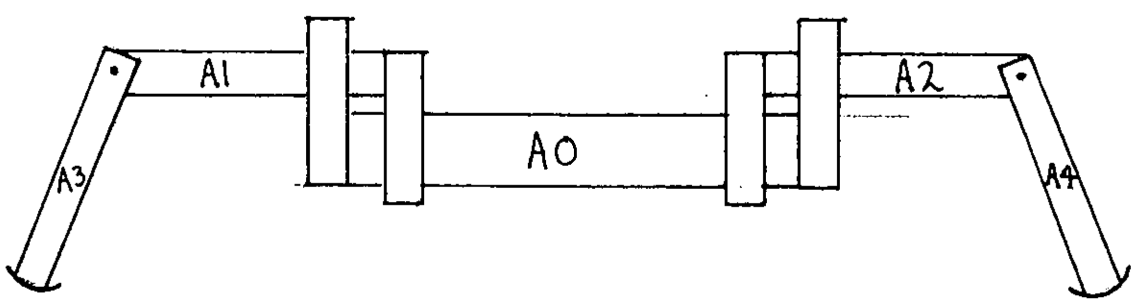


DIAGRAM 2

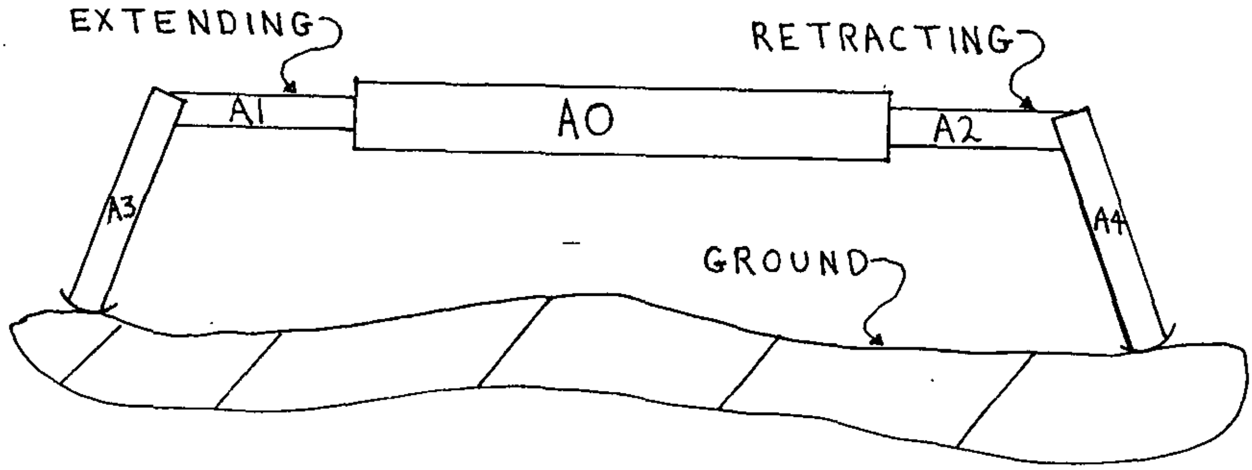
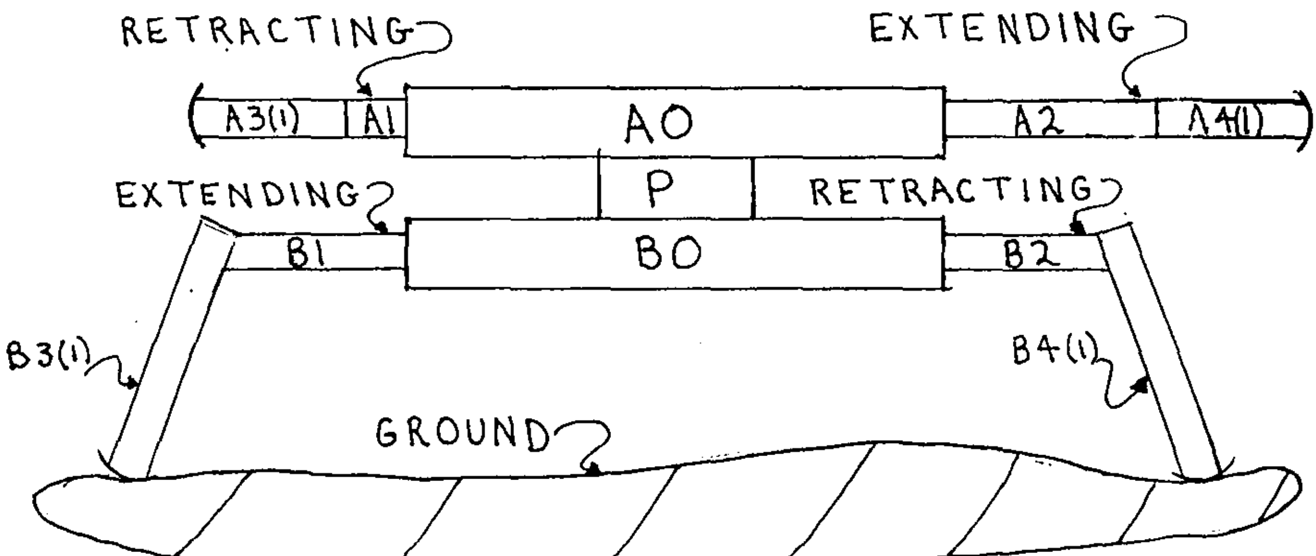


DIAGRAM 3.

DIAGRAM 4.



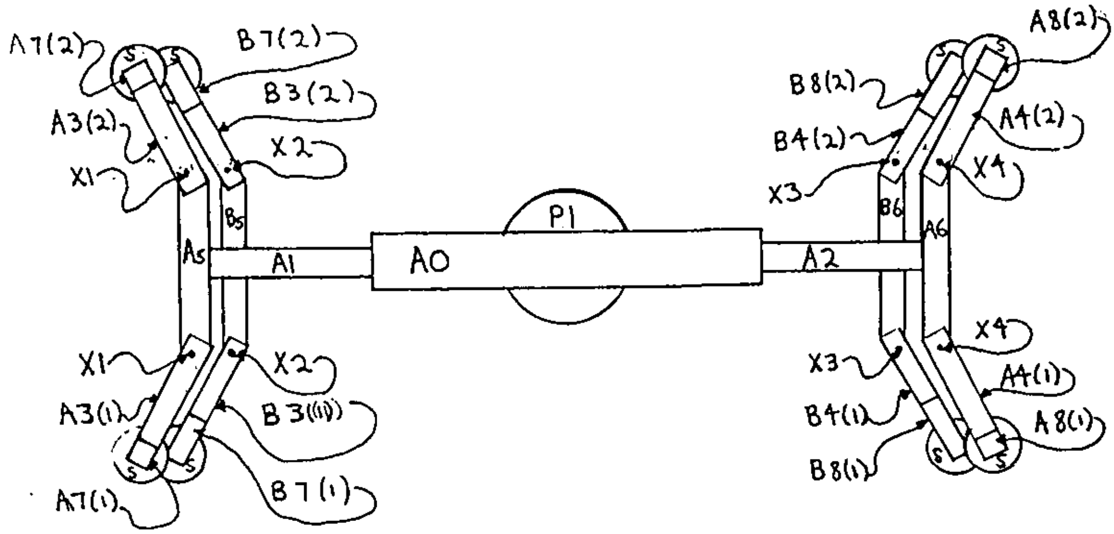


DIAGRAM 5

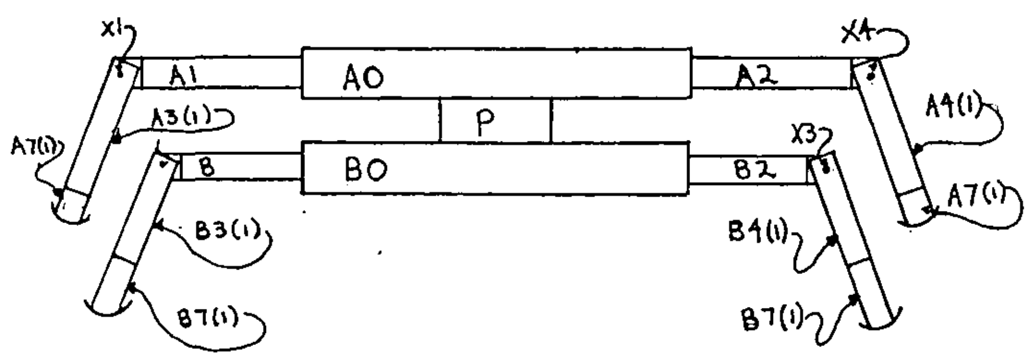


DIAGRAM 6

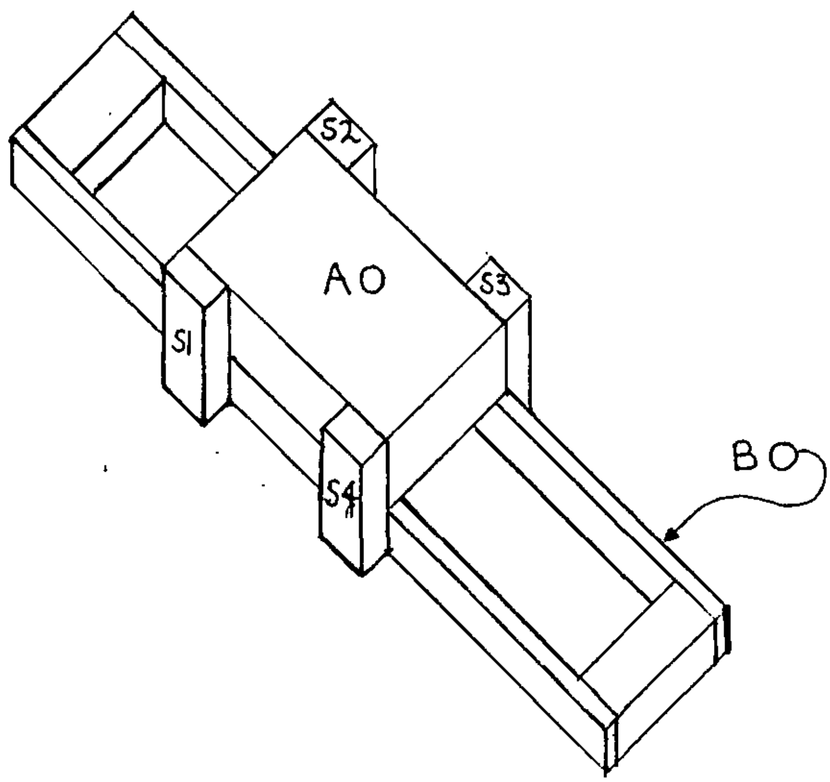


DIAGRAM 7.

Province of British Columbia — Ministry of Forests — Forest Service

Planting Difficulty Rating

Planting Project No. ______________ Forest District ______________ R.D. ______________

Block/Unit No. ______________ Method of Site Preparation ______________

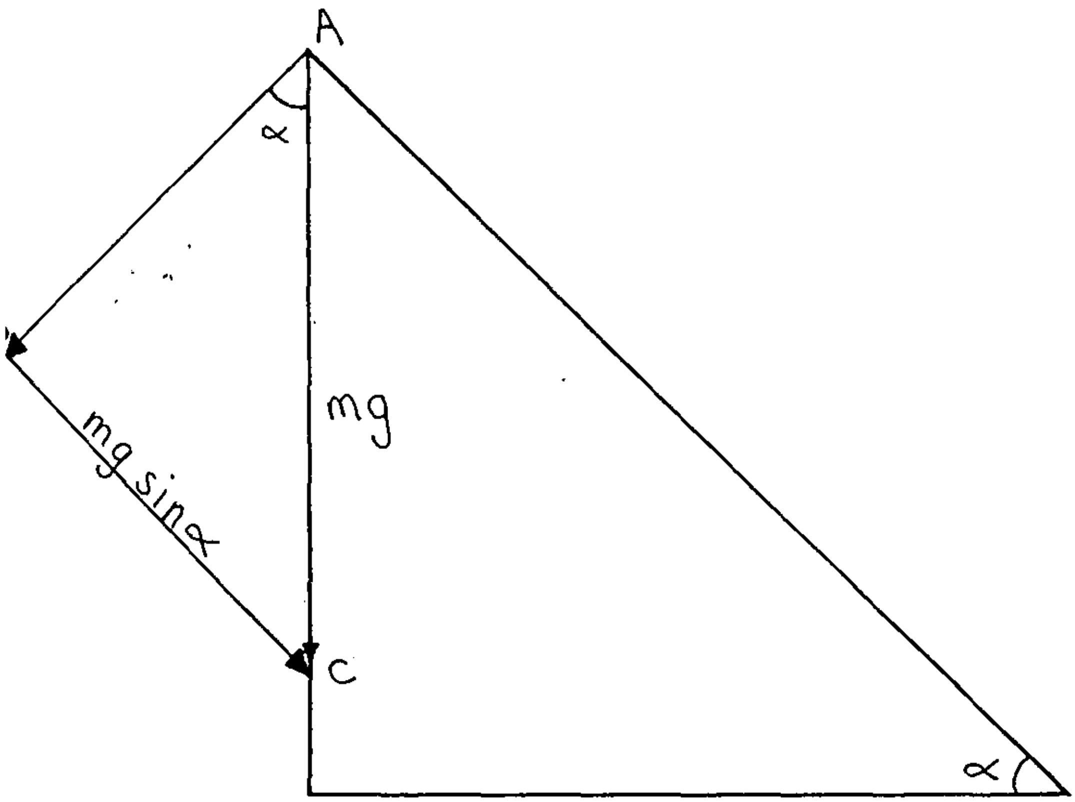
FACTOR	SITE CHARACTERISTICS AND POINTS RATING		
1. Vegetation	Infrequent grass, herbs and low shrubs. 1 point	Frequent grass patches, herbs, low shrubs, infrequent naturals. 3	Continuous grass or other vegetation, naturals planted trees. 6
2. Thickness of duff or litter	Less than 5 cm (2 inches). 1	5 - 20 cm (2 - 8 inches). 3	Over 20 cm (8 inches). 6
3. Fine Debris	Scattered branches and tops. 1	Grouped branches and tops, less than 1 m (3 ft.) high, loose arrangement. 3	Piled branches and tops, more than 1 m high (3 ft.) or in a continuous mat. 6
4. Coarse debris	Scattered logs. 1	Frequent logs, some grouped and crossed, less than 1 m (3 ft.) high. 3	Frequent logs grouped and crossed, more than 1 m (3 ft.) high. 6
5. Stoniness	Infrequent stones or boulders. 1	Frequent stones, boulders or coarse gravel. 3	Continuous stoney layer and/or frequent boulders, gravel. 6
6. Compaction	Loose. 1	Occassional compact areas, e.g. landings. 3	Definite hardpan or compact layer throughout. 6
7. Slope	10 - 35% 1	0 - 10% 25 - 65% 3	Over 65% 6
8. Unplantable areas	Infrequent patches of surface water, bedrock, etc. 1	Frequent patches of less than 0.2 ha (½ ac). 3	Frequent patches of more than 0.2 ha (½ ac). 6

Circle one point rating in each of the eight factors and total = ______________ points = Planting Difficulty Rating.

Planting Difficulty Class:		
	Less than 10 points	EASY
	10 - 20 points	MODERATE
	21 - 30 points	DIFFICULT
	31 plus points	SEVERE

F.S 703-o

FIGURE 1



Assumed mass of vehicle = 5,000 Kg (maximum)

Assumed maximum slope = 45°

Assumed average speed on slope = 0.5 mph ($\approx \frac{800}{3600} ms^{-1}$).

Theory for this condition: $ma - mg \cdot \sin\alpha = 0$, where m = vehicle mass, a = acceleration of vehicle and g = gravitational acceleration.

$\longrightarrow \quad a = g \cdot \sin\alpha \longrightarrow a = 9.8 \sin 45° = 6.93 ms^{-2}$.

"Power" $\triangleq$ Force x velocity

$\longrightarrow$ Power required (ideal) = $5000 Kg \times 6.93 ms^{-2} \times \frac{800}{3600} ms^{-1}$

= 7.7 Kw $\cong$ 7.7 × 1.34 hp $\simeq$ 10.3 hp.

Adjustment for efficiency:

10 % efficiency : 100 hp
20 % efficiency : 50 hp etc.

FIGURE 2

Chapter V.

SILVICULTURAL/MECHANICAL: INTRODUCTION

This chapter and the next two chapters deal with the automatic handling of trees and with their automatic placement into the ground. Both bare-root seedlings and package root seedlings are to be handled by the same mechanisms. Appendix 2 contains a review of seedling types. A review of competing devices is to be found in Appendix 1.

Review of the overall problem of mechanical tree planting. The following problems need to be addressed in the design of mechanical tree planter:

(1) Carriage of the tools over the ground.

(2) Correct spacing of the trees and hence of the tools which plant the trees if several tools operate simultaneously.

(3) Correct choice of planting spot (amid a chaos of ground obstacles).

(4) Storage of the seedling trees on the device.

(5) Maintenance of seedling vigour in storage in case of machine failure; if the device is operating properly the trees are not in storage for more than ten hours.

(6) Transfer from storage to a placement device.

(7) Placement. This includes the placement of both bare-root and packaged trees. Placement involves:

   (a) Possibly light ground preparation - the clearing of organic overlay to expose mineral soil or possibly the mixing together of the organic overlay and mineral soil.

   (b) Excavation. This could be combined with ground preparation. Two methods exist which simultaneously place and excavate. One of these is the design to be described here.

   (c) Placement of a tree.

      i) Bare roots lowered or dropped into an excavation or root packaged lowered or dropped;

ii) Backfilling and tamping. At least one placement does not require backfilling or tamping;

(8) Tool retracted from the ground.

(9) Tool reloaded.

Whilst these functions certainly need to be performed they may not be performed as separate operations or be performed by distinct machine elements.

Introduction

The handling of seedling trees mechanically is difficult because the trees have an odd shape for machine handling, they do not have a uniform size, there is a variety of root preparations, the trees are not rigid, they are subject to damage by bending, abrasion, pressure and tearing. Trees are subject also to damage by dehydration and by over-watering. The conditions of storage are understood (British Columbia Ministry of Forests, 1984). Here they are put aside whilst a basic method of handling is got clear.

To obtain automatic handling four interconnected functions need to be mechanised. The trees have to be stored. They have to be retrieved from storage. They have to be transferred from the store to the ground or transferred at the point of retrieval to a device which carries them to the ground. They have to be placed into the ground.

Two functional sequences and some subtypes related to one or the other of them have been explored.

In one group of methods a tree is retrieved from storage and transformed to the ground for placement in a continuous operation. Each tree is firmly held until firm placement into the ground has been achieved. No intermediate transfer loose or otherwise is performed. It was intended that loose transfer (e.g. by dropping or blowing) be avoided. It was intended also to avoid the need for intermediate loose transfer, for example, following retrieval from the magazine and before transfer to the ground. Loose transfer is an obvious potential source of malfunction. A point of transfer even where loose transfer is not used is also a potential source of malfunction.

A difficulty with the approach which avoids transfer is that of keeping the magazine away from the ground. If it is too close to the ground interference with the magazine (or store) and ground obstacles may occur. The removal of the magazine from the ground gives rise to a subsidiary problem to do with the orientation of the trees (see below) before they are placed into the ground. This problem can certainly be overcome but doing so involves the use of at least one sub-mechanism which it would have been preferable to have done without.

The orientation problem can be overcome by the use of an intermediary transfer mechanism; several storage methods can be used. Whilst it was preferred to avoid transfer there appear to be advantages in the use of a non-loose transfer. For patenting purposes there are distinct mechanisms which use a transfer and which need to be described.

A key observation.

In the literature of silviculture (e.g. ASAE, 1981) the problem is discussed of mechanically separating an individual tree from a bunch of bare-root seedlings; the same problem arises when packaged root seedlings are used if one approaches in this way. It appears to be a difficult problem and it has not been solved. The methods used here avoid the problem.

When in the tree nursery bare-root seedlings are lifted for transplanting into the final growing site they are root trimmed and packaged into bundles (25 to 50 or so). The trimming is done by hand. Each tree is picked from a lifted pile. The roots are shaken free of soil. The roots are trimmed if this is necessary. A counted bundle is then made up. In the course of this process each tree is singled out and then merged back again into a collection so that re-singling becomes necessary in order to plant a tree. A human planter can perform this separation effortlessly. It is a difficult problem for a machine to perform. It is a particularly difficult problem for a machine which has no sensory system. The time honoured methods used in agricultural machinery of performing sequences of sorting (by shaking, rolling, dropping, etc. over meshes) seem not to be applicable to the handling of trees. Hand feeding of course overcomes the problem but it is intended that a system be designed (vehicle/tool) which uses one human operator. Hand separation and feeding of each planting tool is not possible in this case.

Our solution to the problem of mechanically separating trees before placement is to avoid having to do it. At the point where in the lifting and bundling process a tree is separated (here "tree" means either a bare-root tree or a packaged root tree) instead of bundling each tree, hand fed magazining is to take place. The trees in a magazine are to be kept separate. They are to be automatically retrieved separately from the magazine.

In the section on handling a variety of magazine types is described. They share in common a "clip" sub-mechanism; each tree is held in a separate clip.

In all but two existing methods of placement an excavation is made and a tree placed into the excavation. The sequence is followed in machine furrow planting and in hand planting. In the existing automatic planting systems for packaged trees placement consists of loose dropping into an excavation. We have attempted to avoid loose dropping and to avoid the sequence in which a tree (its roots or root package) has to be placed into an excavation which has been previously made. This type of placement gives rise to problems to do with getting the desired root placement and to do with getting vertical placement of trees, problems which are difficult to deal with other than by hand adjustment. They are best avoided. The placement system which has been used here affects simultaneous excavation and root placement. The tree being placed is held firmly and vertically until closure of the excavation occurs. The method used is a development of the hand operated tobacco transplanter; a different structure is used and a different functional sequence.

In the sections which follow placement is dealt with first then handling and then conceptual exploration of the structure of a device, a combination of the placement and handling methods which have been explored which could act as an automatically operating tool, a member of an array of identical planting tools.

In the vehicle section and in the section on placement only one principle of operation is discussed. We have found no workable alternatives. In the section on handling one method was found originally which would suffice to handle the full range of bare-root and packaged root transplants. With the use of this method sub-problems occur. In attempting to solve them a collection of further methods was found. They are all related to the original method in their use of an individual gripping element for each tree. Each magazine is conceptually a sequence of gripping mechanisms. There is sufficient variation to give rise to the need to discuss the individual methods and the sub-problems which each one has associated with it.

Three types have been singled out there as having advantage enough to make a more detailed exploration of them worth undertaking.

It was intended that enough detail be entered into in the sections on the vehicle, placement and handling to provide a clear context for the work on spacing and choice. Enough work has been done here so that an operational sequence can be abstracted from at least one of the placement/handling concepts, among the variety of handling devices which have been found. Once these sequences can be abstracted work on their control can proceed.

The level of detail entered into when dealing with the range of variation of handling methods is that which is sufficient for an International Patent specification.

Chapter VI.

SILVICULTURAL/MECHANICAL; PLACEMENT

The device described here is intended to automatically place into the ground tree seedlings, the seedlings of other plants, plant cuttings and seeds as single entities (pelletized). A major application is in the large-scale planting of seedling trees in commercial forestland.

There are three main families of commonly used seedling trees.

(1) Bare-root transplants.

(2) Packaged root transplants derived rom the bare-root type.

(3) Packaged root transplants which are grown as such.

The following families of mechanical planting methods can be distinguished.

(1) Furrow planting.

(a) Continuous furrowing

(b) Intermittent furrowing

Furrow planting methods do not work in typical logged ground because of the presence of obstacles which include the stumps and root systems of trees. Hand fed versions of furrow planters exist. With them bare-root and packaged root trees can be planted in ideal conditions (i.e. obstacle free and preferably cultivated soil). The handling methods which are described in the next chapter could be used to make furrowing devices self feeding.

(2) A family of automatic tools and hand operated tools making use of the principle of operation of the hand operated tobacco transplanter (Diagram 1). These tools are used to plant individual spots. They are in principle suitable for planting in logged ground in the presence of ground obstacles.

There exist automatic planters (Appendix 1) based on the tobacco transplanter principle. They each spot plant (i.e. place in a specific spot rather than in a furrow) a small number of types of package (commonly one type). They are not able to handle and place bare-root seedlings. Neither can the existing devices handle and place the full range of commonly used packages.

The present device is a member of this family and is claimed to have significant advantage over the standard placement principle opening it up to being able to be automatically fed by non-loose transfer from a magazine and to being able to place the full range of commonly used bare-root and packaged root transplants. The present device combined with a handling device of one of the types described in the section on handling forms a tool which could operate automatically handling and placing the full variety of commonly used bare-root and packaged root seedlings.

(3) Injection Planting.

In this method which is an experimental one, trees are grown in hard cases. The tree in its case is injected into the ground (like driving a nail) by a hand operated mechanical device with no excavation having to be made. To date the method has not proven biologically satisfactory and the cases used have been too expensive. (Apt, 1981: Riley, 1983) The method is inherently one to be used for a specific type of package.

(4) Friction Dibble.

This method is an experimental one. It is specifically designed to place bare-root seedlings into the ground in well cultivated soil. In this method the seedling roots are placed by hand between two paired plates which are held above the ground. The inner surface of one of the plates has a greater co-efficient of friction than the other plate. The plates with the roots between them are plunged into the ground. The plate having the lower co-efficient of friction is withdrawn. The roots are held by the plate having the higher co-efficient. This last plate has a lower co-efficient than the soil which now impinges on the side of the roots where the first plate has been withdrawn. When it in turn is withdrawn the soil holds the roots.

The method is reported to work in well cultivated soil (Hassan, 1981). It may be observed that if the edges of one or both plates become turned (by use in stoney soil) there is a danger of plate withdrawal either damaging the roots or drawing them up out of the soil.

In operation the hand tobacco planter opens an excavation by opening two paired plates which have been plunged into the ground (Diagram 1). The seedling or the thing to be planted is then dropped by hand into the slot which has been made.

The automatic mechanical planters which are based on this principle (Appendix 1) use a sequence of action which is functionally identical to the hand tobacco transplanter. The seedling to be placed is loosely dropped into the excavation or loosely blown in by a mechanical device rather than by hand.

Automatic transplanting using this principle is in practice confined to packaged root seedlings. It is difficult using any form of loose dropping to place correctly bare root seedlings. It is difficult to place correctly by loose dropping even packaged root seedlings.

The present device resembles the hand tobacco transplanter. However, it has an additional structure - a gripping device for holding the seedlings or the things which are to be placed - and it performs a different functional sequence.

The gripping structure is an essential part of the present device though will be seen they may be incorporated into the feeding mechanism in a fully automatic system (Diagram 40, Chapter 7). For explanatory purposes the gripper can be thought of as a clothes peg like structure or any calliper like structure which is either sprung or in some other way kept either open or shut. In the present discussion a gripper which is sprung shut may be imagined to be used. Grippers working by other principles are described in Chapter 6. The use of these latter grippers renders the feeding of the placement mechanism automatic.

The present device can be distinguished from the hand tobacco transplanters and the family of related automatic mechanisms by comparing the functional sequences performed by it and these other devices.

In all forms of the present device:

(1) The object to be planted is held firmly above the ground by a gripper (Diagram 40, Chapter 7).

(2) Excavation plates are correctly positioned around the seedling roots or root-pack whilst the seedling is held above the ground.

(3) The plates and the gripping device (and hence the seedling) descend to the ground together.

(4) The plates and seedling roots, bare or packaged, enter the ground together.

(5) The seedling is still held by the gripper. The roots are straight down in the excavation.

(6) The plates widen and withdraw. The seedling is still held by the gripper.

(7) In the preferred method a fill is injected around the root pack or the bare-root from the plates as they withdraw (as is preferred) or subsequent upon the withdrawal of the plates. Injection is to occur preferably from the plates, from an orifice or more than one on the inner surface of each plate. In this position there is less likelihood of the injection ports becoming plugged with soil.

Mechanical closure could be performed but is less preferred because of the presence of ground obstacles. This closure could be performed by the placement plates or by other plates, rotating cams, etc.

(8) Once the placement plates are free of the ground and the excavation has been closed and the closure mechanism if any is free of the ground the gripper is released automatically.

(9) The whole tool is withdrawn as necessary and prepared for subsequent operation.

The following sequence of action is performed by the tobacco transplanter and the automatic versions: there is no functional equivalent to the gripper operation.

(1) Two or more plates are driven into the ground.

(2) The plates are separated, opening an excavation.

(3) The seedling is dropped between the plates (by hand, dropped mechanically or blown).

(4) (a) In one version filling material is dropped into the excavation and then the plates are withdrawn (Panthe, Appendix 1).

(b) In the hand version the plates are withdrawn and the seedling is hand adjusted to get it vertical. The excavation is hand closed.

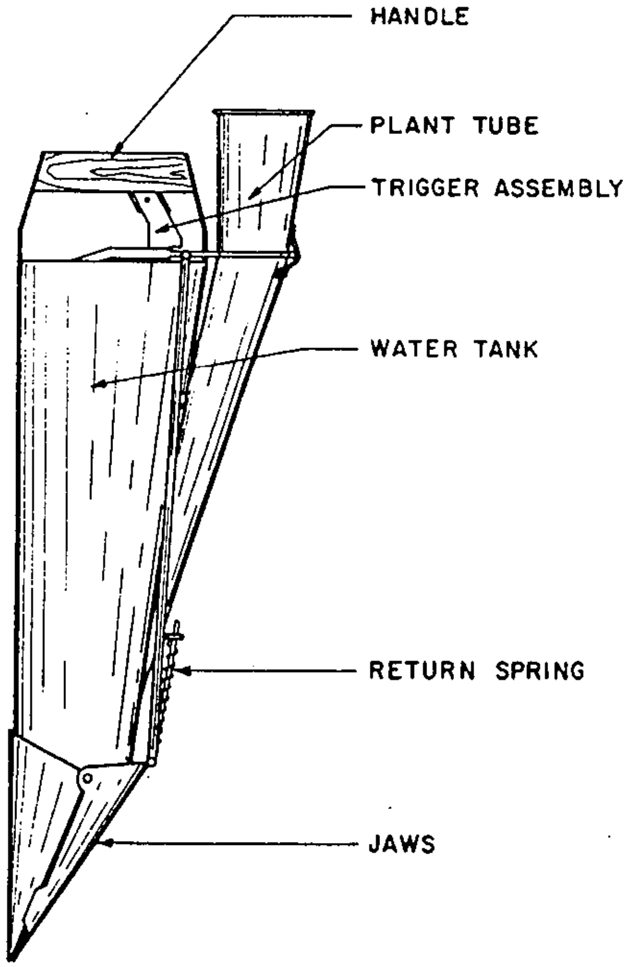
(c) In the other automatic versions closure appears to be mechanical. On the sites on which these tools are being tested mechanical closure may be satisfactory; the methods are still experimental.

There are three residual problems:

(1) Control of the depth of placement.

(2) Halting of the planting sequence if a surface or a sub-surface obstacle is met with which presents full penetration of the plates. An examination of these problems is begun in Chapters 12 and 13, System Review I and System Review II.

(3) The design of the slot filling mechanism and of the filling material. These problems are put aside until later.



[redacted]. Hand operated transplanter for tobacco and other field crops.

DIAGRAM 1.

Chapter VII.

SILVICULTURAL/MECHANICAL: STORAGE AND HANDLING

The devices described here store and feed trees, both bare-root and packaged. One sub-group can be used to package bare-root trees.

A choice has been made to hold firmly in a clip each tree being planted. A variety of magazine/feed devices has been discovered which store trees in clips. A summary of this variety is given later in the chapter. In the main body of the chapter a sub-selection of the solutions implicitly defined by the summary is examined, a collection which appears to be useful. The summary is followed by a discussion of "hybrid" solutions which it does not define. These solutions overcome some problems of detail. The chapter ends with a note on the size of a particular type of magazine.

A major difficulty in mechanising the planting of seedling trees is that there is a variety of bare-root seedling types and sizes and there is a variety of package root seedling types and sizes. There are three main families of commonly used seedling trees:

(1) Bare-root transplants.

(2) Packaged root transplants which are derived from the bare-root type.

(3) Packaged root transplants which are grown as such. In the target market area (North America) the pattern of use of the different types varies. In the U.S.A. at least two thirds of the trees planted are bare-root. In the prime silvicultural region of the country, the south-east, there is deep soil, good moisture supply and a comparatively long growing season. Bare-root stock does well. In Canada there is very little top soil, comparatively short growing season, within some regions a dry summer. Packages survive better than bare-root trees in these conditions. In Canada the American proportion of bare-root to packaged root trees planted is more than reversed; in British Columbia only 5% - 7% of trees planted are bare-root. (Information verbally from the British Columbia Forest Service: February 1, 1989).

These facts point to the need for an unspecialized device, at best one that can store and handle the full range of commonly used bare-root and packaged seedlings, less preferred a family of devices each one a minor variant of another, the whole family being able to store and handle the full range. (There are some unusually large seedling types - up to 1m in length from root tip to crown top with each tree weighing nearly one half pound.) They are very rare. It will be seen that in principle handling and planting such trees is no different to handling and planting the smaller trees. The smaller types have been concentrated on. Handling the larger types mechanically would involve a larger calibre tool of a type identical to that for handling the smaller trees.

Information about tree sizes and weights is to be found in Appendix 2.

Each member of the family of devices which is described here is designed to store and handle the full range of commonly used bare-root and packaged root seedlings with no preparation of the seedlings (such as re-packaging) being necessary. The seedling are used as they are.

There is no existing mechanism with these abilities.

There is no automatic mechanical storage and handling system for bare-root transplants. The mechanical planters of bare-root trees which exist are all hand loaded.

There exists experimental automatic planting devices for package root trees (Scandinavian). Each of these devices is able to handle a limited number of package types (commonly only one type). The handling which is performed is in the form of loose dropping or blowing of a tree into an excavation.

There is no automatically operating storage and handling device which will hand both bare-root seedlings and package root seedlings.

The family of devices which is described here is claimed to be an improvement over the prior art inasmuch as each device will store, retrieve from storage and handle the full range of commonly used bare-root and packaged root seedlings; each device is unspecialized.

Further advantage is claimed inasmuch as loose transfer to the ground from storage is avoided. The seedlings are in one sub-group of devices continuously transferred from the magazine to the ground. Each tree is gripped and held vertical until it has been placed in an excavation (See Chapter 5 on

Placement) and the excavation has been closed around the roots or root pack. In a second sub-group a non-loose transfer of each tree occurs from a magazine to an intermediary mechanism which then transfers each tree to the ground. As before each tree is held vertical until its roots have been placed in an excavation and the excavation closed.

The placement method used by both sub-groups is the same. The method should result in a higher percentage of properly placed seedlings than can be achieved by loose dropping. It avoids the need for hand adjustment of the seedlings subsequent to mechanical placement.

Continuous transfer is preferred because a point of transfer either loose or non-loose is potentially a point of malfunction. It also seems functionally wasteful to grip (at the time of hand fed magazining) and then either ungrip and regrip, or regrip with no ungripping (e.g. a closed clip containing a tree is transferred from a magazine). However a disadvantage of using continuous transfer is that a sub-mechanism is required to re-orient each tree to a vertical position. This need arises from the prior need of keeping the magazine well above the ground, that is, at some remove from the point of placement, so as to avoid the possibility of the magazine case being interfered with by ground obstacles. The removal of the magazine from the ground and the needed re-orientation of the trees can certainly be achieved (but other forms of solution were explored). In attempting to avoid re-orientation whilst keeping the magazine at some remove from the ground a second sub-group of storage and handling devices was discovered.

First Family: storage and handling devices having continuous transfer.

In this family of devices transfer from a magazine involving gripping and ungripping before a tree is placed in an excavation is eliminated. Retrieval from a magazine and lowering to the ground is a continuous operation. All the devices in this sub-group make use of a sequence of clips, each of which holds a tree. A division of the sub-group can be made based upon the means by which the clips are opened to release their trees.

Three types of magazine can be distinguished:

(1) A "reel" magazine.

(2) A "box" magazine (like that used in early machine guns).

(3) A continuous "band" magazine.

Type 1 Clips mounted on paired bands.

Clips opened and closed by movement of the bands.

Reel magazine or box magazine used.

Static device (cam-like) re-orienting the trees.

Diagram 1 shows the basic idea of a handling and storage device of the First Type. It consists of two bands B1 and B2. They are rolled separately on the reels RB(1) and RB(2). They are either:

(1) Rolled on top of each other on what is a store reel R (Diagram 1). or

(2) Folded into a box store BX (Diagram 2). (The clip halves must snap together if a box store is used; see below).

Trees (other objects could be similarly handled) are held between the bands by means of paired attachments, one of a pair being attached to one band the other to the other band (Diagram 3 and 4). Each pair of attachments is designed to hold securely and without damage rigid and non-rigid objects.

For the handling of trees the use is made of pairs of "blades" one of a pair fitting onto one band, the other onto the other band. Upon movement of the bands over rollers, onto reels or around guides each pair of blades acts functionally like a tongs or like the blade of a gripper. Opening is achieved by "forward" motion of the bands (Diagram 3). Closure is achieved by "reverse" motion of the bands (Diagrams 1 and 3 direction reversed). An example of a blade and its attachment is shown in Diagrams 4 and 5.

The use of rollers is shown in Diagrams 3 and 6. Their use enables the reels RB(1), RB(2) and RS or the box BX to be arranged in a variety of ways. The use of longer runs between the reels RB(1), RB(2) and RS is shown in diagram 6. Such an arrangement would enable the storage reels RB(1) and RB(2) and either the reel RS or the box BX to be at any desired distance from a point of delivery.

A natural way of storing trees between paired bands is to have them with the stems perpendicular to the long axis of each band (Diagram 7, 8 and 9). Trees stored in this position may be rolled onto a reel (spacers preventing crushing and guides and/or the stiffness of the blades preventing abrasion) with no danger of the stems being bent. If the magazine (box or reel) is at some remove from the ground (Diagram 6) then since each tree must be placed vertically it is necessary either to arrange for a rotation of a tree or to place each tree into the bands in such a way that they are delivered in a vertical position (Diagrams 10 and 11).

If the box store is used then the clips will have to "lock" as there is no pressure such as that obtained from the reel RS to hold the bands together. This "lock" must be such as to open when the bands turn around the guides (Diagram 3) and to close when pressed between the bands. The use of the following "locks" suggest themselves:

(1) Velcro.

(2) A non-hardening glue.

(3) Paired magnets.

(4) A mechanical clip; an immediately useful type and one readily available in a range of sizes is the "snap" clip commonly used on clothing. (Diagram 12).

(5) Button stud (Diagram 13).

The snap clip looks to be a ready solution. The attachment will need to be sturdy. They exist in robust form for industrial uses. With the use of this clip, guides may have to be placed on the blades to prevent slippage of the blades when the bands are folded in a box magazine, Diagram 14.

For all but the largest trees paired bands which are large enough to cover completely both roots and crown of a tree can be used. Spacers need to be used (Diagrams 3, 5 and 15) to prevent crushing of the crowns. Such spacers with have to be handled without crushing of the root package and to prevent more general damage occurring if the loaded bands are rolled on a reel.

If narrower bands are used (Diagrams 7, 8 and 9) so that the crowns and roots are root pack protrude from the bands, a difficulty arises with the store reel. The commonly used reel guides (such as those used on a movie-film guide, Diagrams 16 and 17, cannot be used. Without these guides there is a danger of rolled bands collapsing. This problem can be overcome (Diagrams 18, 19 and 20) but our preference is to use the wider band with normal reel or with a box store.

Action of tongs or gripper.

Once the tong blades reach the position shown in Diagram 3 further "forward" motion of the bands will open the blades. This opening will, in the ideal mechanism, involve no horizontal motion of the three which is being held. In a practical mechanism the release should have a small enough horizontal component to prevent the roots being disturbed or the stem being abraided.

The blades need to be long enough to attain the correct presentation of a tree to the excavation plates.

The weights which have to be carried by a magazine are low. One thousand bare root trees weigh averagely 30 pounds (this includes a cardboard container and packing paper). This number is that which needs to be carried for one days work for one tool. Three hundred to three hundred and fifty package trees (boxed) weigh between twenty five and fifty pounds. Let us say that three hundred package trees weigh fifty pounds. Enough trees for one day's work for one tool will weigh less than two hundred pounds (one thousand trees). Again low weight involved. The weight which has to be carried by a gripper (½ oz - 1½ ozs) is low. The potentially most disruptive forces acting on the blades are the dynamic one which occurs when the planting plates are plunged into the ground and the dynamic force applied to the blade structure by the mechanism of rotation if such a mechanism is used.

In its use as a magazine for trees it is intended that the magazine by hand loaded. An operator will control the movement of the bands; they could be power driven, hand or foot treadle driven. He will place by hand a tree stem and/or crown between a pair of open grippers just before the bands are pressed together in the run to the store reel and, hence, the grippers closed (Diagram 21).

If bare root trees are packaged they could be run through a packer having the form of the device shown in Diagram 22 and collected at the other end by a regular magazine which would then grip them as they emerge from the packer by the crown and stem.

For hand loading it is probably more convenient to place trees between the grippers in a horizontal position (Diagrams 21 and 23). The slices of growing medium could be glued together or stapled (Diagram 24). Experimental sandwich packs already exist (i.e. "BRIKA" packs: ASAE, 1981). Their production is not mechanised.

It would be possible to cold store magazined trees. It might be possible to further grow packaged trees whilst they were magazined. For growing packages would need to be held by the root pack.

Type 2

A band (e.g. a leather belt) with its long axis parallel with the ground (Diagrams 25 and 26) can be bent so that the long axis remains parallel to the ground. Unless the band is made of elastic material or has a circular cross section or has a particular joint structure which allows it, only limited bending is possible so that the long axis ceases to be parallel with the ground (Diagram 26).

In contrast a chain (bicycle type) held with its long axis and with joint bars horizontal (Diagram 27). It has limited flexibility in directions which keep the long axis parallel to the ground. This difference of flexibility can be used to overcome the "rotation" problem - that is, the problem of getting presentation of a tree between the plates.

For the purpose of explanation, imagine a clothes peg mounted on a chain plate. For explanatory purposes the peg may be imagined to the side of a plate. As the chain rotates around a sprocket each side plate changes direction (Diagram 28). At one point each plate is parallel to the ground. A peg mounted on a plate would at this point be also parallel to the ground. If the peg were long enough the tree which it holds would be vertical and presented clear of the chain (Diagram 28 and 29). A tree gripped by a peg mounted as has been described can easily be transferred and brought to a vertical position with the "chain" magazine shown in Diagrams 30 and 31. With the use of the chain and "peg" the automatic gripping and ungripping of the tree by the movement of bands is lost. Each peg would have to be opened by an opening device or closed by a closing device. The use of cams, callipers, etc. suggest themselves.

Type 3

Belts share the properties of chains but depending on construction and cross section they can also have some lateral flexibility. Consider a pair of belts of elastic material and for ease of discussion having circular cross section arranged as a band store. This double belt can now be carried through a vertical angle (Diagrams 32, 33 and 34). The motion through this angle will not open the bands. It is possible to make use of a device which was seen being used to achieve the transfer of seedlings into a furrow (it was hand loaded) in combination with double bands to achieve automatic separation of the bands.

If the sheaves (Diagram 34) are angled as shown then further rotation from the position shown in Diagram 32 and in the direction as is indicated will open the grippers.

We have here a hybrid between a chain mounted system and a band mounted system. There are various alternatives which can be explored. One is to mount the two sheaves so that they can be rotated to obtain a clean release (Diagram 35).

Second Family: storage and handling using intermediary transfer use of band mounted grippers with opening and closure achieved by the motion of the bands. Use of a transfer mechanism.

Type 2A

Transfer involves gripping and ungripping.

Type 2B

Transfer does not involve gripping and ungripping.

The first type is shown in diagrams 36 to 40. The second type is shown in diagrams 55 to 57. Types 2A and 2B both use a band store which is mounted horizontally. This store does not move to the ground with the placement tool.

The placement sequence is identical with that which has already been described.

No re-orientation of the tree to be placed is necessary.

Third Family: storage and handling devices having intermediary transfer of both the clip and its gripped tree.

Trees gripped in clips. Clip with a tree gripped in it magazined as a separate entity. Magazine options as those of the First and Second Family plus the use of firearm style magazines. If the last mentioned type of magazine is used the magazine shape achieves correct orientation (Diagrams 41 to 43). Transfer of clip and gripped tree to an intermediary handling device.

Sub-type 1. Motion used for the transfer is the same as that used to get the placement tool to the required planting spot.

Sub-type 2. Motion used for transfer is in addition to that used for the placement tool motion; transfer mechanism moves.

Sub-type 3. Neither tool nor transfer mechanism move to affect transfer; movement of tree by magazine brings about transfer.

To prevent damage to the crown and the root and to prevent jamming of a firearm type magazine by overturning of a clip a substantial clip can be used. This clip must "lock" so as to hold together in the magazine.

A spring closed clip provides a straightforward solution, a straight opening type being useful for this application (Diagram 15).

The sequence of action used in Third Family mechanism which uses the "firearm" magazine is as follows:

(1) The tool gripper is moved to the magazine "gate".

(2) Each of the blades slots into the tree clip in the magazine gate.

(3) The transfers must fit tightly enough to allow withdrawal of the tree clip (and the gripped tree) to occur.

(4) The sequence to the ground is then the same as has been described.

(5) The "lock" holding the tree clip together must be such as to allow opening by the transfer gripper.

(6) Removal from the ground of the tool is as already described.

(7) A sub-sequence has to be interpolated into the sequence already described; the now empty tree clip must be ejected into a collecting box;

it would be convenient to blow the clip from the transfer gripper (air tool style).

(8) The loading and planting sequence can then begin again.

A functional sequence of a complete planting tool.

The system described is that of a Second Family device shown in Diagram 40. The magazine used can be a reel or a box. A transfer mechanism is used. Each tree is positioned relative to the frame by its handling mechanism which brings about vertical presentation to the plates.

(1) Assume that Type 1 transfer has taken place, the tree is gripped by the transfer mechanism and is in the position shown in Diagram 40.

(2) The tool frame (hence gripper and plates) is lowered to the ground.

(3) The plates and hence the tree roots are plunged into the ground.

(4) Further detail to do with obtaining the correct depth of penetration and with the halting of the placement sequence in case sub-surface obstacles are met with has to be dealt with. (This detail is put aside here.)

(5) The tool plates are drawn up by the yoke. This motion opens them (e.g. by cam action).

(6) The gripper still holds the tree.

(7) As the blades spread and are pulled clear of the soil a fill is extruded from the inner side of each plate (detail put aside).

(8) Once clear of the soil the plates continue to be pulled up until they are placed high enough so as not to interfere with the spreading of the magazine gripper as it releases a tree.

(9) The planted tree is released by the transfer gripper. (It may be advantageous to stop the plates once they get clear of the ground, release the gripper, raise the whole tool whilst simultaneously further raising the plates. The plates would guard the transfer gripper and could act as a rest to react minor tool motion. The device sequences are to be microprocessor controlled so that considerable flexibility as to the sequences which might be used is available.)

(10) The yoke reaches full travel and is stopped by an end-stop. (There are of course other ways of controlling this travel. They include software methods.)

(11) The tool frame is raised until the transfer gripper is correctly positioned relative to the magazine. (Endstop, etc) The sequence of raising the

placement device and replacing the gripper blades on the magazine is performed.

(12) A tree is driven forward by the magazine.

(13) The transfer gripper seizes the crown and stem.

(14) The magazine gripper releases and is driven clear of the tool.

(15) The plates descend around the gripped tree. GOTO (2).

A family of handling devices: summary.

Clip held trees.

A. Sequence of clips on a single band which forms a magazine.

Clips opened or closed by a mechanical device.

Magazine carried on each tool.

Clips permanently attached to band (they may be detachable from a band but are not detached during operation).

Continuous transfer from magazine to ground.

Either	(1)	Continuous tree orientation (e.g. using guides, etc.).
or	(2)	Orientation by a non-static mechanism (e.g. a pneumatic cylinder).

Either	(1)	Storage reel used.
or	(2)	Box storage used.
or	(3)	Continuous band used.

Either	(1)	Clips carried on a flat band.
or	(2)	Clips carried on a chain.
or	(3)	Clips carried on a segmented band.
or	(4)	Clip carried on a belt having circular cross section.

B. Sequence of clips carried on two paired bands, one half of a clip on each band. The double band forms a magazine.

Clips opened and closed by movement of the bands.

Either	(1)	Double flat band used.
or	(2)	Double circular cross sectioned belt.

Either	(1)	Continuous transfer to the ground. i) Orientation options as in the A-group.
or	(2)	Non-loose transfer of each tree {(a) Clip transferred from magazine, or (b) Clip remains in magazine

i) No orientation needed.

ii) It is possible to use magazines in which orientation takes place in combination with a transfer mechanism.

iii) Orientation may be also affected by means of motion of the transfer mechanism.

Magazine options as those in the A-group.

C. Sequence of separate tree holding clips.

Clips not permanently attached to the carrier.

Intermediary transfer used. Clip and tree transferred.

Magazine options those of the A-group plus firearm type case magazines.

Either (1) Motor system in addition to that used for tool manipulation used for transfer.
i) Translation
ii) Translation and rotation.

or (2) Only motor system for tool manipulation used. Orientation of trees: the options of the B-group plus orientation affected by means of the magazine case shape.

Either (1) Magazine carried on planting tool.
or (2) Magazine carried on frame which supports the planting tool.

Applying to all groups:

Either (1) Hand changing of empty magazine whilst working in the field.

or (2) Automatic change of magazine.
i) By static means (e.g. array of magazines presented to tool which loads in a sequence from the magazines in the array).

ii) Non-static means (e.g. empty magazine rotated from the operating position and replaced by full magazine).

or (3) No change of magazine necessary. Magazine holds.

Some of the configurations which are defined by this summary have been described. The summary does not exhaust the possibilities. Combinations can be obtained from the summary which do not appear to be useful. Combinations which are not derivable from the summary may be found. One such combination is described below.

If continuous transfer is used our preference leans towards a double band system with the clips being opened by the motion of the bands, with a box or a reel magazine being used, continuous transfer, static orientation of trees or with no orientation being necessary (i.e. the magazine movement accomplishes the necessary orientation), magazine attached to the tool, and with the magazine holding one days work (see the note on reel capacity below).

If transfer is used our preference is for a system using a double band magazine mounted horizontally and with a non-loose transfer taking place as in diagram 57. The magazine should hold a day's work.

A hybrid solution for continuous transfer.

Both chain carriers and circular cross section belt carriers solve the orientation problem with no auxiliary mechanism being used. The disadvantage of these types is that as they stand neither one can be used with the box magazine or with the reel magazine. Unless they are very large neither the continuous chain nor the continuous belt looks to have good packing density.

The device described here is an attempt to combine the advantages of the flat band (collection on a reel or in a box with the reel preferred as it is easier to load) with those of circular cross section belts.

The belt can be made to pass through both vertical and horizontal angles. Although it can be wound onto a reel, a device making use of two belts such as we will propose here - with trees held between them - are not readily wound without danger of tree damage and of entanglement. The reel guide problem which arises when narrow bands are used also arises here.

The winding problem and the reel guide problem can be overcome with one device, that of winding onto the reel with the double belt a single wide band; for certain purposes double bands can be used (see below). Diagrams 47, 48, 49, 53 and 54 show such an arrangement.

The concept shown solves the orientation problem simply and robustly. It also enables reeling to be made use of. The device could be used for packing. It does have a residual problem which is shown in Diagrams 50 and 51. Held in the manner shown in these diagrams the stem of a bare-root tree has little danger of bending under the weight of the roots. Depending upon the weight, the length of a root pack, its state of thaw if frozen in cold storage and the length of the stem which acts as a cantilever and takes the bending moment bending of the stem or the pack or both the stem and the pack could occur. The problem can be alleviated by using a gripper of the kind shown in Diagram 52. It would be easy to grip the pack as well as the stem and this would solve the problem. If this is done then the pack gripping mechanism will end up in the excavation made for the root pack. Our plan was to hold the tree during back-filling. If this is done the root pack gripping device becomes surrounded by fill.

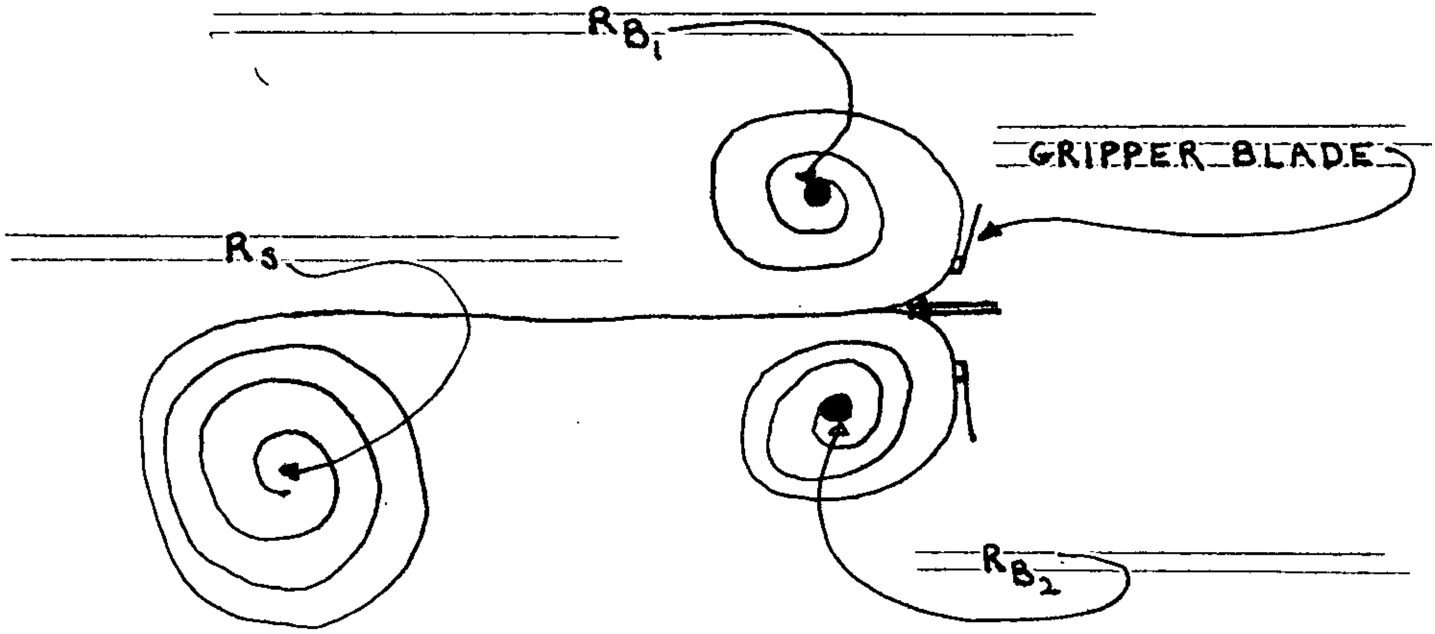
If just the corners of each pack were gripped then the use of sheaves to open the gripper will have the effect of both spreading and lifting the pack grippers as they are removed from the pack. This may leave the pack shoulders exposed with no fill around them.

The bending problem hinges on the question of the stiffness of a given tree stem under a pack load (with different lengths of cantilever, etc.). This is a question which will have to be resolved empirically. It is left for the next phase of work.

A second hybrid.

In anticipation of the problem of bending having to be solved more strongly a further solution is described in Diagrams 53 and 54.

Other hybrids can be found.



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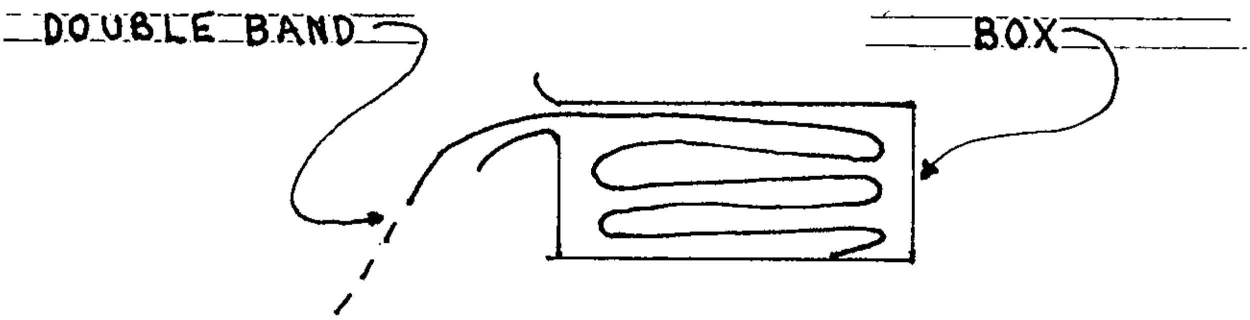


DIAGRAM 2

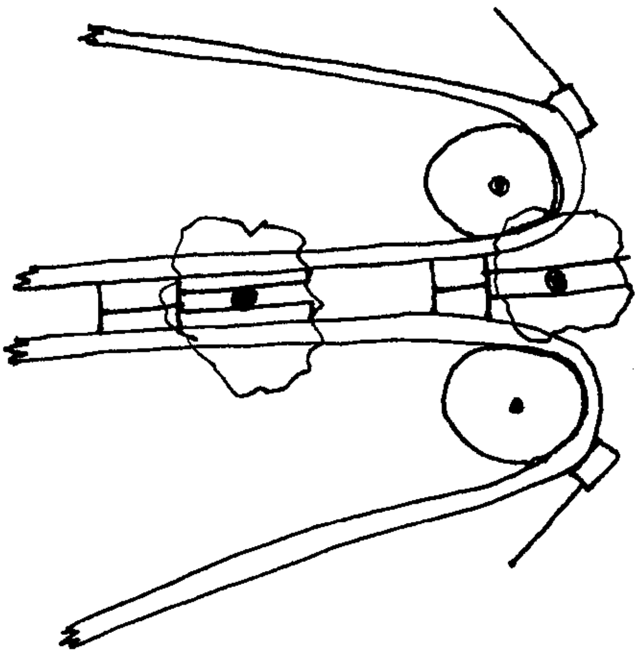


DIAGRAM 3

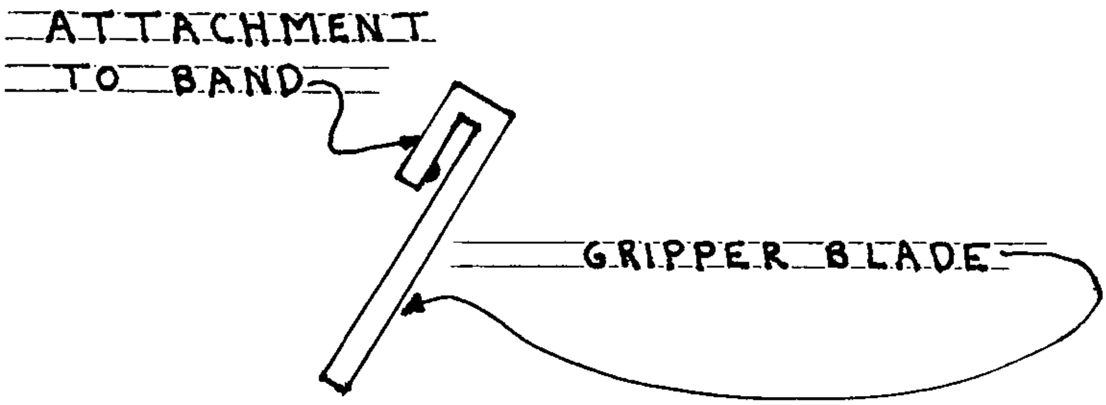


DIAGRAM 4.

Note: The blade attachment must either precede the trailing end of the gripper blade or be at the gripper blade trailing end to achieve proper opening.

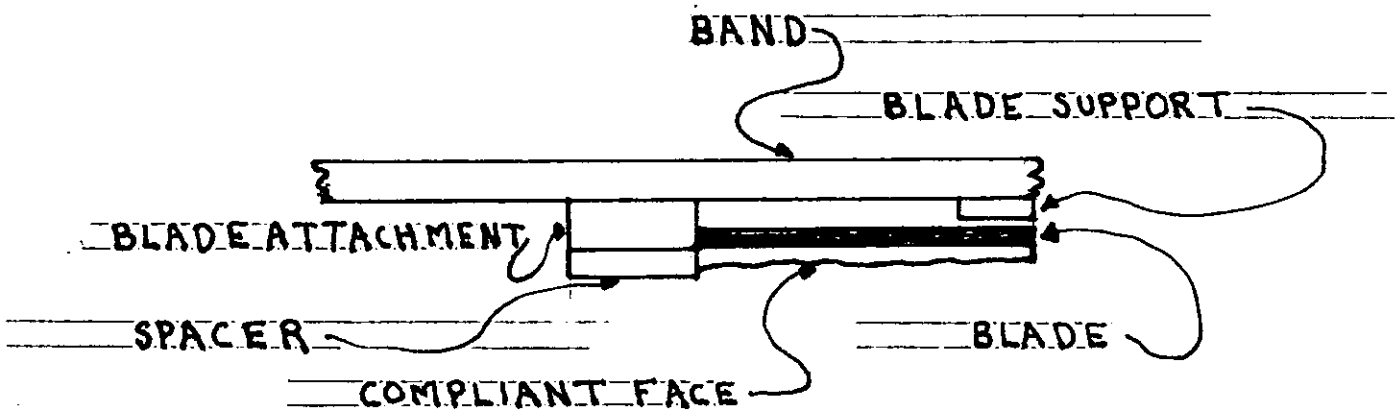
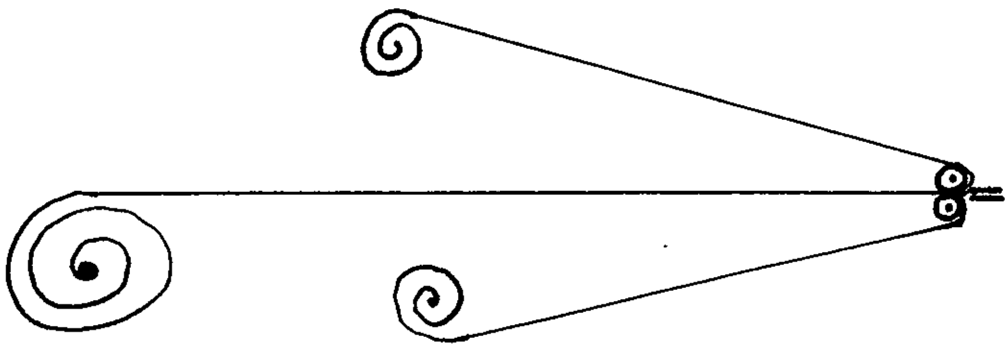


DIAGRAM 5.



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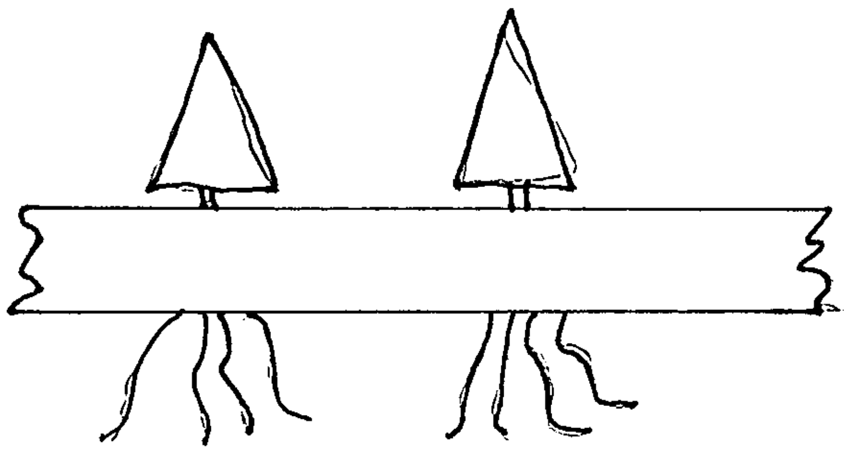

DIAGRAM 7.

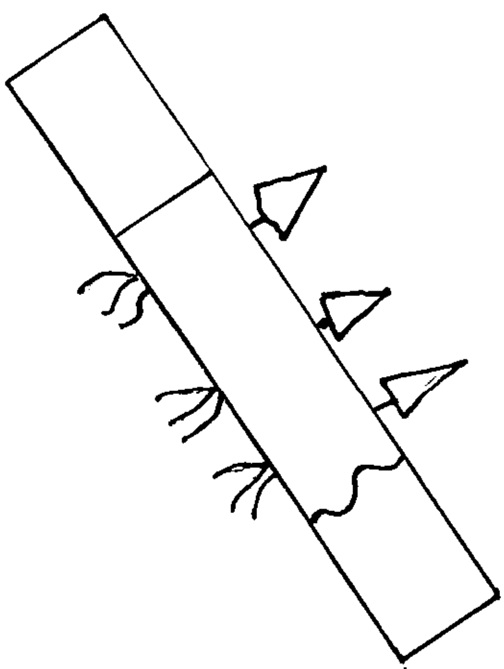

DIAGRAM 8

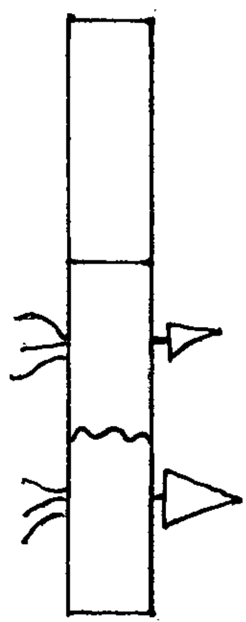

DIAGRAM 9

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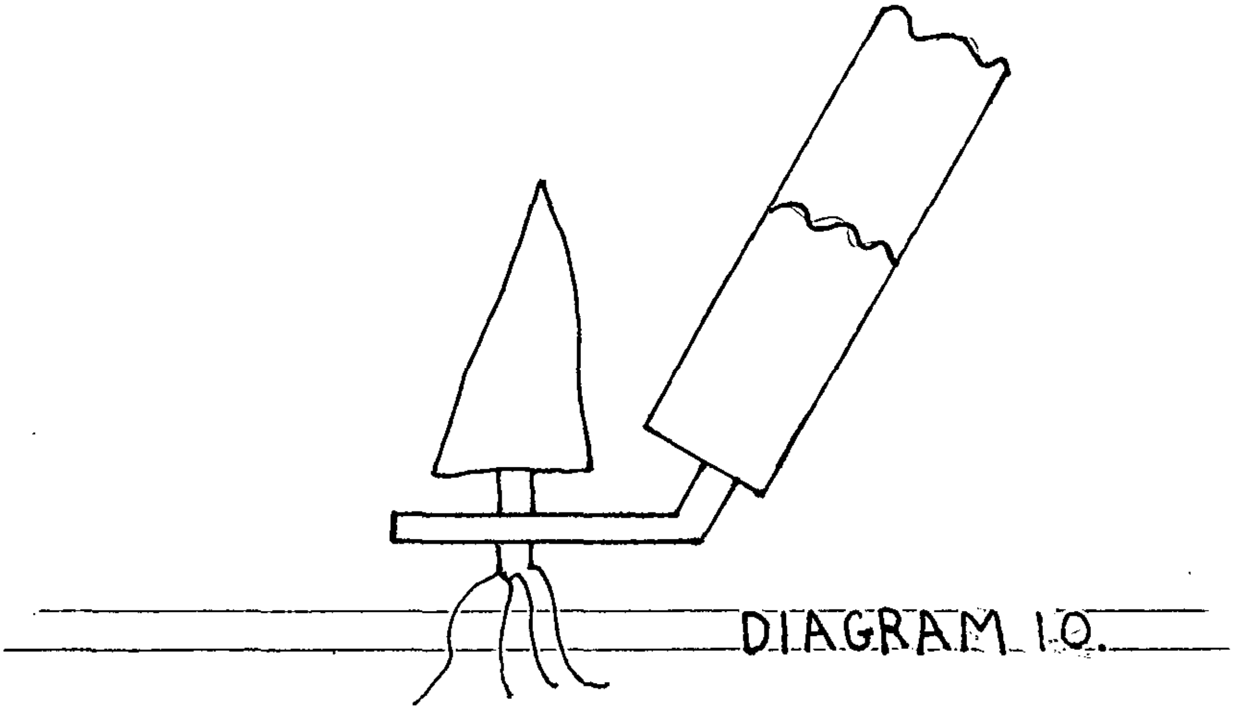


DIAGRAM 10.

TO B_1 or B_2

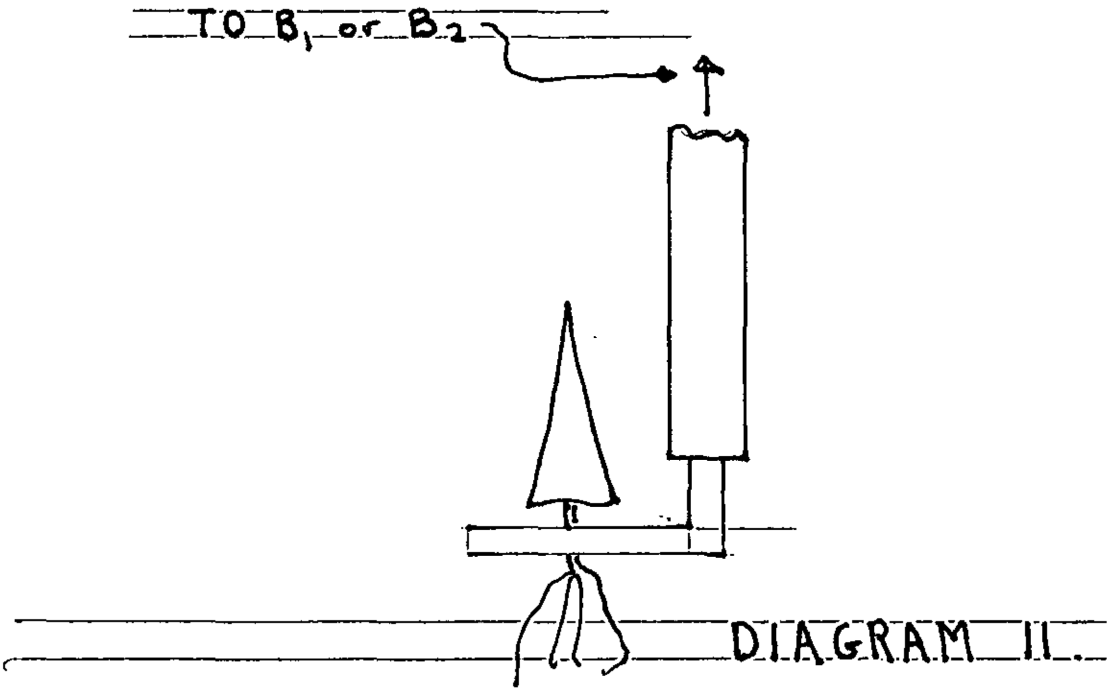
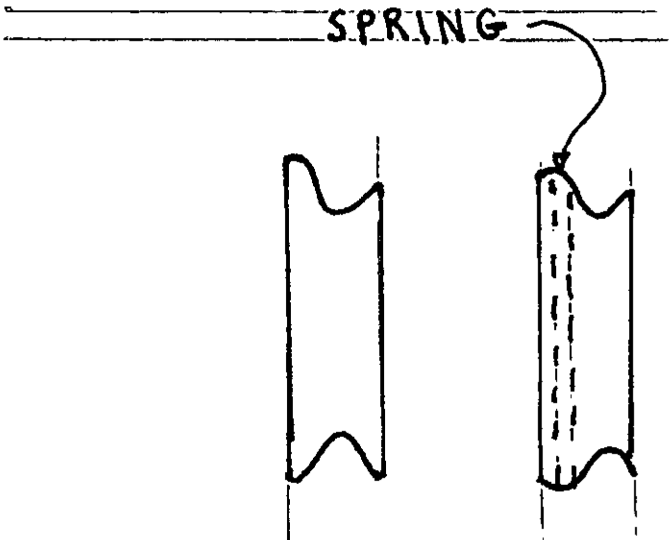


DIAGRAM 11.



DIAGAM 12.

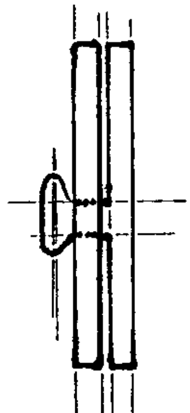
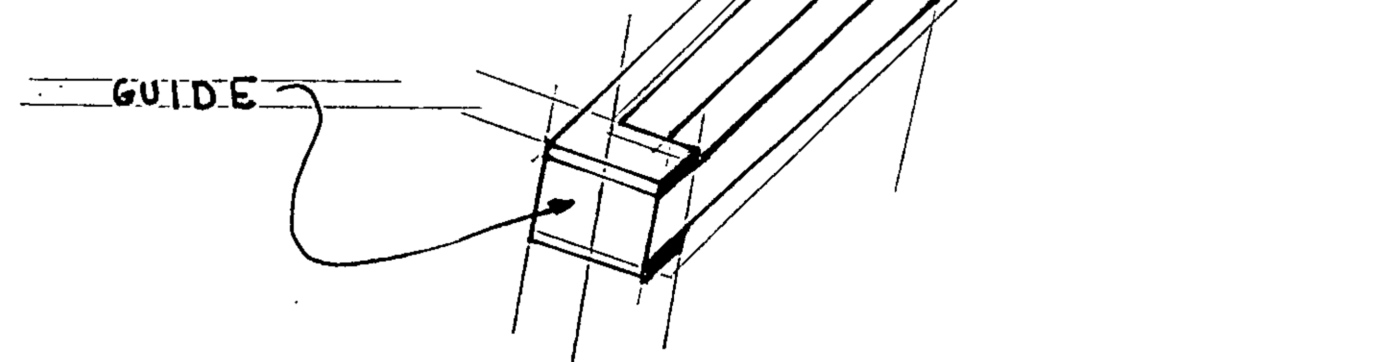


DIAGRAM 13.



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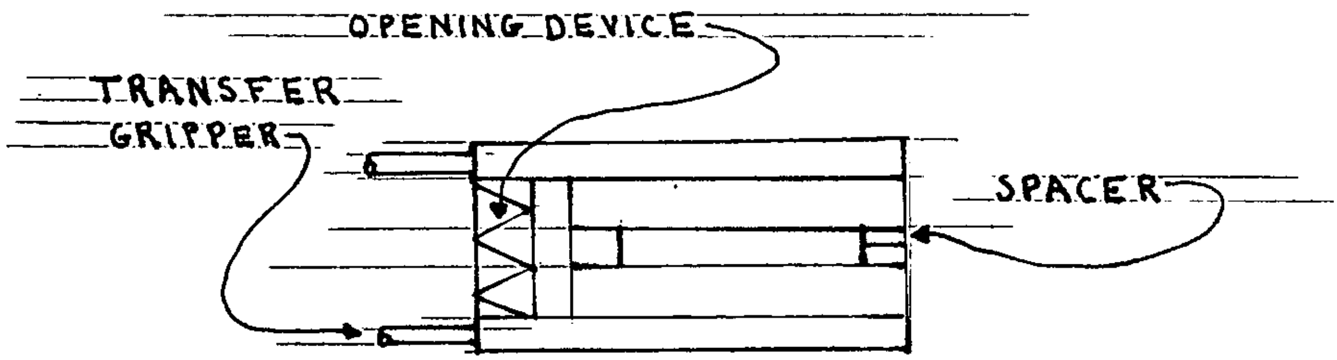
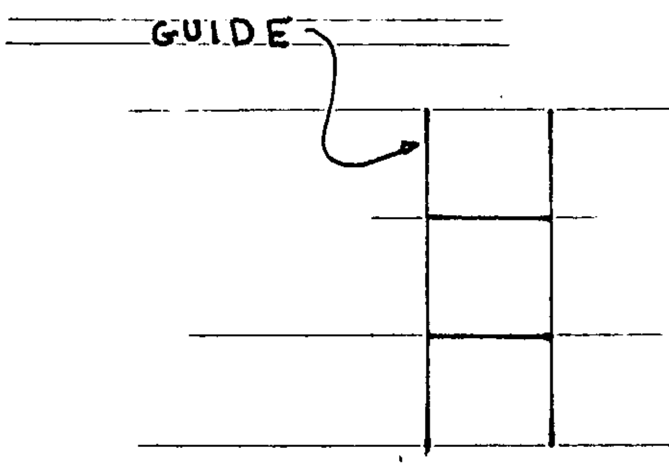


DIAGRAM 15.



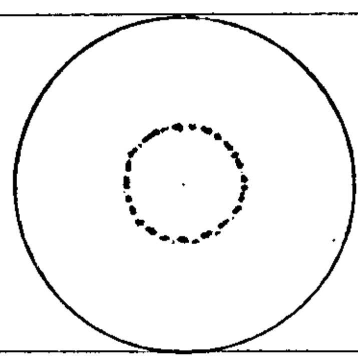


DIAGRAM 16. DIAGRAM 17.

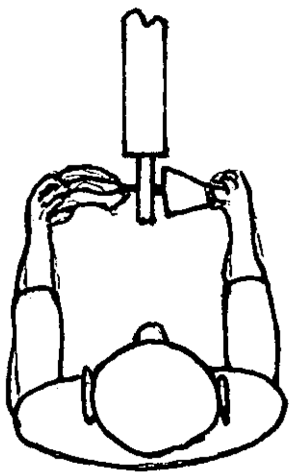


DIAGRAM 21

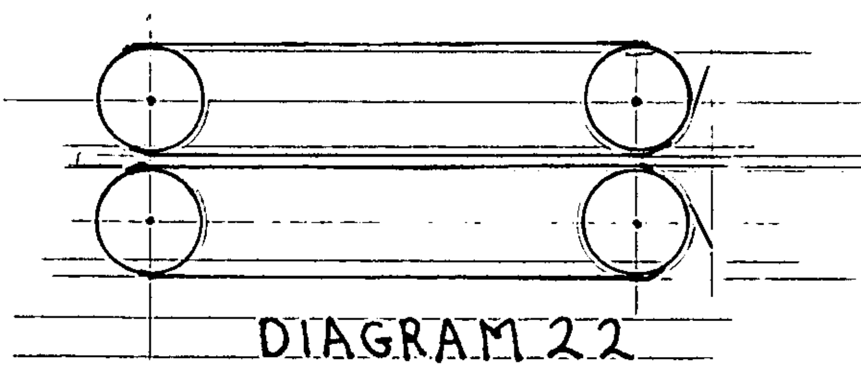


DIAGRAM 22

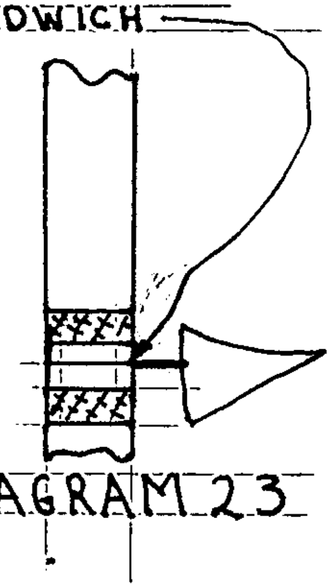


DIAGRAM 23

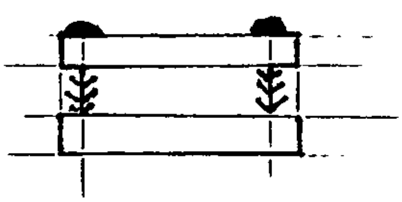


DIAGRAM 24

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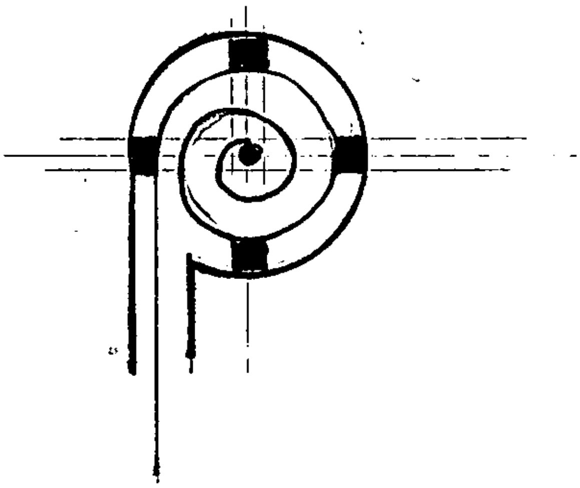


DIAGRAM 18.

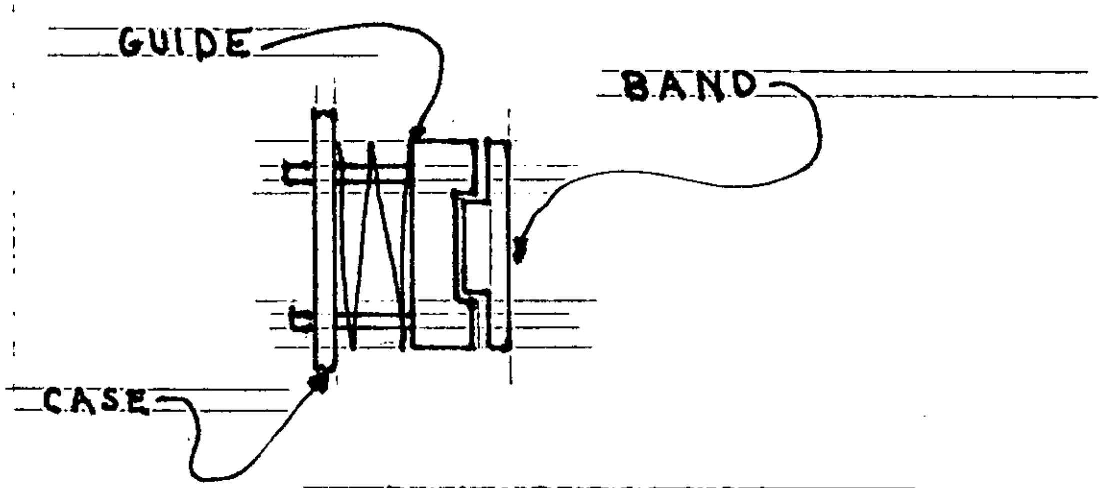


DIAGRAM 19

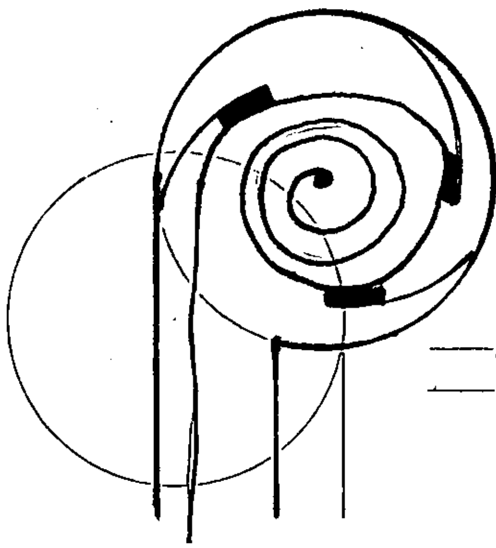


DIAGRAM 20.

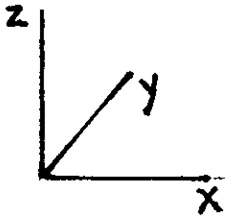


DIAGRAM 25

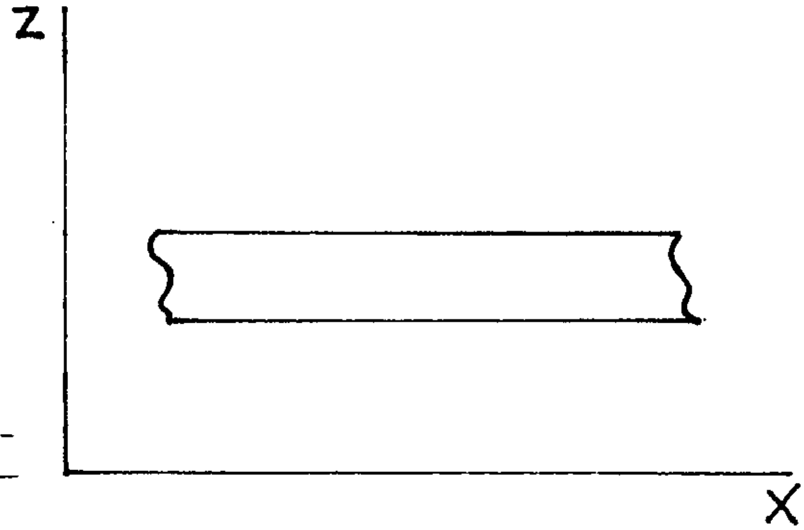


DIAGRAM 26

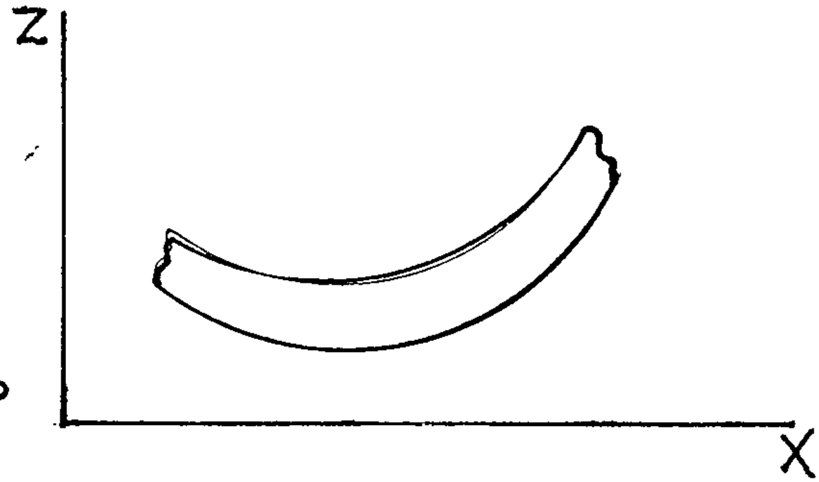
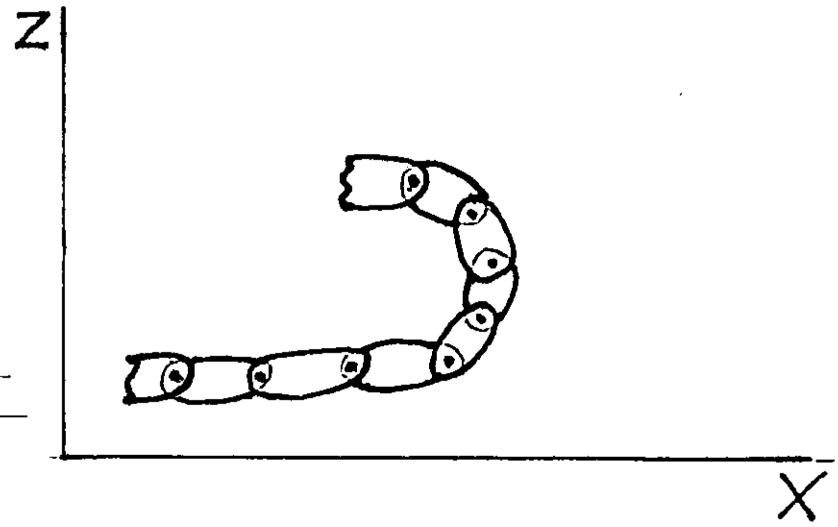


DIAGRAM 27



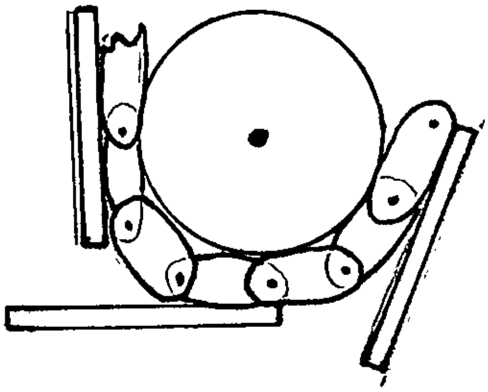


DIAGRAM 28.

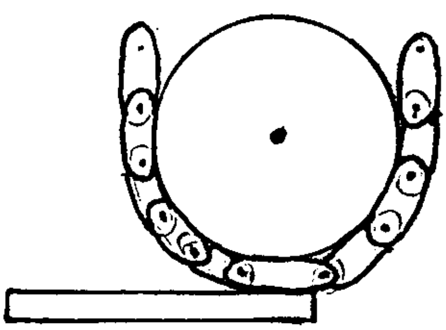


DIAGRAM 29.

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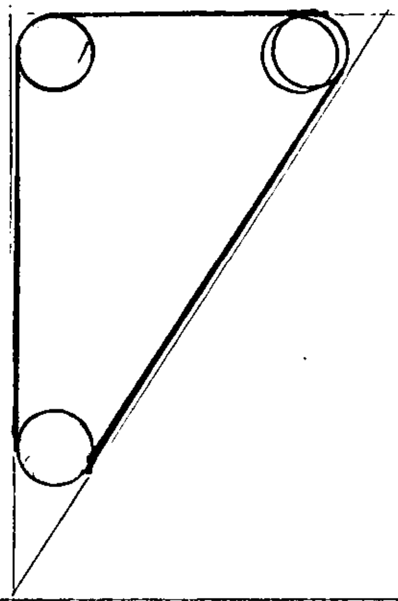
DIAGRAM 30

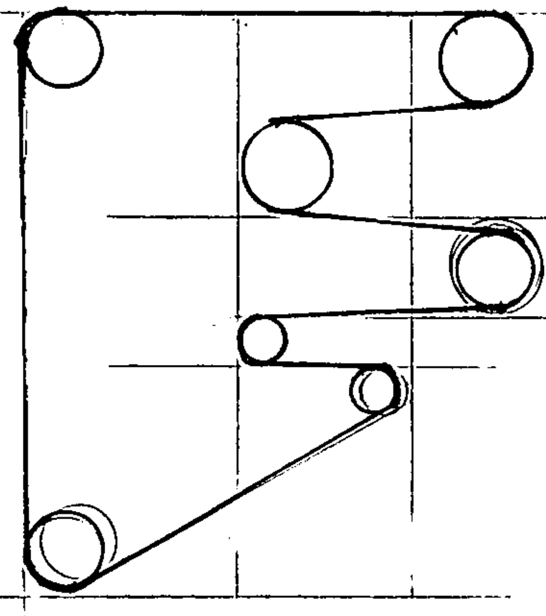
DIAGRAM 31

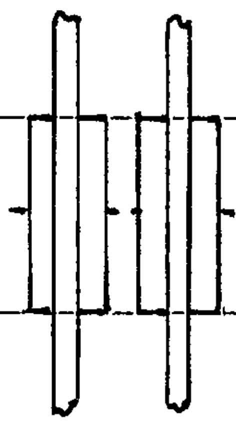
DIAGRAM 32

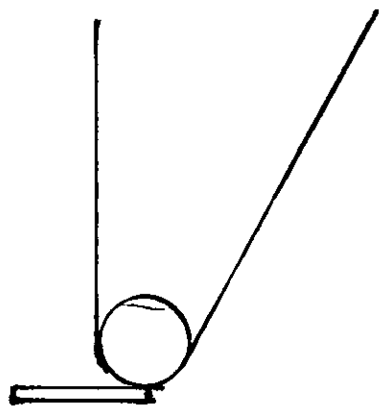
DIAGRAM 33

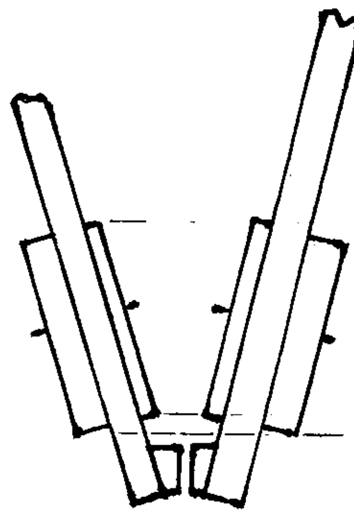
DIAGRAM 34

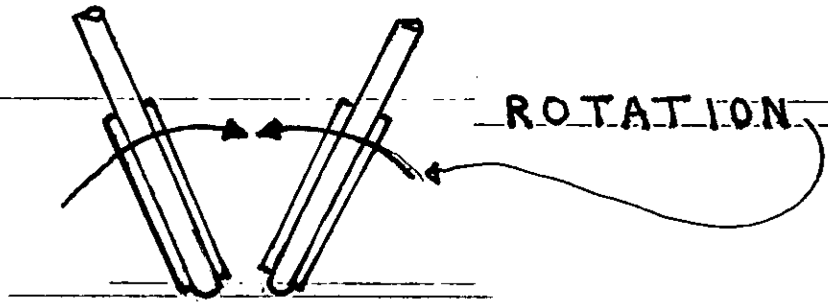

DIAGRAM 35

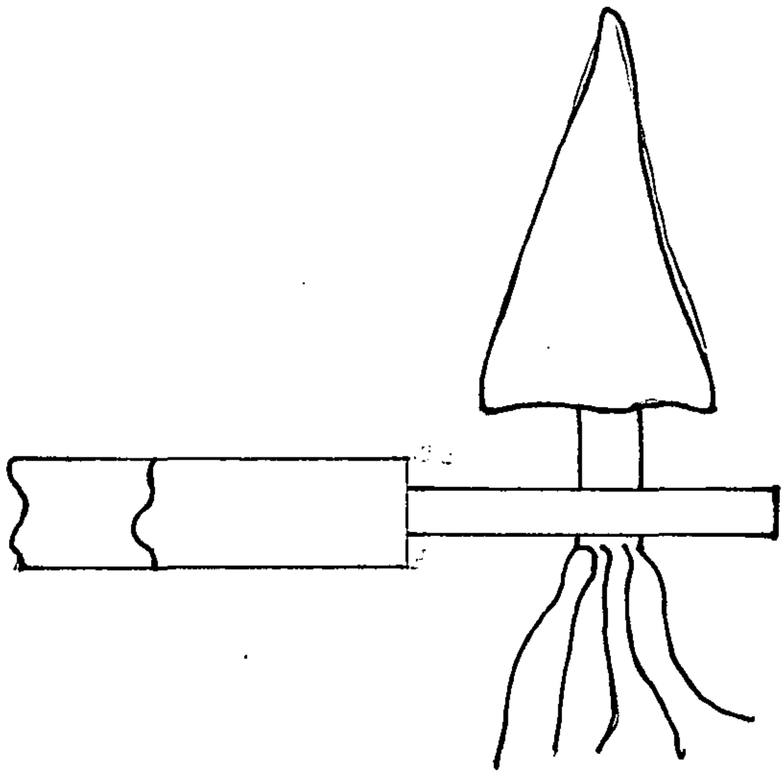

DIAGRAM 36.

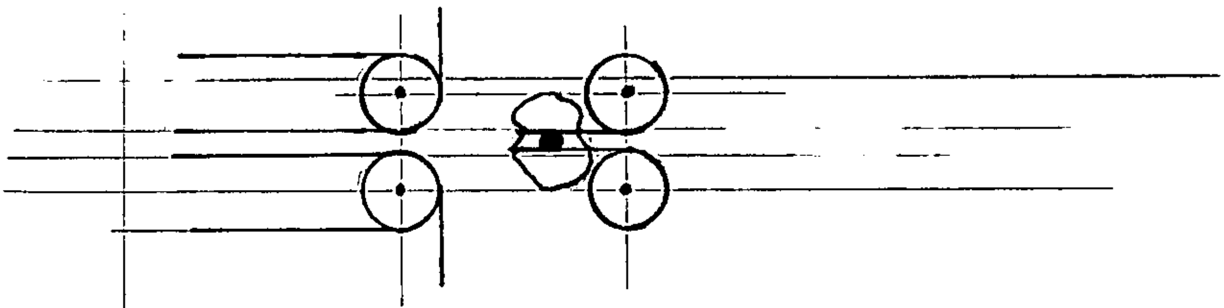

DIAGRAM 37.

SEEDLING GRIPPED BY TRANSFER MECHANISM - VERTICAL AND ORIENTATED FOR PLACEMENT.

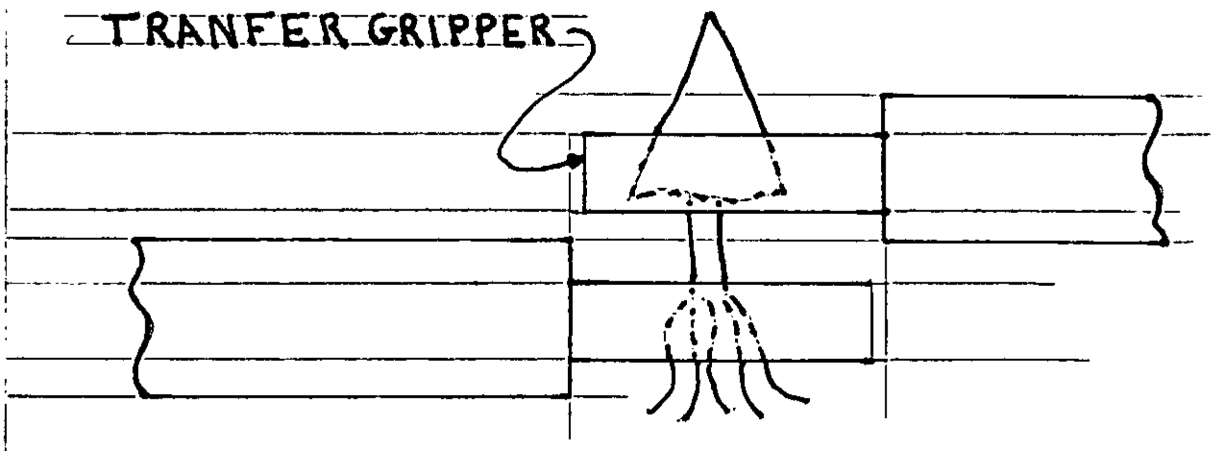

DIAGRAM 38.

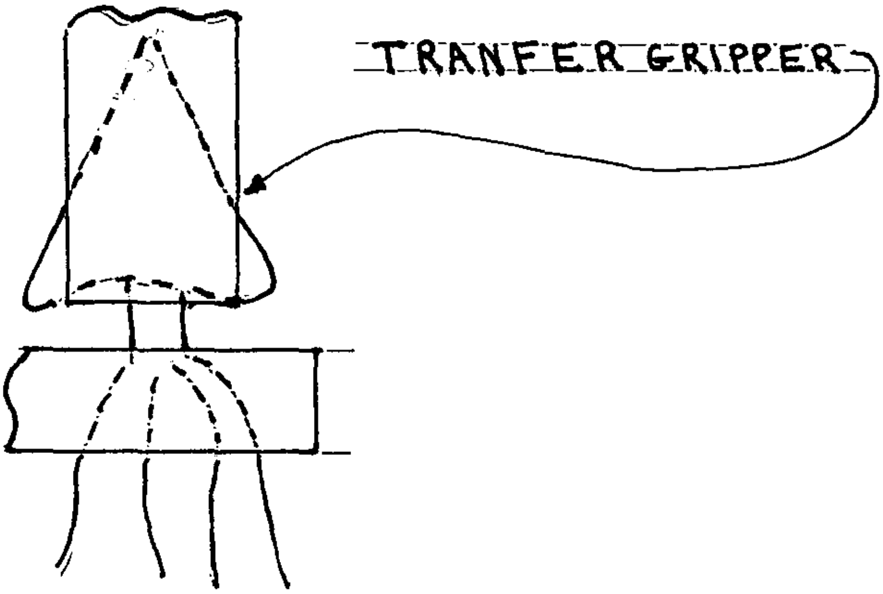

DIAGRAM 39.

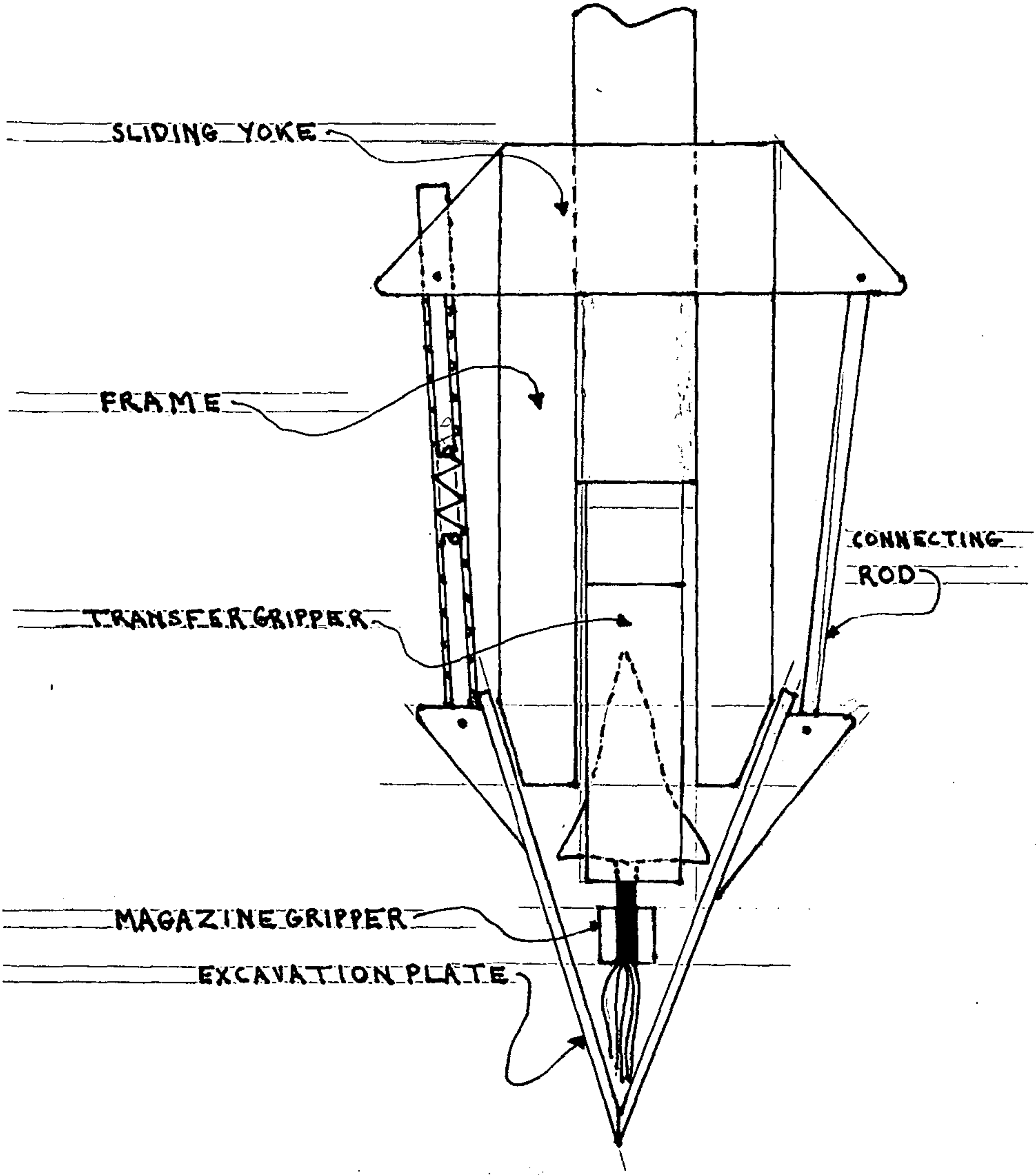
SLIDING YOKE
FRAME
CONNECTING ROD
TRANSFER GRIPPER
MAGAZINE GRIPPER
EXCAVATION PLATE

DIAGRAM 40.

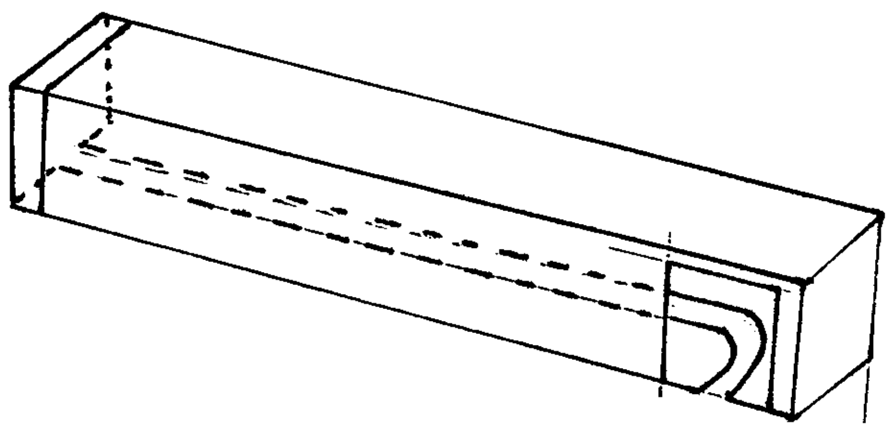

DIAGRAM 41

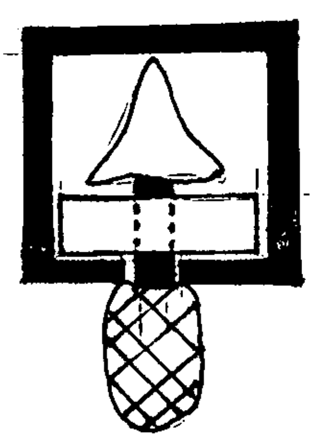

DIAGRAM 42. Section of box shown in DIAGRAM 41.

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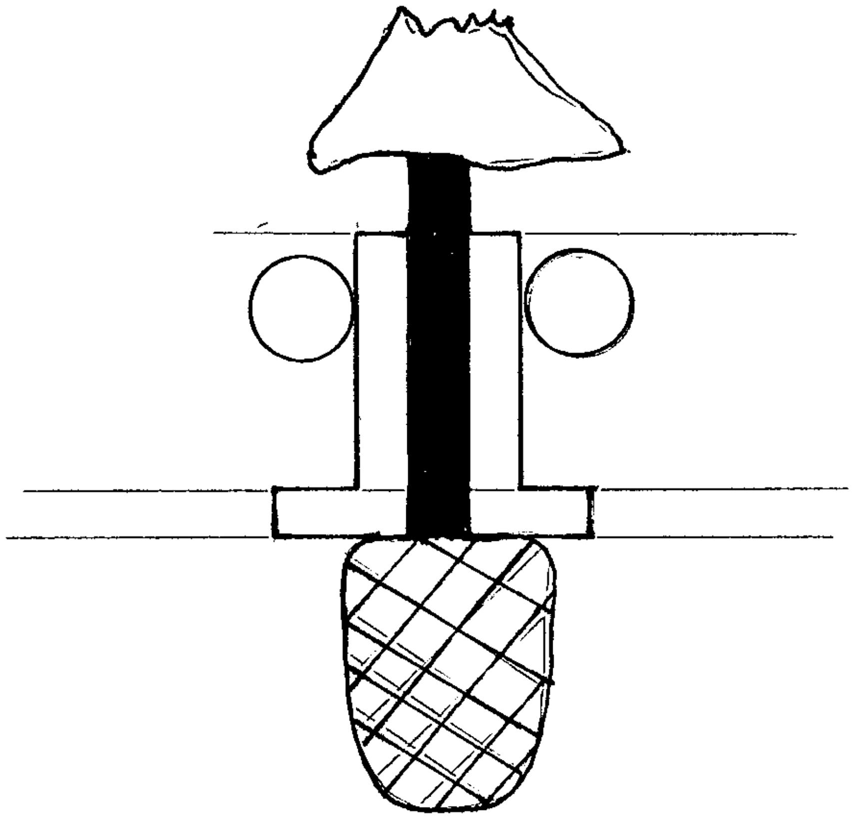


DIAGRAM 43

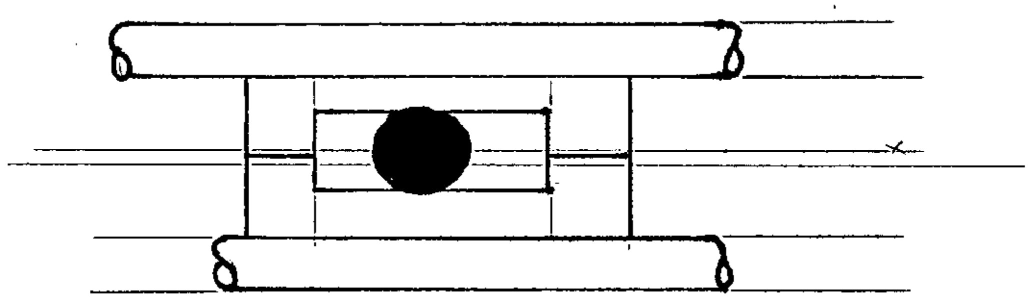


DIAGRAM 44.

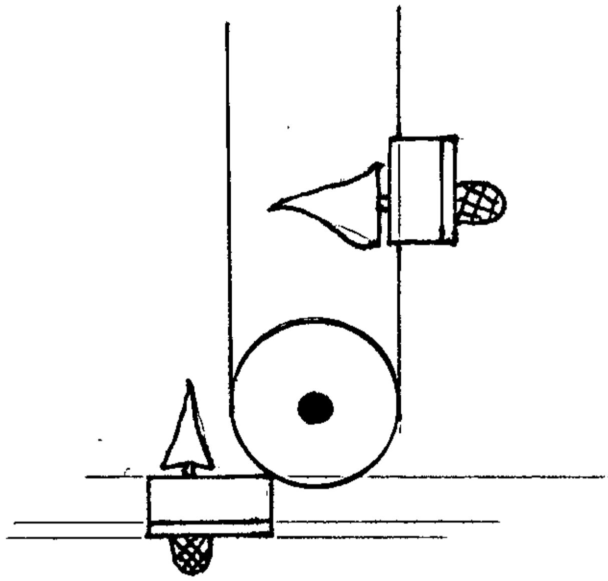


DIAGRAM 45.

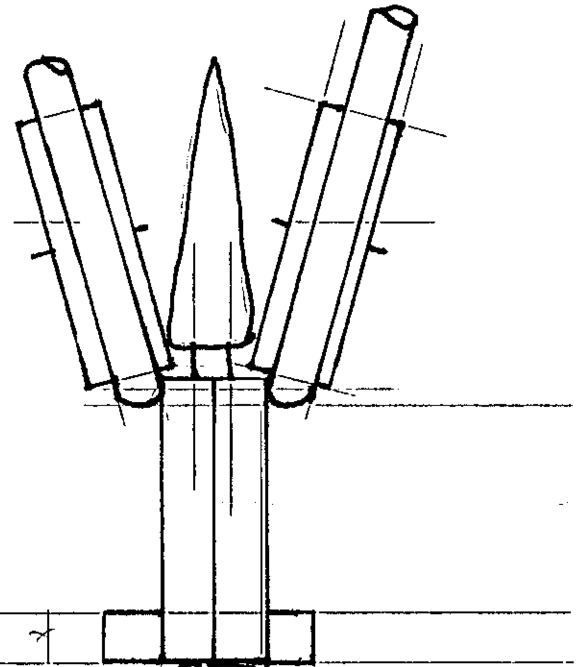


DIAGRAM 46.

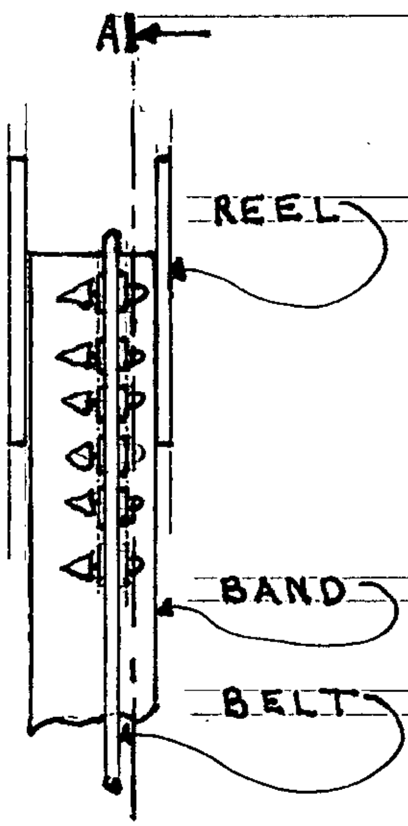


DIAGRAM 47.

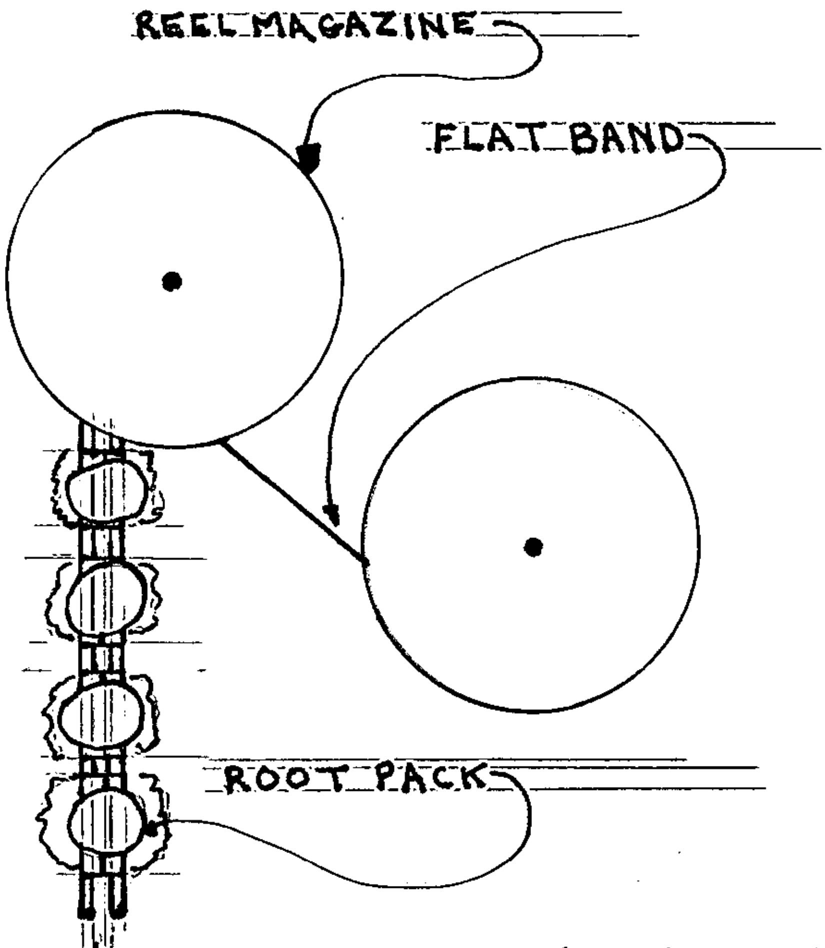


DIAGRAM 48. ("AA" of 47)

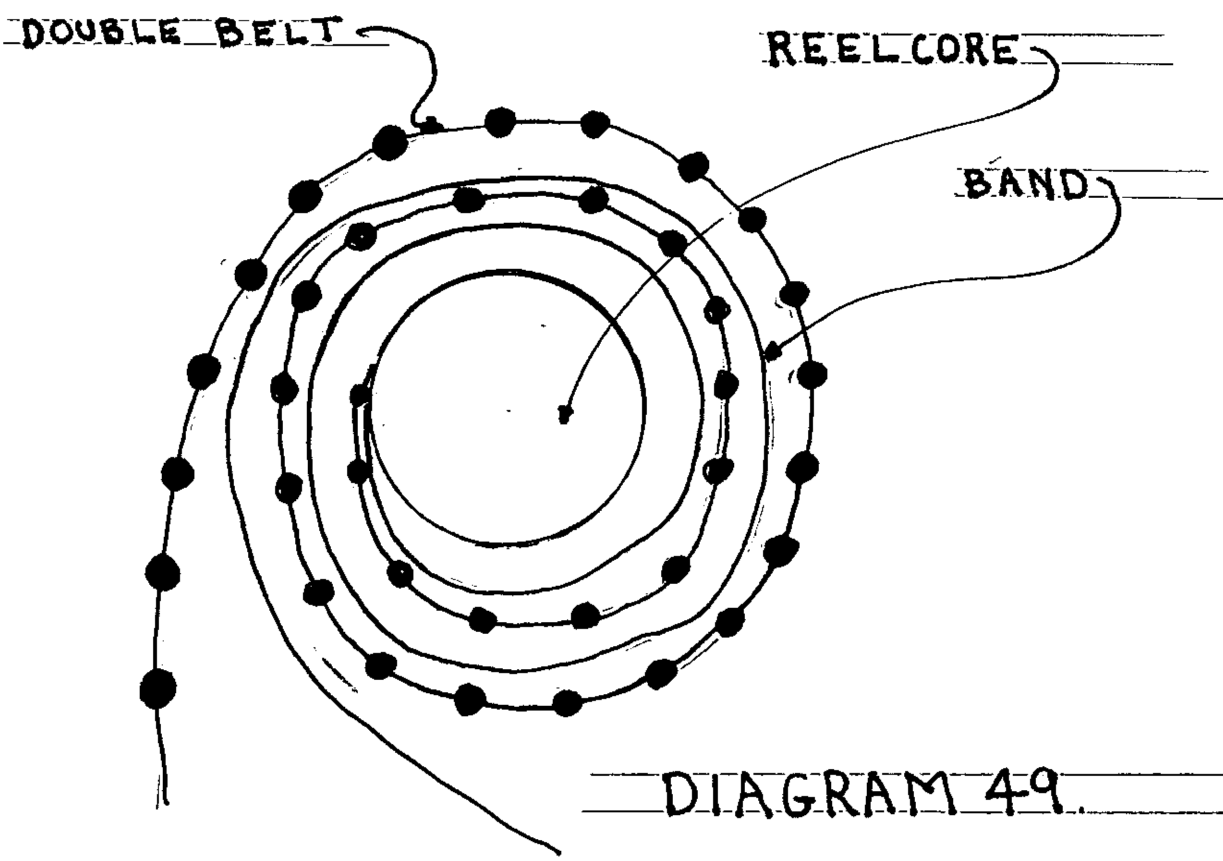


DIAGRAM 49.

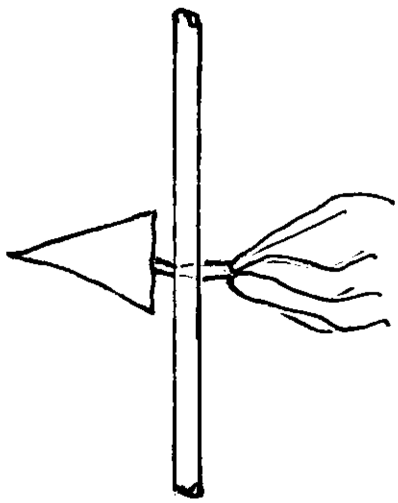


DIAGRAM 50.

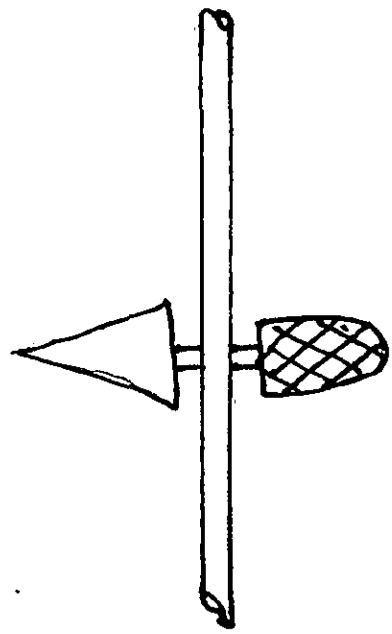


DIAGRAM 51.

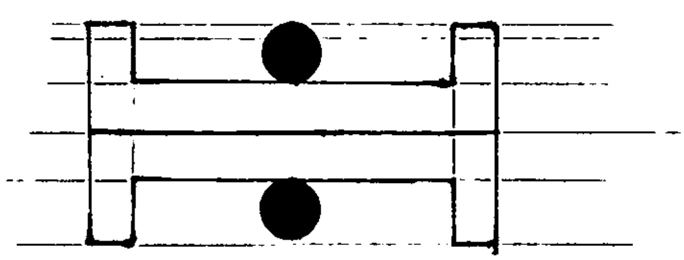


DIAGRAM 52. The gripper shape must be such as to lower the risk of the belts overturning when being wound on the reel.

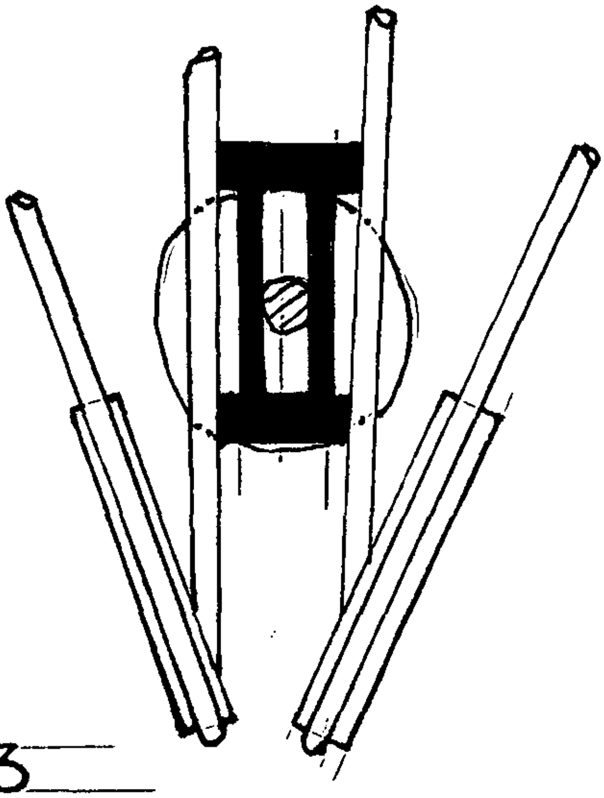


DIAGRAM 53

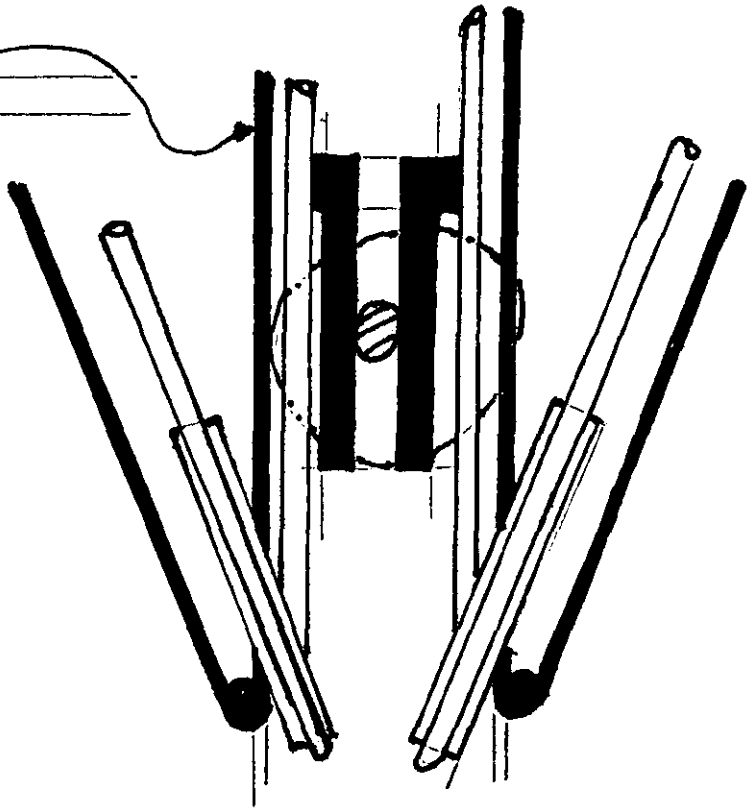


DIAGRAM 54. Bands support root pack.

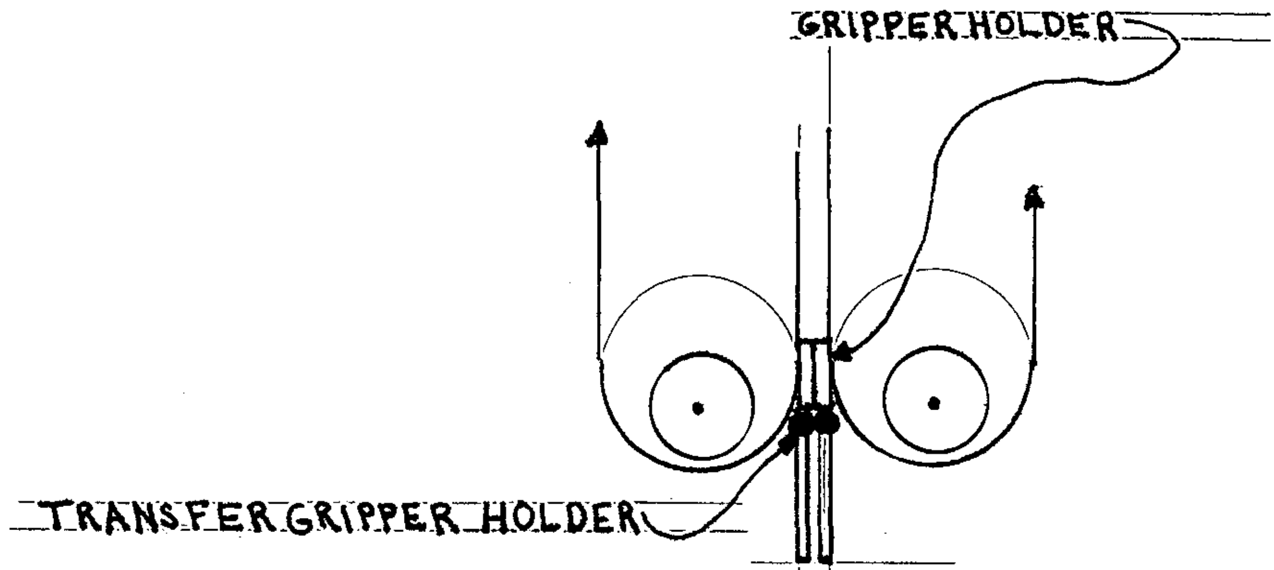


DIAGRAM 55

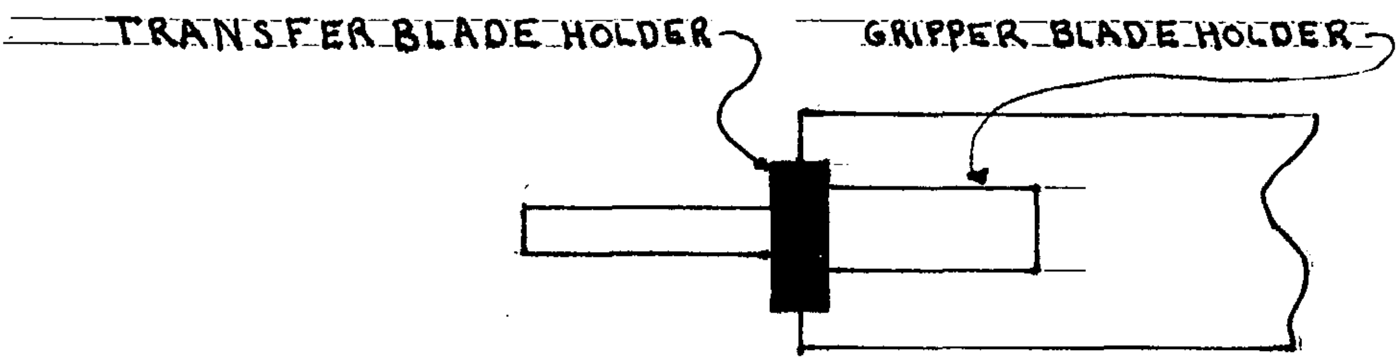
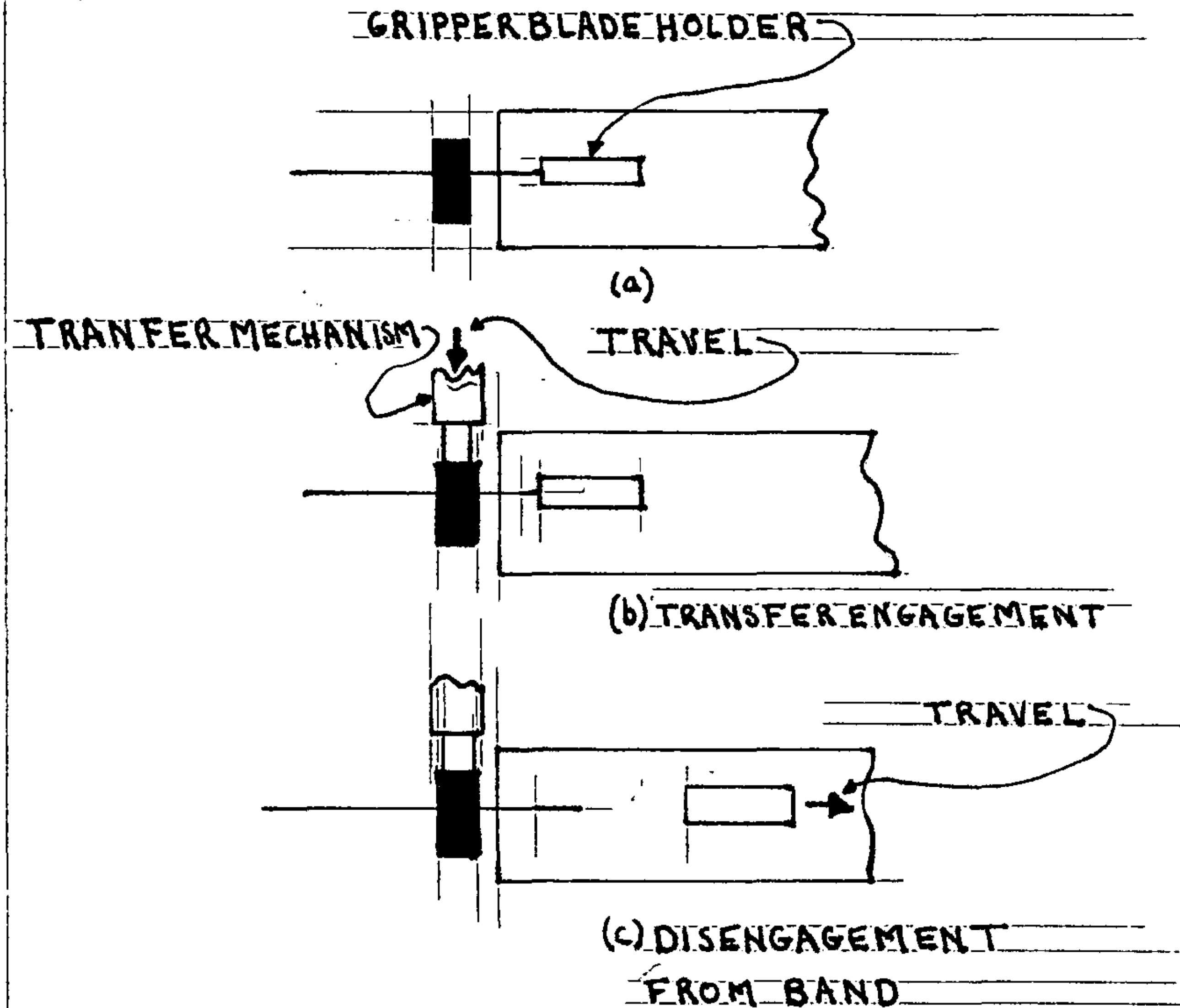


DIAGRAM 56.



After (c) the transfer mechanism moves to the ground. The mechanisms functions as a gripper opener. It then returns to position (c). A reverse sequence re-engages the gripper with the band and disengages the transfer device.

DIAGRAM 57.

Chapter VIII.

INTRODUCTION TO SPACING AND CHOICE

This chapter and the three chapters which follow describe work which has been done on the problems of spacing and choice. Following the introduction semi-automatic choice is dealt with. This work is described first as its results are needed for spacing, for initial tool set-up and for automatic choice. Spacing and initial tool set-up are dealt with next and then automatic choice. The results on spacing, initial tool set-up and on semi-automatic choice are applied to automatic choice. Two chapters System Review I and System Review 2 follow. In them an attempt is made to gather together and organize the results of work described in the three preceding chapters.

The level of detail aimed at in this work is that demanded by the U.S., European and Canadian patent examiners.

In earlier discussion the need for a tool carrier was described and an attempt made to solve the tool carriage problem to a level of detail suitable for patenting purposes.

The presence of ground obstacles and the present rate of travel achieved by logging tractors over the work sites suggested that the tool carrier, using reasonable means both technical and economical would be restricted to a rate of travel of less than 1.5 mph.

The presence of ground clutter prevents the use of furrowing techniques unless heavy clearing is undertaken. It is necessary to choose placement spots for each tree ("spot" plant). For exploratory purposes a rate of planting for an individual tool was chosen which is identical to that of the human hand planter. There is, of course, no single rate. A human planter does not plant steadily day after day, week after week and rates vary with the type of planting being done, the terrain and the weather: personal factors will also vary the rate. Nonetheless "typical" rates for different types of hand planting are given in the B.C. Ministry of Forests, Appendix 6 - 22, 1984). These rates have been used as a guide. A rate to work with has been chosen based on this data and on our own experience.

A system planting rate has been chosen which was initially suggested by the rates being aimed at or claimed by rival planting tool designers. It was found that this rate (1,000 trees/hour) would provide an acceptable rate of return, for a chosen bid price range, on conservatively based estimates (order of magnitude) of the costs associated with machine planting. The choice of this system rate combined with the rate of travel of the tool carrier (in the region of 1 mph) point to the use in a purely planting system, of an array of simultaneously operating tools (8 - 16). Each tool in the array is to have an individual planting rate which is in the range adopted as reasonably representing that of an entirely steady human planter (an idealization). (The number of tools used would be less in a "one-pass system" where site preparation and planting are performed in one operation).

The use of an array of simultaneously operating tools gives rise to the need to unload the human operator of the task of guiding the detailed action of each tool. There is no time for such guidance.

An attempt has been made to expose the tasks which are involved in planting. These tasks have then been apportioned between the human operator and the "tools" (i.e. the data processing system of each tool). The operator uses his judgment to deal with the more complex decision. In one case, that of choice of planting spot, an exploration has been made of an organization based on a choice made by the operator ("semi-automatic" choice) and an organization based on a choice made by each "tool" ("automatic" choice).

The following plan was adopted.

(1) Planting tool operation is to be automatic. Retrieval from storage, handling and placement into the ground are to be automatic.

(2) Tools have to space correctly from the following objects:
   (a) Already planted trees. The operator will align the tool array with already planted trees.

   (b) Naturally regenerated commercial tree species ("residuals"). The operator will use his judgment to deal with this problem.

   (c) Cut-block boundaries, road boundaries, landing, etc. The operator will use his judgment to deal with this problem.

To deal with these tasks the operator needs to be able to bring a tool to a desired position and either halt it there or cause it to plant.

(d) Other tools. Inter tool spacing is to be automatic. Some initial "hand" set-up may be needed.
This spacing is crucial for automatic operation. It is useful in a semi-automatic system. The method which is described in the chapter on spacing can be generalized and applied to more complex problems of individual tool guidance and to more complex problems having to do with the interaction of a collection of tools.

(3) The initial set-up of the tool array for either semi-automatic operation or automatic operation is to be semi-automatic.

(a) Set-up is to be performable by one man.

(b) An initial hand setting of the responses needed to obtain a given spacing may be performed.

(c) An initial hand setting of the position of one or more tools may be performed or of one or more tool carrying structures. The need to set the initial position of every tool in an array is to be avoided if possible.

(d) Following the initial set up of one or more tools in an array and if necessary tool carrying structures, the array is to come to a "start" position automatically.

(4) Tool/operator communication, tool/tool communication.

(a) Each tool is to carry a single-board-computer (SBC) based data processing system.

(b) Inter-tool communication is preferably by means of light signals. The use of incoherent light is preferred. (For other applications additional or different sensitivity could be used.)

(c) Communication among the sub-systems of an individual tool is preferable to be achieved by means of light carried signals. The light can be incoherent or coherent depending on the particular problem. The use of incoherent light is preferred unless there exists suitable off-the-shelf emitter/collector pairs of integrated circuits (IC's) which can be applied to a given problem.

(d) Operator/tool communication is to be via light carried signals. The use of incoherent light is preferred.
The use of incoherent light provides a straight forward solution to communication among a collection of objects where distances to

be communicated over measure less than ten meters. The use of incoherent light enables well tried robust components to be used such as those used in road, railroad and airport signal systems.
It has been found that the use of light for tool/tool and operator/tool communication simplifies the design. It reduces greatly the wiring which needs to be done and also signal scheduling problems and problems which arise when transmitting digital signals over comparatively long inter-component distances (a meter is a long distance).
The use of an SBC on each tool together with light carried communication simplifies the overall design task considerably.

(e) Modularity. Each tool and its sensory system is to be interchangeable, with no adjustment being needed, with any other tool and its sensory system.

The use of an SBC on each tool together with light carried communication facilitates the achievement of modularity.
Modularity if it can be achieved will reduce the design task to that of obtaining a solution for a single tool (the communication of its parts and the means by which it communicates with the operator and with other tools).

In the case of tree planting, a modular design makes for ease of practical operation in the field.

(5) Specific data processor. For exploratory purposes a Texas Instruments (TI) 9900 microprocessor based SBC is to be used. Boards and accessories for this family of 16-bit microprocessor based systems are well tried well accepted and readily available in a variety of standards which include "MIL" and "Industrial". (Whitworth, 1984)
For the type of machine task being dealt with here, which can be mediated by sequences of "shallow" sub-routines which are conveniently called via the SBC interrupt system in response to what are for practical purposes randomly occurring "perceptual cues" the 9900 (and the more powerful 99000) architecture is particularly suitable. It allows readily for "context switching" - the interruption of the programme sequence and the switching from one sub-routine to another. Return to an interrupted routine is simply arranged. In addition, the 9900 family (and the related 99000 family) has a particularly powerful and flexible input/output organization. It is well suited to the type of problem being dealt with.
A 9900 based system was chosen also because the family provides a good entry point into microprocessor based machine control. The 9900 family is centrally placed among the microprocessors. An understanding of the other 16-bit systems can be reached from it and also the 32-bit systems. In the other direction, the 8- and 4- bit systems can be reached from a knowledge of the 9900 family. The economy of effort in the acquisition of knowledge of microprocessors which is afforded by the 9900 family was factor in the decision that the family was suitable.

Because of the expense no microprocessor development system is to be used. The main system design is to be worked out in English first of all and then if necessary in more detail in quasi-Pascal. It will then be written in 9900 assembly language and hand entered using the system monitor. This need only be done for one SBC. The program can then be down loaded onto tape (standard facility on SBC's) and the other SBC's loaded from copies of this tape.
In the early stages no system read-only-memory (ROM) will be used erasable or otherwise. Tape loading and downloading with initial hand loading of one machine enable the use of system ROM to be avoided initially.

Working in this way keeps the cost and the complexity of the techniques needed for system development to a low order.
A choice has been made to use an off-the-shelf SBC based data processing system rather than to attempt to design from scratch (using IC's) a microprocessor-based system. The skills of the writer are at the logical end of design rather than the hardware end, but there are commercial reasons for choosing an SBC-based system as well as reasons having to do with the potential value of the knowledge of their use. The choices open to the microprocessor user have been clearly set out ~~in a United Kingdom~~ (Department of Industry, 1980). Figures 1 to 8 are reproduced from it.

The financial environment for machine development assumed at the beginning of the investigation suggest keeping the needed investment in "hardware" and hardware development to a minimum. By using an SBC based data processing system development costs for the data processor are greatly reduced; one can purchase an already tested system. The first phase of development is then largely confined to logic, sensors. actuator action and the interfaces which are needed. Again as far as possible when dealing with these parts off-the-shelf components are to be used. A problem of this kind largely confined to questions of logic in the first phase of design is manageable.

(6) Control mode. The control mode is to be "on/off". As far as possible the sensory response is to be to either the presence or the absence of a signal. The motor action to which this gives rise is to consist of the turning on or the turning off of one or more "switches". Again this choice makes for a manageable design problem.

(7) Tool motion. Tools are to be moved along Cartesian axes. The control of the motion of a given tool on one axis is to be as far as possible independent of that on any other axis. "On/off" control triggered by perceptual cues and with straight line motion of tools again makes for straight forward design and, with "perception" being used, for a low computational "load".

Two directions have been explored for solutions to the problem of choice of planting spot. An exploration has been made for a semi-automatic solution and for an automatic solution.

In the semi-automatic solution the operator chooses for a given tool a suitable spot and points to it from the cab with a "light" pointer. There is one pointer for each tool. (In a more complex solution which uses light signals and a sensory system which focuses and fixates one or more pairs of sensors, a single pointer could be used for the whole array. In the semi-automatic solution which it is preferred to use there is no focusing and no fixation.) A tool follows the directions of its pointer, moving towards and halting over the spot pointed to: tools are automatically levelled. It does so by responding to the point via a sequence of "instinctive" sensory motor responses to light. Whilst a particular tool is following its pointer the operator is free to point to a spot for another tool. And so on.

The tools of an array have imposed upon them an order of precedence. This order is needed to obtain a consistent arrangement of tolerance regions. (Associated with an ideal inter-tool spacing of tools in an array is a tolerance region. Each tool, which starts at the ideal position, may plant a tree in any position within its tolerance region.) Without this order there is a danger of wrongly spacing trees. A means has been found of facilitating the initial tool set-up and of setting the order of precedence (four cases need to be dealt with) using the pointer system which is made use of for semi-automatic choice.

Each tool in the array is identical to any other tool in the array. The members of any pair of tools perform identical functions and respond identically to a given sensory input. A single spacing prescription and a single tolerance prescription applies to any pair of immediately adjacent tools (as defined). Non-adjacent tools have no immediate effect on each other. In no case does the work area of one tool overlap that of another. This organization will suffice for tree planting.

The results on spacing and choice applied in this particular case are not isolated. They spring from other work which is in progress on the formal analysis of behaviour. They are a particular application of this work. It is possible to describe more general organizations, applying the work to tool organization, where finite arrays of tools of any required diversity and where sub-collections of arrays and sub-arrays may combine for some purpose and being such that:

(1) Over time different sequences of sub-collections of tools may combine to work.

(2) The work areas of one tool may at times overlap that of another.

(3) The inter-tool spacing prescription may vary over time.

(4) The inter-tool spacing prescription applying at a given time to one class of tools may not be the same as that applying to another class of tools.

(5) The spacing response may not be confined to immediately adjacent tools. (Where tools are automatically set up using perceptual cues a response of this sort could be used to avoid a stacking of tolerances).

(6) An order of precedence may exist between individual tools or between sub-collections of tools.

(7) A given order may vary over time.

(8) The rate of individual tool response could vary over time.

(9) Any action may vary in response to randomly occurring perceptual cues which arise in the tool environment.

It should be possible to obtain tool actions and tool interactions of considerable diversity even with arrays of identical tools by the use of a varying order of precedence or a varying spacing and/or tolerance prescription.

It is possible to consider still more general cases. In the spacing of planting tools and in the more general possibilities which have been described the "atomic" sensory/motor sequences which make up the behaviour of any tool are "instinctive" - the implicit definition for the tool action resulting from sensory input contains only constant terms over "input" and "output" (tool action). Cases can be constructed where the implicit definitions for the potential behaviour of a tool contain variable and constant terms over "input" and "output". Where such terms occur a means will be needed (having algorithmic form) whereby the variables are potentially instantiated (the content of an instantiation will not in general be predictable). Such a system would "acquire" its behaviour.

In other work which is in progress cases containing variable terms arise. In the present work the concern is with a particular case. An attempt has been made to obtain a solution to a specific problem. The more general cases have been mentioned to indicate that the solution proposed here is not an isolated result but one of a collection of results having, it is believed potential application to practical problems.

Three perceptual/motor atoms have been used repeatedly.

(1) A fixed motor response to a "threshold" value of input.

(2) A fixed motor response to the balance of input on a pair of sensors identical or non-identical.

(3) A fixed motor response to an increasing (decreasing) input - a response to a "gradient".

The three responses occur in natural systems. The earliest artificial use of the second atom which is known to the writer occurs in Weiner (1961) where it is used to guide the direction of motion of a toy sun-seeking (avoiding) motor boat. The response is commonly used to guide automatically guided factory vehicles.

The earliest artificial use of the first and third atoms known to the writer occur in Walters (1953) where they are used to guide the motion of a small wheeled device. The material in the literature on natural systems and the existing applications have been developed to obtain what looks like a workable solution to semi-automatic choice, semi-automatic tool set-up, the setting of a tool order of precedence and to automatic spacing.

Our aim in the work on spacing and choice has been that of finding solutions to a practical problem to a level of detail which will satisfy the U.S., European and Canadian patent examiners. To get the whole problem much further beyond this level of detail cannot be done unassisted; it is the work of a team. We set out to construct the main form of a practical, economically reasonable seeming solution to the whole problem. An attempt has been made to expose pivotal problems and to find solution to them, the degree of detail being entered into being guided by the requirements of patenting. How much detail this involves has been found to depend on the type of problem and on the amount of prior art. It has been necessary to enter into considerably more detail in order to deal with spacing and choice than was necessary for the vehicle problem and the silvicultural/mechanical problems.

No attempt has been made to obtain a finished solution for spacing and choice. System behaviour which is needed to effect a solution has been worked out for the semi-automatic case. Some physical effects which could be used to trigger the required behaviour have been described. The logic mediating between the reception of input and the production of tool action has been isolated and described at a high level. For semi-automatic operation a pivotal empirical problem has been found and investigated. It is that of whether or not the available, practicable, off-the-shelf sensors which are likely to be used in a tool sensory system can recognize a "bright" spot on a diffusely reflecting surface in a range of naturally occurring conditions of illumination and ground dampness. (The problem can be approached also from the point of view of how such recognition can be facilitated.)

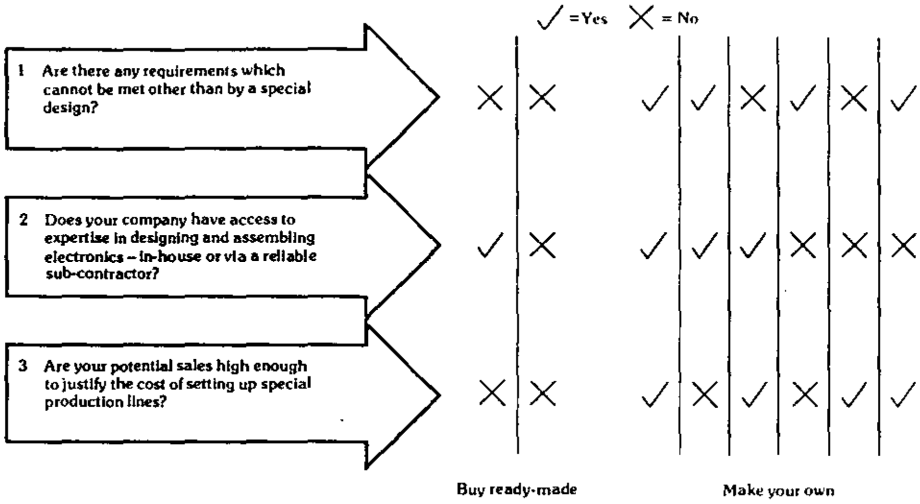
Some main parts of a solution to automatic choice, one based on a colour analysis of ground patches, have been described. A workable solution here hinges also on empirical questions. An important one is that of the pattern of variability of the reflectance from a diffusely reflecting ground patch in a range of natural conditions.

An exploration has been begun into the recognition of texture. Whilst it is simpler, and for a practical solution it is preferred to use recognition by colour only, cases arise where a spot is covered with debris but where with reasonable effort this may be cleared to possibly reveal a plantable spot. In a semi-automatic system the operator can use his judgment to deal with such cases. If they are to be dealt with automatically either some attributes of colour must be found by which they are recognized (a brief preliminary enquiry of this possibility has been made) or textural quality must be recognized. If the latter is to be done it must be done simply and with a low computational "cost". A preliminary enquiry has been made into the design of a low-cost, low-computational "load" recognizer of texture/colour. An idealized device has been described which under simplifying assumptions will compare for likeness two two-dimensional patterns. Some generalizations of this system have been briefly explored. Some refractory problems have been found. Pivotal practical problems here are those of analog/digital conversion and digital/analog conversion. The existing methods are not suitable. A cursory examination of these problems has been made.

Figure 13. Do you buy your microcomputer ready-made, or design and make it yourself?

Three questions to ask

Answering the following three questions will help you decide which course to take:



If you answer 'no' to the first and third questions, or to all three, abandon any thought of developing your own microcomputer from scratch, and concentrate on the ready-made boards available.

If you answer 'yes' to all three questions, or to both the first and the second, or to both the second and the third, a special design is the course for you.

If you answer 'yes' to the first and/or third, and 'no' to the second, a special design is still your best course, but it's going to be rough going until you acquire the requisite expertise. In that case, start off by using a consultant.

How you answer question 3 will depend on the volume of potential sales at which the cost of developing and producing your own design equals the cost of buying-in ready-made units (see the accompany chart). Various figures have been suggested for this crossover, ranging from as low as the 10-off mark to as high as 1000.

Obviously, then, each case has to be treated on its merits, taking into account such factors as the complexity of the computer, and the microelectronics experience and expertise available within the firm. If you're not absolutely sure about your market, it might be sensible to compromise: buy off-the-shelf to launch your product, and then invest in a purpose-built design if the sales warrant it.

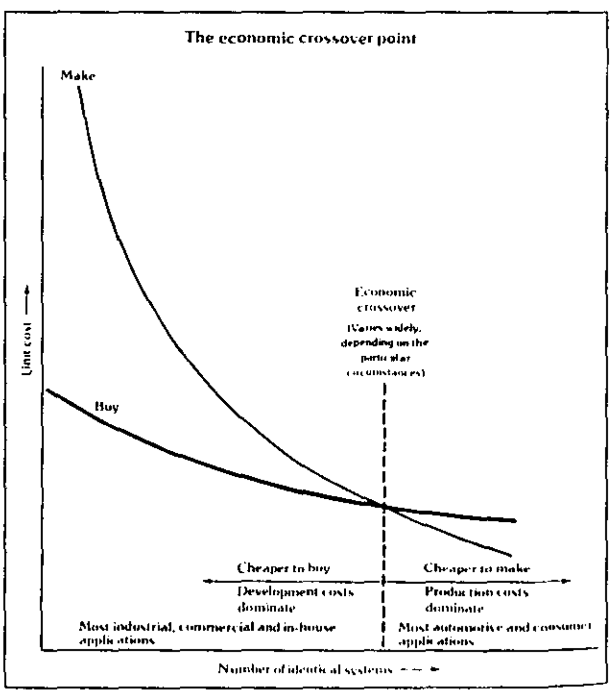


Figure 1

Chapter 8. Introduction to Spacing and Choice

Table 1. Choices available in selecting a microprocessor.

Choice	Factors involved in the choice
Number of bits in a word	The type of data being processed
The technology used in constructing the circuit	Speed; cost; power consumption
Single-chip, multiple-chip or bit-sliced	Market volume; complexity of interfacing; quality of memory required; speed; space
Microprocessor with a large or small family of companion products	Reliability; time required for hardware and software development
Power-supply requirements	Portability; cost of additional power supplies
Choosing between broadly equivalent competing microprocessors	Special environmental requirements; delivery time; cost; investment in development aids; experience of staff; security of supply

Based on a table compiled by the Open University.

Table 2. Comparison of the properties of chips produced by different technologies.

KEY: 1 = Best; 6 = Worst. Asterisks indicate significantly good features.

Production technology	Speed	Circuit element size	Cost	Power consumption	Maturity
PMOS	6	3	1	3	2
NMOS	5	1	1*	3	3
CMOS	3	6	4	1*	4
TTL	2*	3	3	5	1
I^2L	3*	2	5	2*	6
ECL	1*	5	6	6	5

Based on a table compiled by the Open University.

Table 3. Summary of program-storage alternatives.

Type of chip	Technology and drawbacks	Main factor (excluding software) contributing to: Initial cost (other than that of the integrated circuit)	Cost for a new product	Cost of correcting an error	Output at which economic
Mask-programmed ROM	Any technology	Mask manufacture	New mask	Create a new mask, and discard batch of faulty ROMs	High
PROM	TTL uses more power than MOS	Small setting-up charge	Small setting-up charge	Discard faulty PROMs	Low
PROM plus programmer	TTL uses more power than MOS	Purchase of programmer	None	Discard faulty PROMs	Low/Medium
EPROM	MOS slower than TTL	Purchase of programmer and erasing lamp	None	Erase and re-program	Low/Medium
EAROM	MNOS. Relatively low number of rewrites possible.	None	None	Re-write the program	Low

Based on a table compiled by the Open University.

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Figure 2

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Figure 14. What level of microcomputer? – Some factors to consider.

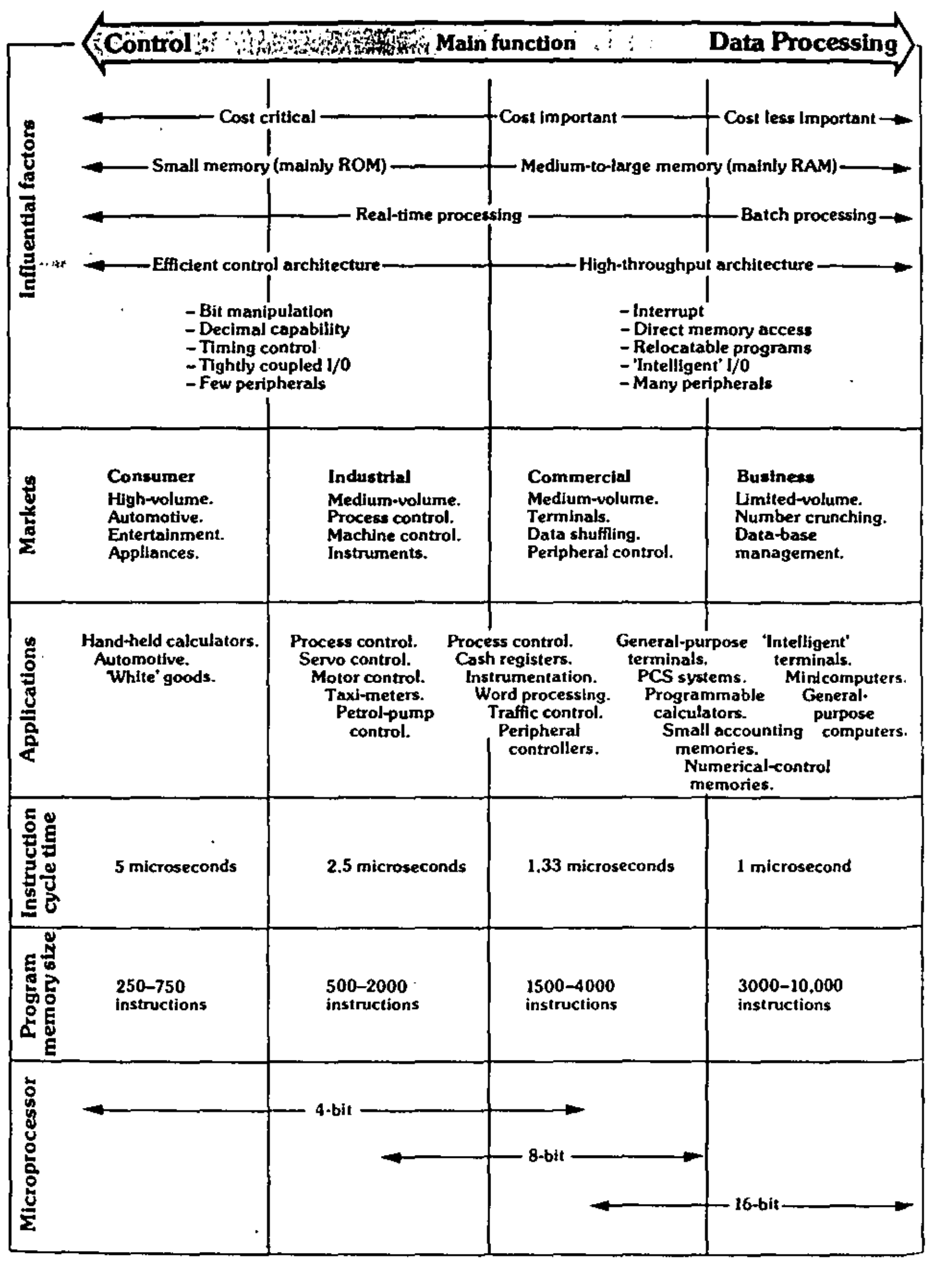

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Figure 3

Chapter 7. Introduction to Spacing and Choice.

Figure 15. Selecting the microprocessor – Narrowing down the choice.

Compare the functions and performance specifications of the candidate microprocessors

Word length? Architecture (eg, the registers available, the internal organisation, I/0 capabilities, bus structure, memory-addressing systems)? How complex is the power supply – one voltage or many? How versatile and comprehensive is the supporting family of microcomputer hardware? What's the 'package count' for a minimum working system? Possibility of upgrading to a more powerful machine? Security of supply? Second sourcing?

Compare the features affecting software writing

What operating systems and languages does the microprocessor support? What software- and hardware-development aids are available? How effective is the instruction set? How many instructions is it based on? How many branch and jump instructions are there? What are the memory-addressing modes? Are I/0 instructions needed?

What about the program-execution time? Is the execution time per instruction adequate for the application? If not, is a hardware/software trade-off possible?

Benchmarking

Choose a representative segment of your program and write software for each of the microprocessors. Compare the results. How easy was program writing? How many instructions were needed to implement the segment? Estimate the execution time. How many bytes of memory storage does the program need?

Compare the microprocessors in terms of cost vs performance

Short-list them.

Compare the support offered by the suppliers of the short-listed microprocessors

Engineering advice and technical back up?
After-sales services?
Technical literature?
Delivery dates?

Select your microprocessor and manufacturer

Place your pre-production order.

(Prepared in co-operation with Motorola Ltd)

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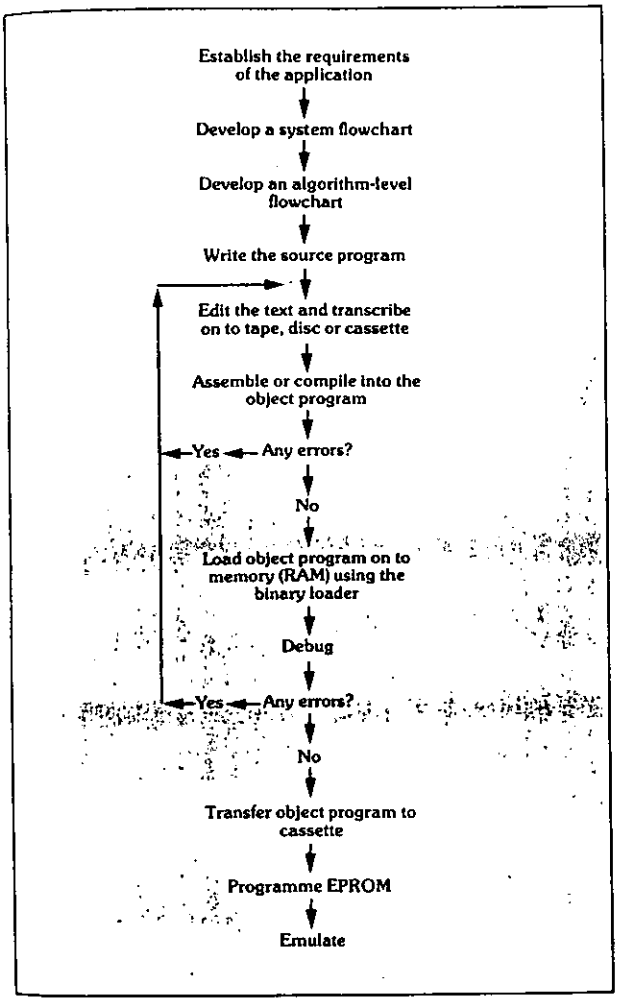
Figure 4

Figure 17. How the software-development aids fit into the development sequence.



18).

Figure 17 summarises the development-aid sequence, and Figure 18 illustrates some of the development systems available.

Assuming that the above has convinced you that you're not going to progress very far without a development system, how do you go about getting one? You have three choices:

1 You can use a commercial time-sharing network equipped with a mainframe computer and the development software appropriate to your microprocessor.
2 You can buy the appropriate development software from the microprocessor manufacturer and run it on your own computer, using, if necessary, a cross-compiler or cross-assembler to adapt the software to the configuration of your computer.
3 You can buy or build a development system to suit your particular needs and/or pocket. The systems available range from the very basic (which obviously have limitations) to ones equipped with all that you need to assemble, test and debug your program, and evaluate your hardware as well.

All three approaches could take you satisfactorily along the road to your object program: it all depends on your circumstances.

Option 1) involves no capital expenditure, and could be your best bet if your project is a one-off.

If you're likely to be heavily involved in microcomputer projects over a long term, options 2) and 3) are the most cost-effective.

Option 3) is by no means cheap if you choose a comprehensive system, but the outlay is non-recurring, and what you'll get for your money is a sophisticated package with all the development facilities you could possibly need. So if you see your firm's future keeping steady company with microcomputer technology, give serious thought to option 3). A full-scale development system will probably earn its keep in the time and trouble it will save at the system-debugging and -evaluation stage alone.

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Figure 5

Chapter 7. Introduction to Spacing and Choice.

The microelectronic choice

Deciding which of the microelectronic options is best for you is not just a matter of looking at the technical requirements of your application. Other factors – cost, development lead-time, the electronic expertise available (or lacking) in your organisation, and so on – are also important. It is difficult therefore to compare the various options in any concise way. Our attempt to do so in this table should be regarded as only a very rough guide.

Option	Wired logic	Custom special	ULA	Off-the-shelf microcomputer	Purpose-built microcomputer	Single-chip microcomputer
Physical form	Printed-circuit board (pcb)	Chip	Chip	Programmable, general-purpose system on pcb(s)	Self-designed, programmable pcb system built up from standard components	Programmable chip
Functions determined by	Hardware	Hardware	Hardware	Software	Software	Software
Circuitry	Dependent on the application	Dependent on the application	Dependent on the application	Basically same for each application	Basically same for each application	Basically same for each application
Critical factors	Logic and circuit design	Design and development	Logic design	Software development	Software and hardware development	Software development
Number of components per system	High	Low	Low	Medium	Medium	Low
Versatility	Specific to one application	Specific	Specific	Adaptable to a range of uses	Adaptable to a range of uses	Once programmed, specific to the application
Adaptability to improvement, modification or change of function	Low	Nil	Nil	High	High	Once programmed, nil
Unit cost optimum at	Low production runs	Very high production runs	High production runs	Relatively-low production runs	Medium production runs	Medium production runs
Main disadvantage	High assembly cost	High development cost	Relatively-high development cost	Software development	Cost of hardware and software development	Software development. Mask programming
Main advantage	Simplicity. High speed. Little pre-production cost.	Bespoke system	Semi-bespoke system	Basically ready-made. Versatile and adaptable.	Purpose-built and hence highly efficient. Versatile.	Simplicity. Compactness. Adaptable to an application by programming

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Figure 6

**Custom chips? . . . wired logic ? . . . microcomputers?
The go/no-go route to each.**

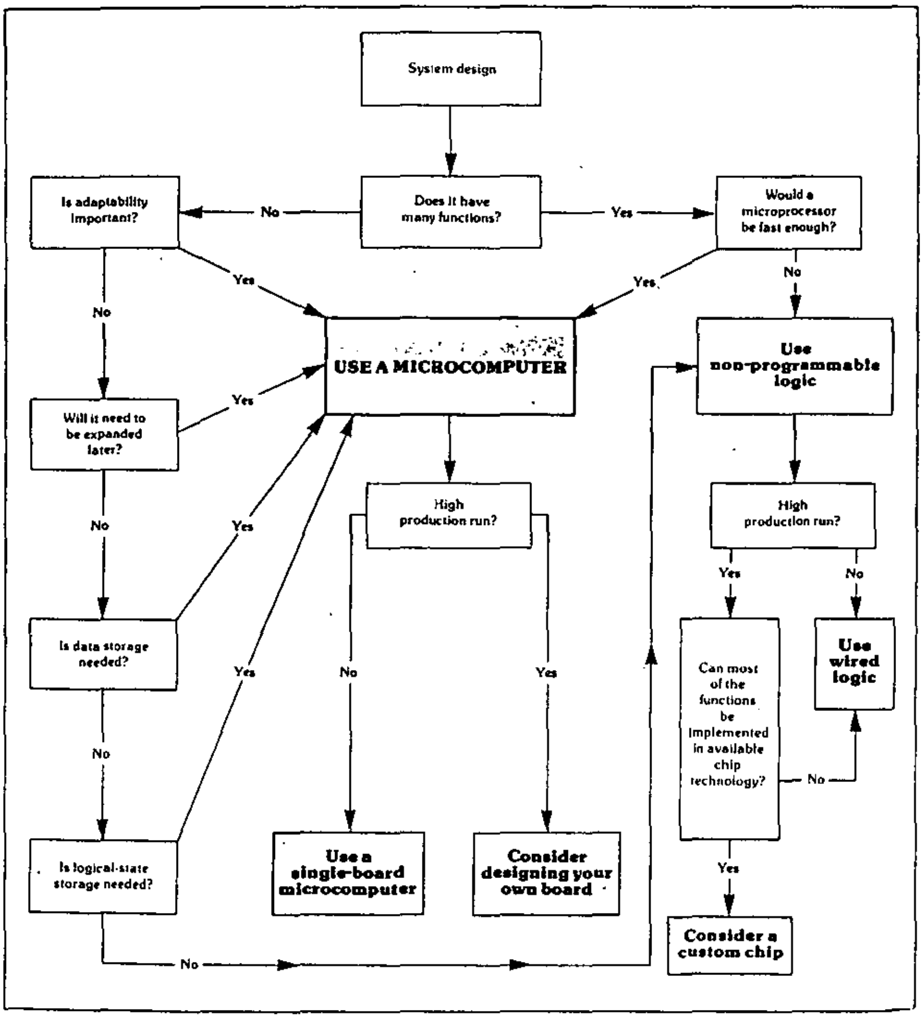


Figure 7

Chapter IX.
SEMI-AUTOMATIC CHOICE

A method is needed which will enable a machine operator, whilst remaining in the vehicle cab, to choose a spot for a given tool, mark the spot in a machine recognisable way and call the tool to the spot. The calling device should be such that it can be left, the tool following its directions automatically to the mark at which the tool will halt. Whilst this is happening the operator can attend to the next tool. And so on.

In the first part of the chapter the main form of a preferred solution is described. At the end of the chapter a second method is described for comparison with the preferred solution.

The approach which has been adopted after considerable trial and error, is based on an analogy with pointing. The problem which an attempt has been made to solve has been cast in the form of the question of how to enable a man who is guiding the operation of an array of simultaneously working tools to be able to direct any tool by "pointing" to a chosen work spot. The machine is to move automatically to the position pointed to. A man can understand (especially with the addition of verbal instruction) what is being pointed to without the necessity for pointing to be continued. With the simple perceptual system which is to be used in the present application (mechanical tree planting) the pointer is to remain pointing until the tool reaches the spot pointed to. The pointer (a device) must be such that it provides input to the tool which "releases" an automatic motor response which carries the tool to the spot pointed to.

It is assumed here that before "pointing" takes place the tools are set-up for a given spacing and tolerance prescription (see Chapter 10), that they have moved to a uniform "start" position and that they will space themselves automatically from each other. The operator then attempts to choose a suitable planting spot, within the tolerance region surrounding the start position and preferably as close to this position as possible (in order to reduce the time needed for tool travel). Having chosen for a given tool a work spot the operator points to it. Thereafter tool operation is automatic.

Semi-automatic guidance of this kind is useful where a choice needs to be made among work spots which are randomly placed within a tolerance region, where a choice needs to be made quickly, where the choice is such that it is not easy for a machine perceptual system to make, which it is easy for a man to make but where there is no time to provide detailed manual guidance to a tool.

Diagrams 1, (i), (ii), (iii) and (iv) show a schematic pointer. It consists of two light sources surrounding a sighting device which can be thought of as a "tube". By means of the device the operator points to the spot which he has chosen. The two light sources produce different coloured light; let us say red and green. The spot pointed to is thus on the line of colour discontinuity.

The use of the pointer in an idealized case will first be described. Two complications which stand in the way of a practical device are then dealt with.

In the ideal case the device is to be used on a flat, unobstructed, horizontal plane with the pointer being able to be translated parallel to the "X" axis of the plane or to the "Y" axis of the plane. It is arranged that the intensity of both the light sources vary with the angle of the pointer from the horizontal so that the spot chosen is always directly beneath a "contour" of intensity having a chosen value - a "threshold" value. (Diagrams 2 and 3) This contour and the line of colour discontinuity fix the position of the spot pointed to. If it is then arranged that a tool possesses two sensors, one sensitive to red light the other sensitive to green light and that the sensory system can recognize a threshold (in this case that of the fixing intensity contour) then by the use of a response to the balance of light intensity received on the red and green sensors, and a response to a threshold value - move in the direction of increasing (decreasing) intensity until a given intensity value is reached - a tool can be made to move from any position in its tolerance region to the line of colour discontinuity and then along this line to the threshold contour when it will halt, its being directly above the chosen spot. (A method which does not use a fixed threshold contour is described later.)

The position of the threshold contour (TH) can be made to vary as a function of the angle of the pointer tube with the horizontal (Diagrams 2 and 3).

This can be achieved by such means as the dimming or brightening of the pointer light sources with a change of angle of the sighting tube. The effect can be achieved by such means as a rheostat whose setting is altered by the rotation of the tube, giving rise to brightening of the light sources as the tube is rotated towards the horizontal and to dimming of the light sources as the tube is rotated towards the vertical. As the light sources are brightened TH is position farther from the light sources. As the light sources are dimmed TH is positioned nearer to the light sources.

To bring a tool onto the line of colour discontinuity from any position in its tolerance region, a fixed motor response to the state of balance or unbalance of the light being received via the red and green sensors is used (Diagrams 4 and 5 and Figure 1). In Diagram 4 it is seen that if the tool is in the red sector the red sensor will be receiving input but the green sensor will be receiving no input. The tool moves "to" the sensor which is low. (The logic of this response is shown in Figure 1. The implementation of this logic is discussed later.) This response will move the tool towards the line of colour discontinuity. When the green sensor crosses the line it will become illuminated. At this point both sensors are "balanced" and "Y" - motion (Diagram 4) halts. The tool will move along the line of colour discontinuity to the TH value. If deviation from the line occurs the state of balance/unbalance of the sensors will trigger a motor response which brings the tool back to the line.

If the tool is in the green sector then an identical response (move to low) to that already described will move the tool towards the red sector and hence towards the line of colour discontinuity.

This scheme must be modified to deal with two practical difficulties. Slopes have to be dealt with and local severe unevennesses. In a practical solution a pointer is to be in a fixed position relative to a tool tolerance region (Diagram 13). It will rotate around this position horizontally and vertically. These "vertical" and "horizontal" rotations are such when the vehicle is standing on a smooth horizontal plane with its transverse and longitudinal axes parallel to the plane. In this condition and with the vertical axis (let us say that the longitudinal axis of each tool is vertical) of a given tool positioned at the intersection of the line of colour discontinuity and the threshold contour, TH, will be able the spot which is being pointed to (Diagram 3).

The planting tool has to be kept vertical in order to place trees vertically. Suppose for ease of discussion that the planting tool is symmetrical around its longitudinal axis and that this axis is automatically brought to the vertical. Diagram 3 shows the plane defined by the line of extension of the pointing tube and the line of colour discontinuity (pointer plane). On uneven ground unless this plane is also brought to a vertical position a tool travelling along the line of colour discontinuity will not necessarily point to the chosen spot when it reaches TH (Diagram 6). Furthermore, in the presence of sharp local unevennesses even if the tool and the pointer plane are vertical, when the tool reaches the threshold, TH, it is still not necessarily above and pointing to the spot which has been chosen and is being pointed to (Diagram 7).

The planting tool has to be levelled and it is assumed that this takes place automatically. It was preferred to avoid the need for any pointer-plane levelling. However on an extreme slope (e.g. 45°) with the pointer pivot assumed to be two meters above the ground, the position pointed to will be outside the tolerance region of a tool (Diagram 8). A compromise solution has been used. Rough levelling will be performed which is guided by two spirit levels (Diagram 9); this is a straight forward solution. Each pointer could be balanced. The operator releases a "lock" to move a pointer whereupon it will tend to come to a level position. To deal with any remaining mismatch between the spot pointed to by the pointer and the spot (at TH) pointed to by the longitudinal axis of a tool, a "bright" spot is introduced and a scan which the tool is to perform if it has reached TH but has not sensed the bright spot. The use of the two colour sector pointer, the bright spot, TH and the scan has been found to simplify the remaining problems in semi-automatic and automatic choice. (In later discussion a method which does not use a bright spot is described.)

With the use of a bright spot and a scan the threshold could be disposed with and also the colour sector response. However the use of TH and the colour sectors provides the basis of a solution to other problems. In semi-automatic choice the threshold TH is needed to "Tell" a tool which direction to travel in; the direction of travel needed will vary with array position and the particular case; tools are to be interchangeable. The colour sector response will carry a tool rapidly either to a position above the spot pointed to or to the vicinity of the spot pointed to.

Diagram 10 shows a modified pointer. It consists as before of a sighting tube and two coloured lights which define the line of colour discontinuity. On either side of the tube and rotating with it are two further lights which produce a bright spot. The lights can be coloured (e.g. red and green) and the same response as that used to bring the tool to the discontinuity line can be used to centre a tool above a spot pointed to. These two lights, parallel to the longitudinal axis of the tube will provide an adequate solution. A design which uses lights such that the point of incidence of their beams coincides with the spot being pointed to for all positions potentially pointed to is not as easily obtained and has no advantage over the parallel beam solution.

With a two coloured bright spot being used and with rough levelling bringing the bright spot close to being vertically below the line of colour discontinuity, a tool which has reached TH will either sense the bright spot (its red sector or its green sector or both sectors) and come under its control or it will not have sensed the bright spot (i.e. local unevenness). In this case it will perform a scan around TH until the bright spot sectors are sensed. With rough levelling having been performed, in the case being considered the tool need only advance along the discontinuity line to come under the influence of the bright spot sectors (Diagrams 11 and 12). If it happens that the bright spot sectors are sensed before TH is reached then the "bright Spot" response overrides the move to TH response.

The pointer for a given tool, in a practical solution, will be mounted in the cab or on the cab structure (Diagram 13). The pointer plane of a given pointer will not when pointing to a position be in such a position that the continuity line is parallel with an axis of horizontal movement of the tool which being controlled. Even so the perceptual/motor response which has been described will still be useable. A tool will now move along the line of discontinuity in a sequence of steps (Diagram 14). To as much as possible equalize the input to both sensors ("red" and "green") they are turned towards the vehicle centre. It may be advantageous to have them turnable rather than in a fixed position. Having them thus will aid tool interchangeability. Diagrams 15 and 5 show the arrangement of sensors.

The sensors need to be hooded (Diagram 5) so that, for example, a green sensor in the red sector is largely unlit, but once the discontinuity line is crossed (it will usually be crossed at an angle (Diagram 14) so that neither sensor faces the light source to which it is sensitive) the previously unlit sensor receives sufficient input for a decision to be made (using the status register of the SBC) as to whether both sensors are lit and as to whether the difference between the input received by one is within a given distance from that received by the other.

Depending on the distance apart of the green and red sensors and the angle at which they straddle the line of discontinuity, one sensors (which depends on the position in the array of tools Diagram 16) will reach the threshold value before the other. One sensor reaching the threshold value can either halt the tool (in fact if this occurs the tool will have come under the influence of the bright spot) or send it into a scanning motion (i.e. threshold reached no bright spot sensed).

These modifications provide the basis for a practical solution. Whether it is workable depends on the obtaining of a positive answer to the question of whether a standardly available receptor can sense a bright spot on a diffusely reflecting surface in a range of natural conditions of illumination and of dampness. This problem is discussed in the chapter on empirical work on spacing and choice.

Other solutions have been found to the problem of semi-automatic choice. They are briefly discussed.

Diagram 7 shows a case where the spot pointed to does not coincide with the spot fixed by the threshold contour and the line of colour discontinuity. Provided that the pointer plane (the plane shown in Diagram 3) is vertical the spot will be reached by moving on the discontinuity line. It would be possible to use a sonar IC (integrated circuit) and to measure the distance to the spot. The discrepancy with the ideal condition could be calculated from this measurement and a signal produced (e.g. bringing TH closer to the light source) which causes the tool to move in the needed direction. Suitable adjustments could be made for the condition where the pointer plane is not vertical. This type of solution is judged to have no advantage over the one already described. It has disadvantages; the pointer design would be more expensive.

It would be possible to avoid the use of multiple pointers by the use of a pair of tool carried sensors which are able to rotate in vertical and horizontal planes and which are able to focus and together fixate a point (Diagram 17). In the absence of obstacles the position pointed to (e.g. the position of a bright spot) could be focused on by both sensors (i.e. fixated). The spot could be removed. By a process of continuous re-focusing and fixation the tool could be guided to the chosen spot, halting in the condition shown in Diagrams 19 and 20. This solution is not as straight forward to implement as the preferred one. Without considerable elaboration it will fail in the presence of obstacles (Diagram 21).

The logic of motor actuation for this case is straight forward. Automatic focusing systems already exist. There is a variety of camera focusing systems. No mechanism of automatic fixation (Marr, 1982, discusses natural cases) has been found.

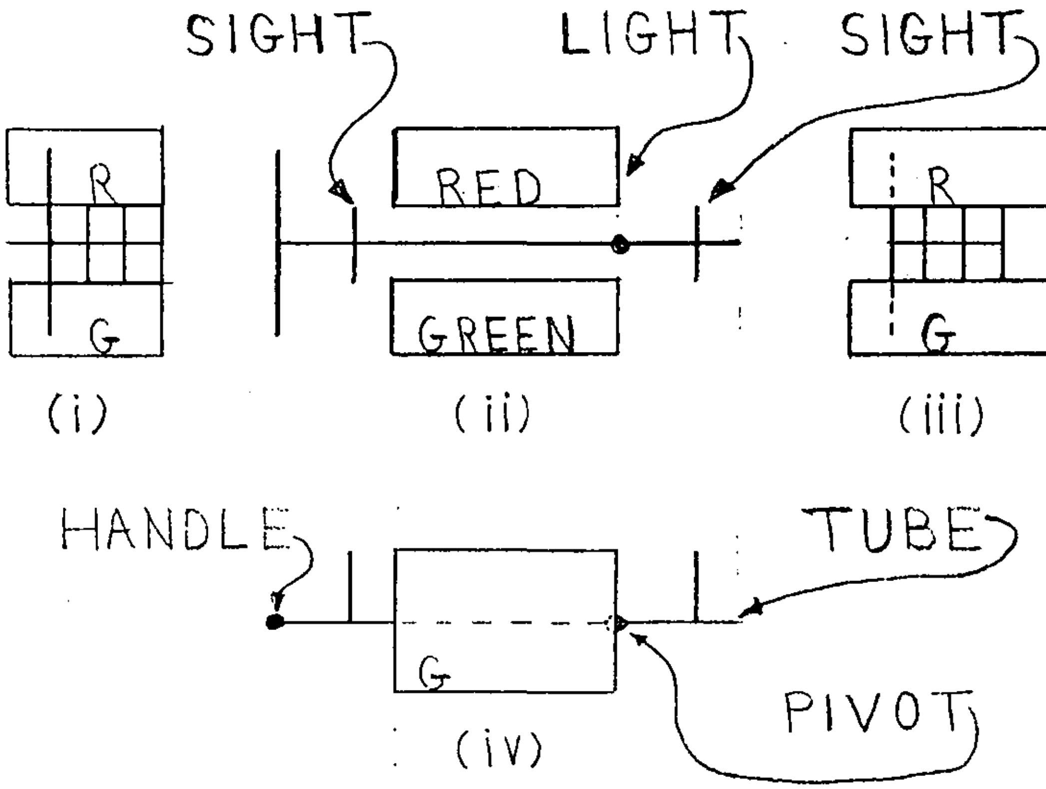


DIAGRAM 1. SCHEMATIC POINTER

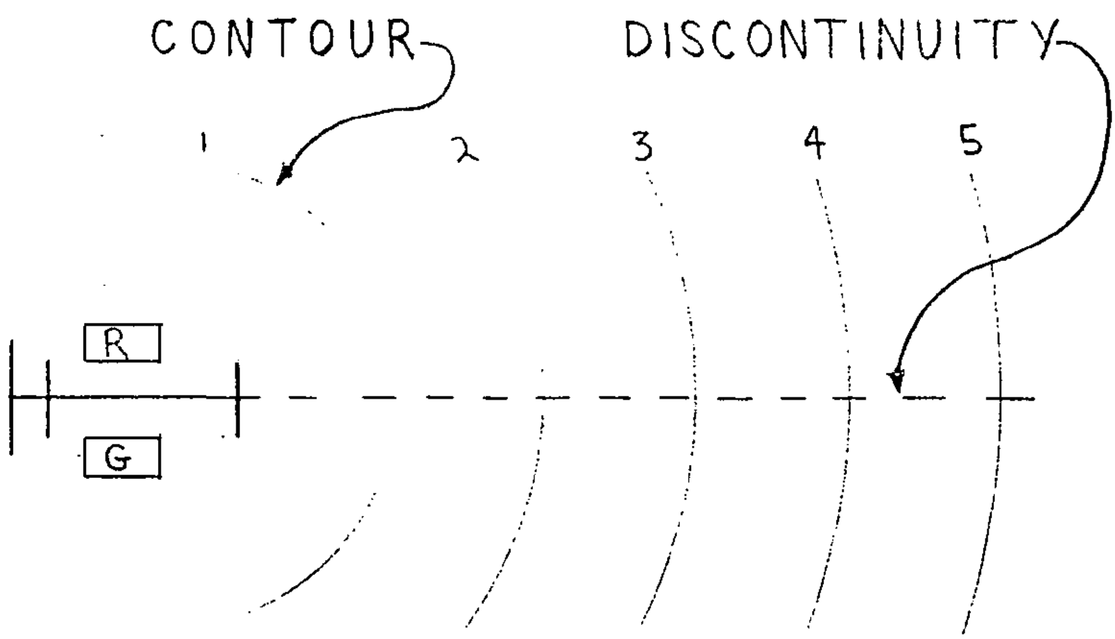
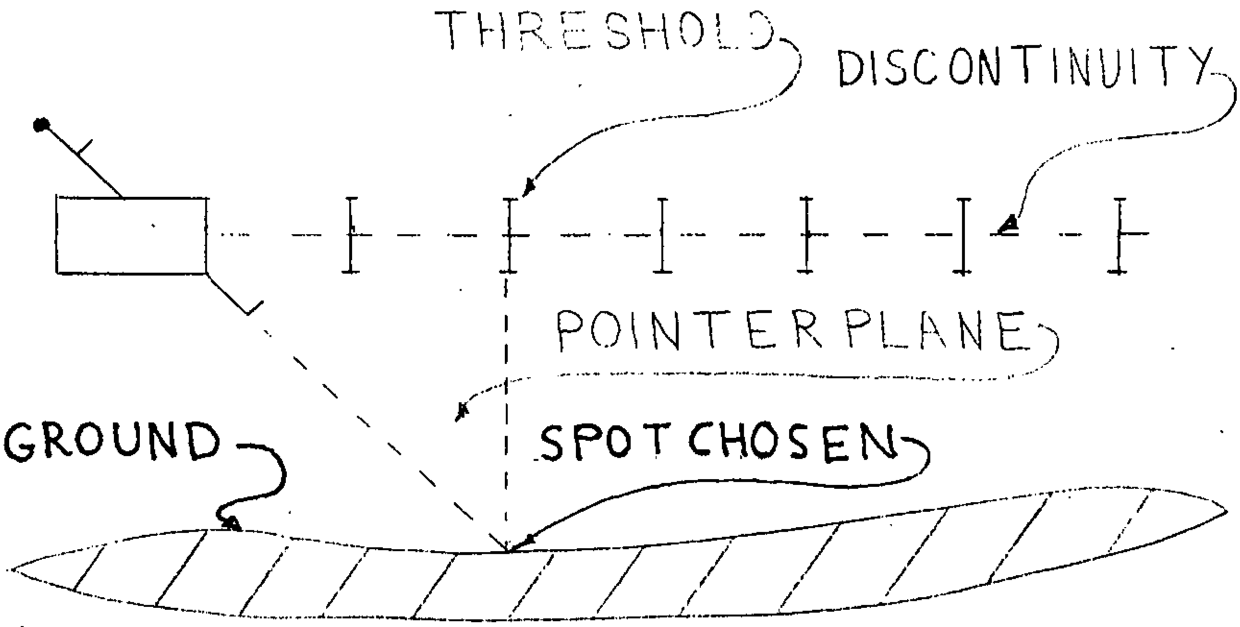


DIAGRAM 2.

DIAGRAM 3



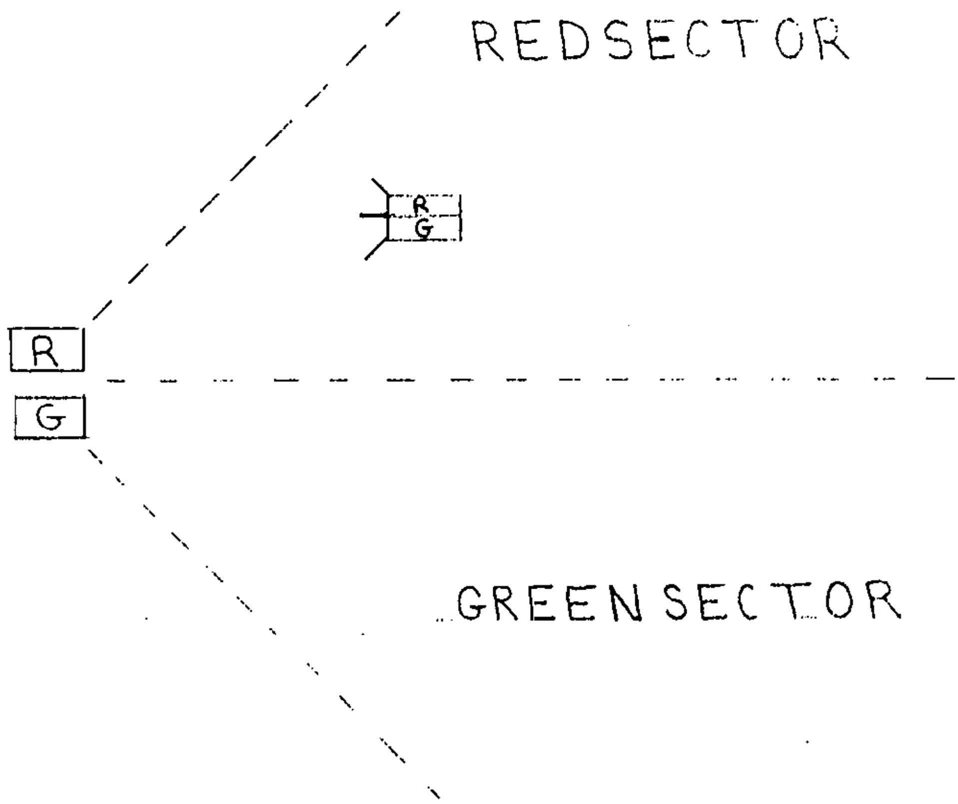


DIAGRAM 4.

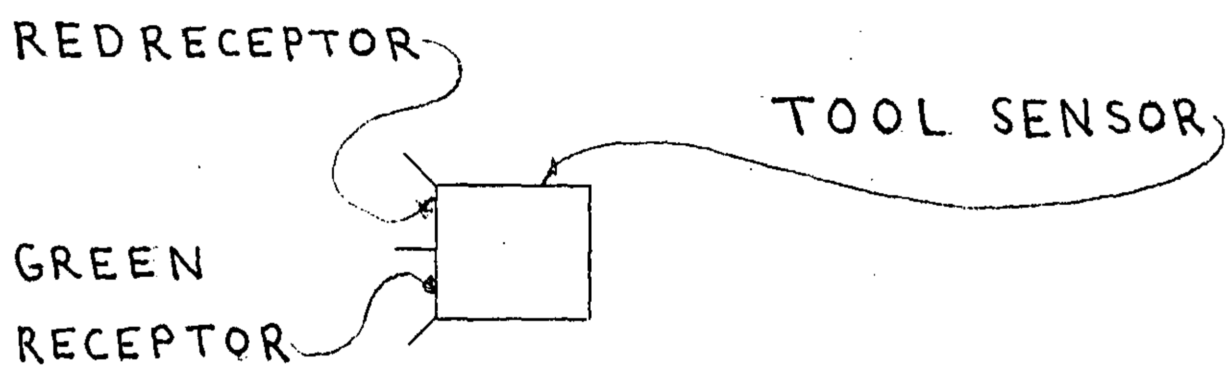


DIAGRAM 5.

SENSOR / CONDITION	RED	GREEN	MOTOR ACTION
	1	0	MOVE TO GREEN
	0	1	MOVE TO RED
	1	1	HALT
	0	0	NO ACTION

FIGURE 1. [1 = lit, 0 = unlit]

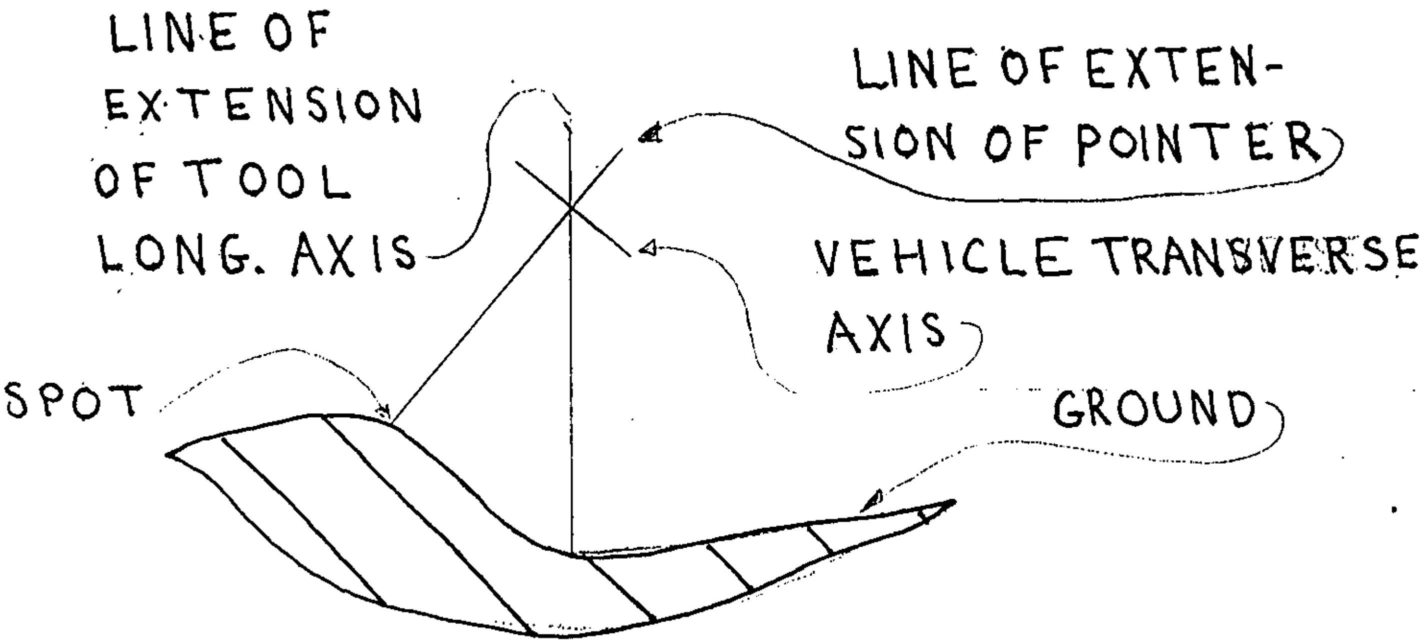


DIAGRAM 6.

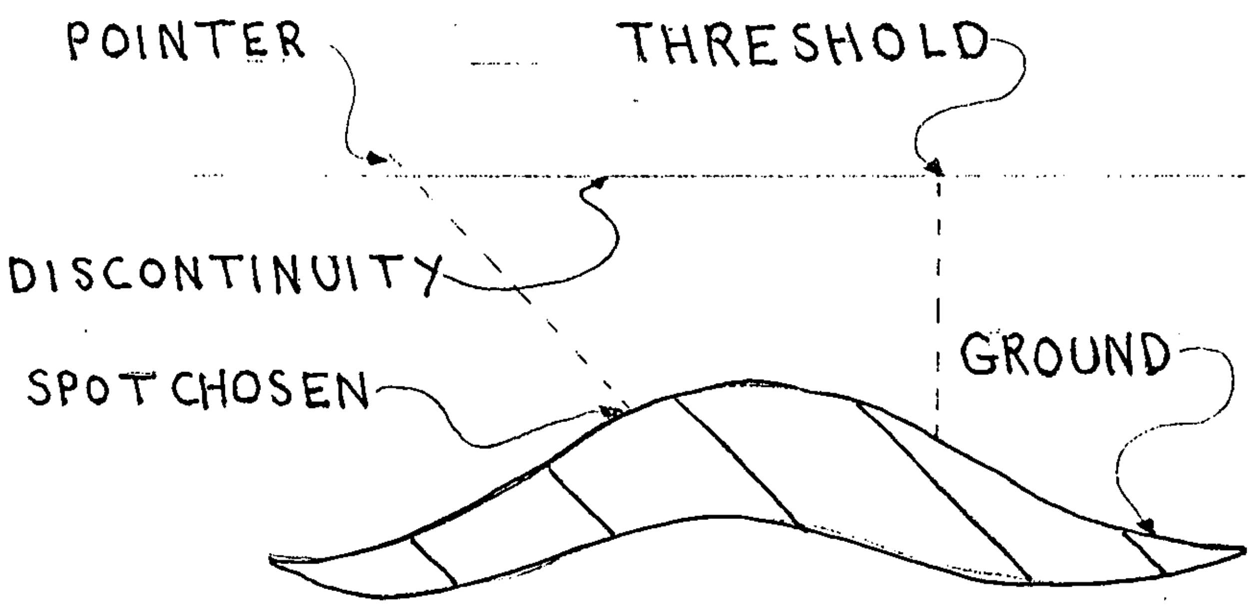


DIAGRAM 7.

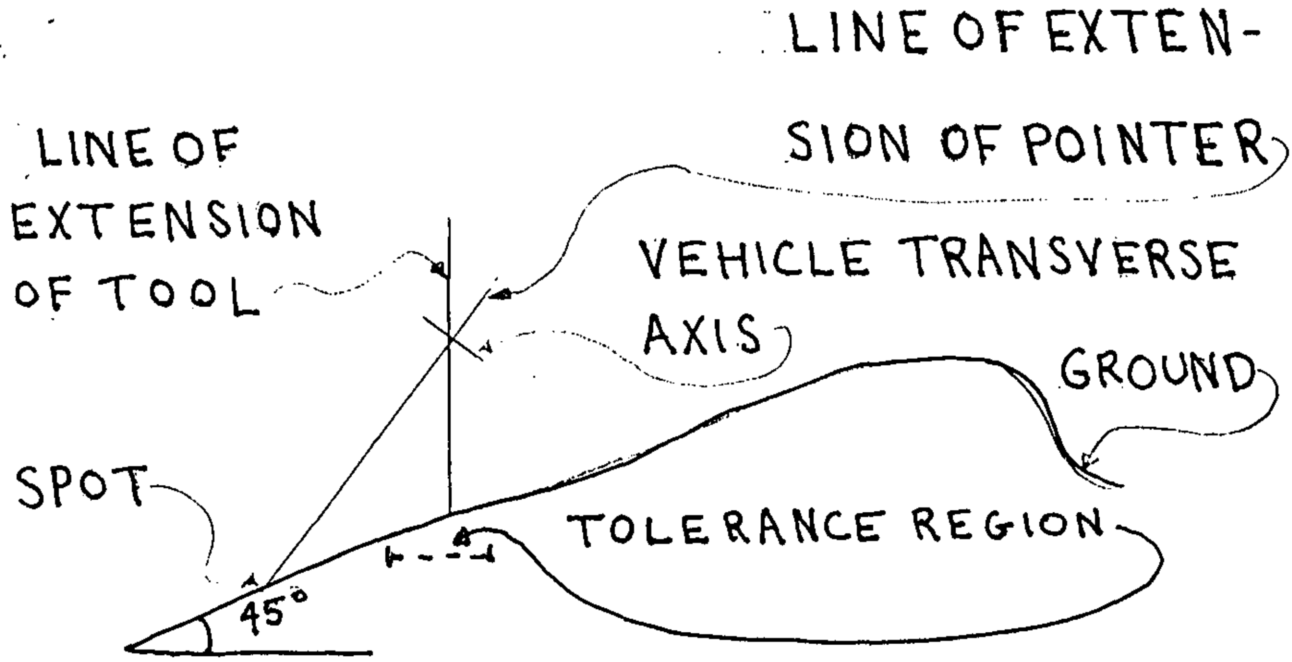


DIAGRAM 8.

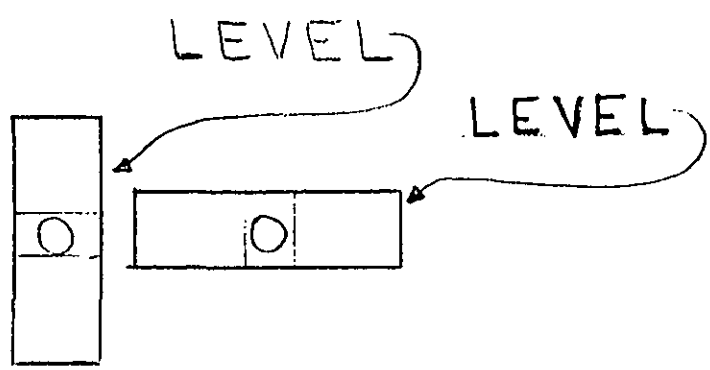


DIAGRAM 9

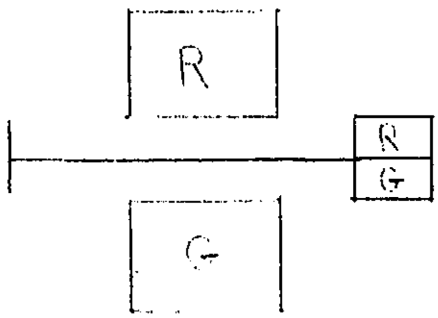


DIAGRAM 10.

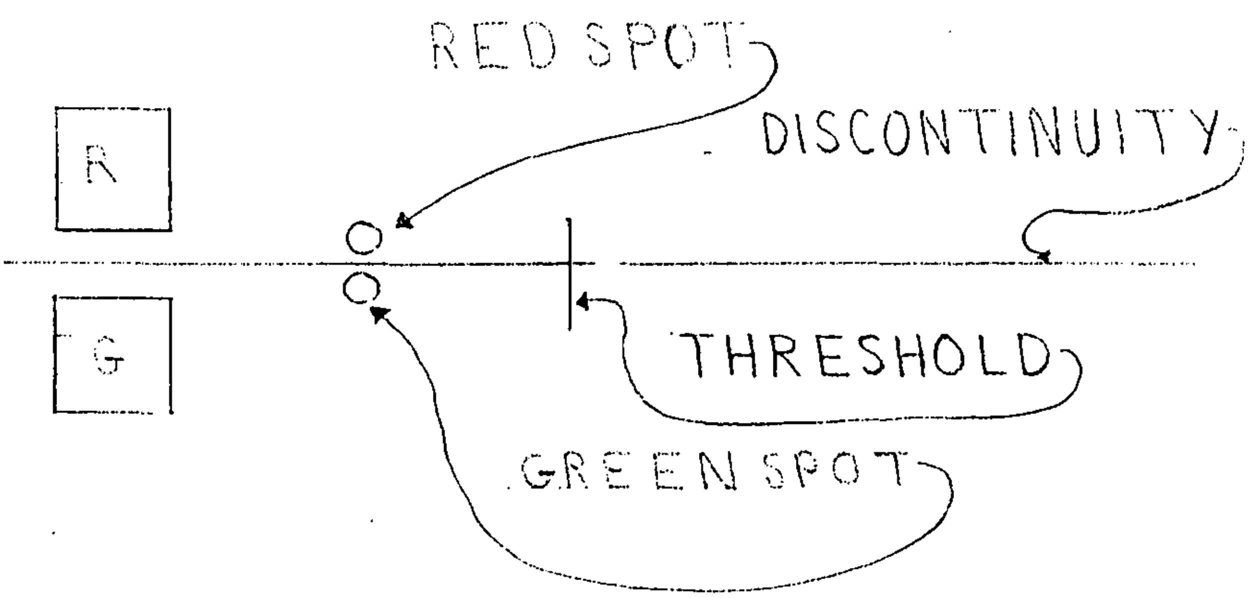


DIAGRAM 11.

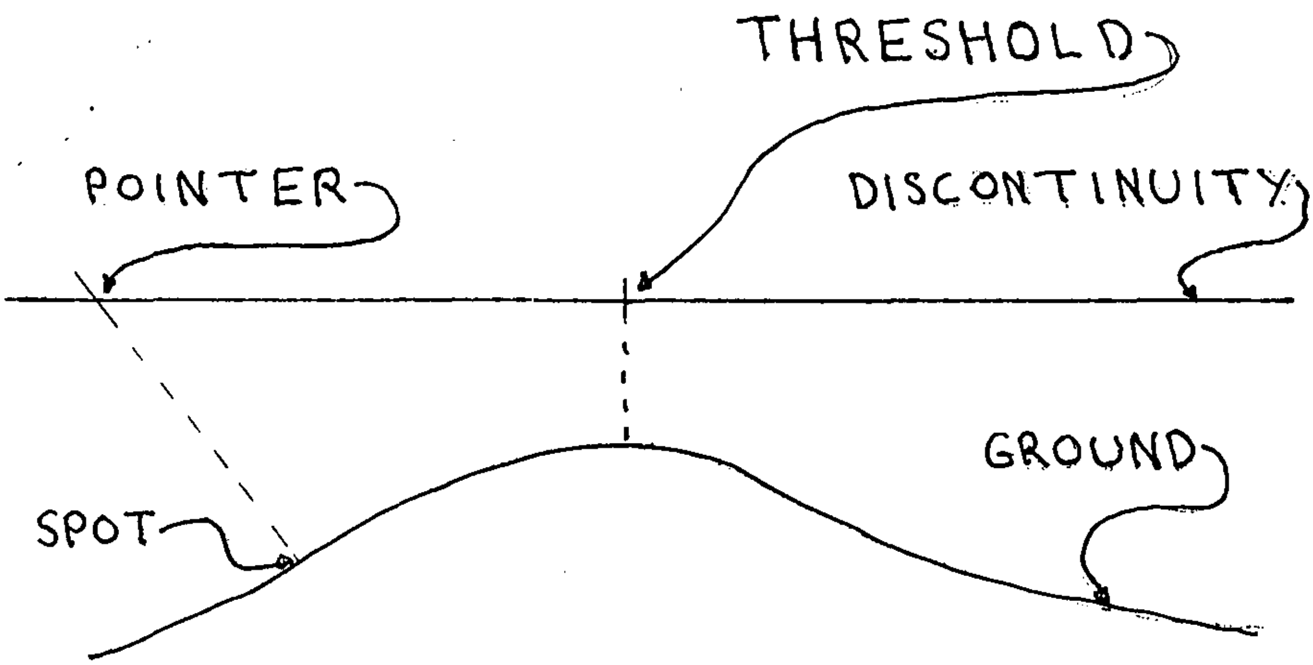


DIAGRAM 12

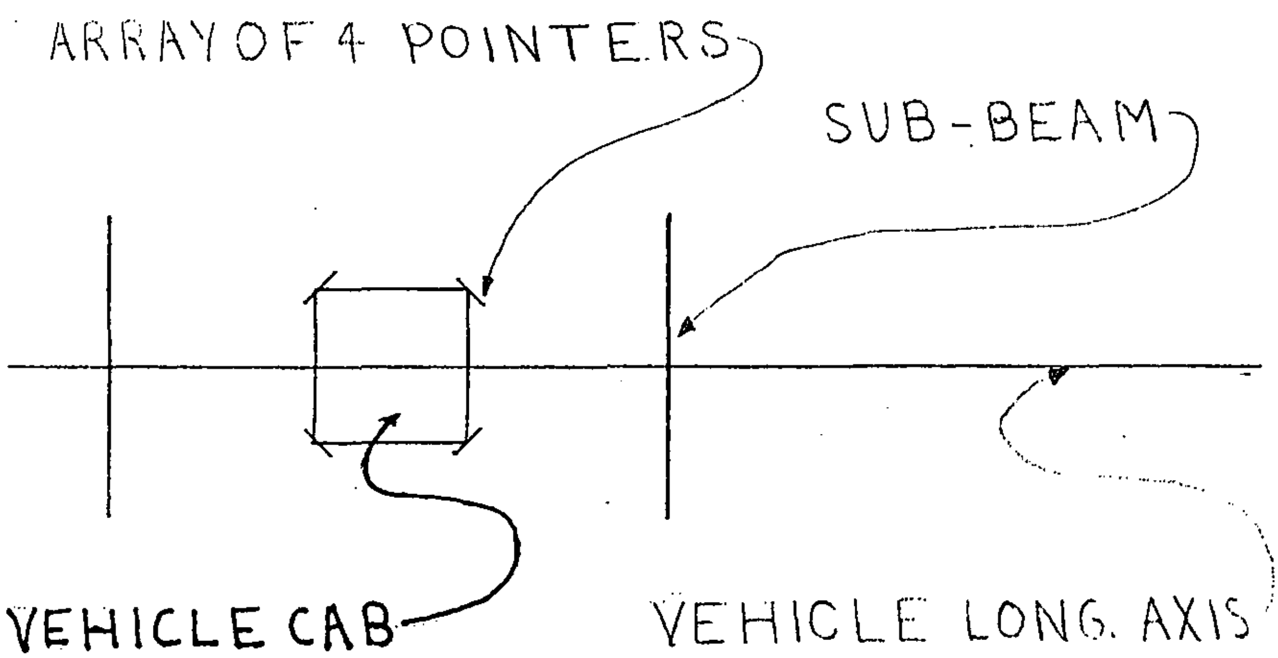


DIAGRAM 13

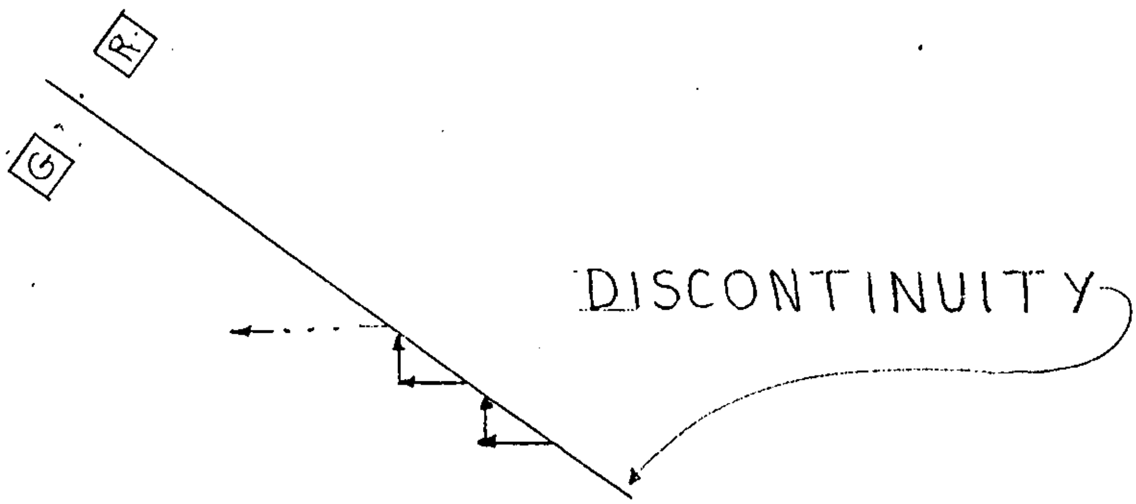
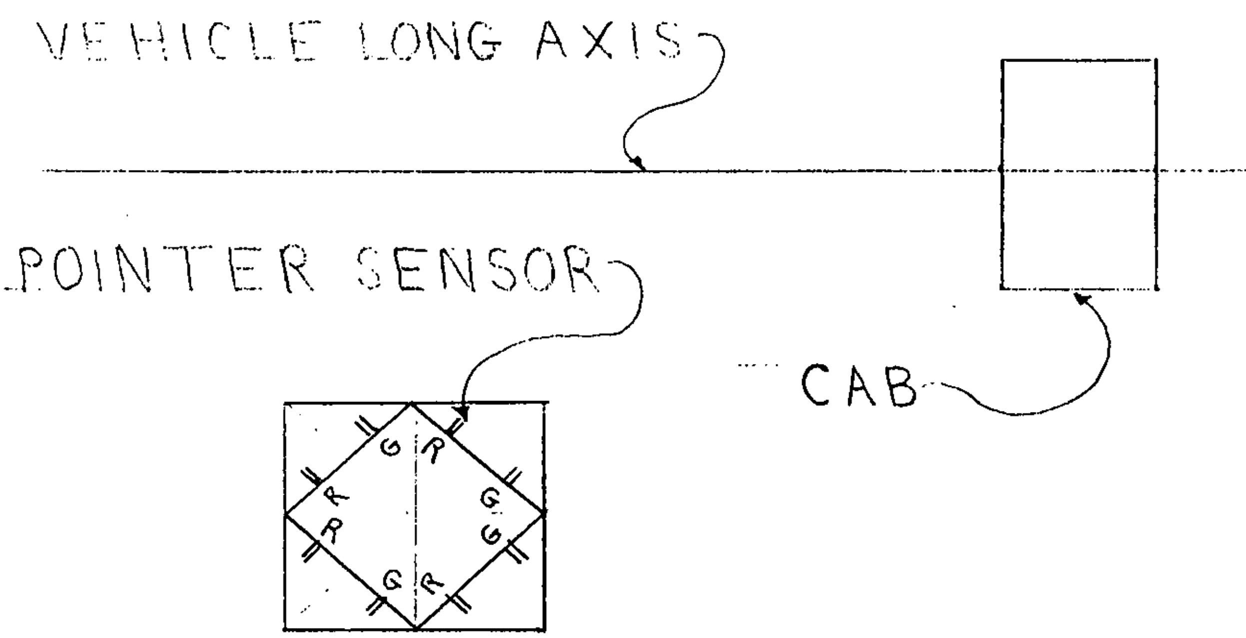


DIAGRAM 14. (↼↑ ≙ IDEALISED TOOL MOTION)



TOOL SENSORY SYSTEM

DIAGRAM 15

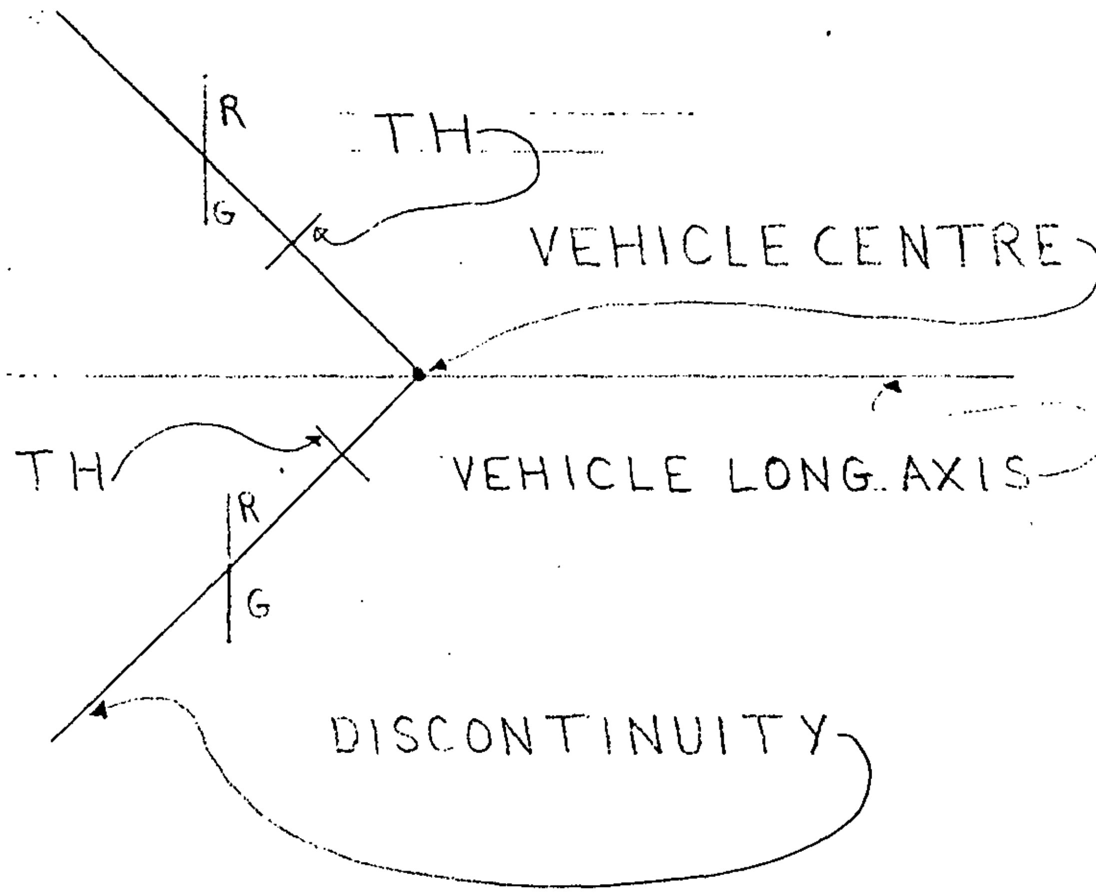


DIAGRAM 16.

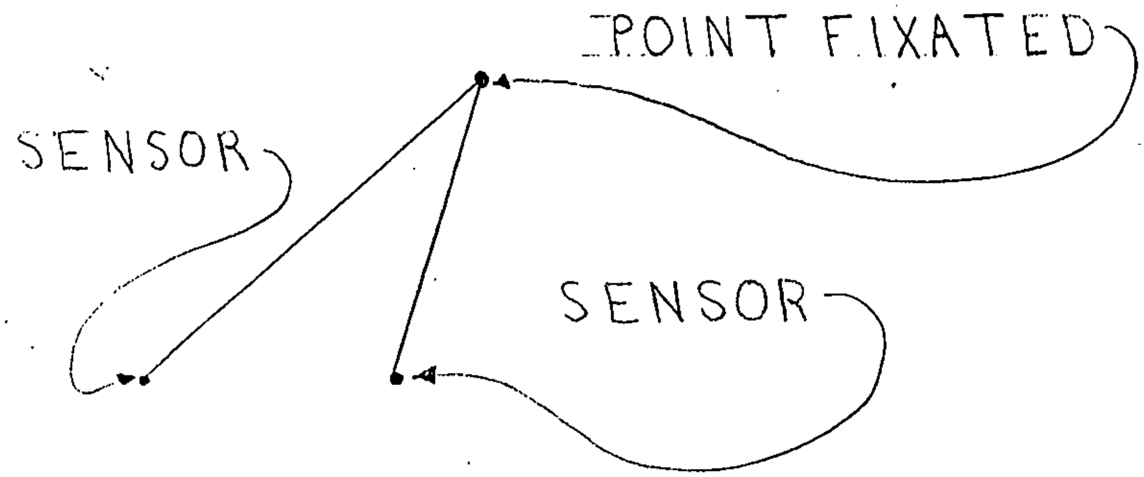


DIAGRAM 17. "PLAN"

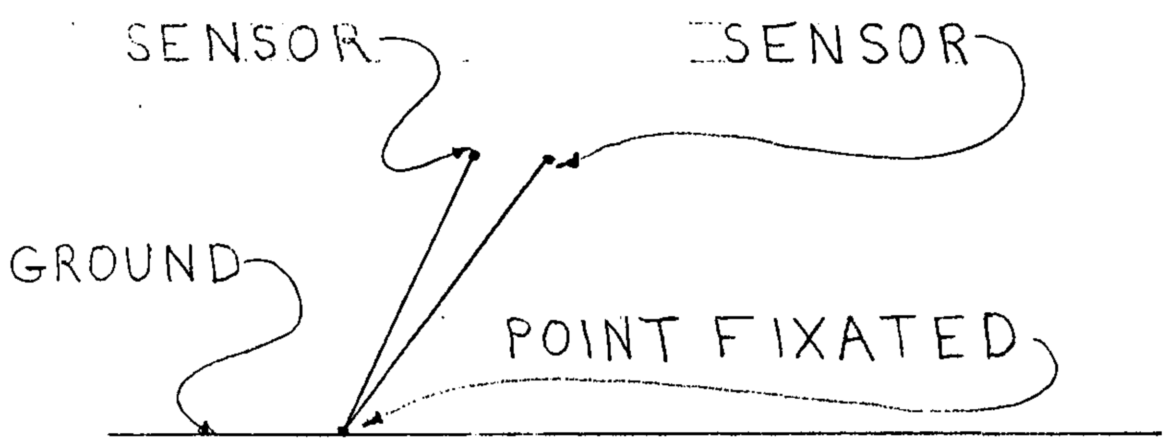


DIAGRAM 18. "ELEVATION"

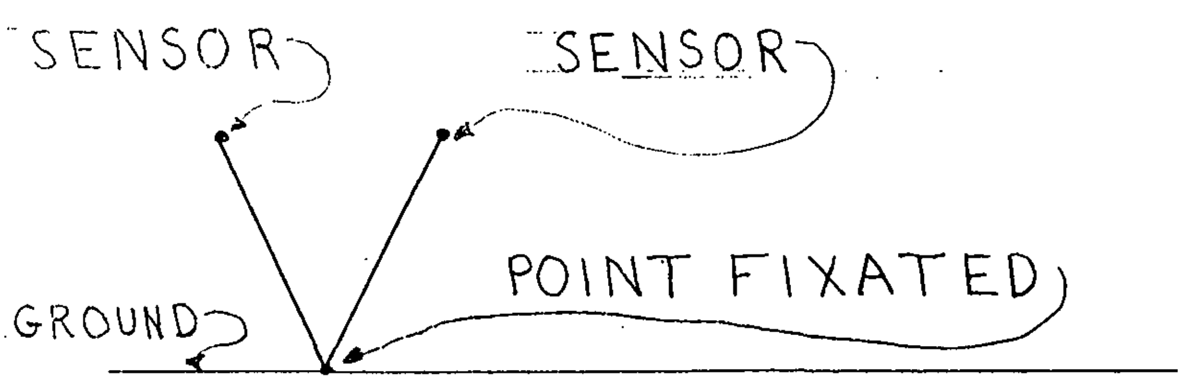


DIAGRAM 19. "ELEVATION"

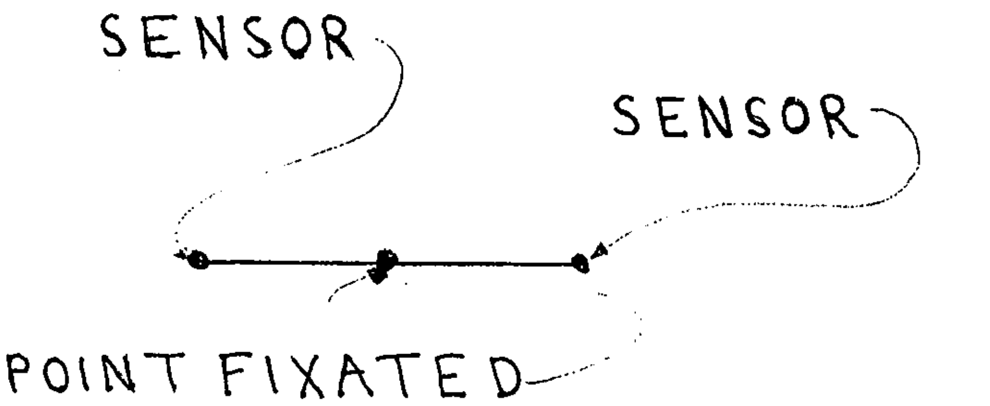


DIAGRAM 20. "PLAN"

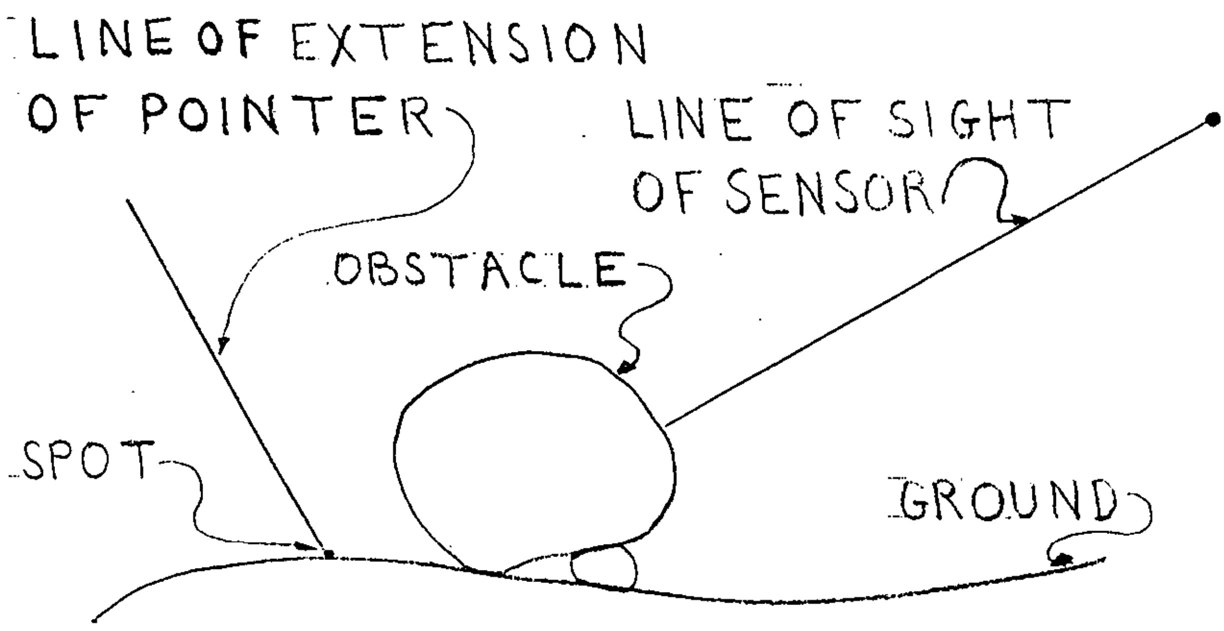


DIAGRAM 21

Chapter X.
SPACING AND TOOL SET-UP

The main problem dealt with in this chapter is that of causing an array of planting tools to space themselves appropriately from each other, from already planted trees, from residuals and from other significant objects such as cut-block boundaries which may fall within a tool array area. The spacing motor-response is to be driven by machine perceived cues. Detail enough for patenting purposes is aimed at. The techniques developed here can be applied to other situations (individual tool guidance and the guidance of a collection of interacting tools) and if necessary generalized. The practical requirements for a system which fulfils the needs of planting tool spacing are firstly clarified. More detail of the sensory-motor responses needed and their organization are then dealt with. Some complications which are needed for a practical solution are found to be solvable by an application of the pointer system which has been used for semi-automatic tool guidance. A means by which a tool array can be initially set-up for work semi-automatically falls out of the work also.

In the case being dealt with each tool in the array is to be identical to any other tool in the array. The members of any pair of tools perform identical functions and respond identically to given sensory input. Tools are to be interchangeable. A single inter-tool spacing prescription applies to any pair of immediately adjacent tools (as defined). In no case does the work area of one planting tool overlap that of another planting tool. If semi-automatic or automatic site preparation were to be performed then clearing tools would work in the region of work of each planting. This possibility is considered briefly at the end of the chapter.

In the specification for a tree planting contract an "ideal" inter-tree spacing ("D") is given (Figure 1 contract form). It is one which if it could be adhered to would produce a perfectly spaced planted area, one having the desired density of trees per hectare. Because of the way in which the planting of this inter-tree spacing is able to be implemented the ideal spacing cannot be achieved (Diagram 1 - square spacing and diagonals). It cannot be achieved additionally because of the presence of obstacles. In order to enable as far as possible the desired stem density per hectare to be closely approximated despite the presence of ground obstacles, a "tolerance" ("T") is allowed in the inter-tree spacing. A given tree may be moved from the ideal position up to a given minimum distance from immediately adjacent planted trees (Diagram 2).

The inter-tree spacing prescription in a contract must be distinguished from the actual spacing which is used by a planter to obtain the desired stem density per hectare. A commonly used pattern of planting is the square array. Figure 2 shows the empirically arrived at relationship between a prescribed (ideal) square spacing, the stem density associated with this prescription and the practical inter-tree spacing which is needed to obtain an approximation to the ideal spacing, and hence to the required stem density.

In a contract a tolerance relative to an ideal inter-tree spacing is given (Figures 1 and 3). A given tree must not be closer than to an adjacent tree than the ideal inter-tree distance, D, less the tolerance, T (i.e. the minimum inter-tree distance is (D-T)). On the ground the planter uses a practical inter-tree spacing which is less than the ideal inter-tree spacing. This practical spacing (Figure 2) minus the tolerance stated in the contract will produce an inter-tree spacing which is too small. The tolerance used must be adjusted. A straight forward solution is to use as a tolerance (T - (D - Practical inter-tree distance)). Figure 2 shows the combinations of D, T and practical inter-tree distances which are in use. It will be seen that the difference (D - Practical Spacing) is not constant and that it increases, with exceptions, with increasing inter-tree distance. The existence of a difference between any given inter-tree spacing (D) and the practical spacing used which is non-constant gives rise to a need to adjust the tolerance which is used in a way which also not constant. This adds to the problem of spacing a combination in the area of ergonomics - the initial settings which must be performed by the human operator to achieve a required spacing.

It is essential that each tool be able to be set for the range of inter-tree spacings and tolerances which are used. This setting must be able to be done in a simple manner in the field by a person following straight forward instructions.

The need for him (or anyone else) to have to enter parameter values or to make any other change to the program which guides a tool is to be avoided. Our choice is to use a small number of hand altered "dial" adjustments, one for inter-tree spacing and one for tolerance. The dials are to be clearly marked as to the positions which correspond to a given inter-tree spacing and to the tolerance (Diagram 3). To set the inter-tree spacing and the tolerance the operator has only to turn the dials to the chosen settings. He is not required to make any computation nor even to fully realize the effect of the adjustments which need to be made.

The tool spacing response will be based upon a sensitivity to a light intensity threshold, a response closely similar to that used in semi-automatic choice to halt a tool at the threshold (TH).

What the dial adjustments will do is to alter the position of a light intensity threshold value. A spacing distance can be set by dimming or by brightening a light. The tolerance value cannot be obtained quite so straight forwardly. The tolerance value allows a tool to move a given distance towards an adjacent higher order tool (see below) from a given maximum inter-tree distance (D). The actual minimum inter-tree distance which may be moved to depends on the maximum inter-tree distance which is being used; a practical tolerance adjustment as has been explained accompanies each spacing distance which is prescribed (Figure 2). The practical tolerance setting can be obtained by the use of a pair of spacing lights to which correspond on an adjacent tool a pair of light sensors. A first adjustment adjusts the brightness of both light sources for a given spacing distance (D-practical). A second adjustment adjusts a given one of the pair for the practical tolerance to be used (Diagram 3). An adjustment of the receptor system could be used but here an adjustment of the light sources is used, the same effect as that used for semi-automatic choice is used. The spacing sensors and transmitters are discussed further later in the chapter.

A commonly used practical spacing is 2.5m. This figure has been used for illustrative purposes. In the absence of a prescribed tolerance, 0.5m is used (Figure 1). With a 2.5m practical square spacing the practical tolerance which is used will be 0.5 to 0.19m (Figure 2). These figures are used in the examples which follow.

To move a tool to a planting spot straight line motion along two "horizontal" Cartesian axes is to be used, with the control of motion on one axis being independent of the motion on the other. Tool motion will occur within a square tolerance region (Diagram 2) which approximates to the practical tolerance region which a spacing and tolerance prescription defines.

Another pattern of planting is sometimes made use of (Diagram 4). It achieves the same result as the first (square) pattern. It is a rotation of the square pattern. It is more difficult to set a tool for this pattern than the square pattern. The latter has therefore been explored; it is a convenient one for machine planting.

It is preferred to use a gantry structure for tool support and movement (refs). Gantry structures are suitable for use with a Cartesian pattern of motion. For developmental purposes they can be simply and ruggedly produced and may well serve for final application. Three organizations have been explored (Diagrams 5, 6 and 7). With "on/off" control, a Cartesian pattern of motion, independent control of the movement along each axis combined with guidance by perceptual cues a simple "shallow" algorithm is needed.

A tolerance prescription contains within it an implicit order of precedence. The position in which a hand planter is allowed to place a tree is defined relative to already planted trees. Each tolerance region is, so to speak, pulled in the direction of already planted trees. A perfect arrangement of tolerance regions is shown in Diagram 8. Here the order of precedence is from "west" to "east" and from "north" to "south". Let an arbitrary number of rows be already planted in this pattern. In order to obtain this pattern and its continuation in the next row (Diagram 8) an order of precedence must be imposed on the tool array. This direction of precedence is shown in Diagram 9 with the highest order tool marked with a "No. 1" in its tolerance region.

Having reached the end of the row (Diagram 8) the vehicle can either turn to begin a new sequence of rows (or equivalently, a new sequence of array blocks) or move sideways and then "reverse" (Diagram 10) down the new planting path. (The vehicle is fore and aft symmetrical so that reverse and "forward" motion require the same motor action. It is convenient if reversal does take place for the driver to be able to swing his seat - a common arrangement in such tools as backhoes. The vehicle controls would have to be organized to allow for this.)

If reverse motion is performed, then by maintaining the order of precedence of the previous sequence of planting the required arrangement of tolerance regions is obtained.

If a turn is made (Diagram 10 (d) note) then maintenance of the previous order of precedence can give rise to over-spacing (Diagrams 11 and 12).

By the use of reversal in this case no change of order of precedence is needed. Planting in an inwards spiral or an outward spiral achieves the same result (Diagram 15). However, the need to either set initially and possibly during the course of a workday reset the order of precedence cannot be avoided without, in our judgment, undesirably restricting the freedom of choice of the operator as the order of planting and direction of planting which is to be performed.

It will be seen from Diagrams 13 and 14 that there are four significant orders of precedence. Which is chosen to be used will depend largely on the direction of travel which is chosen relative to a boundary or relative to already planted trees (Diagrams 13 and 14). There is then, a need to be able to set an order of precedence of an array. For the moment the ability of the operator to do this is assumed. How it is done is discussed later.

A choice has been made to use a tool starting position which is shown in Diagram 14. In an automatic system, when an array of trees is being placed simultaneously, the order of precedence will "pull" a lower order tool towards the relevant higher order tools. It will scan towards the immediately adjacent higher order tools. (When an array of trees is being placed simultaneously, a lower order tool spaces from a higher order tool which may be moving within its tolerance region.) The tools on the boundary with planted trees or on another type of boundary (Diagrams 13 and 14) will not be under the influence of two higher order tools. The No. 1 tool will not be under the influence of any other tool. Nonetheless its motion must be constrained to a given tolerance region (relative to an ideal start position). The motion of the boundary tools will likewise have to be constrained. These problems are dealt with in the section on tool set-up.

A choice has been made to use the judgment of the operator in aligning the tool array with already planted trees. This task as well as that of moving the vehicle from one array planting position to a successive position are to be under the manual control of the vehicle operator. Alignment with a boundary or with already planted trees is to be achieved with the aid of side markers and end markers (Diagrams 16 and 17). Pole markers are in use on agricultural machinery for such operations as the sowing of seed. Alignment will not usually be taking place with ideally spaced predecessor arrays. The operator will have to attempt to align the array to be planted as best he may. The decisions involved here would be difficult ones for a machine perceptual system to make. The operator can make them at a glance.

Each tool in an automatic system scans its tolerance region until it finds a good planting spot at which point it halts and enters a "Plant" sub-routine. Once it has entered "Plant" it cannot be moved by spacing signals. To prevent possibly over-spacing of adjacent higher order tools (Diagram 18) the order of precedence of a stationary tool becomes locally high (Diagram 19). This gives rise to a "chain" effect (Diagram 19).

In a semi-automatic system the operator will set the order of precedence (see the section on tool set-up). This will bring each tool to a start position and will at the same time define a tolerance region relative to the start position of each tool. If the operator chooses for any tool a planting position which is outside this region then the spacing response will prevent the tool from moving to it. This response (the tool does not move to the spot pointed to and plant) will warn the operator of a wrong choice.

The members of an array of tools can be made to space themselves correctly from already planted trees and from each other if:

(1) An order of precedence is imposed upon the tools.

(2) Any given tool responds to a D-signal (inter-tool distance) from immediately adjacent higher order tools.

(3) Any given tool produces a D-signal which is received by immediately adjacent lower order tools.

(4) Any given tool responds to a T-signal (tolerance) from immediately adjacent higher order tools.

(5) Any given tool produces a T-signal which is received by immediately adjacent lower order tools.

Inter-tool and operator/tool communication is to be via light carried signals. An example of operator/tool communication by means of light carried signals has already been described in a general fashion in the chapter on semi-automatic choice. Here some further detail on the basic perceptual/motor activity of a tool and its sensor/transmitter lay-out are described.

In Diagram 20 four sides of the tool sensory system for spacing are distinguished.

In Diagram 21 four sides of the pointer sensors (for semi-automatic choice) are distinguished. In an exploratory system they are distinguished from the D and T sensors.

In Diagram 22 two sensors and two transmitters (of light) are shown on each side of the "spacing" sensory system. One sensor is a D-sensor, the other sensor is a T-sensor. Corresponding to each of these sensors, on immediately adjacent tools, there are transmitters (Diagram 22). Each D-transmitter emits a red light. Each T-transmitter emits a green light (Diagram 22). These pairs of green (red) transmitters and receivers will be used for spacing, obtaining an order of precedence and for semi-automatic tool set up. The "logical" responses which are used are those already used for semi-automatic choice with some additions. The basic responses used are those listed in the introduction to spacing and choice - the state of balance on a pair of receptors, the recognition of a threshold, the recognition of a gradient.

The order of precedence. Higher order tools transmit light to lower order tools. A given tool spaces from tools from which it is receiving light. The order of precedence can be altered by arranging for a different pattern of inter-tool transmission and receipt of light. How a given pattern of transmission and reception is arranged is discussed in the section on tool set-up.

Diagrams 13 and 14 show the four orders of precedence which are relevant to planting. The arrows in the diagrams show the direction of transmission (and hence that of reception) of light.

In Diagram 23 the squares represent tolerance regions. Dots represent the start positions of tools. Tool 5 spaces from tools 2 and 6. Tool 4 spaces from tools 3 and 5. Tool 1 is "immediately adjacent" to tools 2 and 6. Tool is immediately adjacent to tools 3 and 5. Tools 5 and 3 are immediately adjacent to tool 4. Only an immediately adjacent tool need effect a spacing response in a given tool; see the later discussion and System Review and System Review 2.

The adjustments for D (inter-tool distance) and T (tolerance) are made to the transmitter of light. The means used is identical to that used to set the threshold TH is semi-automatic choice. The "D"-light and the "T" light are adjusted together by being dimmed or brightened. The effect of this is to bring a chosen threshold value farther from or nearer to the light sources. The T-value is then set from the D-value by a further dimming of the T-light.

The T-value allows a tool to move towards the T-light source of an immediately adjacent higher order tool to a minimum inter-tool distance. The D-value allows a tool to move away from an immediately adjacent higher order tool to a maximum distance. In the circumstance where the movement of a higher order tool brings the inter-tool distance either too low or too high a response to a discrepancy with either the T-threshold or with the D-threshold (via the status register of the SBC) will cause the lower order tool to move to a position where it receives input which is between the T and D threshold values.

The input from a given D-sensor with a given setting no matter what its position in an array and no matter on which of the four sides of the spacing sensor it is placed always gives rise to the same motor response. (An advantage of the square tolerance region is that interchangeability is obtainable without further adjustment of each tool.)

The input from a given T-sensor with a given setting no matter what its position in an array and no matter on which of the four sides of the spacing sensor it is placed always gives rise to the same motor response.

Any two D sensors are therefore interchangeable. Any two T sensors are therefore interchangeable. A given tool may be placed anywhere in the tool array and with any sensor pair in any one of the four spacing sensor positions (Diagram 20).

The effect by which a lower order tool is halted at a D or a T boundary is either identical or analogous to the effect used to turn street lamps on or off automatically or that used to cause vehicle lights to dim (dip) or brighten automatically. A halt can be effected by the signal from, for example, an XOR integrated circuit - one side of the XOR being kept activated, the other side activated by input at the threshold. The signal produced could give rise to an interrupt (in the SBC system) which triggers an appropriate motor response. A "hardware" link to the actuators which are involved in tool movement could also be used. However, is simpler to use the SBC as there is a complication in the motor response which is needed, due to the demand for tool interchangeability, which can be readily dealt with by a software sub-routine which uses the SBC status register.

An array of tools is shown in Diagram 24. The diagram and figure 4 show the actuator action needed to move a tool in the +X, -X, +Y, -Y directions for all positions in a sixteen tool array. The sensory system can in whichever position it is placed and in whatever orientation in that position always sense correctly "too far", "too near". The processing system can derive from these signals the instructions "move nearer", "move away" or "halt" (threshold reached), "reverse direction" and so on. The meanings of the instructions in actuator terms will be seen to vary with the position in an array, with the orientation in that position and with the order of precedence which is being used.

The fact that the correct response which is needed in terms of increasing and decreasing intensity of input can always be sensed regardless of the variation due to position and to the order of precedence enables the correct actuator action to be obtained in all cases. Consider a case where -X "is" extension and +X "is" retraction. Suppose that two outputs exist, "a" and "b". Let the required action be "move nearer". In input terms what is required is an increase in the light intensity received. The system can output either "a" or "b". Suppose that it outputs "a" which gives rise to an extension but "move nearer" in this case is affected by retraction. The actuator (assume that a single actuator is involved) having received the output "a" extends. The sensors will then record a diminution of input; rather than moving nearer to the signal source the tool is moving farther away. The processing system logic can recognize this situation (by a standard comparison) and respond by outputting "b". The actuator will now bring about a retraction. Using the same sub-routine as that used to sense that the direction travelled in was incorrect the system can sense that the required increase of input is in fact occurring.

Output can therefore be uniformly "connected to" actuator action throughout an array, with for example "a" output always linked to extension "b" output always linked to retraction.

It is necessary to arrange that an array of tools plants in a consistently spaced pattern. This can be done if a consistent pattern of tolerance regions can be obtained; each tool plants a tree in an associated region.

For illustrative purposes a sixteen tool array is shown (Diagram 8).

Diagram 25 shows the frame of reference which is used for the position of the main beams.

The following sequence is followed:

(1) With the vehicle on reasonably level ground and blocked, the main beams are set for a given inter-tree spacing by hand operated controls and end-stops. The required end-stop positions on the longitudinal axis for a given spacing are marked on the vehicle frame.

(2) All corner tool sub-beams (Diagram 8) are end stopped (Diagram 26). To move a sub-beam to a position within the end-stops, so as to allow their being set a pointer is used (Diagram 27). Placing the pointer horizontal (pointer fully "up": Diagram 28) places TH (the threshold) far enough away from the pointer light sources that full extension or retraction of a tool support will result. Intermediate positions will cause a lesser amount of motion. If the pointer is swung horizontally so as to cause one side of the pointer light receptors to be more brightly lit than the other the tool support will move the receptors to the low side. By these means movement of a tool to any desired position within a tolerance region can be achieved (Diagram 26).

The need to maintain interchangeability of parts gives rise to two cases. How they arise is shown in Diagram 29 where the arrangement of pointer lights and their receptors is shown. The "Y" axis response is tabulated in Figure 5.

From the point of view of the operator there is one case. A tool will move to the line of discontinuity and TH (Diagram 27).

(3) Setting the order of precedence. The order of precedence is set in the field. Before the planting direction and the position of the vehicle relative to a boundary is known the order of precedence needed will not be

known. The four relevant orders of precedence are shown in Diagrams 13 and 14.

The operator will set the order of precedence using the trailing tool which is closest either to a boundary or which is bounded on two sides by planted trees (Diagrams 19 and 13). It is best if the four choices are shown diagrammatically on a plate in the vehicle cab and also in the operator manual. The instruction is that the No. 2 tool is always "behind" at the start and that it is always on the "hand" which is closest to either planted trees or a boundary. (Throughout the work it has been kept in mind that the control of the system must be such that the average machine operator will be able to deal with it after a short course of instruction (say four to six weeks as is used for instruction in the handling of logging equipment.) The device organization must be such also that the average fitter and the average maintenance mechanic will be able to readily learn to deal with.)

Diagrams 21 and 22 show the pointer sensors on a tool and the spacing sensors and transmitters (i.e. coloured lights).

The start position needed for each order of precedence is shown in Diagram 14. The processes of setting the order of precedence and obtaining the start position are combined. The same sequence of operator action with a pointer is needed for all orders of precedence. The first order of precedence is assumed to be needed in what follows. The sixteen tool array of Diagrams 8 and 9 is to be dealt with. Before the No. 1 tool is brought to the start position the other tools which are immediately adjacent will be assumed to be in any position allowed by the actuator motion; they will probably be fully retracted at the start of work. The order of precedence needed is signalled by the pattern of illumination of the tools in an array. The pattern which it has been assumed to be needed is shown in Diagrams 8, 9 and 13. Higher order tools illuminate the spacing sensors of lower order tools. This pattern is obtained throughout the array from the actions of the No. 1 Tool.

Method 1

A semi-automatic method of tool set-up is sought which is triggered by simple operator initiated signals.

In outline this method requires that the No. 1 tool be moved by pointer to a position shown in Diagram 30. The basic effect used is that if a tool is illuminated on a given side it turns on the spacing lights (D and T) on the opposite side (Diagram 31). All lower order tools except those on a boundary having in it the No. 1 tool (Diagram 30) will come to be illuminated on two sides. Their correct spacing lights on two sides can be turned on by the effect. A difficulty arises because the boundary tools (Diagram 31) are only lit on one side so that a second effect is needed to cause them to turn on correctly a second side. This is done by using the pattern of motion of the higher order tool which is illuminating one side. For the second order tools (Diagram 30) this pattern is recognized as the No. 1 tool moves back from the position to which it was moved by pointer to the start position. The motion of the second order tools signals the same thing to the boundary third order tools and so on.

Once the second order tools light on both sides a "chain" effect runs through the array causing the remaining tools to light. Each higher order tool receives a signal from the immediately adjacent lower order tools which signifies that they are lit on both sides or lit on one side and require movement information. The signal to the higher order tool is the same in either case. It causes the tool to move back to the start position.

Motion back to start is a chain effect of the spacing and balance responses. The No. 1 tool is moved back to the start position by the pointer. It responds to the pointer only after having received signals to move from its adjacent tools. (An operator "override" will move the No. 1 tool if necessary, e.g. in the case of a wrong choice of No. 1 tool etc.) The second order tools being lit and having received "spacing lights on" signals from both adjacent lower order tools then follow the No. 1 tool to the start position. The response of the third order and lower tools is identical to the second order response.

The overall effect is to bring all tools to the start position correctly lit.

The operator actions needed to achieve this are those of directing the No. 1 tool to the position shown in Diagram 30 and when the No. 1 tool reaches this position moving the pointer so as to cause the No. 1 tool to move to the start position. This second action will cause the lights of the No. 1 tool to turn on. No more operator actions are needed to set the array order of precedence and the correct start position for that order.

Further Detail

(1) The No. 1 tool is chosen.

(2) Power is turned on to the tools.

(3) The tool pointer for the No. 1 tool is turned on and positioned so as to move the tool to the position in its tolerance region shown in Diagram 30. The bright spot is not turned on so that the "Plant" sub-routine cannot be entered.

(4) The spacing lights on two sides of the No. 1 tool are turned by the pointer being moved so to bring the lead tool back to the start position. The lights "adjacent" to the sensors actively receiving pointer input are turned on (Diagram 32 and Figure 6).

(5) Note: In all orders of precedence the leading tool is moved away from the operator. The operator action is identical for all cases (Diagram 33).

(6) The lead tool is now halted at the position shown in Diagram 30 with two sides lit.

(7) The operator has moved the pointer so as to direct the No. 1 tool to the start position.

(8) The No. 1 tool will respond to this signal only after receiving signals that immediately adjacent tools are either lit or in a state where they will light or are in a state where one side can be lit but motion information is needed to light the other side.

(9) With the No. 1 tool halted in the position shown in Diagram 30 and lit, the immediately adjacent tools will move towards balanced input and the D-threshold.

(10) Once an adjacent (second order) tool is receiving "balanced" input and the D-signal a change of state occurs which results in the turning on and then off of either a red or a green spacing light on the side which is illuminated by the No. 1 tool (Diagram 30). This signal tells the No. 1 tool that the side facing it is lit, "balanced" and at D; the No. 1 tool can now move to start.

Signals must be received from both sides (i.e. from both second order tools) before the No. 1 tool responds to the pointer command.

(11) Once the No. 1 tool has received two signals it moves to start being directed there by the pointer.

(12) Its pattern of motion (Diagram 34) gives rise to a pattern of illumination from which the second order tools can "deduce" which second side to light.

(13) The two second order tools are now stationary and lit on both sides.

(14) Exactly the same pattern of action as that followed by the second tools is now followed by the third order tools (Diagram 30). They move to the position shown in Diagram 35 where one is correctly illuminated on both sides; this tool lights. It signals to the light source on each of its sides and turns on the spacing lights on two sides. The other No. 3 tools signal on one side. The second order tools now follow the No. 1 tool to the start position. This motion "lights the second side of the boundary tools in the third order.

(15) A "chain" effect, using a pattern of action in each lower order which is identical to that which has been described for the second and third order tools, correctly lights the whole array and brings each tool in it to the start position.

Non-adjacent tools may be lit by the spacing lights of a given tool or more than one tool on a correct or on an incorrect side (Diagram 36). Tools so lit will respond by seeking balance and D but they cannot when so lit reach either balance or D. No turning on of lights can occur from such illumination.

When a whole array is lit a response may occur to the lights of lower order tools which "contradicts" the response called for by immediately adjacent higher order tools. This situation is dealt with in the system review.

The problem of turning on correctly the lights of the tools in an array has been described for the case of the first order of precedence and for a tool on either side of the No. 1 tool. The events and their order needed in the other orders of precedence are identical to the case described. Their diagrams can be obtained from a diagram for the first order of precedence by a rotation in one plane or by rotations in two planes.

Method 2

In the second method the No. 1 toll is moved to the position shown in Diagram 30 as in the first method. The lights on two sides of the lead tool are turned on. Some of the lights of adjacent tools are turned on when spacing signals are received from the lead tool. A "chain" effect turns on the rest of the lights which are needed.

Further Detail

(1) The number 1 tool comes to the corner position (Diagram 30).

(2) Two lights are turned on as in the first method.

(3) The lead tool waits for signals of balance and D from the adjacent tools.

(4) The second order tools come to balance and D.

(5) They signal this condition (Green or red light on and then off, etc. as before).

(6) They halt and do not turn on lights until a pattern of illumination arising from motion of the No. 1 tool is received.

(7) The lead tool moves to start.

(8) Still halted, the second order then turn on their lights in a pattern which is shown in Diagram 37. In this diagram arrows show the direction of lighting, numbers with arrows denote time intervals, the lower the number the lower the time interval, numbers within a box denote the order within an array of a tool.

(9) The third order tools come to balance and D. They halt with no lights on.

(10) The same sequence of events as has already been described now occurs with the No. 2 tools playing the part of the No. 1 tool and the third order tools playing the part of the second order tools. That is, the second order tools remain halted until they receive balance and D signals on both sides. They respond by moving to start (under the influence of the spacing lights of the No. 1 tool). The movement, altering the pattern of illumination received by the third order tools, causes them to light in a fixed order. The boundary pattern differs from the "Interior" pattern.

The pattern is repeated throughout the array. The effect is shown in Diagram 37.

Variants of both methods can be described. They give the same results.

With a pattern of transmission and reception established tools will space from higher order tools and, in an automatic system, move in tolerance regions which are arranged correctly. Even so, a difficulty arises in automatic systems when a given tool has halted and entered a "Plant" sub-routine. In this condition it will no longer respond to spacing signals. Its contact is lost with higher order adjacent tools. The possibility arise of these tools over-spacing from the halted tool (Diagram 19). To avoid this, as soon as the "Plant" sub-routine is entered the halted tool turns on all its spacing lights; it will now not respond to spacing signals; it has acquired a local highest order. Receipt of light input from the halted tool will now suppress the spacing lights (D and T) on the side of reception.

In Diagram 38 a tool, "P", halts. It turns on its spacing lights on the higher order side. The effect of this is to suppress the lights on the higher order adjacent tools which receive this input. This gives rise, in turn, to a chain action which is identical to that used to set the order of precedence originally. The result is shown in Diagram 19. The spacing prescription (in terms of D and T) will with what is now a mixed order of precedence keep the "R" (reversed) tools within the correct tolerance regions. Tool H is halted in a correct region. The D and T prescription will keep each of the R tools in a correct tolerance region.

The methods of tool set-up, spacing and guidance which have been described in this chapter and the chapter on semi-automatic choice can be used to direct the tools in a one-pass system.

Our judgment is that a semi-automatic system of guidance used in a one-pass system that performs spot site preparation and then plants trees into the sites prepared is the most valuable solution commercially. It is a system whose guidance is readily attainable with the techniques which have been described.

Diagram 39 shows a sketch organization of a one pass system. A tool array containing two planting tools and two sets of site preparation tools is shown. These tools are assumed to be semi-automatic, being guided to a work place by a pointer. Manually guided tools could be carried for dealing with heavier clearance (hydraulic snippers or an air driven heavy chain saw, grippers for moving slash, etc). Spots for planting are prepared. The vehicle moves forward and halts correctly spaced from the prepared spots. The operator points to these, guiding a planting tool to a spot. He then attends to the clearance of further spots. And so on.

A larger array of both tools could be carried if necessary. Fewer planting tools than preparation tools need be carried. The placement operation is likely to take less time than preparation.

A Summary of Operator Actions for Tool Set-up. (D and T dials already set).

(1) The position of each sub-beam is set.

(2) End-stops are set for each corner tool.

(3) No. 1 tool is chosen.

(4) The number one tool is moved out to the corner position within its tolerance region (Diagram 30) using the pointer.

(5) The pointer is moved in such a way as to bring the number one tool to the start position.

The tool array is now set-up and ready for planting. If the order of precedence is not changed during the work day no further set-up is needed. If the order of precedence needs to be changed (e.g. starting in a new sub-site using a different direction of planting from that already used) then the same sequence of operations 3 to 6 will re-set the array. End-stops and dials do not have to be touched from day to day on the same contract unless either the spacing prescription and/or the tolerance prescription needs to be changed on a sub-site. This very rarely happens.

FIGURE 1

Province of British Columbia

Ministry of Forests

This is Schedule B referred to in the contract dated the
____________ day of____________, 19_____
between ________________________
and the Regional Manager of the ________________
Forest Region.

SCHEDULE B

(See also the attached map and Planting Site Prescription - F.S. 739)

Planting Contract ________________ Name ________________________

PLANTING UNIT	ORDER OF PLANTING	AREA TO PLANT (HA)	TREES TO BE PLANTED							
			SPECIES	AGE AND TYPE OF STOCK[1]	INTER-TREE SPACING	SPACING TOLERANCE[2] (METRES)	MAXIMUM NO. OF PLANTABLE SPOTS ALLOWED PER PLOT	ESTIMATED NUMBER OF TREES (000'S)	BID PRICE PER TREE (¢)	TOTAL BID PRICE ($)
TOTALS										

1 Substitution of planting stock may be made in accordance with Schedule A.

Age and Type of Stock	Planting Tool to be Used
BR - bareroot (see below)	☐ shovel or ☐ mattock
PSB211 - styroplug, top diam. 2.5 cm, length 11 cm	☐ styro 211 dibble
PSB313 - styroplug, top diam. 3 cm, length 12.7 cm	☐ styro 313 dibble
PSB415 - styroplug, top diam. 3.9 cm, length 15 cm	☐ styro 415 dibble

Other - describe ________________________

Bareroot explained
2+0 - 2 year old, not transplanted.
2+1 - 3 year old, transplanted 1 year.
1+1 - 2 year old, transplanted 1 year.

2 If not otherwise specified spacing tolerance will be 0.5 m.

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THESIS MECHANICAL SILVICULTURE
Chapter 10. Spacing and Tool Set-Up

NUMBER OF TREES PER UNIT AREA AT VARIOUS SPACINGS

Intertree Spacing in Metres	Trees Per Hectare	Square Spacing in Metres
2.15	2,500	2.0 x 2.0
2.19	2,400	2.04 x 2.04
2.24	2,300	2.09 x 2.09
2.29	2,200	2.13 x 2.13
2.34	2,100	2.18 x 2.18
2.40	2,000	2.24 x 2.24
2.47	1,900	2.29 x 2.29
2.53	1,800	2.36 x 2.36
2.61	1,700	2.43 x 2.43
2.69	1,600	2.50 x 2.50
2.77	1,500	2.58 x 2.58
2.87	1,400	2.67 x 2.67
2.98	1,300	2.77 x 2.77
3.10	1,200	2.89 x 2.89
3.24	1,100	3.02 x 3.02
3.40	1,000	3.16 x 3.16
3.58	900	3.33 x 3.33
3.80	800	3.54 x 3.54
4.06	700	3.78 x 3.78
4.39	600	4.08 x 4.08
4.81	500	4.47 x 4.47
5.37	400	5.0 x 5.0

Appendix 6-6

February '83

Province of British Columbia — Ministry of Forests

SCHEDULE C

SUMMARY OF STANDARDS FOR PLANTING AND STOCK HANDLING

1. Density and Spacing

Spacing distance will be that stated in Schedule B.

The presence of natural regeneration, broken terrain, rocks, stumps and other debris may preclude uniform spacing and affect the average number of trees/hectare that would be attained under the spacing specified.

The actual spacing may be varied from the spacing specified, to take advantage of the best spot available, but spacing control must be resumed after any deviation.

It is the responsibility of the contractor to ensure that correct spacing is maintained.

2. Quality of Planting

Trees shall be planted in the best spot available to favour survival and growth.

(a) Selection of Planting Spot

Spots selected shall be as follows:

(i) Mineral soil or a mixture of soil and well rotted wood or decomposed duff.

(ii) Spots protected by "dead" shade from stumps, windfall, rock, etc.

(iii) Spots alongside a depression in the ground.

Unsuitable spots are as follows:

(i) Rotten logs or stumps.

(ii) Bottom of depressions or gulleys subject to flood.

(iii) Cutbanks, roadside fill, raised humps of loose soil or debris.

(iv) Within 6 m of roads designated on the project map by the Ministry Officer.

(v) Not closer to a planted or naturally established tree than the prescribed spacing minus the allowable spacing tolerance. e.g. if spacing is 2.7 m and the tolerance is 0.75 m, then spacing may not be closer than 2.7 - 0.75 = 1.95 m. Where the spacing tolerance is not specified in Schedule 'B', the tolerance will be 0.5 m.

(vi) Within crown line of larger trees.

Trees shall not be planted on any of the preceding unsuitable spots or locations unless specifically instructed by the Ministry Officer.

(b) Clearing, Scalping or Screefing

Where clearing or screefing is specified in Clause 9 of Schedule 'A' the planter before preparing the planting holes must remove all debris down to the depth specified in Schedule 'A' or down to a suitable soil layer as defined in 2(a), above. Debris to be removed may include duff, rotten wood, loose rock, sod, snow, surface frost and minor vegetation.

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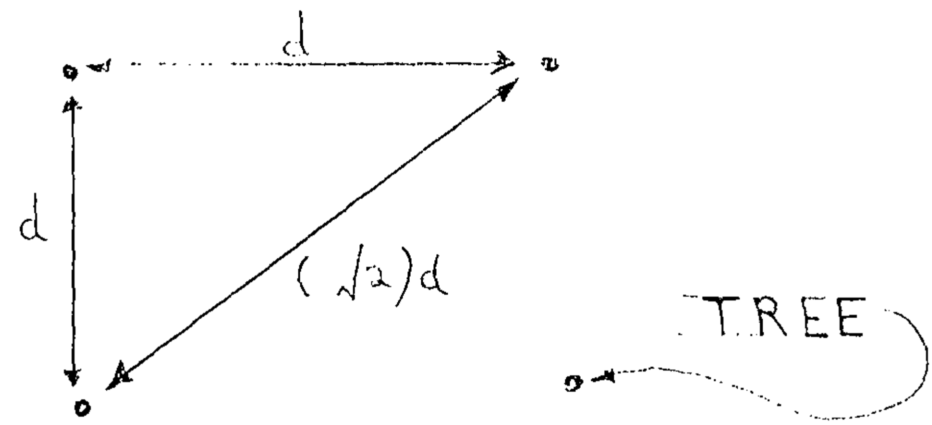


DIAGRAM 1. THIS LAYOUT ("d the prescribed inter-tree spacing) RESULT IN A TOO LOW PLANTING DENSITY

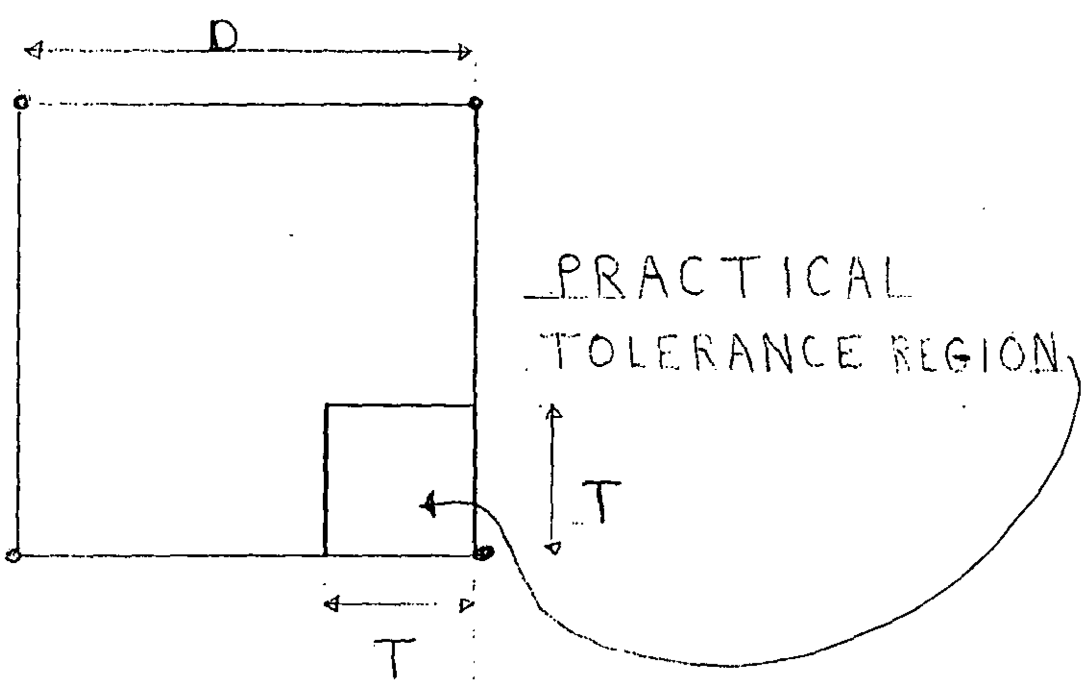
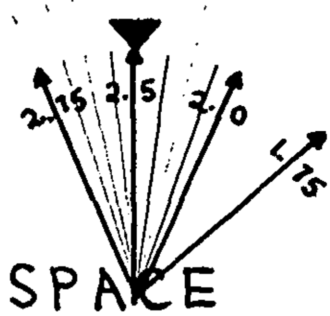


DIAGRAM 2



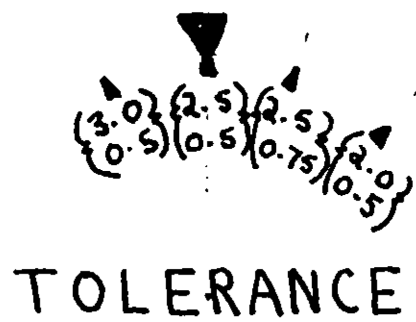


DIAGRAM 3. The tolerance dial is a suggestion. Its design needs careful thought.

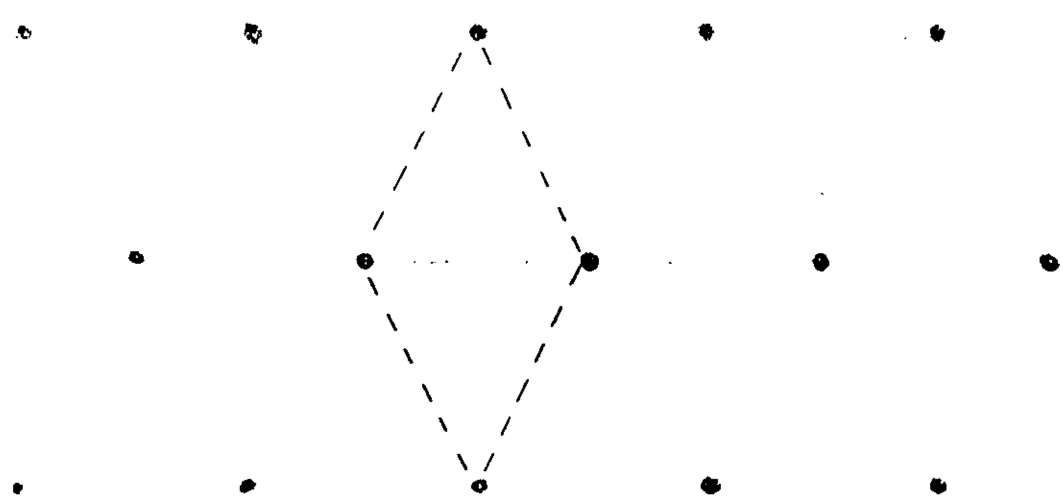


DIAGRAM 4.

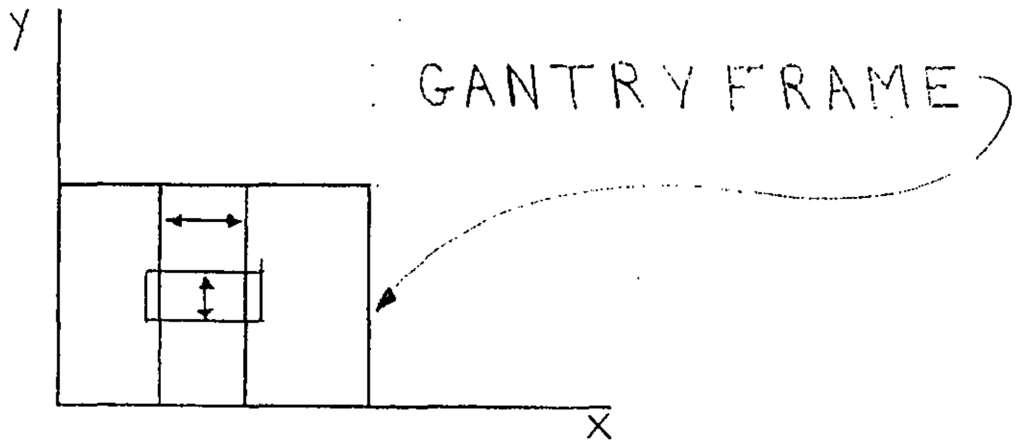


DIAGRAM 5

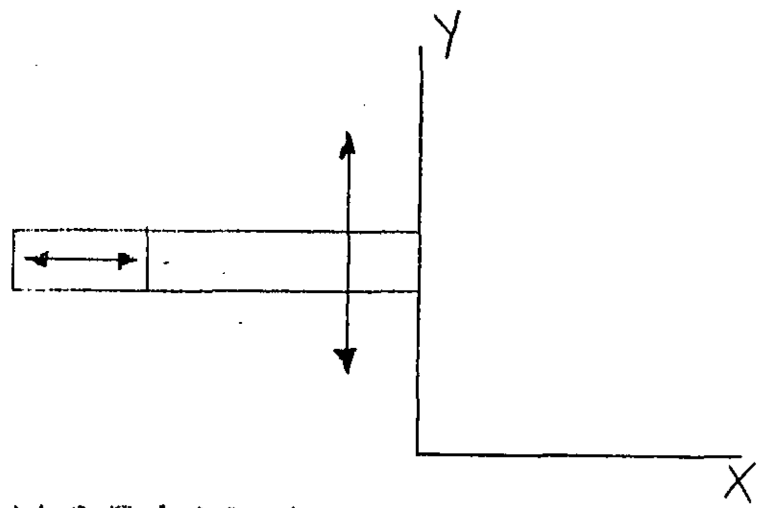


DIAGRAM 6.

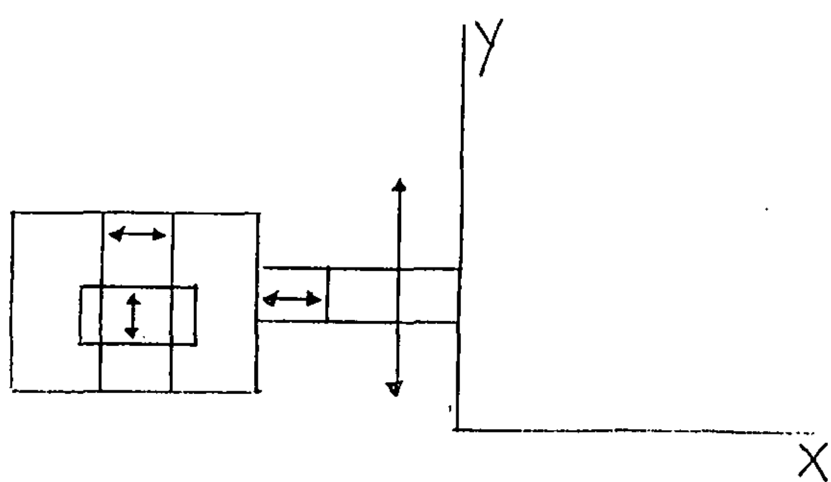


DIAGRAM 7.

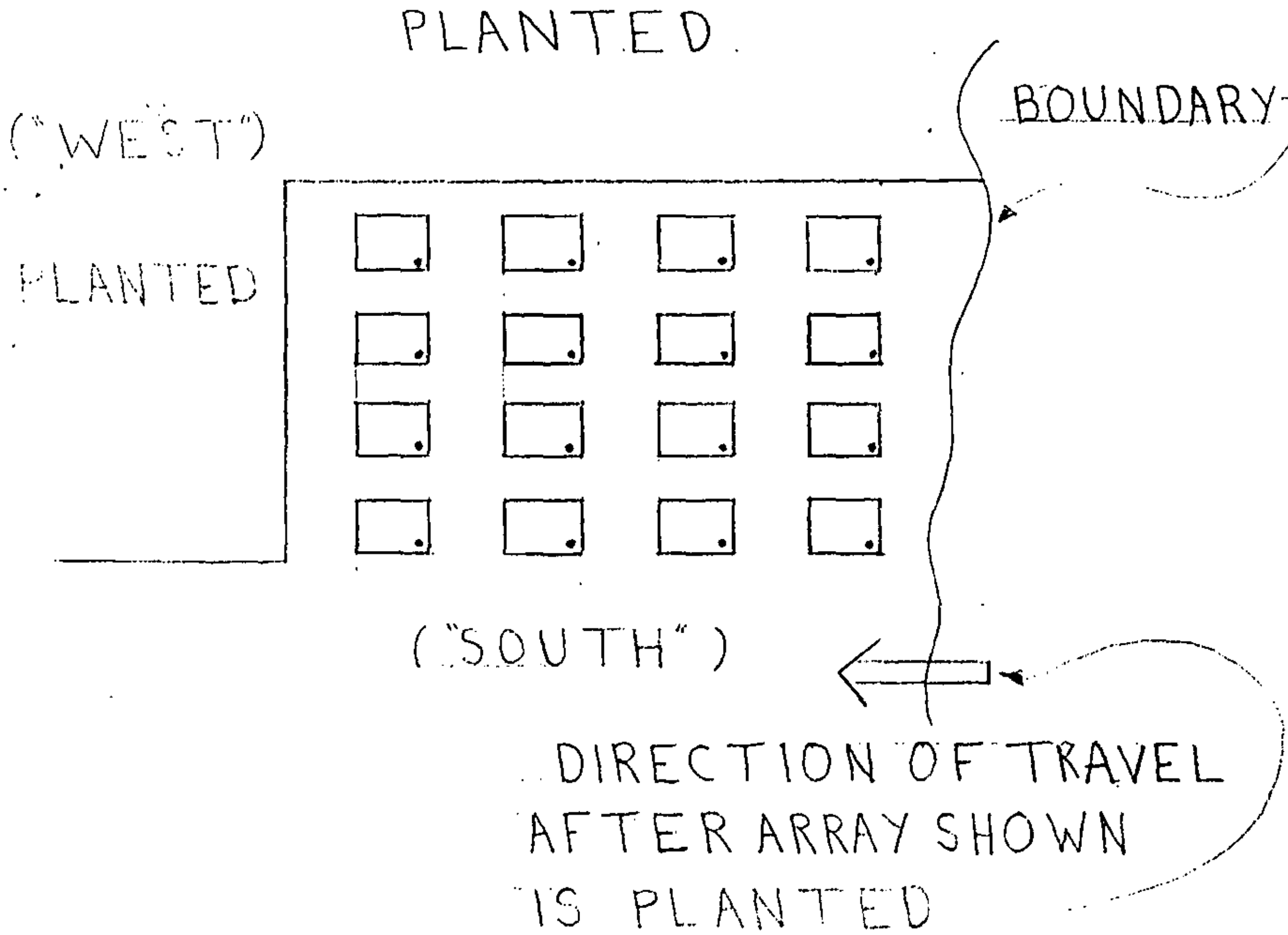


DIAGRAM 8

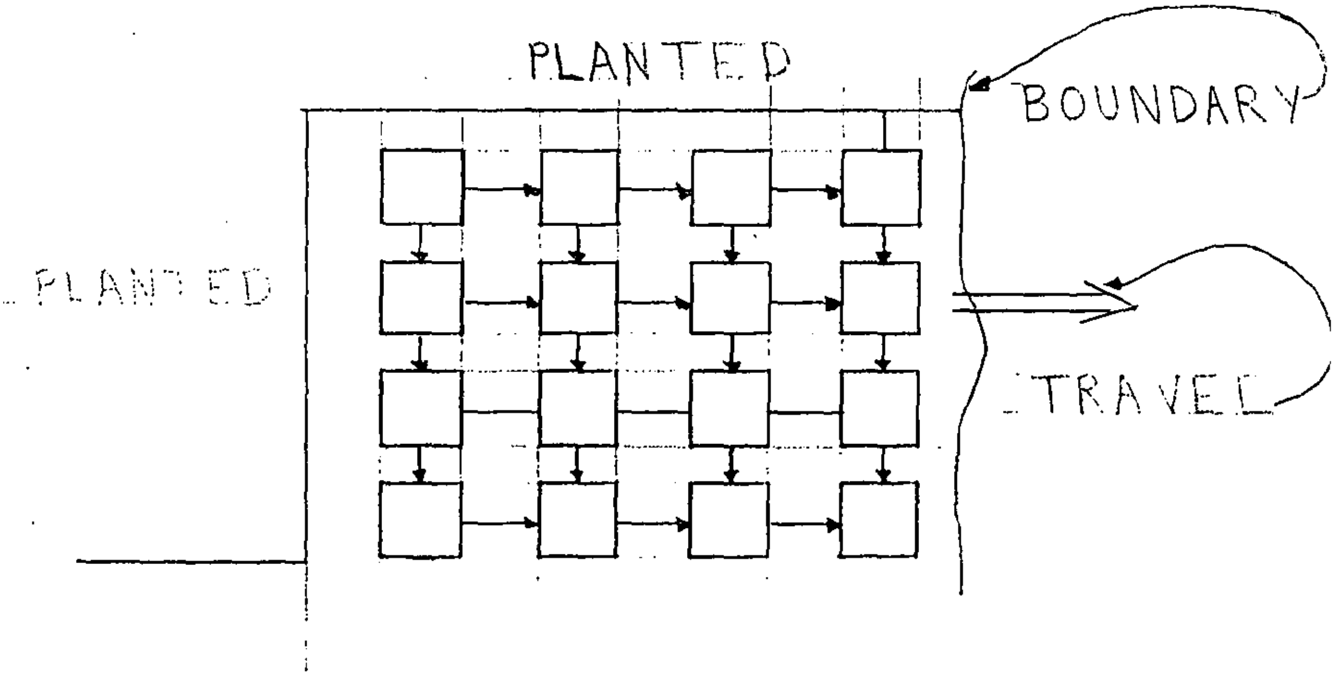


DIAGRAM 9

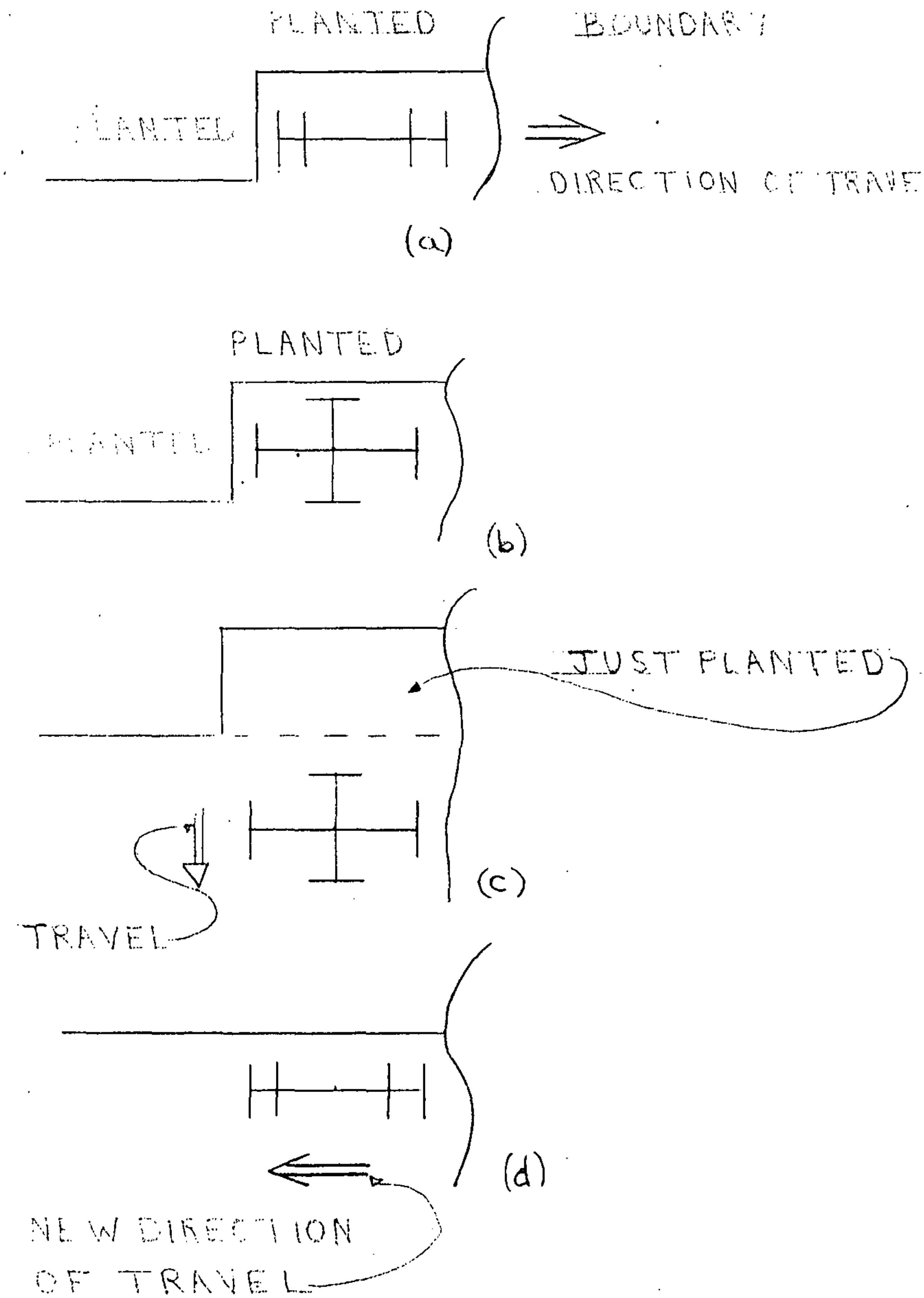

PLANTED
BOUNDARY
PLANTED
DIRECTION OF TRAVEL
(a)
PLANTED
PLANTED
(b)
JUST PLANTED
TRAVEL
(c)
(d)
NEW DIRECTION
OF TRAVEL

DIAGRAM 10.

10.
Tool

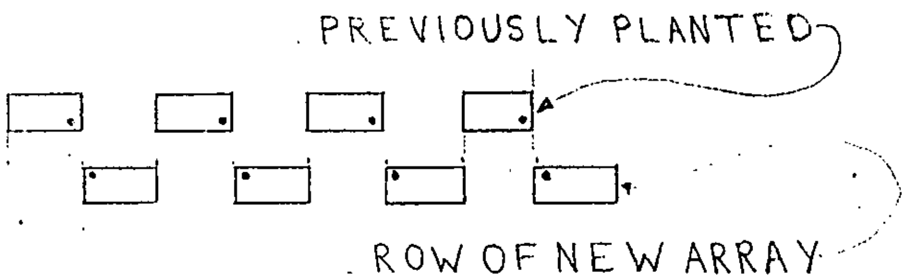


DIAGRAM 11.

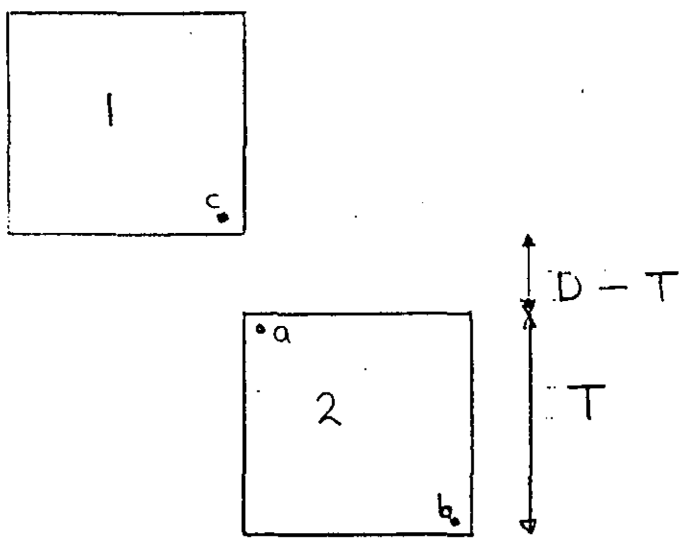


DIAGRAM 12. Area 1 is planted. "a" is the start position of the previous row rotated. "b" is an extreme position in region 2. At this position a tree would be overspaced from the tree "c" shown in region 1. Its distance from "c" is $\sqrt{D^2 + T^2}$.

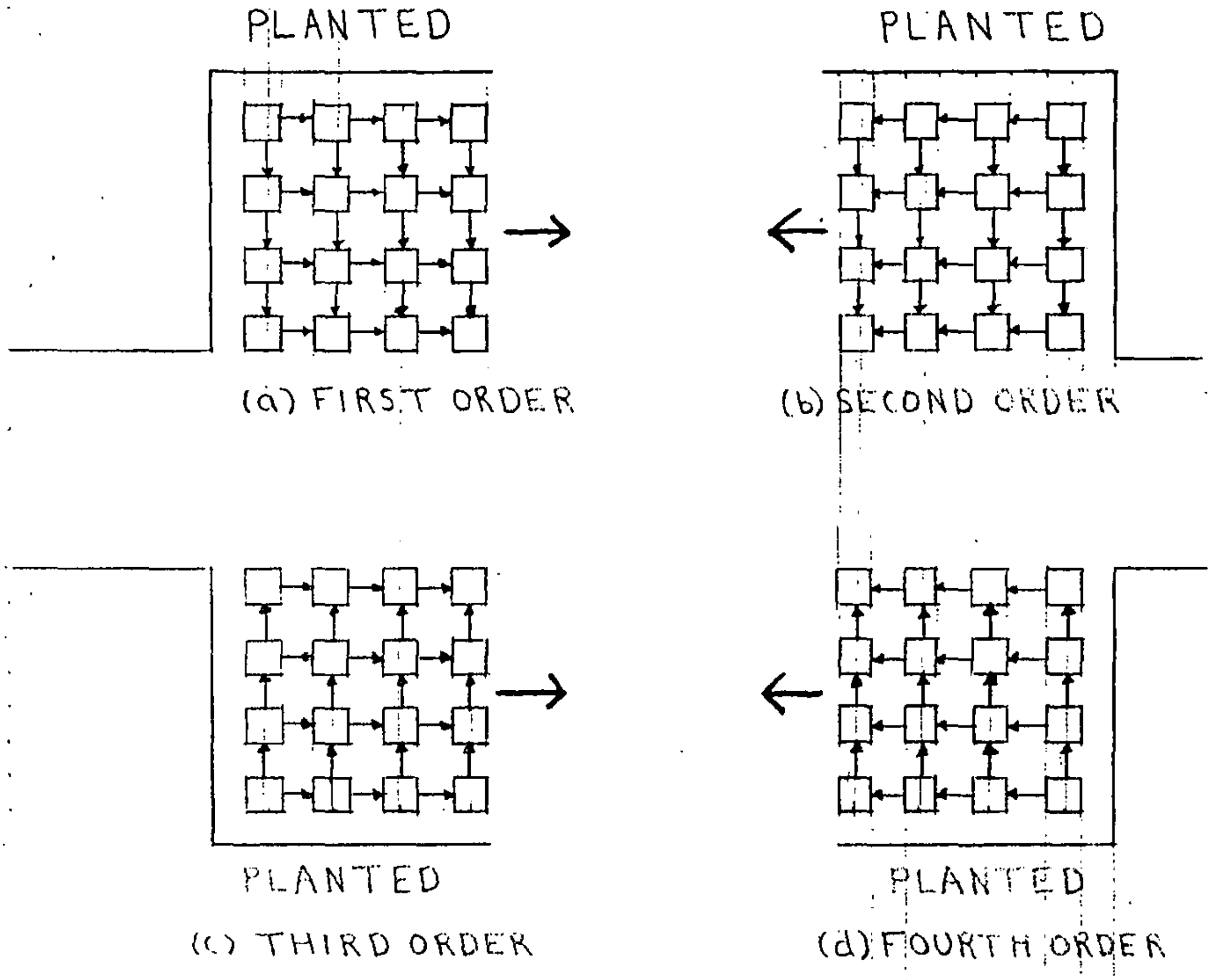


DIAGRAM 13. The vehicle is fore and aft symmetrical. The driver may choose any end as "forward". This choice combined with the possible directions of travel and planted area adjacency gives rise to four orders of precedence. Because of them a tool "start" position may be in any corner of a tolerance region relative to a given tool.

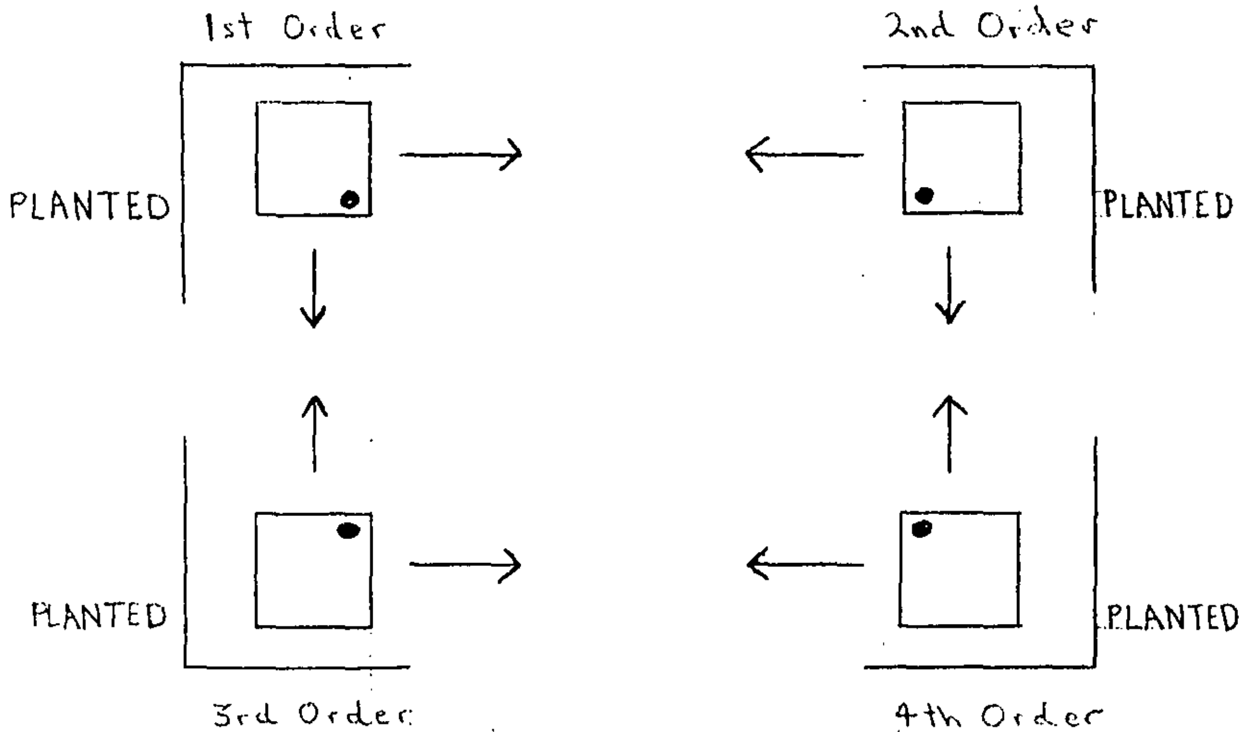


DIAGRAM 14.

The dots show ideal positions within a tolerance region in the four orders of precedence. Arrow show the direction of precedence. The tool positions shown are used as "start" positions.

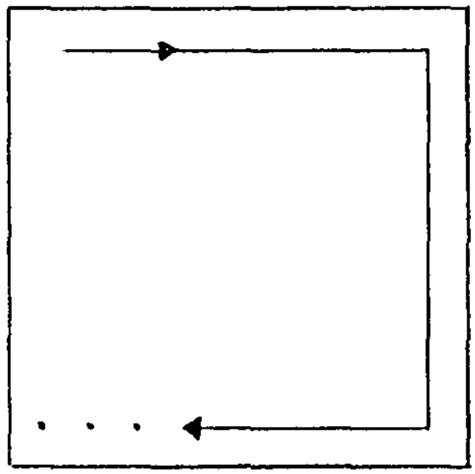


DIAGRAM 15. If the pattern of planting shown is used or an outward spiral the order of precedence started with can be maintained.

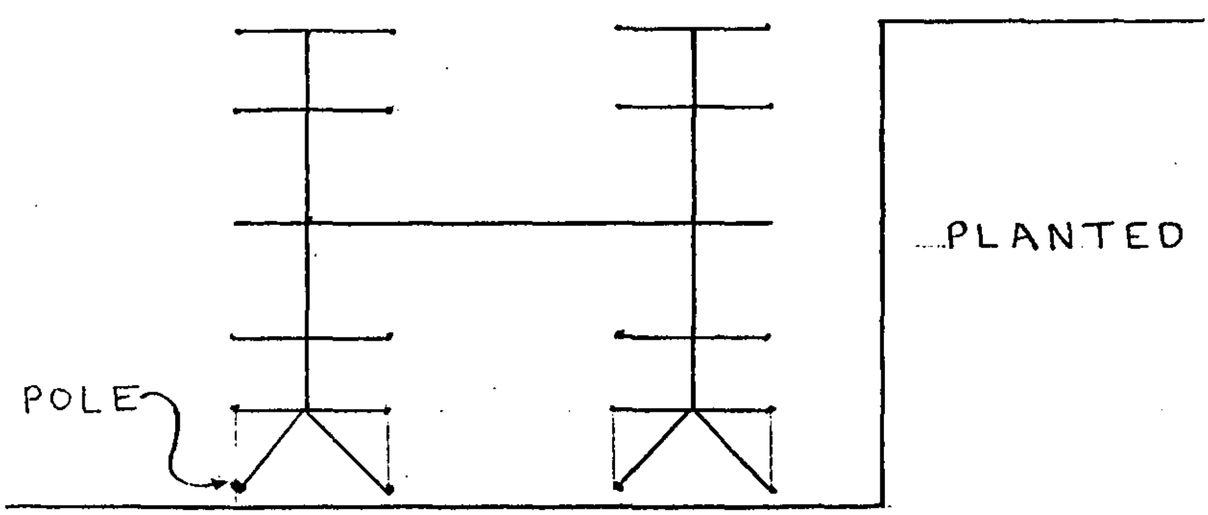


DIAGRAM 16. Pole side markers.

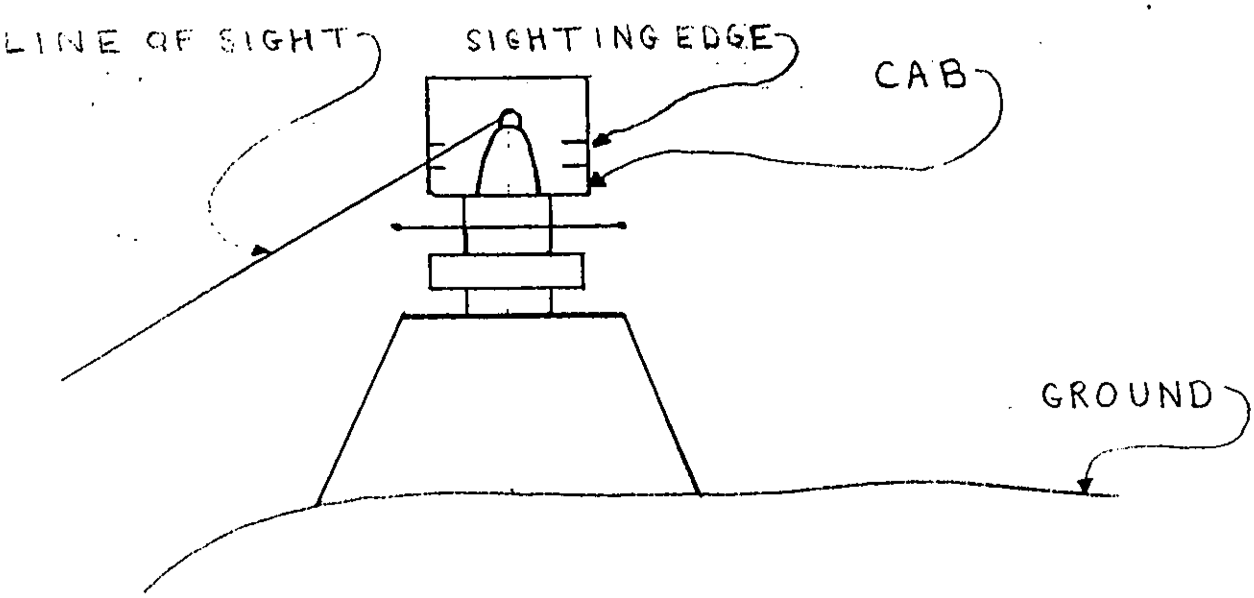


DIAGRAM 17. A pair of parallel "edges" mounted on each side of the vehicle cab and able to slide up and down could be used to aid the judgement of the operator. The distance apart of the edges would depend on the tolerance being used. The operator would set the tolerance and then set the slide height by measurement at the beginning of work.

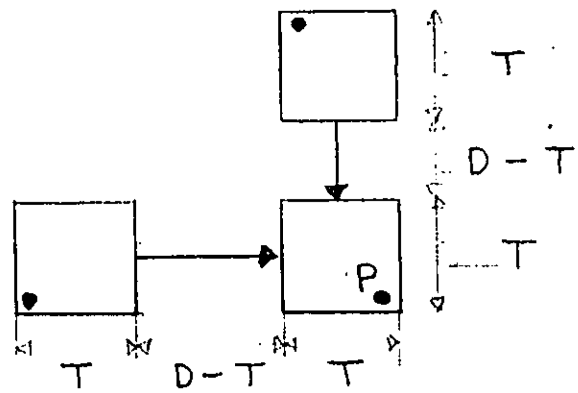


DIAGRAM 18. "P" has halted and entered the "Plant" sub-routine.

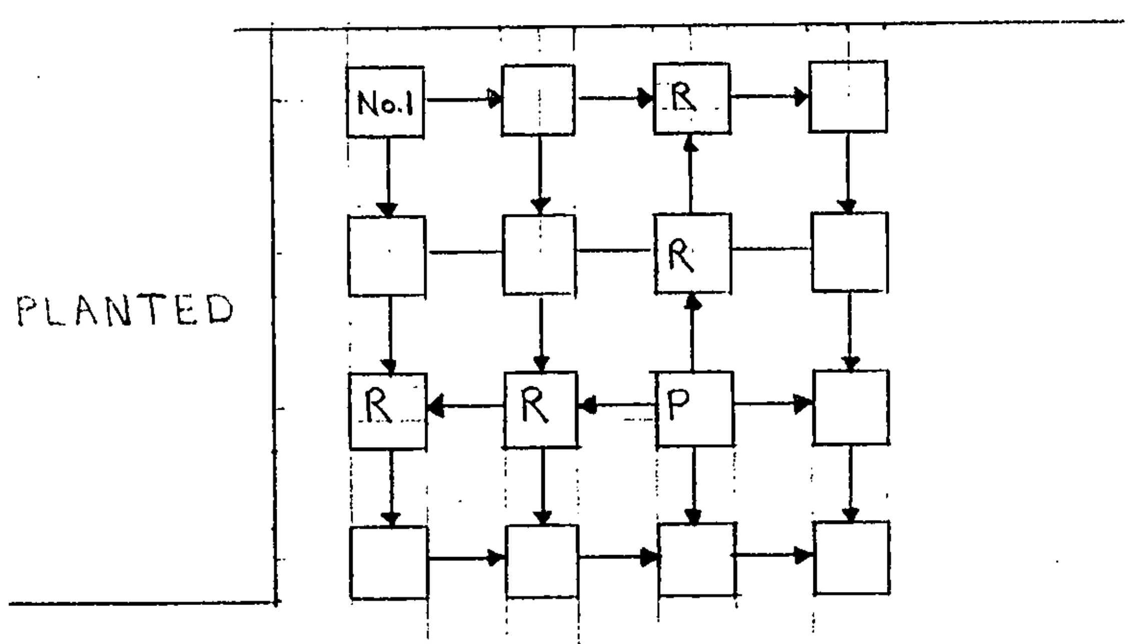


DIAGRAM 19. "P" is halted and planting. The order of precedence of the tools "R" is reversed.

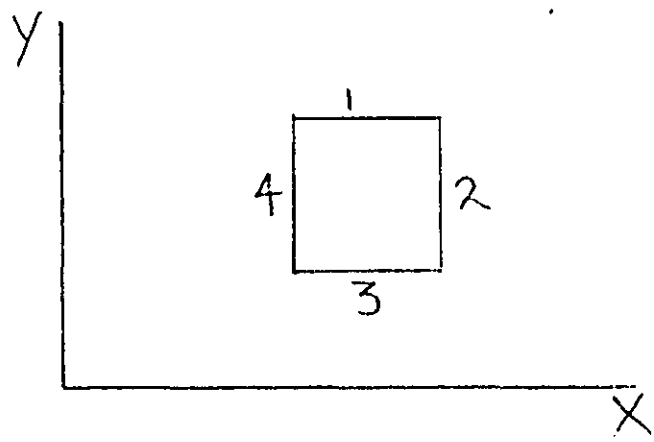


DIAGRAM 20. "Plan"

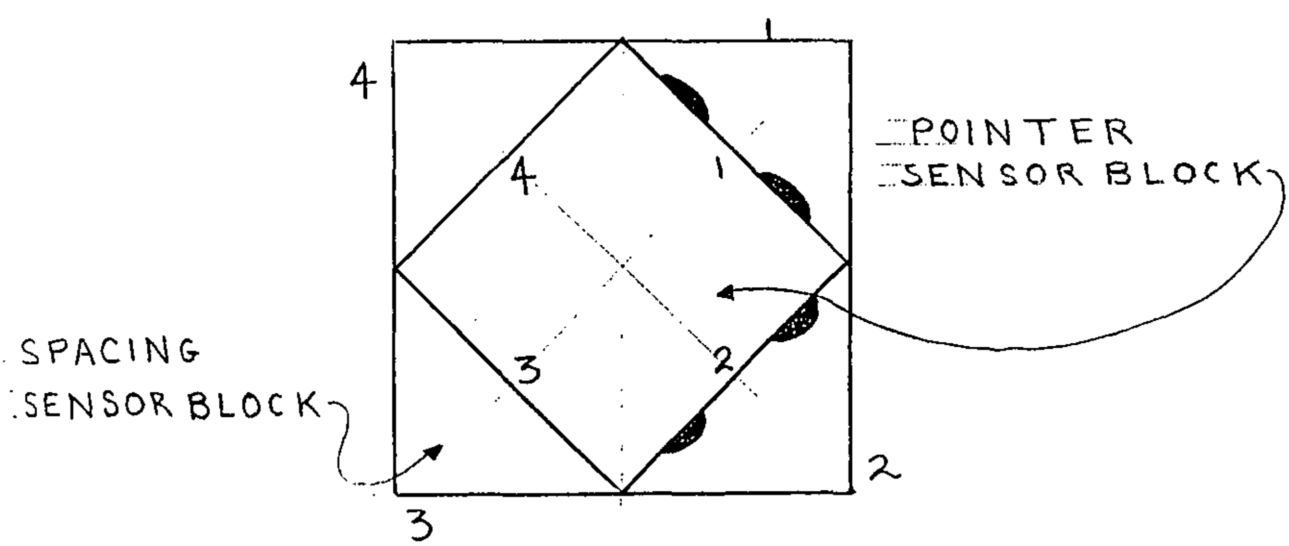


DIAGRAM 21. "Plan." Pointer sensors are shown on sides 1 and 2 of the Pointer Block. There is an identical pair on each of sides 3 and 4.

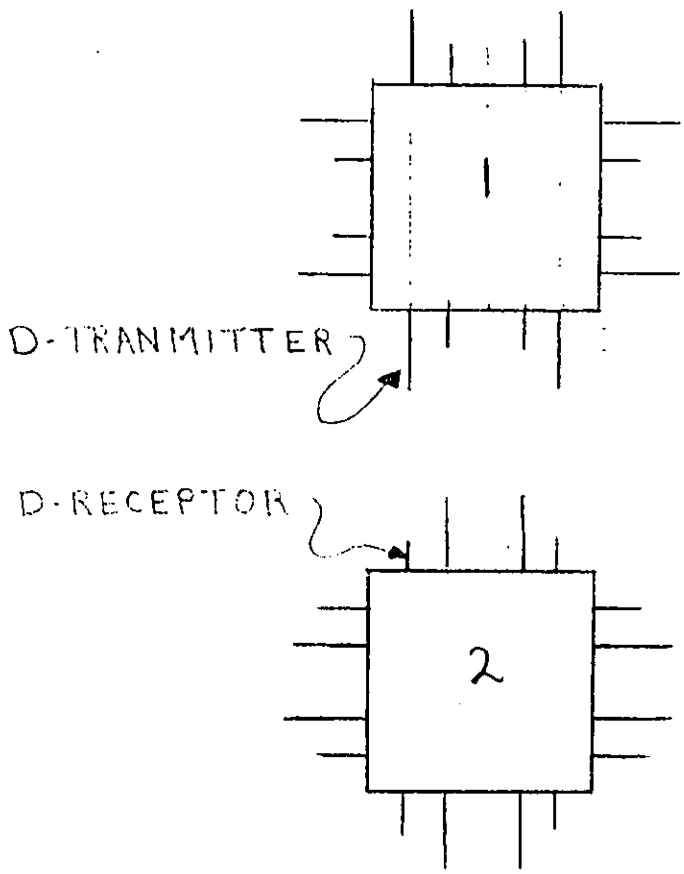


DIAGRAM 22. Schematic arrangement of tranmitter and receptor pairs. The requirement of interchangability will not permit this arrangement to be used.

TOOL	DIRECTION +X	-X	+Y	-Y
1	RETRACT	EXTEND	MOVE FROM LONGITUDINAL AXIS	MOVE TO LONGITUDINAL AXIS
2	EXTEND	RETRACT		
3	RETRACT	EXTEND		
4	EXTEND	RETRACT		
5	RETRACT	EXTEND		
6	EXTEND	RETRACT		
7	RETRACT	EXTEND		
8	EXTEND	RETRACT		
9	RETRACT	EXTEND	MOVE TO LONGITUDINAL AXIS	MOVE FROM LONGITUDINAL AXIS
10	EXTEND	RETRACT		
11	RETRACT	EXTEND		
12	EXTEND	RETRACT		
14	RETRACT	EXTEND		
15	EXTEND	RETRACT		
16	RETRACT	EXTEND		

(The actuator action needed for Y-motion will depend on actuator lay-out.)

FIGURE 4. If tools on a sub-beam are recognised as a "quadrant" the action needed for X-motion divides the quadrants into two classes. The figure gives a description by individual tools.

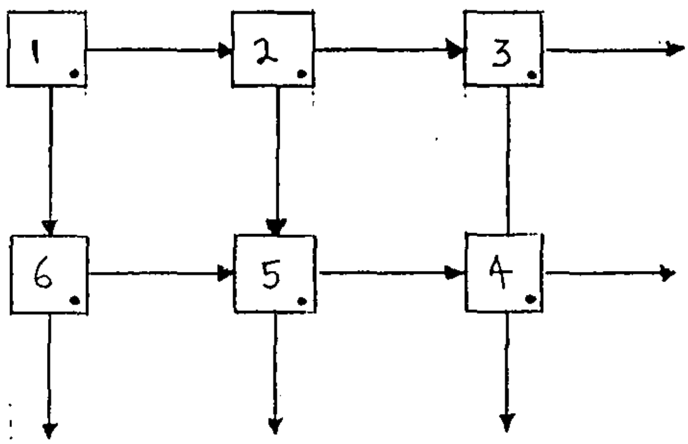


DIAGRAM 23.

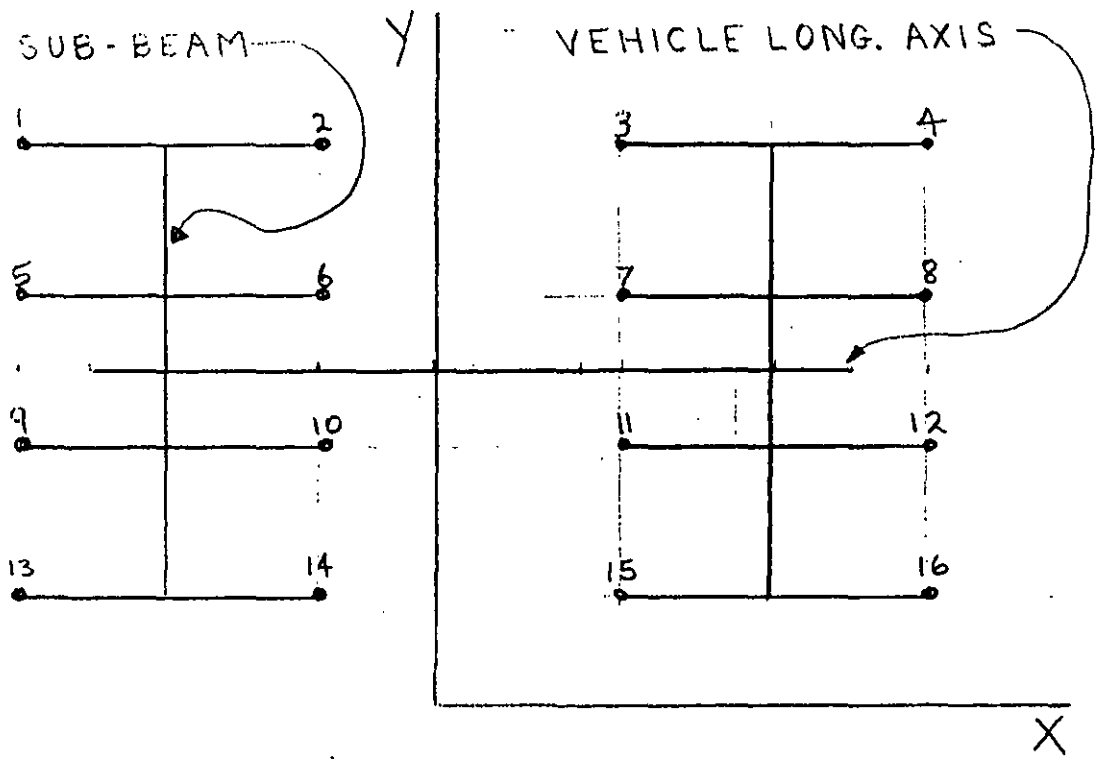


DIAGRAM 24. "Plan"

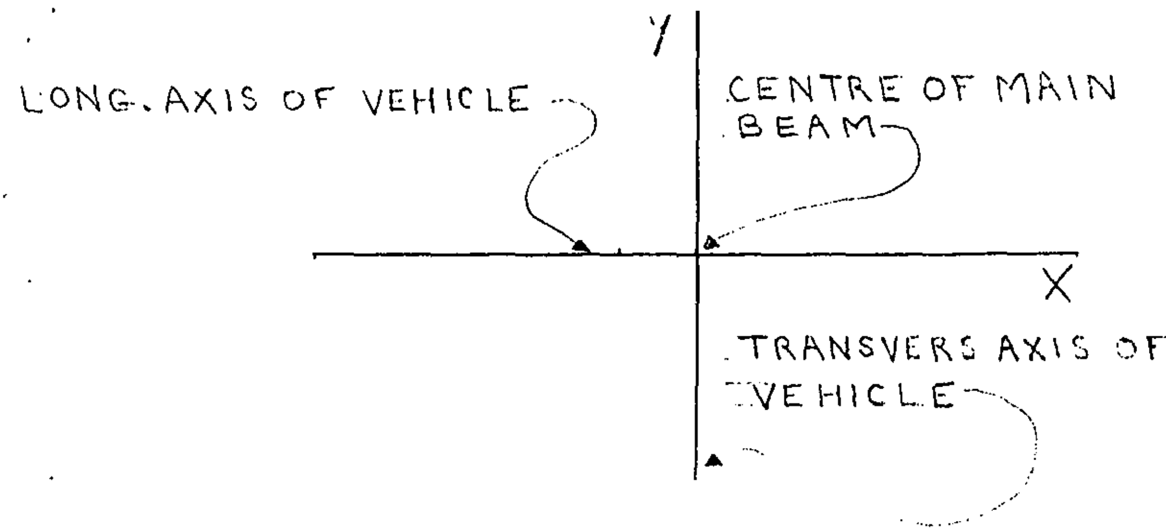


DIAGRAM 25. "Plan"

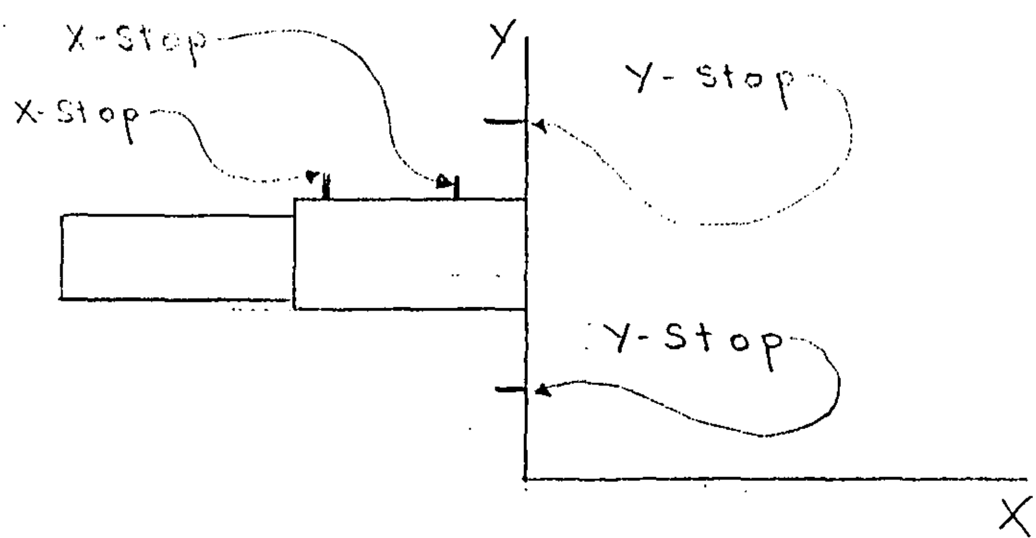


DIAGRAM 26. "Plan"

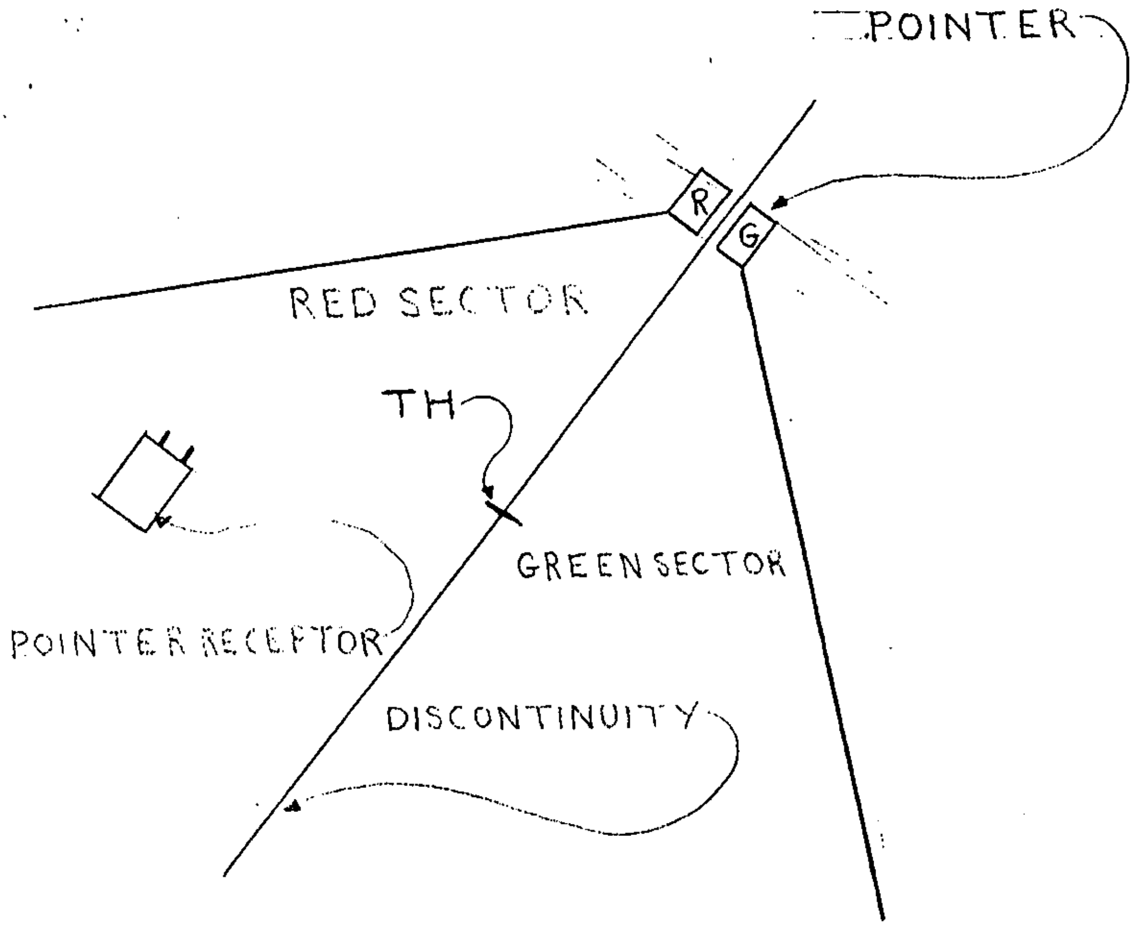


DIAGRAM 27. "Plan." The tool will come to the discontinuity line and then to the threshold TH. R = red. G = green.

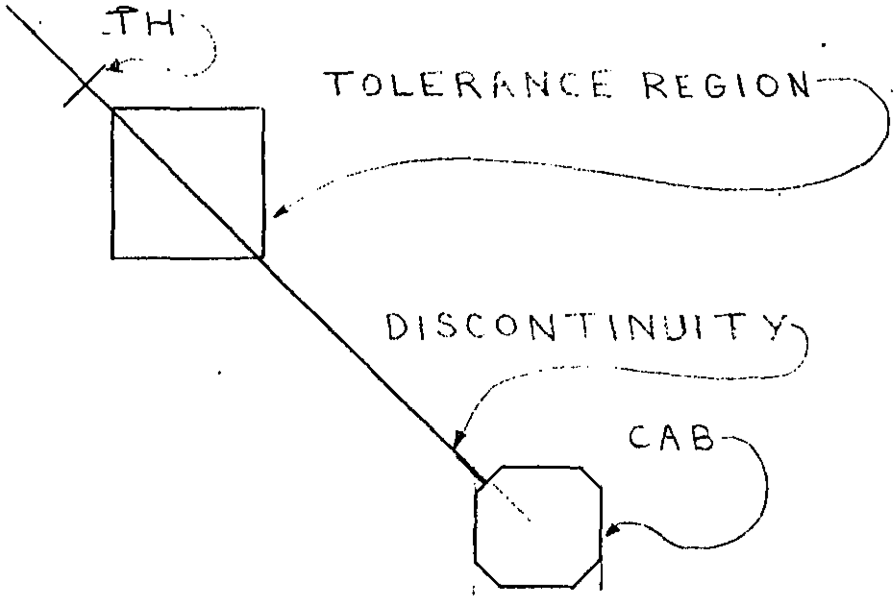


DIAGRAM 28.

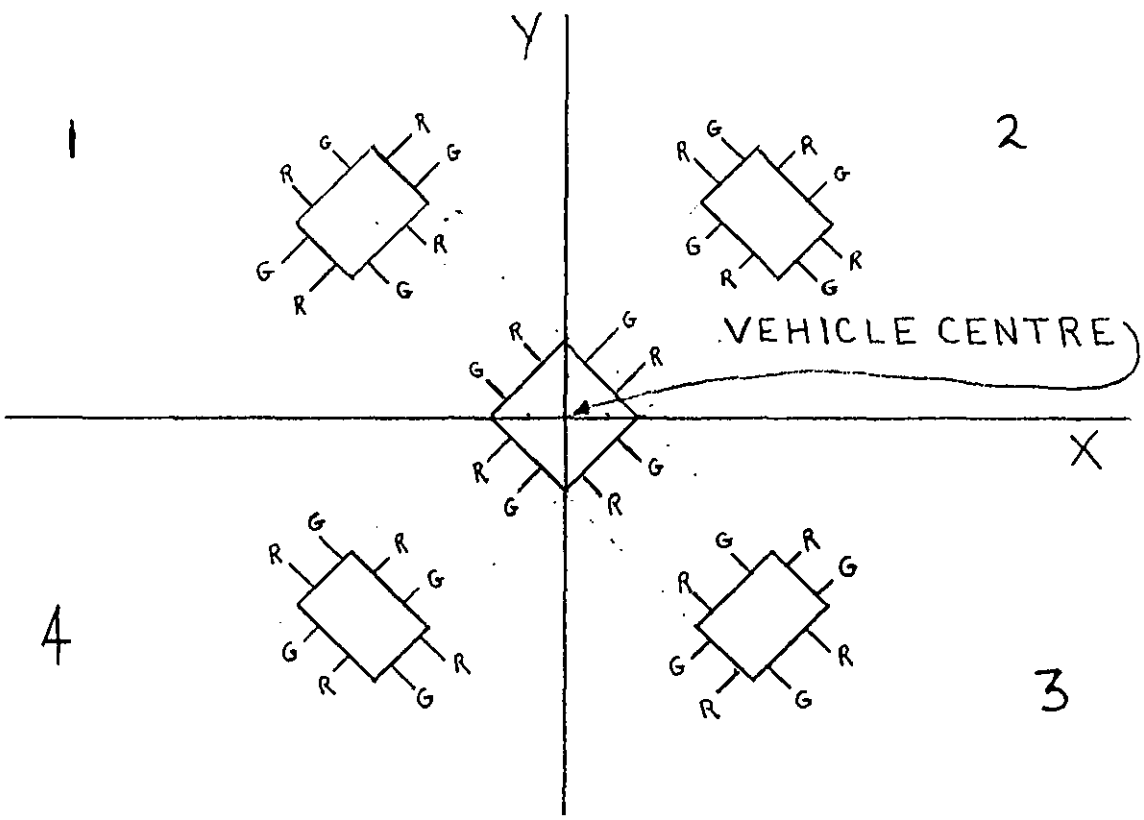


DIAGRAM 29.

COLOUR SENSED	MOTION FOR POSITION			
	1	2	3	4
GREEN	+Y	−Y	−Y	+Y
RED	−Y	+Y	+Y	−Y

FIGURE 5 (Diagram 2.9)

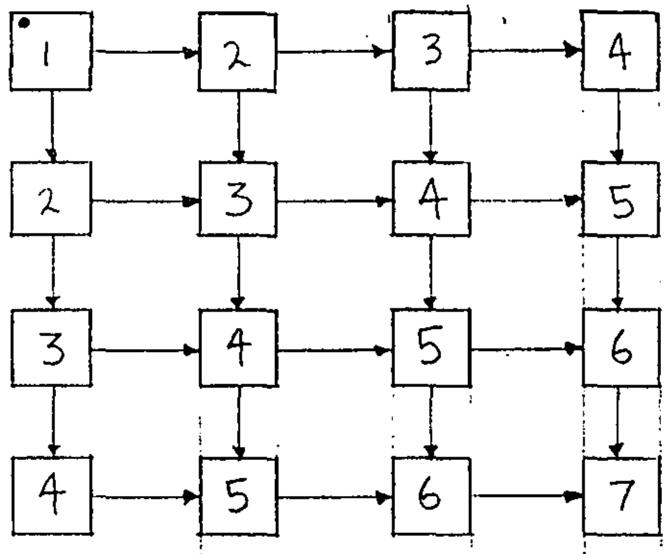


DIAGRAM 30. Numbers denote precedence orders. Arrows show the final pattern of illumination.

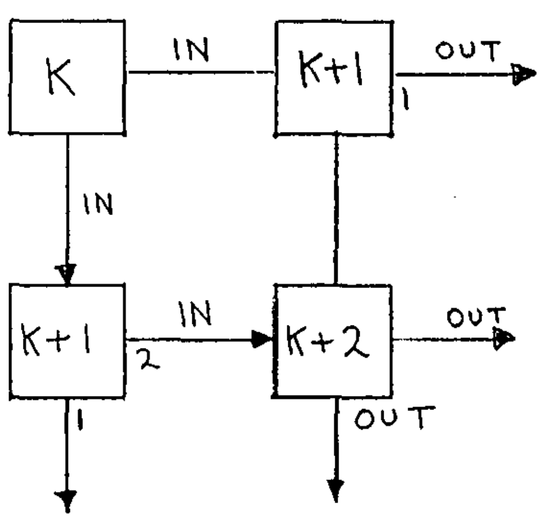


DIAGRAM 31. K+2 is receiving input on two sides (arrow "in"). It responds by lighting on two sides (arrow "out"). Tools K+1 must be lit by one input.

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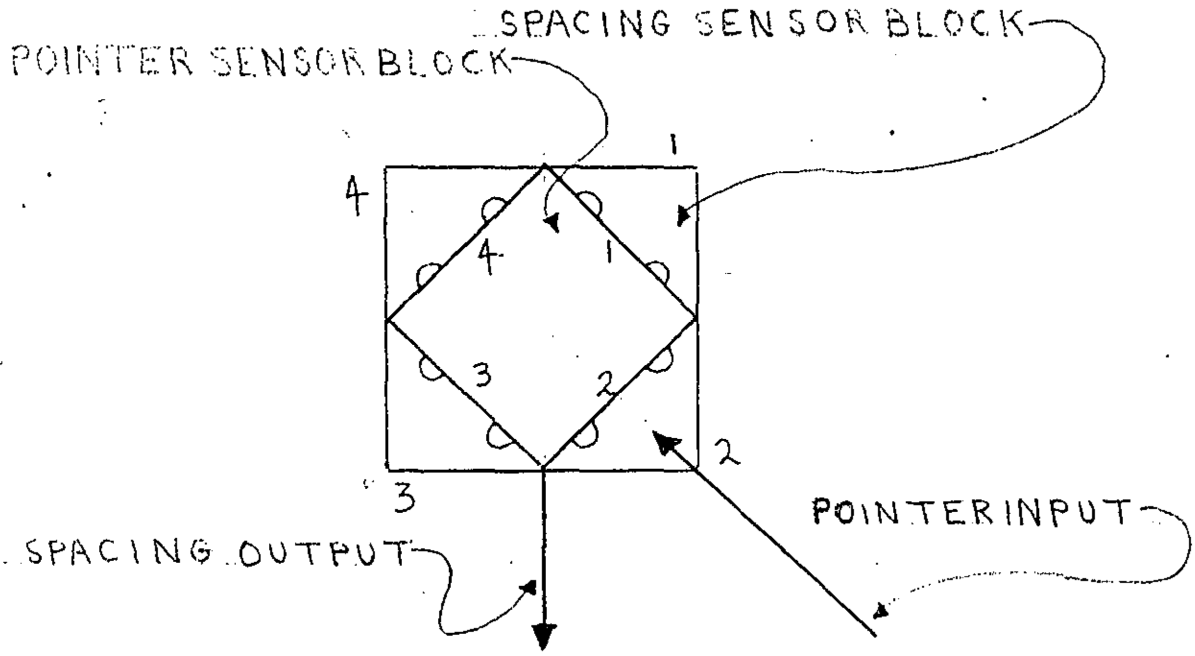

DIAGRAM 32.

POINTER SENSOR "ON" SIDE:	SPACING LIGHTS "ON" SIDES:
1	1 and 2
2	2 and 3
3	3 and 4
4	4 and 1

FIGURE 6. (Diagram 32)

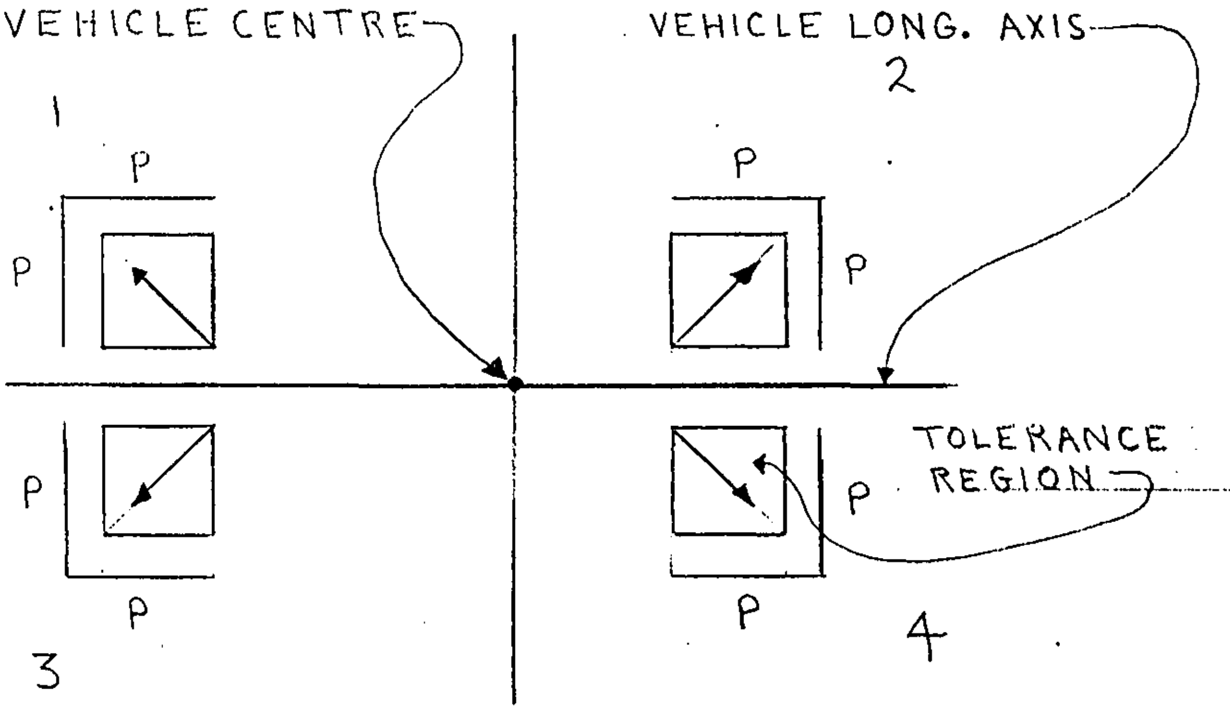

DIAGRAM 33. Each of "1", "2", "3", "4" is an order of precedence. "P" denotes planted ground. The arrow in a tolerance region shows the direction of tool motion described in "Further Detail 5."

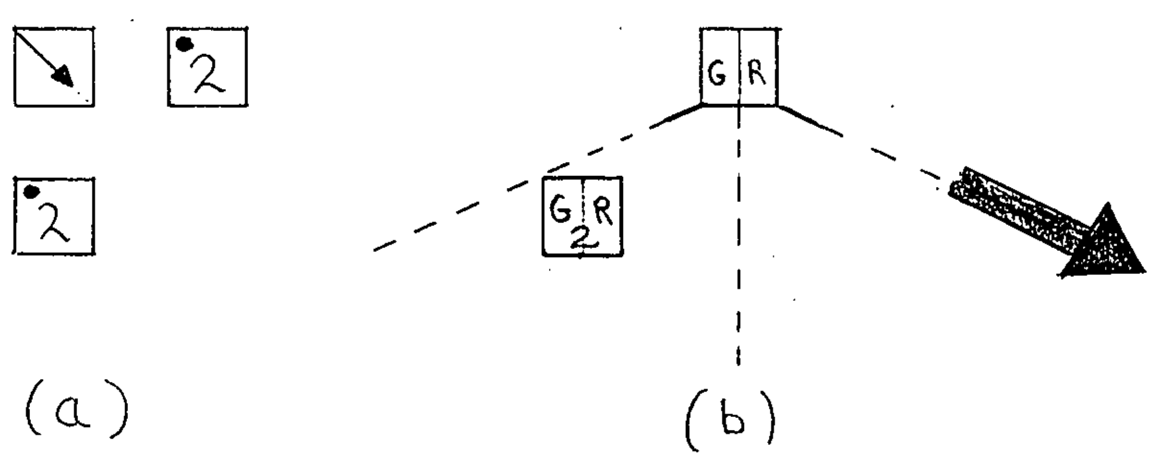

DIAGRAM 34.

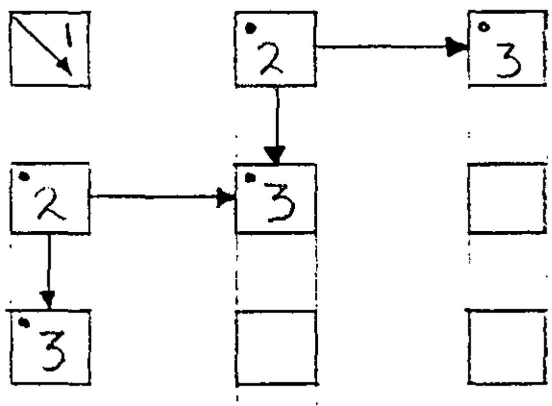

DIAGRAM 35.

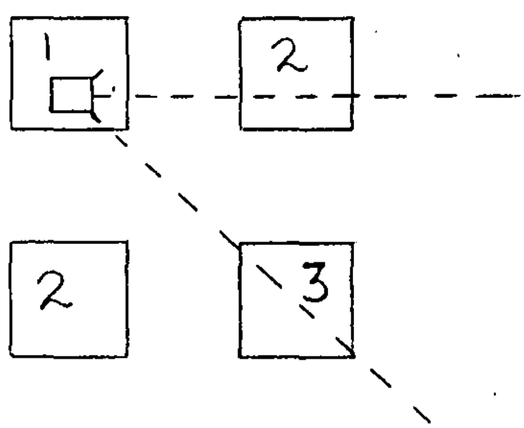

DIAGRAM 36. Tool "3" is "non-adjacent." It is lit by one sector of tool "1."

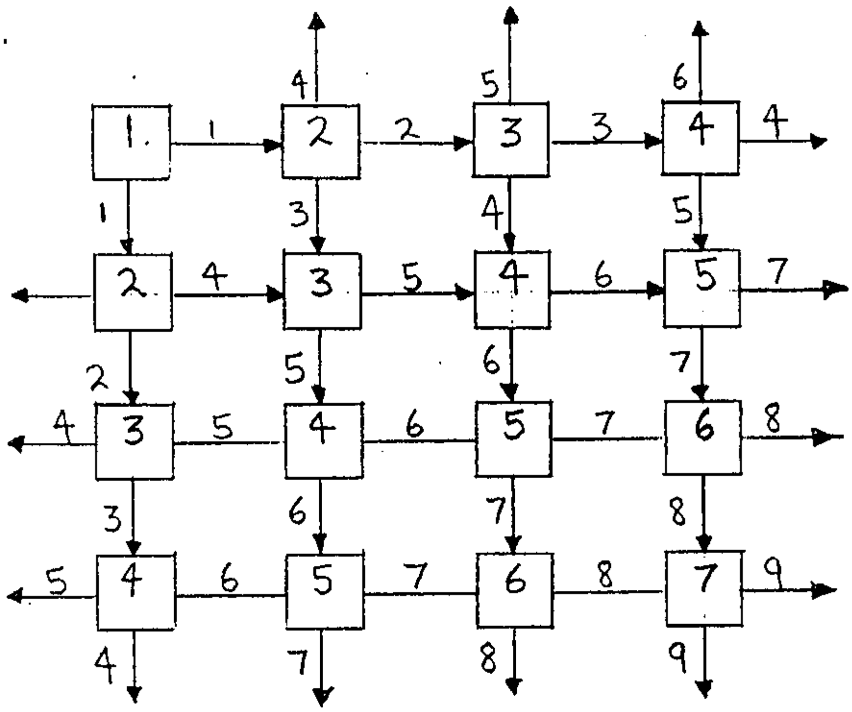

DIAGRAM 37.

Boundary tools turn on their lights in a fixed sequence. Interior tools turn on their lights upon receiving input from higher order adjacent tools.

Interior tools do not turn on any lights until signals have been received (input) on two sides.

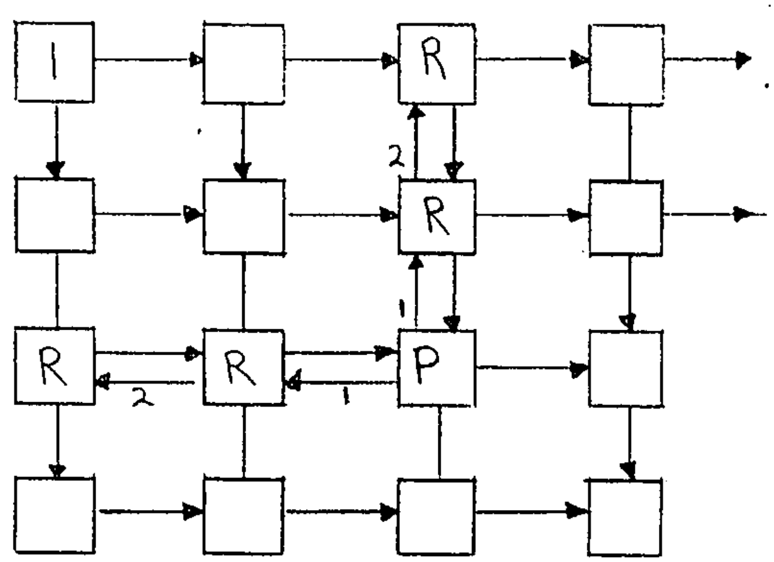

DIAGRAM 38.

"P" has halted. It lights the sides receiving input. This triggers a "chain" reaction in the tools "R".

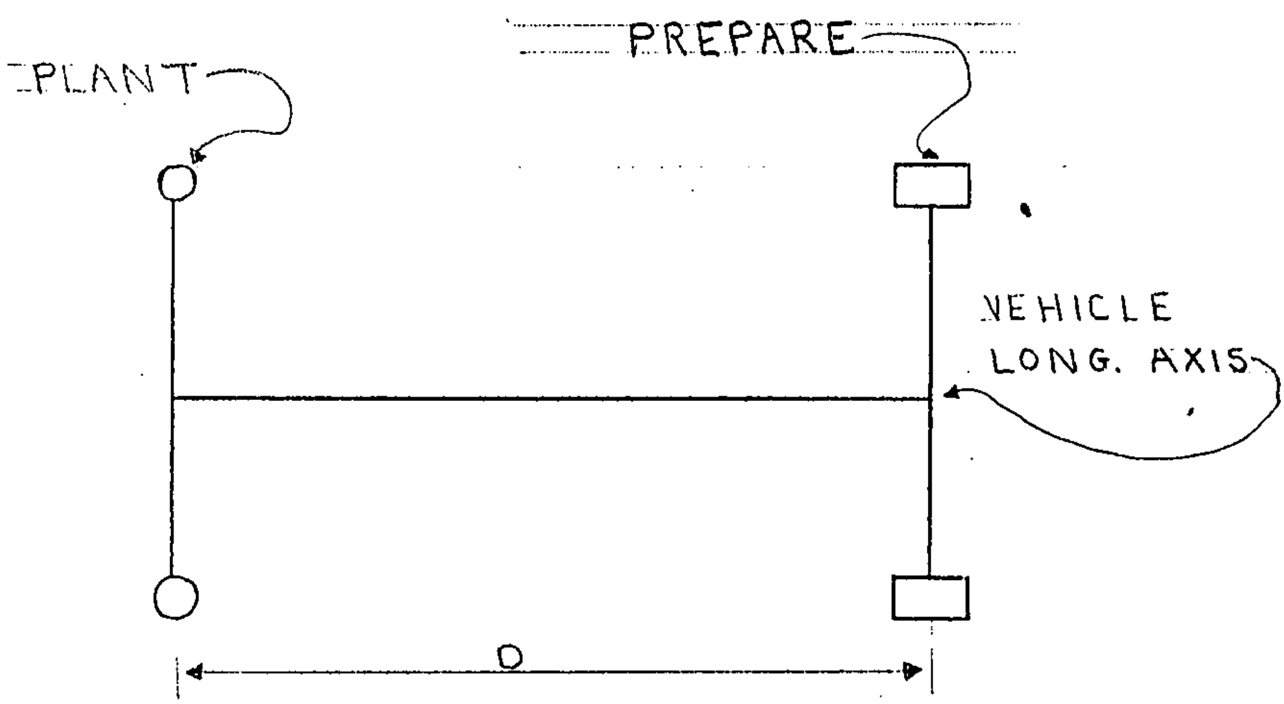

DIAGRAM 39.

Preparation tools end-stopped so as to move them in a required tolerance region.

Chapter XI.
AUTOMATIC CHOICE

The exploration of the vehicle problem, the silvicultural/mechanical problems, semi-automatic choice and automatic spacing has revealed a basis for a practical device for performing mechanical tree planting (and other silvicultural tasks). If site preparation is combined with planting (i.e. a "one-pass" system) then the semi-automatic pointer method can be used to control both the preparation tools and the planting tools. If automatic operation were used (i.e. automatic choice) it is convenient to use the semi-automatic system for tool set-up. In dull wet weather or in sunny weather but with wet ground conditions automatic recognition of plantable spots may not be practicable with the simple method of recognition based on colour matching which it is intended to use. In this case semi-automatic operation would be reverted to. Automatic operation thus rests on the semi-automatic system.

The semi-automatic system looks to be developable. In the next phase of development a semi-automatic planting will be given first priority.

An extensive exploration has been made into automatic choice. The general area of investigation into which automatic choice falls - perceptual guidance of tools - is one of considerable commercial potential (Conigliaro, 1984). The work on automatic choice was undertaken in the belief that an acceptable rate of mechanised planting would not be able to be achieved without it. This has turned out not to be the case; a semi-automatic method fell out of the investigation. However it is still believed that a system of automatic guidance which involves the use of colour and texture recognition should be applicable to such tasks as the automatic welding of vehicle body parts, to the picking of tree fruits and to the weeding of vegetable crops, strawberry picking and so on. Once perceptual guidance is used position/motion control based upon computations over joint positions and rates of change of joint positions can be dispensed with. A tool sensory system need respond only to those attributes and changes of attributes which are significant; some knowledge of joint position or condition such as that of being at full extension will be needed to avoid joint damage. A beginning has been made in the work on spacing and semi-automatic choice to achieve tool guidance and tool interaction based upon the reception of perceptual cues.

In the work done on automatic choice a beginning has been made with the recognition of "good" planting spots by colour matching. The use has been made of motion guidance based on the results of an analysis of reflected light by what can be considered to be an automatic K-stimulus colorimeter (colour references). Work has also been done on the recognition of two dimensional patterns of texture/colour by a system of "parallel" processing. Some logical principles have been extracted upon which this processing could rest. This investigation has revealed problems to do with analog to digital conversion (ADC), digital to analog conversion (DAC), the one-dimensional encoding of two dimensional patterns and the parallel decoding of a serial patterns into a two dimensional pattern. Cost effective simple real-time methods are needed.

These problems have been isolated but not solved. The work needed to obtain even the main form of a solution to any one of these problems is beyond the scope of this thesis.

The work done on automatic planting can at this point be considered to be the beginning of a separate piece of work, one growing from the investigation of mechanical planting. It is one which has the possibility of adding further to the commercial potential of that work. Here a sketch is given of the work which has been done.

The mechanism of choice described here has three parts:

(1) A means by which an automatic scan of the tolerance region of a tool is carried out.

(2) A means by which this scan is halted so that sampling of reflected light can take place.

(3) A means by which a decision is made as to whether a deviation of the scan (towards "good") is to be made or that the place at which the halt has occurred is suitable for the planting of a tree.

Three forms of scan have been examined. In the first a tool or a separated tool sensory system moves horizontally over a tolerance region in a fixed pattern which may be overridden by spacing commands, commands by the operator, the command to halt by the "choice" mechanism, commands to "deviate" by the "choice" mechanism. In the second form the scanning of the tolerance region is achieved by a rotation superimposed on a horizontal translation. The overriding of the scan is identical to that for the flat, horizontal scan (first form). Once the scanning device has halted after having found a good planting spot it directs the tool to the spot using a pointer mechanism which is identical in principle to that used for semi-automatic operation.

The second method leads to a third form. It is one which makes use of a pair of sensors which rotate in both vertical and horizontal planes (mutually perpendicular) and which makes use of a system of automatic focusing and a system of automatic fixation (Marr, 1982) to guide a tool to a chosen spot. The sensors could be mounted with a tool and travel with it or be separate from the tool. In either case a judgment would have to be made by the sensory system of when the tool being guided is above a chosen spot. This judgment is more difficult with a lay-out in which the sensors are fixed at one end of the tolerance region than in one where a flat scan over the tolerance region is made. Automatic focusing systems already exist. A system of fully automatic fixation has not been found but may exist and be in use for such uses as the guidance of modern tank carried cannons. There exist manually operated fixation mechanisms for example in manually operated optical artillary range finders. This last system could be straight forwardly be made automatic. Natural systems seem to be more complex and to involve a shifting line of sight (Diagrams 1 and 2). Some work, not described here, has been done on mechanisms which perform the more complex fixation. The flat scan and its logic.

It is assumed that an order of precedence has been set and that all tools are at the start position. Each tool is to make a flat (first form) scan of its tolerance region.

The motion of each tool other than the No. 1 tool is to be controlled by spacing signals from the immediately adjacent higher order tools. The scan of the No. 1 tool is to be controlled by the pointer. This is set so that the pointer threshold is beyond the tolerance region of the No. 1 tool and so that it is as near as possible diagonal to the tolerance region (Diagram 3). The threshold position "tells" the No. 1 tool the "X" direction in which it is to scan. The No. 1 tool moves parallel to the "Y" axis (it does not matter in which direction on the Y axis it begins to move - it moves away from the Y end-stop which has been last activated - in the case shown in diagram it move in the +Y direction.) It will continue to move parallel to the Y axis until it comes in contact with a Y end-stop. At this point it halts until it has received signals that the immediately adjacent lower order tools have reached the D (practical inter-tool spacing) threshold and are balanced. It then advances by a fixed distance along the X axis (in this case in the negative direction: Diagram 4). It halts. The lower order tools follow it.

The degree of X motion is controlled as follows.

The radiation from an ideal point source which falls upon a unit plane region approximates to a function of r^2. In a practical system using parabolic reflectors, lenses, etc., the decrease approximates to a linear function of r. It is assumed here that the radiation received from the pointer is a linear function of r. With this having been assumed a constant value for either an increment or a decrement of radiation being received will carry the tool sensor a constant distance along the X axis. The measurement of a constant increment of radiation can be straight forwardly arranged for.

Once the X motion has halted, the Y end-stop having already been activated, a change of direction on the Y axis occurs continues until a Y end-stop is activated when the same sequence of events as that described is repeated (Diagram 4). At the end of the scan an X end-stop will have been activated. The motion on the X axis is reversed. Following the same logic the tool will then scan in the opposite direction. It is possible to cause the Y motions and the X motions to interchange (Diagram 5: i.e. short Y legs and long X legs), or to obtain more complex patterns of scanning. The pattern described will suffice to show that a simple automatic means of causing the No. 1 tool, and following it the whole array, to scan is available.

Colour matching

The colour matching system consists of the following parts:

(1) A data base consisting of encoded reflectance data from selected "good" spots. The encoding is into a quadruple of digital numbers; see below.

(2) A mechanism (software, hardware or both) which adjusts the incoming sampled reflectance data for ambient conditions.

(3) A deductive system which operating upon the stored n-tuples enables the sensory system to extrapolate from the data base to a larger set of "good" planting spot reflectance data. By this means the data base is compressed.

(4) A matching algorithm.

"Good" patches are to be chosen in the field by an experienced planter. Each patch is analyzed by passing a sample of light reflected from it through a quadruple of narrow band pass colour filters (Diagram 6). For early development work a choice has been made to use photographic filters, a colour separation triple plus a dichroic green filter (~~Figures 3, Kodak~~ Judd, D.B. 1952). The "brightness" of the reflectance which passes through a given filter is measured. A quadruple of numbers, with the position in the quadruple representing a particular filter and the value at this position the brightness of the radiation passing through it, represents each chosen patch. These quadruples form the data base.

In the ideal case a sample either matches (within an acceptable tolerance) the stored data or it does not match. This ideal condition is not met with in the field. The reflectance which may be collected from a given ground patch varies with:

(1) The diurnal variation of altitude of the sun.

(2) The seasonal altitude of the sun.

(3) The aspect of the patch (for example a "north" slope, a "south" slope).

(4) The condition of overcast.

(5) Shading from obstacles such as logs, stumps and adjacent standing trees. Shading from the planting device.

(6) The state of dampness of the patch.

Because of this a theory for the variation of the data needs to be constructed. If this is not done then the same input source will have to be treated as giving rise to a class of n-tuples of input.

If a large enough collection of "good" choices exists that a search through a list of them (or through some other organization of data) is not fast enough then a deductive system can be added. A deductive system is similar in form to a theory for variability. It would define implicitly a class of "good" planting spots. A given input, modified for variability, is "good" if it is an axiom of the theory, if it can be deduced from a sub-class of axioms of the theory or if it can be deduced from a sub-class of theorems of the theory. To confine the amount of data stored it may be necessary to always deduce from axioms. Whether this needs to be done will depend on the particular circumstance.

It would be possible to build up a data base in the field by the use initially of semi-automatic operation. Once a tool had been halted on a good planting spot, being guided to it by the pointer, the reflectance data could be sampled and stored. A data base would in this way be built up upon which a deductive system could operate. Each new good datum is either in the data base or can be deduced from the data base or is not in the data base and cannot be deduced from the data base. In the last case it is added to the data base. Whilst the vehicle is moving to the next array position which is to be planted the SBC is inactive. The computational activity needed to add or not add a datum to the data base could take place whilst the vehicle was moving. Each tool once in the start position would attempt to operate automatically. If it failed to find a planting spot it would be still scanning when the operator took notice of it. He would guide it to a spot. Gradually the system would come to operate automatically.

It is now assumed that a scan is performable. The sensory structure of the choice mechanism is shown in diagrams. This structure consists of the bright spot mechanism and some additional mechanism. The logic of the deviation and halting of the scan is shown in Figure 1.

In order to implement this perceptual/motor scheme it is necessary to sample the sensory array for its state of input. A sampling trigger is needed which will bring about a sufficient number of samples and in a suitable pattern to cause the tool to be led with high probability to a good planting spot. Our plan is to find some trigger conditions which enter the SBC as interrupts halt the tool and cause a scan of the sensory input to be undertaken. It does not matter what these triggers are as long as the outcome to which they lead is satisfactory.

The actual attributes which are to be used as the input trigger which brings about sampling will have to be found from observation of a sufficient sample of worksites. Here some attributes are assumed and their pattern of use explained.

(1) A condition of unbalance of any pair of sensors. This mechanism is identical to the bright spot mechanism.

(2) A condition of balance of some sub-set of sensors.

(3) Specular reflection - high "brilliancy" of unfiltered input.

(4) Low unfiltered input - black soil or damp ground, etc.

(5) High red (red input and other colour input not balanced i.e. the difference is above a given threshold).

(6) High yellow (comments as at 5.)

(7) High green (comments as at 5.)

(8) High blue (comments as at 5).

The device is to examine anything which is "unusual". What is in fact "high" or "low", etc. will depend on the attributes of the data which is being collected and on the ambient conditions. (The avoidance of high bushes and other unusual obstacles could be under the control of the operator.)

If an interrupt occurs the tool will be halted. All the colour data arrays and their sub-arrays are sampled in sequence. A decision is made as to whether a particular sample of input is "good" or "bad". The state of balance of the colour data sensory array is computered and the appropriate action (Figure 1) taken.

Parallel processing

The situation arises for hand planters where a clear plantable spot cannot be found but the ground cover in places within the tolerance region being worked is such that it can be cleared with reasonable effort to possibly reveal a plantable spot. In such a case a hand planter may make several attempts to uncover a spot before he finds one and places a tree or abandons the attempt to place a tree.

Once a spot has been cleared the decision that it is good is identical to that of used in the choice of a clear spot. (For full mechanization a directive "clear until good" would have to be used with some automatic limitation on the amount of clearing which is to be done.)

To mechanise the choice of a potentially clearable patch the attributes of such patches would have to be made explicit (by a field study) and machine recognizable attributes extracted. Our first guess (from the experience of having worked on planting sites) is that the judgment of the planter is based on colour and texture).

It is possible to recognize the identity of a pattern of colour or of shading falling onto a two dimensional array of light sensors by making a pixel by pixel comparison of the pattern with a stored pattern. We wish to operate in real time with a comparatively simple device which has a comparatively small storage capacity. Pixel by pixel comparison of two dimensional patterns is costly both of computational time and of storage. Alternatives to doing this type of comparison, that is, serial pixel by pixel comparison, having been explored. The following suggest themselves.

(1) Feature detectors. Find by an empirical study a small collection of attributes which characterize "clearable spot" (or a small collection of such attributes and a theory over them which implicitly defines "clearable spot".)

(2) Homogenisable attributes. A sample of colour passed through a diffusing filter produces what may be thought of as an "average" reading from the patch which gave rise to the sample of reflectance. No trace is left of the light pattern which the texture of the surface may have produced in the reflectance. In effect the light which has been passed through a diffuser has been homogenised; it makes no difference how a sensory array is arranged relative to textural features of the patch. It may be that some textures are recognizable, after they have been homogenised, purely c\by colour and/or greyness. This recognition may involve the construction of a theory for the homogenised attributes (e.g. patterns of combinations of greyness and colour).

(3) Speed up the recognition of pattern by pixel to pixel comparison by the use of "parallel" processing. (The storage of two dimensional patterns (the data base) for such processing needs examination.) A preliminary

exploration of this approach has been undertaken. An outline of what has been found follows.

The terms "parallel processing" and "parallel computation" do not have a single meaning. For each of discussion let the Universal Turing Machine (i.e. an implicit definition) be taken as the ideal theory of any "serial" processor; there is too wide a variety of practical devices to discuss them explicitly. Diagram 7 shows a Turing Machine storage tape. It consists of a sequence of "cells" in which an inscription occurs ("1" or "0"). The device performs a computation over this initially given finite inscription, operating upon a single cell at a time in a serial order. Which cell is operated upon, if any, and in which order depends upon the inscription. the n-tuples by which the machine is defined and the state of the machine. A Universal Turing Machine operating upon the inscription in each of a sequence of cells is taken to exemplify "serialness".

A "parallel" processing system could be a system of simultaneously operating serial processors. (It may be that in the final analysis all idealized parallel processors have this nature.) The pattern recognition device "WISARD" discussed by Aleksander (1985) appears to have this structure.

Here an exploration has been made for a means to obtain simultaneous pixel to pixel comparison of two two-dimensional patterns. An attempt has been made to expose the principles for a parallel pattern comparison device which can be embodied by combinational components (e.g. logic gates). These components are fast and densely packable. However initially at least one sequential component is needed or no storage can occur. Our idea is to use as the sequential component a "programmable" inverter/non-inverter. It will act as a non-inverter if a "1" has occurred at the storage input (Diagram 8). It otherwise acts as an inverter. Thus, once initial storage input has occurred the device is entirely combinational. The technical crux is the design of the inverter/non-inverter at the physical level. At first the problem looked as if it will boil down to the problem of causing (storage) input to produce a "link" or to destroy a "link" in an alternative microscopic (i.e. LSI) circuit. Further work, not described here, has revealed alternative means for achieving the desired inversion or non-inversion. The problem is left here. In what follows it is assumed to have been solved.

To simplify discussion input is assumed to be two-valued. Two plane arrays are distinguished, a light sensitive array (sensory array) and a storage array consisting of (ideal) inverters/non-inverters. Again to simplify discussion the two arrays are assumed to be the same size - for every sensory element there is a switch and the input from an element in position <a,b> in the sensory array is assumed to go to an inverter/non-inverter in the position <a,b> in the storage array.

The functional organization of the pattern comparison mechanism is shown in Diagrams 9 and 10. The system operates as follows.

In the presence of a storage enable signal which is activated by a CPU or by a human operator input from a sensory element enters the system (ADC is assumed). If a "1" occurs from sensory element <a,b> then the storage element becomes (or remains) a non-inverter. If a "0" pulse enters from <a,b> then the storage element becomes (or remains) an inverter.

In the presence of a comparison enable signal activated by a CPU or by a human operator a "1" pulse is sent to every inverter/non-inverter in the storage array. If no inversion occurs then a "1" passes to the comparison unit. If inversion occurs then a "0" passes to the comparison unit.

In the presence of a "comparison enable" signal input from each sensory element in the sensory array passes into the comparison unit. On each input line there is gate (Diagram 9 and Figure 4).

Consider the sensory element <a,b>. Suppose that a "1" is input from this element. If a "1" is output to the comparison unit from the storage switch <a,b> the "1" from the sensory element <a,b> will be gated to the "high" collector. (The collector can be thought of as a capacitor). If a sensory "0" is input then in the presence of a storage "1" this "0" will be gated to the "high" collector. If a sensory "1" is input in the presence of a storage "0" then the "1" will be gated to the "low" collector. And so on. The logic of this system is shown in Figure . The output of the storage array acts as a filter, gating input "1"s and "0"s either to the high collector or to the low collector, which depending on whether a storage "1" or a storage "0" is present at the gate.

If a perfect match occurs then for all <i,j> if a sensory "1" occurs at the mark <i,j> gate then a storage "1" occurs at the same gate. In this case all "1"s go to the high collector. At the same time if a sensory "0" occurs at gate <i,j> then a storage "0" occurs at the same gate; a "0" goes to the low collector. Let it be assumed that a collected "1" is represented by an arithmetical "1" and that a collected "0" is represented by an arithmetical "0". In the case of a perfect match (ΣHigh - ΣLow) = ΣHigh. (In a practical device the direction and amount of current could represent the outcome of the charge collected on the high capacitor minus the charge collected on the low capacitor. A potentiometer with input in one direction from the high capacitor and input in the other direction from the low capacitor could provide the needed direction of current and size of current. This macroscopic device may be implementable with already available ICs. It has been suggested to show that the needed comparison can in fact be carried out.)

If a match is imperfect then some sensory "1"s will be gated to the low collector and some sensory "0"s to the high collector. In this case (ΣHigh - ΣLow) < ΣHigh. A function over the outcome (ΣHigh - ΣLow) will be needed to decide if it is to be judged as constituting identity or not. (The maximum number of sensory elements and also switches will be known. Hence the value High for a perfect match. A function over this constant and a term representing the comparison of high and low could be used.)

If a complete mismatch occurs then every sensory "1" will be gated to low and every sensory "0" will be gated to high and (High - Low) = - Low.

A complete system would consist of K storage arrays and what is essentially) one sensory array. Let is be assumed that human operator activates the "store enable" and that he does this if input is from a "good" sample, such as from a good planting spot, Initially in the presence of a "store enable" a good pattern is stored in the first storage array. (It could be an ordered n-tuple of arrays with each array storing input from a single pattern which has a distinctive attribute such as that of colour.) When the operator chooses a second good spot he activates the comparison enable. If the comparison show the first set of data to be identical to the second set then the second set is not stored. If the first set and the second set are not identical then a store enable occurs and the second set is stored in the second storage array. A simple way of achieving this is for the device to signal "good" or "bad" match to the operator (e.g. green light on or red light on). The operator would in the case of no match store the second pattern; it is new good pattern.

In the presence of a comparison enable either:

(1) A comparison is made with the first storage array and then the second array. or,

(2) Simultaneous comparison is made with those storage array which have content (in this case the first and the second). If this is done any good match will count as a match and no match will count as a mismatch.

This type of comparison mechanism could be put into operation as part of a non-focusing device where the image is the pattern produced by an optical mask. A device such as that used to obtain signal detection (Chapter 11) could be used.

To obtain K-valued comparison a means of gating the input from a sensory element to k switch arrays is needed and means of gating the "comparison" input from the sensory array to k gates in the comparison unit. The rest of the logic would then be identical to the two valued case. There is a resemblance here to the problem of obtaining parallel analog to digital conversion. Parallel converters exist. For large arrays the number of components becomes large and with this the expense. For the intended application a physical method other than used in parallel analog to digital conversion is needed. It might then be applied to analog to digital conversion. Some exploration has been made into conversion. Some exploration has been made into conversion based on the gradient of the field around a charge carrier and based on the inductive effect of a pulsed current.

The problem is too large to be considered further here.

The pattern comparison method described in this chapter will fail on "shapes" (Diagram 11).

Imagine a shape and background such as that shown in Diagram 11 against a field of "dots". Let there be a dot for each sensory element in the sensory array. If when a storage occurs dot <a,b> is collected by sensory element <a,b> then unless the same dot is collected by the same sensory element when comparison occurs a mismatch could be recorded of shapes which are judged to be identical by a human observer. Rotation and translation of a shape or the two movements combined could bring about a mismatch.

These difficulties point to a programme of investigation. Again, it is beyond the scope of this thesis.

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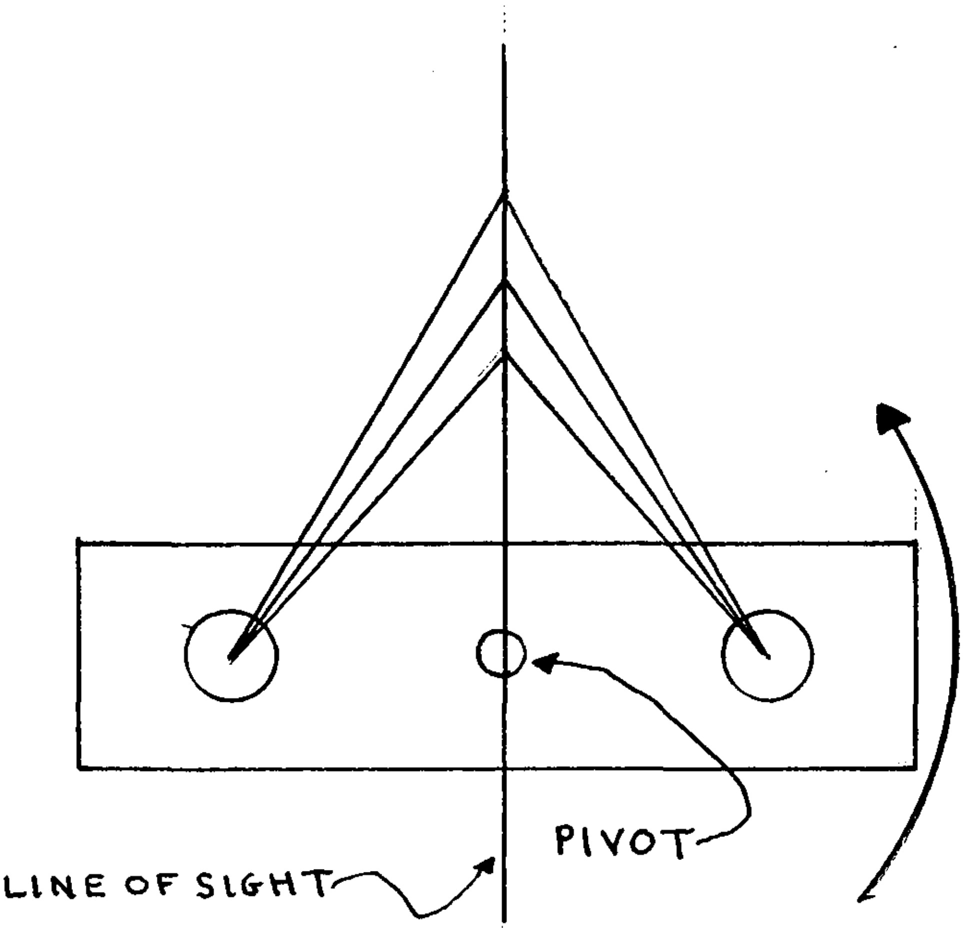


DIAGRAM 1. Range finder.
The line of sight is fixed.

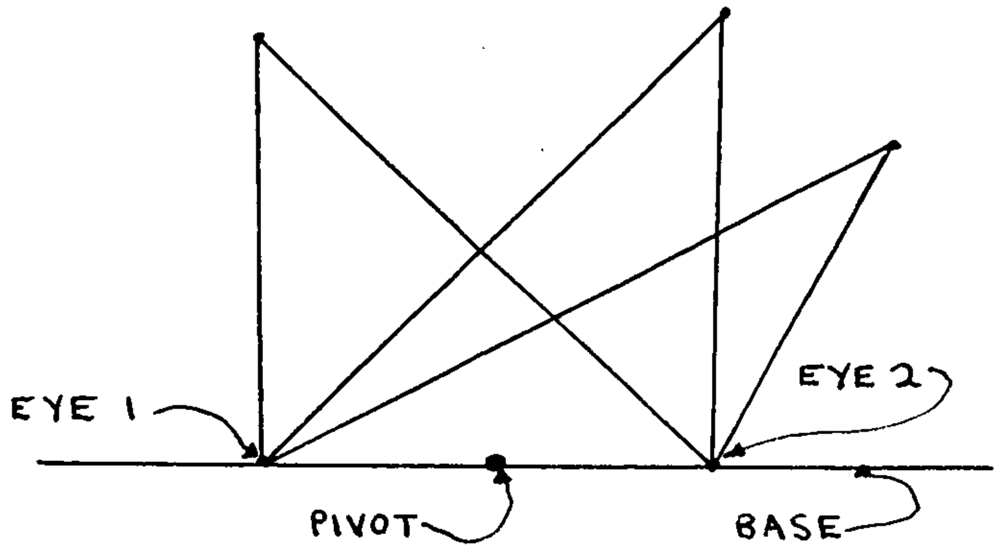


DIAGRAM 2. Natural system. The "base" can rotate. The eyes rotate independently of the base. They can fixate along a range of lines of sight.

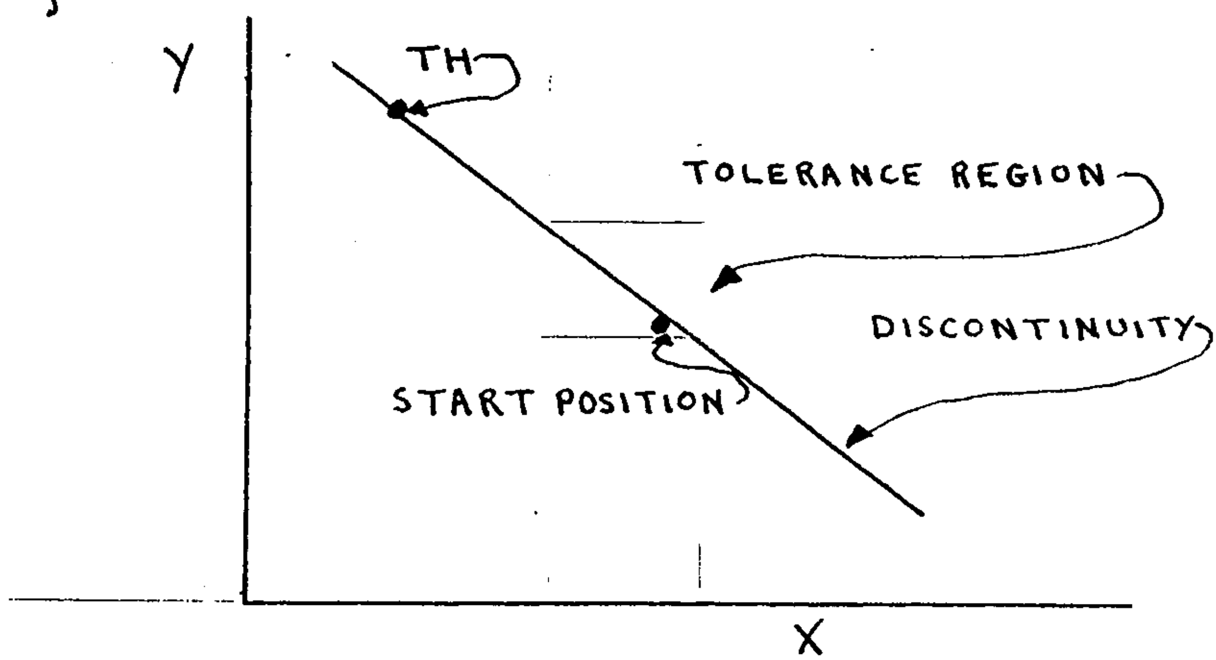


DIAGRAM 3.

Automatic Choice.

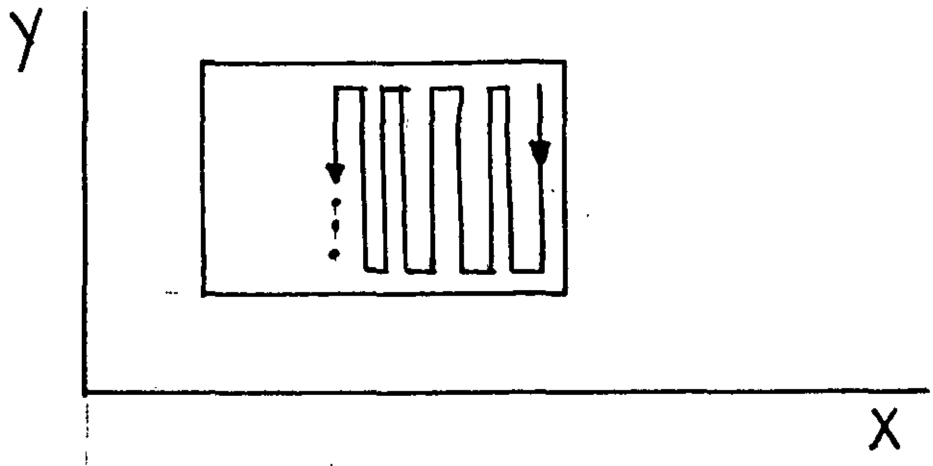


DIAGRAM 4

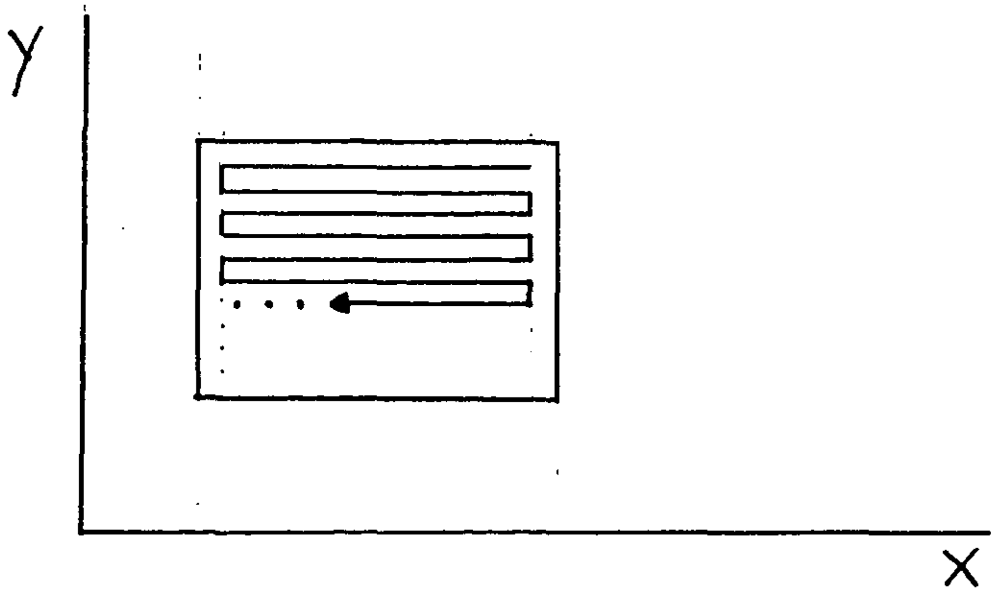


DIAGRAM 5.

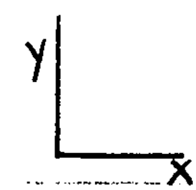
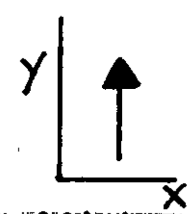
CONDITION	SENSOR 1	SENSOR 2	SENSOR 3	SENSOR 4	OUTCOME (Move (X,Y))	SENSOR CONDITION	COMMENTS
1	g	g	g	g	HALT		■ = BAD
2	b	g	g	g	+X −Y		□ = GOOD
3	g	b	g	g	−X −Y		"b" = BAD
4	b	b	g	g	−Y		
5	g	g	b	g	−X +Y		"g" = GOOD
6	b	g	b	g	SCAN		
7	g	b	b	g	−X		
8	b	b	b	g	−X −Y		
9	g	g	g	b	+X +Y		(HORIZONTAL)
10	b	g	g	b	+X		
11	g	b	g	b	SCAN		
12	b	b	g	b	+X −Y		
13	g	g	b	b	+Y		SCAN
14	b	g	b	b	+X +Y		
15	g	b	b	b	−X +Y		
16	b	b	b	b	SCAN		

FIGURE 1.

To prevent an endless oscillation the outcome of condition 4 and condition 13 may need to be "scan".

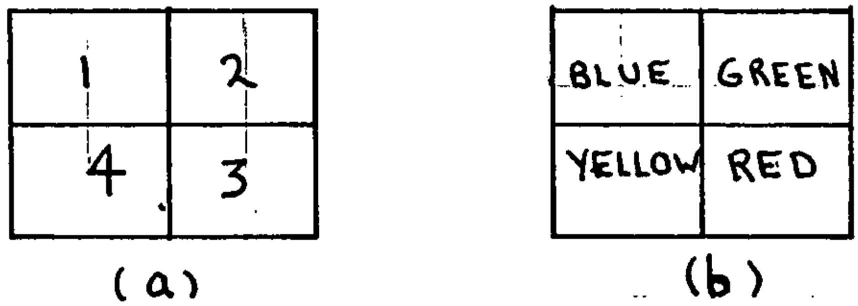


DIAGRAM 6. Sensory array and its colour filters.

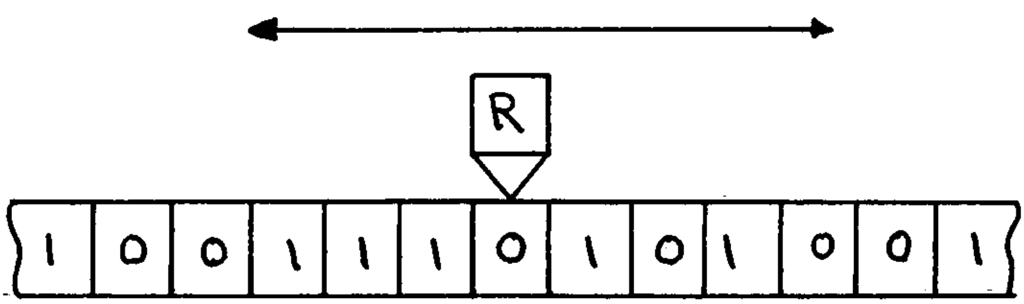


DIAGRAM 7.

Turing machine. "R" = Reading Head. The inscribed strip is two-way potentially infinite. "⟷" = Directions of Reading Head travel.

tic

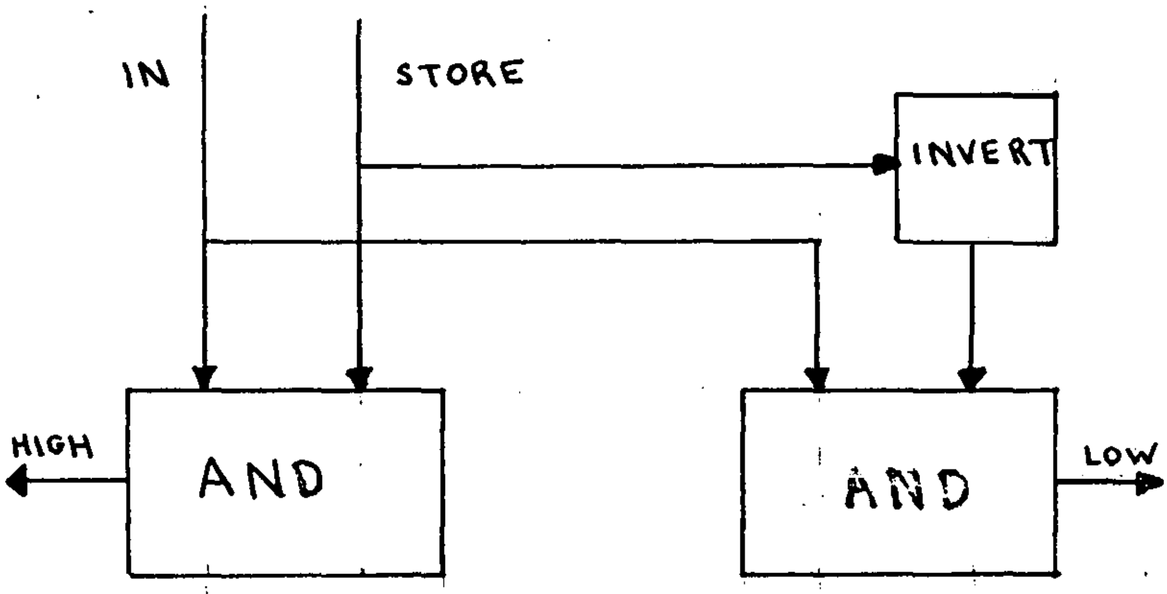


DIAGRAM 8.

IN	STORE	AND
1	1	1
0	1	0
1	0	0
0	0	0

FIGURE 2. "AND."

IN	STORE	NEEDED
1	1	0
0	1	0
1	0	1
0	0	0

FIGURE 3. Truth table needed for "LOW."

A	B	A $\wedge \sim$ B
1	1	0
0	1	0
1	0	1
0	0	0

FIGURE 4. Truth table needed. This table can be embodied by the device shown in Diagram 8. The completa gate is equivalent to $(A \vee B) \vee (A \wedge \sim B)$. A "1" passes to "HIGH" in the presence of a Store "1". A "1" passes to "LOW" in the presence of a store "0."

tic

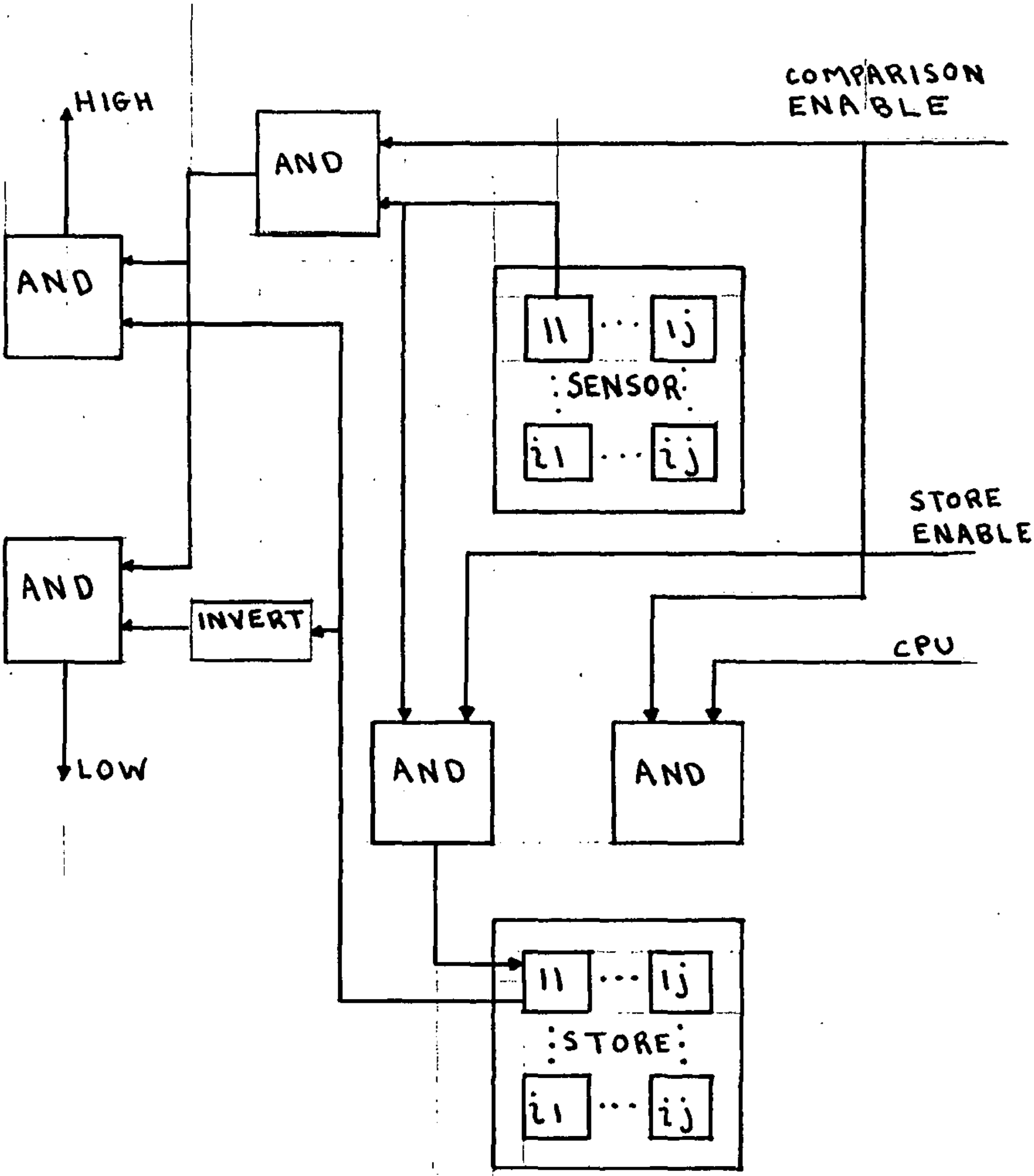


DIAGRAM 9. Logic of parallel pattern-comparison.

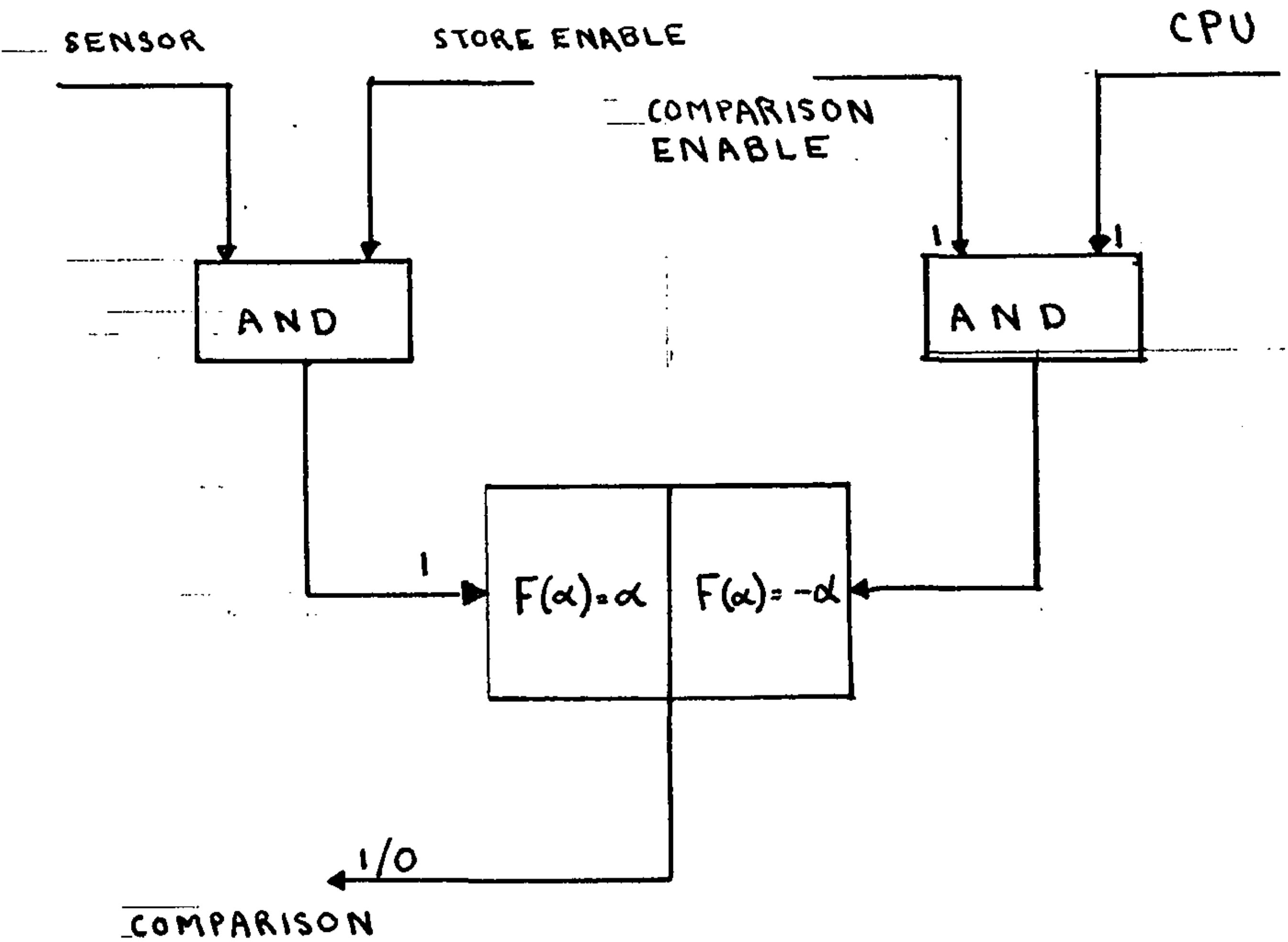


DIAGRAM 10. Structure of Store(i j).

SENSOR	FUNCTION
1	$F(\alpha) = \alpha$
0	$F(\alpha) = -\alpha$

(a) Storage

FUNCTION	CPU	OUT
$F(\alpha) = \alpha$	1	1
$F(\alpha) = -\alpha$	1	0

(b) Comparison

FIGURE 5. Logic of Store(i j).

iomatic
oice .

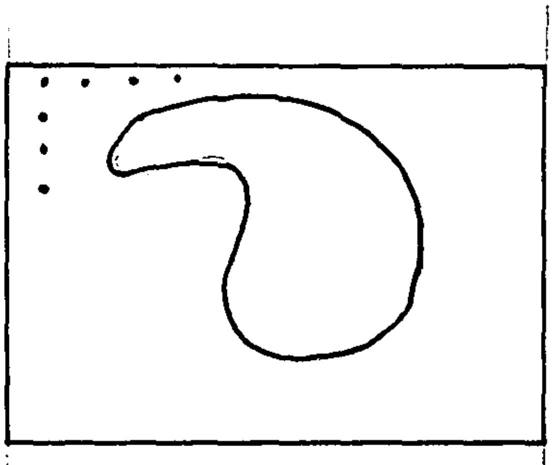


DIAGRAM II.

Chapter XII.
SYSTEM REVIEW 1

In this chapter and the next further detail of semi-automatic operation is entered into. An attempt is made to isolate those sub-parts which still contain unsolved problems of principle and to solve them conceptually. The whole design is to be taken to a point where the main form of a software and hardware design becomes clear. In what follows means for signal conditioning, analog to digital conversion and digital to analog conversion are assumed to be available.

The chapter follows roughly a "top down by stepwise refinement" plan. Major detail is developed first of all. Return is made to previously worked out parts to develop them further. The process is continued until it appears that major conceptual difficulty has been eliminated, the design is fixed and ready to be developed in full detail.

The data processor which is to be used is an SBC based on the TI 9900 16-bit microprocessor. The main interface component to be used is the 9901 PSI (programmable systems interface). This component will deal with input, output and interrupt communication between the central processing unit and the sensors and effectors.

It is intended that a finished software design will be written in 9900 assembly language. Here the software design is worked at a high level but 9900 assembly language is aimed at and the 9901 interface. The full working down of the design to assembly language is a task which is reserved for the next phase of development. At that point detail design will be being performed on a known concept.

Each tool is associated with an SBC which controls its actions. Each tool is controlled by a program which is identical to that of any other tool. The particular sequence of action which a given tool is caused to perform will depend on its position in the tool array.

The control mode is "on/off". It is at this point preferred that tool motion be pneumatically driven.

The following major functional sub-systems are distinguished and dealt with:

(1) Magazining and handling.

(2) Placement

(3) Semi-automatic choice.

(4) Tool set-up

(5) Spacing

(6) Automatic choice.

(7) Tool levelling.

Little is done on automatic choice (see Chapter 10) but the system is to be made expandable to automatic operation without the need for radical re-design of the hardware and software to achieve it.

The first six functions are to be controlled by the tool SBC. Tool levelling is preferably to be separately controlled. The action which is needed is straight forward. It is needed continuously and would if SBC controlled complicate the interrupt structure. The activating cues which are needed (to signal that a tool is or is not vertical) can be given rise to by such means as mercury switches or by the use of a pendulum activated or level bubble activated response. (A pendulum can be used to block communication between a transmitter and receiver of light (off-the-shelf integrated circuits); a bubble in an opaque liquid likewise.)

Levelling

The motor response is to be on/off. Air activation is to be used (Air is particularly useful where fast on/off response is needed; air driven devices can be light weight, reasonably low-cost, and robust (Grieg, 1984)). X axis levelling is to be independent of Y axis levelling. Diagrams 1 and 2 show the motion needed for a tool levelling system. It may be necessary for the levelling system to be disabled once the tool has halted and entered the "Plant" sub-routine (see below). This can be done by on/off light communication between the levelling

actuation system and the SBC (e.g. by input to a photo-resister whose output goes to one side of an AND gate having a standing "1" on the other side).
It is preferred that tool to SBC, SBC to tool, operator to tool and tool to operator communication is to be carried by incoherent light.

Pointer output

A pointer can be swung in a horizontal plane and vertical plane. The effects of both movements are shown in Diagrams 1, 2 and 4 of Chapter 8.

Beam and end-stop setting. Order of events in tool set-up.

Set main beams (manual)

Set corner end-stops (manual)

Set spacing (manual)

(Spacing could be set via the pointer and a chain effect. Manual setting is a straight forward solution)

Set order of precedence and a starting configuration (semi-automatic via the pointer)

Point and set bright spot for planting (Manual pointer manipulation, automatic tool response)

Setting the response tool

All tools have the same program. The sequence of action which a tool performs during set-up and thereafter depends on its position in the array. There are four tool classes:

(1) No. 1 tool.

(2) Boundary tool.

(3) Interior tool

(4) Lowest order tool.

If a tool is a No. 1 tool then the first input which it receives is pointer input (i.e. after "power-up"). The reception of pointer input is to occur as an interrupt which calls the appropriate sub-routine.

If a tool is a boundary tool the first input which it receives is spacing input on one side. This input calls the appropriate sub-routine (A complication is dealt with below).

If a tool is an interior tool the first input which it receives is spacing input on two sides. This input call the appropriate sub-routine.

When a boundary tool reaches a position of balance at the D threshold (practical inter-tool spacing maximum) it will still be illuminated on one side. By the time an interior tool reaches balance and D on one side the second side will have been illuminated. It is the condition at balance and D which distinguishes the two tool classes.

The lowest order tool is identical to an interior tool up to the point when it reaches balance and D. In the other tools motion to the start position is activated by a signal from immediately adjacent lower order tools. There is no lower order tool to activate the action of the lowest order tool. A modification of its response is needed to deal with this (see below).

Sequence of events for the No. 1 tool in set-up

Pointer on

No bright spot on

Pointer horizontal and pointed at the No. 1 tolerance region corner (Diagram 3).

At power-up the No. 1 tool may be at any position in its tolerance region.

The pointer is to be moved to the horizontal position, pointed at the required corner and then turned on. The response of the tool is to move along the line of discontinuity toward the threshold (TH). When the tool hits the X and Y end-stops at the corner of the tolerance region it will light its spacing lights and halt until it receives balance and D signals from the immediately adjacent tools. It is possible for the No. 1 tool to light in error at the other corners of its tolerance region if the pointer is manipulated wrongly. This can be undone by turning the power off to the tool array and then turning it on again. The set-up can be then begun anew. The motion firstly to the tolerance region "far" corner and then back to start is needed to signal to the immediately adjacent lower order tools the pattern of lighting which is required. Movement to a uniform start position is used also to guide the operator as to the position of the tool tolerance positions relative to each tool.

No. 1 tool moves to the corner of its tolerance region indicated by the pointer (Diagram 3).

It meets the X and Y end-stops

"End-stop" input in

X motion halts

Y motion halts

All spacing light pairs are lit

The tool waits for a signal from adjacent tools

It receives spacing light signals on two sides (the pointer has been moved to a vertical position)

The tool follows the pointer to the start position

It meets X and Y end-stops

End-stop input in

X motion halts

Y motion halts

The No. 1 tool now awaits pointer input (this input will occur when the tool is directed to a planting spot)

Sequence of events - Boundary tool

Spacing signal received on one size, an "X" side or a "Y" side

Move to balance

Move to D (the No. 1 tool is halted with its spacing lights on: Diagram 5)

If balance and D or if X and Y end-stops have been reached the tool halts

It signals to the adjacent higher order tool (No. 1 in this case) that it is balanced and halted

It lights one side (Discussion in Chapter 9)

Once the higher order tool receives balance and D signals it moves to the start position. This motion acts as a signal to the immediately adjacent lower order tools as to which second side to turn on. (A second way of causing the second side to light was described in Chapter 9).

It waits for balance and D signals from its immediately adjacent lower order tools

If these signals have been received from two sides the tool moves to the start position under the influence of the spacing lights of the higher order tool

When the end-stops are met motion halts.

The tool is now at the start position where it awaits pointer commands.

Sequence of events - Interior tool

If X spacing input and Y spacing input has been received then,
Move to X balance and D
Move to Y balance and D

If (X balance and D) and (Y balance and D)
OR end-stops THEN

Halt (X,Y)

Light sides (See Chapter 9)

The tool waits halted until it receives signals from the lower order tools immediately adjacent that they have reached balance and D (or the end-stops)

If signals received then move to Start

Sequence of events - Lowest Order tool

This tool (Diagram 4) cannot receive a balance and D signal as there is no lower order tool to send it. The move of the other tools to a "far" corner of their tolerances regions, halting until balance and D signals are received and then moving to start is used to avoid incorrect lighting of lower order tools by higher order tools. This is particularly important in automatic operation. For the lowest order tool the sequence of events up to its reaching the balance and D condition (or having met the X and Y end-stops) is identical to that of the other Interior tools. A signal is needed to send the lowest order tool to the Start position.

This problem can be solved by having every tool signal when it has reached the Start position. For the higher order tools receipt of this signal will be of no consequence. For the lowest order tool it will bring about a movement to balance and D, in other words a movement to the Start position. Having every tool signal in this way enables complete interchangeability to be maintained. Any tool may be the lowest order tool. Any two tools may be the higher order tools immediately adjacent to the lowest order tool.

Tool response to the Pointer; some further detail of pointer operation.

A tool responds to the threshold TH (pointer threshold) by moving towards the threshold. A tool responds to the state of balance of the pointer sensors which are receiving input, moving towards balance (Chapter 8).

If a tool has reached the threshold but has not received end-stop input or Brightspot input it continues to move along the line of discontinuity until it meets an end-stop or comes under the influence of the Brightspot (Chapter 8).

If, before reaching the threshold TH a tool obtains Brightspot input then it responds to the sub-routine "Brightspot".

If it hits the end-stops it halts.

After a tool has halted and entered the sub-routine "Plant" it ceases to respond to the pointer. Before this halt a tool can be made inactive by turning off the pointer is then turned on again the tool will respond to it. It will not enter the Brightspot sub-routine until it again receives Brightspot input.

Sequence of events after planting is completed

After having planted the tool program must be prepared to respond to Pointer input and to Brightspot input anew. If upon planting a tool respond to this input then since it will be halted and receiving balanced Brightspot input a tool could plant again in the same spot. And so on forever unless each pointer/Brightspot/Plant sequence is punctuated, that is, separated from its predecessor. One way of doing this is to turn off the Brightspot. The cessation of the signal can be made to act as a punctuation; the sub-routine Pointer could be entered. Since there is no need for any tool to move whilst the vehicle is moving to a new array planting position, it is best if both the Brightspot and the Pointer lights are turned off. It would be unwise to burden the operator with the task of having to keep an eye on every tool and to immediately turn off the lights when he saw that a tool had planted. The turning off can be accomplished automatically by a time delay switch (e.g. similar to the switch used to turn apartment corridor and stair lights off).

A second way of dealing with this problem would be to introduce a sub-routine "TH Negative" which is called after planting is completed. The tool would no longer respond to Brightspot input (the interrupt status of Brightspot input would be downgraded and thus "masked out"). Responding to TH-Negative a tool would follow the pointer lights (still on) back towards the cab (Diagram 5). At some point a tool would hit either an X or a Y end-stop and halt. In the meantime the pointer light and the Brightspot light could be turned off by a time delay switch. The turning off and then the receipt of end-stop input readies the tool to receive Pointer input. (In the 9900 system the receipt of the interrupts End-stop and Pointer Off would upgrade the Pointer interrupt at the same time downgrading other interrupts, the relevant one being Brightspot.) This method has the advantage over the first of bringing the tools close to the Start position. Having them in this position is a help to the operator. It is possible to in fact bring them to start (see below) with methods which are already available for other purposes.

The spacing response in semi-automatic operation

In semi-automatic operation the order in which the operator deals with tools in an array is of no inherent importance. This being the case there is a possibility of encountering difficulty if a lower order tool is dealt with before an immediately adjacent higher order tool and the spot chosen for the lower order tool is under spaced or is over spaced relative to the higher order tool. In this case the lower order tool will not be able to move to the chosen spot. If such a situation arises then a signal will need to be sent to the operator drawing his attention to the fact that a tool cannot reach its chosen spot. Where a conflict of this sort arises the tool could halt, the operator could deal with the higher order adjacent tools pointing out a spot for them. Their subsequent motion within their tolerance areas would either enable the lower order tool to move to its spot or would not enable it to move to the spot. Another choice would then have to be made for it to escape from the situation.

To simply avoid this kind of situation the array could be dealt with in order of precedence (Diagram 4). An experienced operator could be expected to have no difficulty doing this. For a less experienced operator numbers might have to be placed on the tools. The disadvantage of having to do this is that the order depends on the choice of the No. 1 tool and the choice of this tool is made in the field just before planting begins.

Our preference is to allow an unordered choice. If a uniform start position is used and a choice is made of a planting spot which is as close to the start position as possible (i.e. close to a tool) then over spacing and under spacing will be avoided. Unfortunately the random occurrence of obstacles may prevent the putting into operation of this solution. Diagrams 6 and 7 show a solution to the problem of numbering: a fixed numbering system is used.

Even with a fixed numbering system the operator must still exercise judgment as to where in the tolerance area of a lower order tool he may make a choice of planting spot. He must judge this by the positions of the spots chosen for the immediately adjacent higher order tools (Diagram 8).

The sequence of events in "Brightspot"

The operator points at a planting spot for each tool. This action sets the pointer threshold (TH). The tool moves towards TH. If it reaches it but has not received Brightspot input then it continues to follow the line of discontinuity until it does come under the influence of the Brightspot. If the Brightspot is encountered before TH is reached then it comes under its influence.

A complication arises due to the position of the pointer relative to a tool tolerance region. It is necessary to ensure that no matter how the vertical projection of the pointer discontinuity line falls on a tool's tolerance region the Brightspot sensors can always reach a state of balance. Diagram 9 shows the difficulty, Diagram 10 - 13 show a proposed solution. In the solution the shape of the Brightspot is to approximate to a circle. In the ideal case the Brightspot shape is then invariant relative to the Brightspot receptors no matter how the pointer line of discontinuity is placed. In a practical system there will be some distortion from the circular of the Brightspot image, the distortion depending on the angle from the horizontal of the pointer. Here this distortion is ignored whilst the main form of a solution is being worked out. If it is shown experimentally that the distortion is serious enough to affect operation then it will be dealt with. The possibilities available are to adjust the image so that any distortion is averaged out. The greatest distortion will occur at the low angles of the pointer. The image cast by a vertical pointer could be distorted from the circular (by the use of a mask) to accommodate the distortion to a point where a workable solution becomes available.

In the lay-out shown in Diagram 12 motion by a tool along the pointer discontinuity line will eventually bring both the sectors A and B within the circular region of the bright spot. In this situation continued translation along the X-axis will cause the two sectors to be equally lit when motion will halt. The tool will in the ideal case be vertically above the spot chosen.

In the practical system a tool will be "zig-zagging" along the pointer discontinuity line in which case one or the other of the bright spot sensors may obtain input before the other. This input may impinge upon only a part of the sensory array of a sector (A or B). It must be arranged for both X motion and for Y motion to be controlled by the Brightspot input in a practical system.

Each Brightspot sensor is divided into two parts, X1 and X2. This division underlies X-motion control. The division into the two sectors A and B underlies Y-motion control.

If in any sector (A or B) X1 is not equal (as defined) to X2 then X motion occurs towards the brightest side until equality is reached. This motion will carry the tool into the Brightspot. If sector A is not equal (as defined) to sector B then Y motion occurs towards the brightest side.

The two responses acting independently of each other should suffice to bring the two sectors to a state of both "X" input balance and "Y" input balance. This solution is modified in later discussion.

Signal detection

Two questions need to be answered in the affirmative if operator to tool and tool to tool communication using incoherent light as a signal carrier is to prove to be possible.

The first is whether a standard light sensing device (diode, photo-resister or photo-transister) can sense incoherent light from a source which uses standard readily available components (such as those used for road vehicle lights) against a background of bright sunlight.

The second question is whether a standard light sensing device can sense against a background of bright sunlight incoherent light from a standard source which has been reflected from a diffusely reflecting surface, in this case soil.

Diagrams 14 and 15 show the distances and the angles of incidence which are involved.

The two problems can be approached from the point of view of whether it can be arranged for a standard light sensor to be able to detect a signal carried by incoherent light from a standard source in the presence of sunlight. This is how both problems have been approached.

If a light source, such as a vehicle headlamp, is shone at night in the absence of either moonlight or other artificial light the beam can be seen from the "side" and from the "front" (Diagram 16). A relatively insensitive photographic exposure meter will respond to this light.

If in the same circumstances the same light source is shone onto a diffusely reflecting surface such as that of soil, the point of incidence is visible from any position above the surface and within a range of distances which are of interest for the tool guidance application. An exposure meter, suitably hooded will respond to the point of incidence (System Review 2).

Suppose that a filter were available which excluded the sun's light (reflected or direct) and which allowed light from the artificial source to pass. Such a filter placed before a sensor (e.g. photographic exposure meter) in the presence of sunlight would place the sensor in darkness. If now the artificial source were introduced the situation would be identical in its effect on the sensor to that of being in the presence of an artificial light source in darkness. If the light source were confined to a narrow beam then moving the sensor out of the beam (sensor assumed to be hooded) would place the sensor in darkness. Moving the sensor into the beam would illuminate it.

The possibility of approximating the dark condition in the presence of sunlight by the use of filters and by the use of optical masks has been investigated.

Method 1

In chapters 8, 9 and 10 it was explained that colour filters were to be used for pointing, spacing and for planting spot detection. It may be that a dominant colour will be detected against sunlight. Whether this is the case or not has been investigated experimentally. (Chapter 13)

Method 2

It is possible to achieve a useful approximation to the darkness condition by the use of polarized light.

Our problem is that of ensuring that a signal carried by incoherent light is distinguished from sunlight. To begin with it assumed that all planes of vibration of the wave fronts which occur in the sun's light are equally represented. It is known that polarization by reflection and by refraction occurs. For the moment these phnoma are assumed to have no practical importance; the main form of a solution based upon polarization is worked out. Given the assumption, two identical polarizing filters (let us say plane polarizing) arranged as shown in Diagram 17 and with their planes of polarization perpendicular to each other will transmit equal amounts of the sun's light. Two identical light sensing devices one placed behind each filter should in this case record identical input.

Two identical plane polarizing filters placed one in front of the other with their planes of polarization perpendicular will not transmit light. The two facts together - the fact (assumed at present) that polarizing filters placed side by side as in Diagram 17 transmit light equally and the fact that "crossed" polarizing filters transmit no light - point to a detection method.

Consider the arrangement shown in Diagrams 17 and 18. P2 and P3 are polarizing filters. Ideally each will transmit the sun's light in equal amount so that in the presence of only solar radiation the input from Receiver 1 (a light sensor) will "balance" the input from Receiver 2 (a light sensor). P1 has the same plane of polarization as P3. If light from the transmitter is passed through P1 and then falls upon P2 and P3 then P2 will not transmit the light (P1 and P2 are "crossed") whereas P3 will transmit it. The reception of this light will "unbalance" the signals from Receivers 1 and 2. The condition of unbalance can be used as a signal that communication is occurring between the pointer and the tool, or brightspot and tool or tool and tool (spacing).

There is as has been said a possibility of complication due to the phenomena of polarization by reflection (e.g. from the ground) and by refraction (e.g. by passage through the atmosphere). These two effects are considered further in the chapter which follows.

Method 3

The method which has been described consists of two sensors which in the presence of sunlight produce equal input and in the presence of a signal produce unbalanced input. The third method uses the same scheme. The means of producing unequal input to the two sensors differs from that of the second method.

In the article by Klimera,(BioKybernetiK, Band V) on "associative" memory the storage and retrieval of an image by the use of an optical mask is described. His experimental set-up can be put to use to solve the optical signal detection problem.

In the article a transformation of an image is projected onto a photosensitive screen (photographic film). The image recorded on the screen is used to make a mask, with perforations occurring where bright spots occurred on the film (Diagram 19). If now the set-up of Diagram 20 is used with the film replaced by the transformed image mask then a light shone through the mask will produce an approximation to the original image on screen 1.

Consider now the set-up shown in Diagram 21. Ideally, R1 and R2 are receptors which are equally lit by sunlight; the use of a diffusing filter should cause this to be the case. Suppose that the original image had the form shown in Diagram 22. If the transformed image is projected at the receiver the original image is recovered and projected upon the plane of the receptors R1 and R2. It is intended that this projection fall upon one half of this plane, R2 in Diagram 22. The reception of the original image will unbalance the input from the pair of receptors R1 and R2.

Depending upon the angle of incidence of the transmitted light which is projected upon the ground more or less distortion of the transformed image will occur. The collimating lens is used in an attempt to hold the image together and to produce an identical image (up to brightness) at any practical distance from the point of transmission without having to resort to automatic focusing (The use of a "pinhole" camera will give sharp focusing with loss of "brilliancy"). (Jenkins, 1984, pp5)

The receiving device collects the reflection (which will be diffusely reflected) of the transformed image. Whether the image obtained from reflection bears a useable resemblance to the original (untransformed) image is something which is reported upon in the chapter which follows. The logic of balance/unbalance is the same as that already described.

Method 4

The fourth method is based on the use of a modulated signal.

In the two previous methods a pair of receptors is used which in the presence of sunlight produce balanced input. In this method a filter is used which admits an oscillating signal but not a steady signal. Filters exist which have the required properties. A simple way of obtaining an oscillating signal is to use a heat sensitive resister. No further detail of this type of method is described here. It is held in reserve.

Methods based on the use of infra red

Infra red emitters and detectors exist which will solve the detection problem. Our preference is to use standard incoherent light sources. (Methods based upon the use of sonar avoid the problem of detection of diffuse reflection from the ground.)

With a solution to the signal detection problem assumed solved a lay-out of a sensory system and its logic can be described. The pointer system, the spacing system and the Brightspot system are based on this organization and logic.

Diagrams 23, 24 and 25 show two pairs of sensors. Each pair is a system for detecting a signal against ambient light input. A signal will pass in from the +Y sensor if a difference between its subparts occurs which is above a threshold value. Similarly, a signal will pass in from the -Y sensor if a difference between its sub-parts which is above a threshold value occurs.

The Brightspot sensory system is further differentiated, as has been described, into a "+X" system and a "-X" system. The "X" system also contains two pairs of sensors, one sensitive only to sunlight the other sensitive to sunlight and to light from a single source.

Diagrams 23, 24 and 25 show the lay-outs and logic needed for spacing, pointer and Brightspot. The input/output and interrupt structures needed to implement these systems are discussed later. The sequence of events in the sub-routine "Plant. A sub-routine "Plant" is recognized.

When the Brightspot sensors are lit and balanced the tool halts - there are no move (X) and Move (Y) directives. The system enters the sub-routine "Plant". In this section some problems of detail are examined.

It is assumed for ease of discussion that a band magazine is to be used with continuous transfer and continuous vertical positioning of trees (Chapter 6). Each magazine is to be hand loaded. Retrieval of trees from a magazine is to be automatic. Placement is to be automatic.

The magazine is to have one speed. Two directions of motion are distinguished "forward" motion, which occurs when the magazine feed mechanism brings a tree from the store into a position for placement, and "reverse" motion, which occurs when trees are being loaded into the magazine. The magazine is to be able to be reversed or driven forward under "manual" control. This is needed for loading a magazine, and emptying a magazine (e.g. to remove trees at the end of a work period, to undo a jam, etc.). When planting under automatic control the magazine drives only forward.

The drive mechanism must respond to the following commands (the magazine is to be perceptually "driven" via off/on light signals) feed forward until a tree is positioned correctly in the placement mechanism, feed forward until the tree (now placed) is released, halt forward motion (tree correctly positioned in placement mechanism or tree released sufficiently for planting tool to be raised from the ground without disturbing it; this last halt must come before the next tree being fed is moved into a vertical position: Chapter 6._

Once a tree is in position the following sequence takes place.

The planting plates are extended. The whole tool is lowered to the ground until the depth of plate penetration which is needed is reached or until an obstacle to full penetration is reached.

If full-depth is reached then the planting plates are retracted. Simultaneously fill is injected. This injection continues until the plates are clear of the ground.

If an obstacle is met then the plates remain extended, the whole is raised from the ground and halted loaded.

Structures are needed for:

(1) Full depth recognition.

(2) Obstacle recognition.

(3) Recognition that the plates are out of the ground.

(4) To overcome a possible disturbance of tree placement between the time when the plates are withdrawn and the release of the tree.

A signal is needed from the tool to the operator which indicates that a tool has run out of fill. A shortage of fill must be dealt with before a planting sequence is begun.

Solution to these problems are sketched which satisfy the functional needs. Obtaining them will enable an input/output structure to be designed. However more thorough conceptual exploration of them is needed: this work is reserved for the next phase of development.

Problem 3, recognition that the plates are out of the ground arises from the use of injected backfill. Stating the problem in the way in which it has been stated biases the approach to the problem. It can be solved in a variety of ways:

(1) By an adjustment of the extrusion mechanism.

  (a) Software - an example is a hand set switch which is thrown to a marked position corresponding to a planting plate length. The switch position gives rise to an interrupt which result in a parameter value being entered in the sub-routine which governs the turning on/off of the injection mechanism.

(b) A mechanical adjustment such as an end-stop, which stops the throw of a plunger which extrudes the fill.

(c) An end-stop (hand set) which gives rise to an interrupt signal which in turn gives rise to an output signal which turns off the injection mechanism.

Solutions to the "full-depth" and "obstacle" problems are sketched which have the form of the (c) - solution to the control of injection. These solutions combined will solve the problem of controlling injection. The fourth problem, avoidance of root disturbance, is solvable by the introduction of an additional frame on which a planting tool is to be mounted. The introduction of this frame gives rise to another solution to the first three problems which requires a minimum of hand setting. It is described after basic solutions to the four problems have been sketched. These solutions are illustrated by Diagrams 26 and 27.

Once the planting plates are free of the ground the only contact which is left between the planting tool and the tree being placed is the gripper which is still holding the tree stem. At this point, just before the gripper releases the stem, a movement of the tool as a whole (e.g. from a jolt arising from the plunge into the ground of the plates of another tool) could move the gripper and disturb the placement of the tree which it is holding. To prevent this happening a frame is introduced on which the planting tool slides (Diagram 26 and 27). The frame makes contact with the ground before the planting tool is lowered. The sub-structure on which the tool is mounted is connected to the rest of the gantry frame. Contact with the ground compresses the spring (s) giving rise to an interrupt which results in the halting of lowering. Now vertical movement of the tool gantry will either compress the spring further or allow the spring to expand. In the case of either a compression of the spring or the case of an expansion of the spring the tool mounted on the frame will not be pulled from the ground.

The use of the frame gives rise to the possibility of mounting end-stops on it, of mounting light ground clearing tools on it and of using a different lay-out for the end-stops needed to solve the full-depth, obstacle recognition and plates clear problems (Diagram 26 shows an example).

It is now assumed that interrupt signals are available from a "full-depth" mechanism, an obstacle sensing mechanism, and from a "plates clear" mechanism.

System Actions

(1) Plant.

Raise frame	-	until "end-stop": pressure activated transduced to light activated interrupt.
Lower frame	-	until "end-stop": as raise frame.
Feed tree	-	until light activated interrupt.
Release tree	-	until light activated interrupt.
Magazine empty	-	the action is the sending of a signal to the operator; initial activation from light signal.
Raise tool	-	until end-stop: as raise frame.
Lower tool	-	until end-stop: the end-stop is "Full-depth" or "Obstacle" - see below.
Lower plates	-	until end-stop: as raise frame.
Raise plates	-	(a) until clear of ground: as raise frame.
	-	(b) until full raised end-stop: as raise frame.
Feed fill	-	activated by "Full-depth" end-stop.
Cease fill	-	activated by "Plates Clear" interrupt.
Fill empty	-	a signal to the human operator. It must be sent before the "Plant" sub-routine is entered. Activated by a signal from the injection mechanism via the CPU. Detail design on the injection mechanism is reserved for the next development phase. Here the needed signals are assumed to pass to the CPU via an interrupt.

2. Gantry Actions

Move X, Y	-	from CPU, activated by pointer, brightspot, spacing response.
Halt X, Y	-	from end-stops (gantry), pointer, brightspot, spacing response.

Movement signals in the program are not expressed as a directive to move in a specific direction (X, Y, etc). The directives are those of reducing input (e.g. when above a threshold) increasing input (when below a threshold), moving to a state of balance or a state of unbalance. Threshold directives always result in an "X" motion or a cessation of "X" motion. Balance directives always result in a "Y" motion or a cessation of "Y" motion. In a given case (particular position in an array, particular orientation in an array, particular order of precedence) whether a threshold directive needs a positive "X" motion or a negative "X" motion to fulfil it will not be known by the system when the directive is first encountered during tool set-up or planting.

Likewise, whether a "Balance" directive needs a positive "Y" motion or a negative "Y" motion to fulfil it will not initially be known by the system.

In order to inform the system what actual motion is needed a sub-routine "Find Direction" is introduced. This sub-routine upon receiving a call such as "Find (X)" outputs a signal directing a positive "X" motion. As long as this motion results in the needed receptor input it is maintained. If the motion results in a worsening of the condition or a continuance of the condition which called the sub-routine then a signal resulting in a reversal of motion is output (i.e. motion in the negative "X" direction is begun). After having encountered the difficulty once after power-up the output needed, for example, to increase input to a threshold, will be known (a parameter will have been assigned a value, the address of an output bit). Further detail of "Find Direction" is given later.

(3) Level Tool

This is a system of motion separate from the gantry motion system.

Move = X

Move = Y

Halt = X

Halt = Y

These motions are under the influence of a "balance" mechanism.

All the movements of the tool system have now been given.

Further detail on the motor response to the Pointer

Our initial plan was to use independent "X" and "Y" motion. Response to a threshold was to involve "X" motion only. Response to a state of balance was to involve "Y" motion only. Because of the central position of the pointers (Chapter 8, Diagram 13) movement to or from the pointer threshold (TH) along the discontinuity line involves both "X" and "Y" motion because the tool zig-zags along the discontinuity line. To enable this motion to occur a modification of the sensory structure is needed; two additional limiters of "Y" motion must be introduced in addition to a limitation based on the state of balance of a pair of sensors (Chapter 12, Diagrams 4 - 12). A modification of the X-motion and Y-motion sub-routines is also needed (see below). The main modification being that these sub-routine are no longer independent of each other.

Sub-programs (High Level)

Plan of the Pointer Sub-routine

A. Y-motion. When the pointer is turned on the position of the discontinuity line is either:

(1) Between the limit 1 and the limit 2 (Diagram 28)

(2) Outside limit 1 (Diagram 29)

(3) Outside limit 2

B. X-motion. The pointer input is either:

(1) Less than TH

(2) Equal to TH

(3) Greater than TH

Case 1. A1. (between limits) and B1 (at TH).

No X motion is needed. Y motion occurs which balances the input. The system attempts to enter a condition which is within the tolerance for balance and within the tolerance for TH.

Case 2. **1 (between limits) and B2 or B3 (not at TH).**

X motion towards the threshold occurs. This motion will involve the "Find Direction (X) trial and error routine. The X motion which results will result in the discontinuity moving towards and possibly beyond limiter 1 or limiter 2. Motion to either limiter will give rise to an interrupt which is ignored (has low priority and is masked out) until Find Direction (X) is completed. Once the needed direction is found a parameter value is entered in a sub-routine of Find Direction. (The outputs to X-motion actuators are numbered - they have a CRU address in the 9900 organization - the parameter value entered is the CRU (Communication Register Unit) address of the output which resulted in the correct perceptual input).

Case 3. **A2 or A3 (outside either limit) and B1 (at TH).**

This case should not occur unless the pointer is not levelled. A signal to the operator is needed that the pointer plane is not vertical (Diagram 6, Chapter 8).

Case 4. **A2 and A3 (outside limits and B2 or B3**
(less than TH or greater than TH).

(1) Find direction parameter values have not been entered. Assume the situation shown in Diagram 30. A "Y" motion to the low side occurs. This motion will involve Find Direction. When balance has been reached Y motion halts, a parameter value is entered. An X motion towards the threshold then occurs. This will involve Find Direction. Either the needed direction on the X-axis is found and the X parameter value is entered before either limit 1 or limit 2 is reached, or this is not the case. If the X direction is found before the limits are reached then X motion continues until a limit is reached. X motion then halts. A Y motion to the other limit occurs. Then an X motion occurs and so on. A limit need not be physical. It could be a Halt (X) signal triggered by the difference between the input of the Y sensors which is designed to allow for adequate X motion (Chapter 12, Diagrams 4 to 12).

If the X direction needed is not found before the Y limits are crossed then the moment that the X parameter value is entered the Y interrupt has priority. A Y interrupt will occur. X motion halts. Y motion occurs until balance occurs. Then X motion occurs until the Y limit is reached. Then Y motion occurs until the other limit is reached. Then X motion occurs. And so on. Motion continues until the TH and Balance condition is reached, or the end-stops are reached, or a spacing signal causes a deviation in the X and/or the Y direction, or a pointer signal causes either a cessation of motion, a change of motion but with continuation in the same X direction, or a reversal of motion.

(2) A2 or A3 (outside limits) and B2 or B3 (greater than TH or less than TH). Find Direction parameters have been entered.

This case occurs when the pointer is used to plant the second tree planted by a tool and all subsequent trees whilst one set-up is used.

The tool moves to Y balance. A motion to TH then occurs which involves both X and Y motion like that described in Case 4(a).

Further detail of Brightspot (The sonar based method does not use Brightspot)

Find direction parameters for Pointer directives will have been entered during set-up and thus before the Brightspot sub-routine has been entered. If only one tool were being used then Pointer directed initial motion would set the parameters. The tool could be directed the Pointer with hand turning Off/on of the Pointer overriding the sub-routines which would be called by signals from other tools in a larger array. The Brightspot could be turned on after initial Pointer directed motion and when a planting spot had been chosen.

The Pointer Find Direction parameters are relevant for Brightspot directed motion. Sides of the Brightspot sensor are distinguished and sides of the pointer sensor (i.e. a "green" side and a "red" side of both systems). Motion, for example, the "green" side of the Pointer is motion in the same direction as motion to the "green" side of the Brightspot sensor. Motion towards TH is the same direction as that needed for continued motion beyond TH which may be needed for Brightspot controlled motion (Chapter 8, Diagram 11).

If the Pointer Plane is vertical (Chapter 8, Diagram 3) or close to vertical and the Brightspot discontinuity is parallel to and vertically below the Pointer discontinuity (Chapter 8, Diagram 4), then the limits of Y motion which are to be allowed when the device is under Brightspot control can be signalled by the Pointer Y limiting mechanism. A basic lay-out for the Brightspot sensor and the logic needed for it have already been described (Chapter 8). Diagrams 4 to 12 of Chapter 12 show a modification which makes use of the Pointer Y limiters and Pointer balance mechanism and the X motion mechanism which carries a tool from one Y limiter to the other. In effect, the unbalanced condition of the

Brightspot sensors causes continued Pointer motion regardless of whether TH has been reached or exceeded. A balanced condition halts both X and Y motion.

Further Detail of the Space sub-routine

For the No. 1 tool the Find Direction parameter values are entered from Pointer input. For the lower order tools the Find Direction parameters are entered from spacing input.

During set-up the No. 1 tool receives Pointer input first of all. (It is necessary to consider what happens if another tool one in the same quadrant as the No. 1 tool responds to the No. 1 Pointer signals. This matter is dealt with later). The No. 1 tool will try to move to balance and TH. Then it hits the X and Y end-stops (Chapter 9) it will halt and turn on its spacing lights. The pointer is moved back to the vertical. There it waits for signals from the immediately adjacent lower order tools.

A order tool which receives No. 1 tool pointer signals (Chapter 9) will try to move to balance and TH. It can be seen from diagram that no tool in the No. 1 tool's quadrant can move to balance before it hits the X and Y end-stops.

Case 1

Pointer parameters entered from anomalous Pointer input, no balance reached, X or Y end-stops may or may not have been reached.

In this case the tool upon receiving spacing input from the immediately adjacent higher order tool or from more than one tool enters the sub-routine "Space". Find Direction parameters based upon spacing input are entered. The tool moves to Spacing sensor balance and D (the maximum inter-tool spacing threshold).

Case 2

No Find Direction Parameters have been entered. The Space sub-routine is entered. Find Direction parameter values based upon the input to the spacing sensors are entered. The tool moves to spacing balance and D.

Further Problems with Find Direction

Some automatically guided factory vehicles are guided along a reflective strip by a motor response based upon the balance of a pair of sensors. In one system the sensors are either both in the position shown in Diagram 32 or one sensor is over the strip. In this last condition the sensors are unbalanced. An automatic motor reaction, "steer towards the high side", brings the sensors back to the condition of Diagram 32. To operate this system two fixed sides are distinguished. Movement to a particular side is brought about by a fixed motor response ("If side 1 is higher then turn on motor 1", etc.)

In the present case in order to allow for interchangeability of tools and to allow also for freedom or orientation of a tool in a given position and to enable a single program to drive any tool no such fixed association of a higher (lower) sensor of a sensor pair with a fixed direction of motion can be used. Find Direction in effect makes the connection between motor response and sensory condition. Its pattern is to cause a movement to occur if a sensory condition demands movement. If this movement does not improve the sensory condition then a movement in the opposite direction is initiated. In the environment of the tool one direction will always work with the exception of anomalous pointer induced movement, a difficulty which has been dealt with.

If an X motion is called for then movement to or from a threshold is being made. There is a gradient in the X direction by which the tool sensory system can tell whether it is improving its condition or worsening it.

A difficulty arises when Y motion is being made before Find Direction parameter values have been entered. A Y-gradient is needed (similar to the X gradient) by which the tool sensory system can judge the suitability of its motion.

In the case of Pointer or Brightspot input some Y direction motion can be controlled by the limiters, Diagram 13. If the situation shown in Diagram 29 arises then the limiters will not halt erroneous tool motion. If no Y gradient exists then an incorrect initial tool motion will not be stopped unless either the gantry end-stops have been reached (No. 1 tool) or an extreme of gantry motion has been reached (lower order tools). Both movements are wasteful of time and energy. To enable Find Direction (Y) to operate efficiently a sensory cue which tells the system that it is moving to the high side or the low side is needed (Diagram 29). Some possible solution to these problems are:

(1) To mask both sensors of a pair. (Diagram 33) In this condition movement to one side or another may be accompanied by an increase of sensory input to one member or to both members of a pair, or it may be accompanied by a decrease to one member or to both members of a pair. The beginning of an investigation of this question is described in Chapter 10.

(2) Introduce a Y gradient. This would have to be done for the spacing field and for the pointer field:

   (a) Use a sequence of density filters in front of each light source: Diagram 34.

   (b) Arrange the sensory structure and the logic so that movement toward a high (low) side or away from a high (low) side can be recognized by the system. This solution would be facilitated by the use of a system of fixation which it is our intention to avoid. We have no solution at present.

   (c) Introduce a fixed relationship between the sector colours and directions on the axis. This could be done by establishing a "red" side and a "green" side of the vehicle longitudinal axis (Diagram 35). When each tool is placed into its position in an array the filters are arranged so that the "green" filter is on the green side and the "red" filter is on the red side. Pointer filters would have to be set up, spacing filters, bright spot filters and pointer sensor filters. This solution would do away with the need to use Find Direction (Y). A fixed sensory/motor response could be used, like that of the factory vehicle. Our opinion is that the advantages of this solution are overbalanced by the increase in the work involved in tool set-up and the increase in complexity.

From now on it is assumed that the Y-gradient problem is solved. Interrupts are assumed to occur which will tell a tool sensory system whether it is moving in a direction which is improving or which is not improving a sensory condition.

A problem with the spacing response

During set-up the inter-tool spacing response is a motor action - move from immediately adjacent higher order tools until the inter-tool distance is between D (maximum) and T (minimum) thresholds. The tools will respond this way in fully automatic operation (i.e. with choice automatic). In semi-automatic operation to avoid an awkward interaction of the pointer response, the spacing response and the Brightspot response, the spacing response after set-up has been completed is no longer a motor response. The pointer always retains control of the tool. If a tool is under-spaced or over-spaced this condition is indicated to the operator by a (flashing) light. The presence of the light will block entry into the "Plant" sub-routine. (The actual blocking can be achieved by having the first instruction of "Plant" be a TB (Test Bit) instruction. If the spacing light is on then the output bit which controls the light will have the value "1". If it is not on then its value will be "0". The state of this bit will control entry into "Plant".)

Pointer and Brightspot lights are turned off automatically or manually. The Brightspot is to be able to be turned on/off independently of the Pointer lights.

Further problems with spacing

It has been mentioned that anomalous illumination by pointer can occur. Anomalous illumination by the spacing lights of a non-adjacent tool can also occur (Diagrams 36 and 37). The problem is with the "Too Far" response. A tool cannot come too near to a non-adjacent tool. These cases can be eliminated by differentiating non-adjacent and adjacent input and/or by providing a receptor with filters which will accept only adjacent input (e.g. by polarity, etc). The problem with this type of solution is that it complicates the tool structure and destroys interchangeability. The problem could be dealt with by leaving input undifferentiated but by making sure that adjacent input is "dominant" over non-adjacent input. This type of solution will need both conceptual and experimental investigation. In the section which follows a beginning is made with the problem.

In semi-automatic operation the difficulty can be partially eliminated by the use of a suitable sequence of operations and, since the spacing response after set-up is not a motor response, by the use of the judgment of the operator.

Anomalous lighting, a preliminary exploration

A solution which makes use of density filters in the manner which was described in the discussion of "Find Direction" is outlined here.

In Diagram 37 a transmitter is shown which consists of a pair of light sources, "red" and "green". In front of each source is an array of density filters. Diagram 38 shows the direction in which light output in the "Y" direction decreases and the direction of decrease in the "X" direction.

Our problem is to find a theory for these decreases of input with distance which will enable the problem of anomalous lighting to be avoided. The field of illumination must be such that the input from an adjacent tool is always greater than that of a non-adjacent tool. If a threshold could be found, a cutoff point for input which eliminated input from non-adjacent tools, this with the first condition would give a workable solution to the problem.

In Diagram 36 2 and 4 are higher order tools directly adjacent to tool 3. In the situation shown in Diagram 36 tool 3 is receiving anomalous lighting from tools 1, 5 and 6. A means by which 1 and 4 may be ignored is explored. A means for dealing with tool 6 comes out of this exploration.

A solution for 1, 2 and 3 will solve 3, 4 and 5; only one case is considered. The direction "Y" is parallel to the plane of the density filter arrays. The direction "X" is perpendicular to the filter plane (Diagram 34).

Diagrams 39 and 40 show two cases. In Diagram 39 tools 1 and 3 are at a minimum distance. Tool 2 is at a maximum distance given the position of tool 3. In diagram 40 tools 2 and 3 and at a maximum distance. Tools 1 and 3 are at a minimum distance given the position of tool 3.

Figure 1 shows the value of D1 and D2 of Diagram 39 for a range of spacing distances and for a tolerance of 1m. Figure 2 shows the same distances when a 0.5m tolerance is used. Figure 3 shows values of the distances D1 and D2 of Diagram 40 for a range of spacing distances with a 1m tolerance. Figure 4 shows these distances with a tolerance of 0.5 m.

The tolerances 0.5m and 1.0m bound the commonly used range of values.

From these figures it can be seen that for all spacing distances and for the two cases considered (Diagrams 39 and 40) the distance D1 between adjacent tool 2 and tool 3 is always less than the distance D2, the "non-adjacent" distance.

The maximum "adjacent" distance is $(D+ T)^2 + T^2$. The minimum "non-adjacent" distance is 2D - T). Figures 5, 6 and 7 compare these distances for a range of spacing distances and with the tolerances 0.5m and 1m. These figures suggest that a system of illumination where the input received by a tool is directly proportional to its distance from the source of input would enable non-adjacent illumination to be distinguished from adjacent input by the level of input. There is an overlap only when the lower bound for inter-tree distance is used and a 1m tolerance (Figure 7). A prescription for 2m spacing and a 1m tolerance is unusual.

It is to be noted that the tool 1 is directly in front of tool 3, whereas tool 2 is not in front of tool 3. This will have the effect of increasing from tool 1 relative to tool 2 (see below).

Diagram 41 shows the tools 2, 3 and 6. The distance D2 between 6 and 3 is a minimum. The distance D1, between 2 and 3 is a maximum given the position of tool 3.

Figure 6 shows that the distance D1 calculated vectorially is always greater than the distance D2 calculated similarly.

This implies that an input which is directly proportional to inter tool distance where distance is defined vectorially will not enable input from tools 2 and 6 to be distinguished in all cases.

An illumination function based on an arithmetical combination of "X" and "Y" distances will distinguish this case (and the 1, 2 and 3 case). Diagram 42 and figures illustrate such a function. It is seen that an overlap occurs when a 1m tolerance is used (* in figure 3). It is still possible to construct a suitable theory for illumination using an arithmetical definition of inter-tool distance (Diagrams 43 and 48: Figures 5-13).

It is possible that a system of illumination which approximates to the theory which has been described might be constructed using an "X" gradient which a linear function of source-receiver distance and a "Y" gradient which follows the same or a more rapidly decreasing function. The "X" gradient can be obtained by the use of reflectors and lenses. The "Y" gradient may be able to be obtained by the use of a density filter array with a sharp cut-off obtained by the use of hinged gates on the source (Diagram 49).

A program of empirical work is pointed to.

Thresholds

It is intended that hardware threshold and balance detectors be used. An exception is the condition of D and T sensor balance. Here a software/hardware solution might be used.

Each threshold detector will have its interrupt port.

Unbalance in one "direction" of a pair of sensors will go to a given interrupt port. Unbalance in the other direction to another port. The motor response to these interrupt will, after "Find Direction" is first applied, be fixed.

The device will in other words be guided by a collection of peripheral "feature" detectors (Marr, 1982). The use of these detectors as initiators of fixed output responses removes the need for the system to constantly sample its inputs and to have to perform a software computation on every sample to ascertain balance, non-balance, direction of non-balance or to ascertain the various threshold conditions. It is intended also that "Deviation" from a regular scan in automatic operation (Chapter 10, Automatic Choice) be triggered by "feature" detectors.

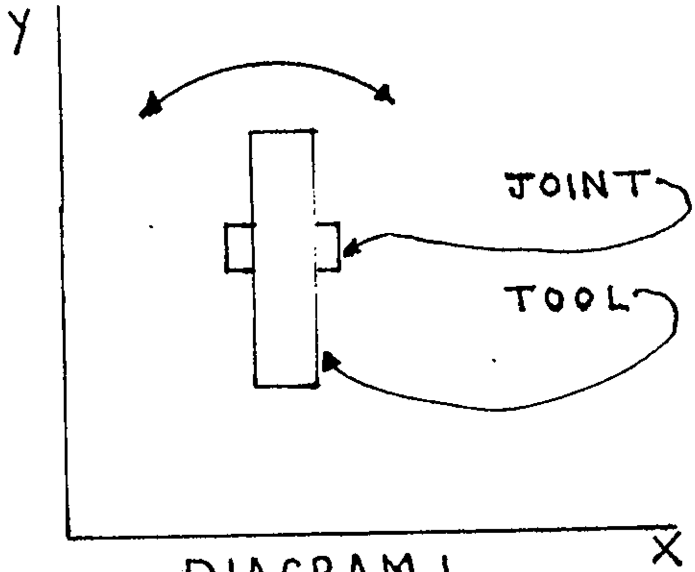


DIAGRAM 1.

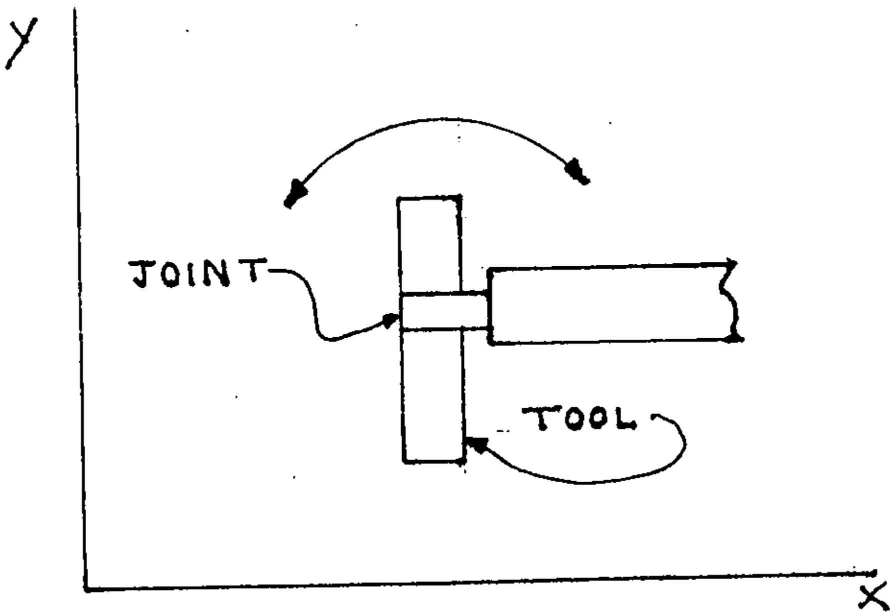


DIAGRAM 2.

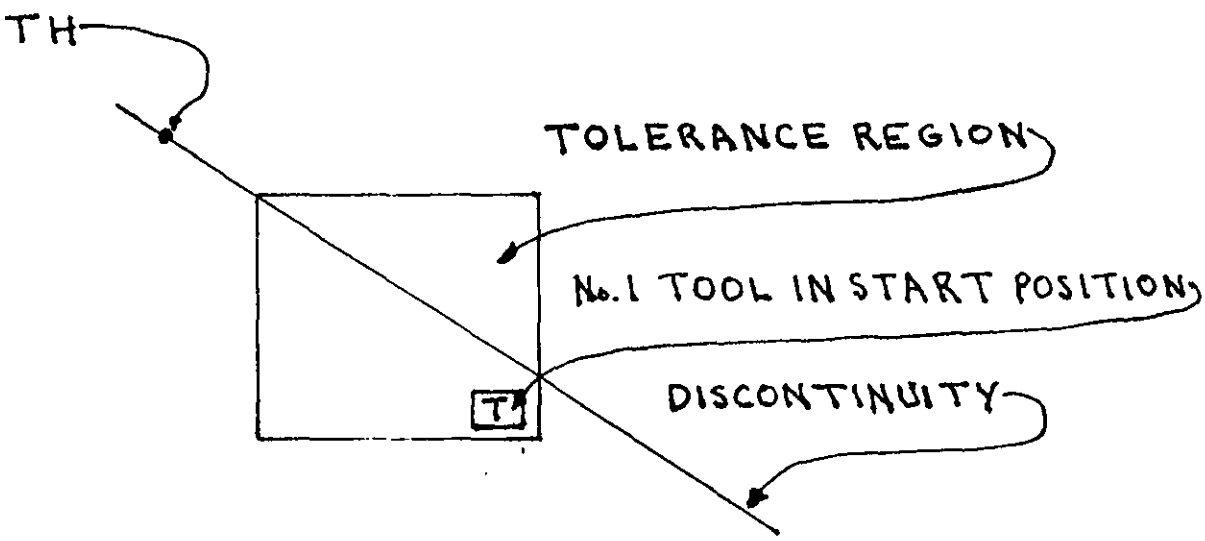


DIAGRAM 3.

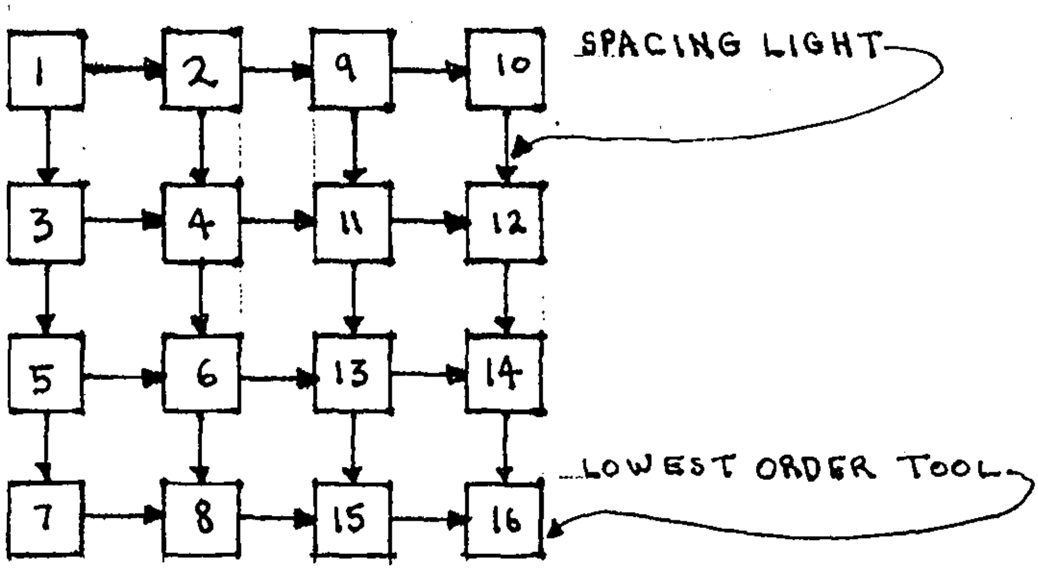


DIAGRAM 4.

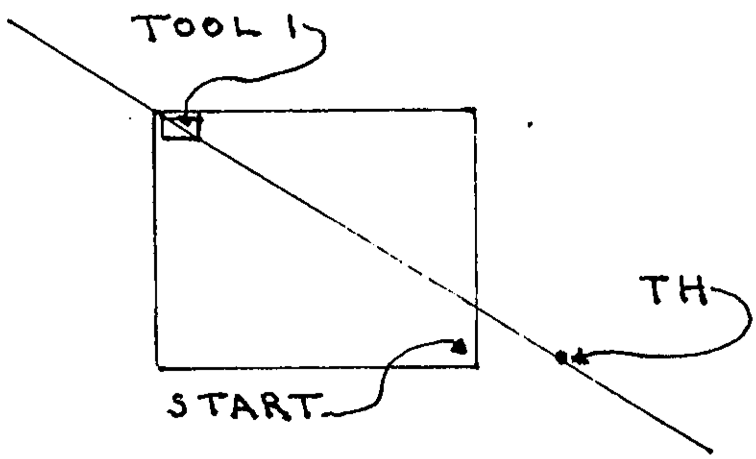


DIAGRAM 5.

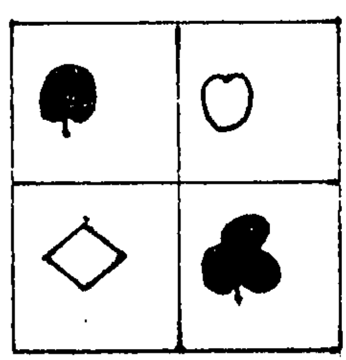


DIAGRAM 6.

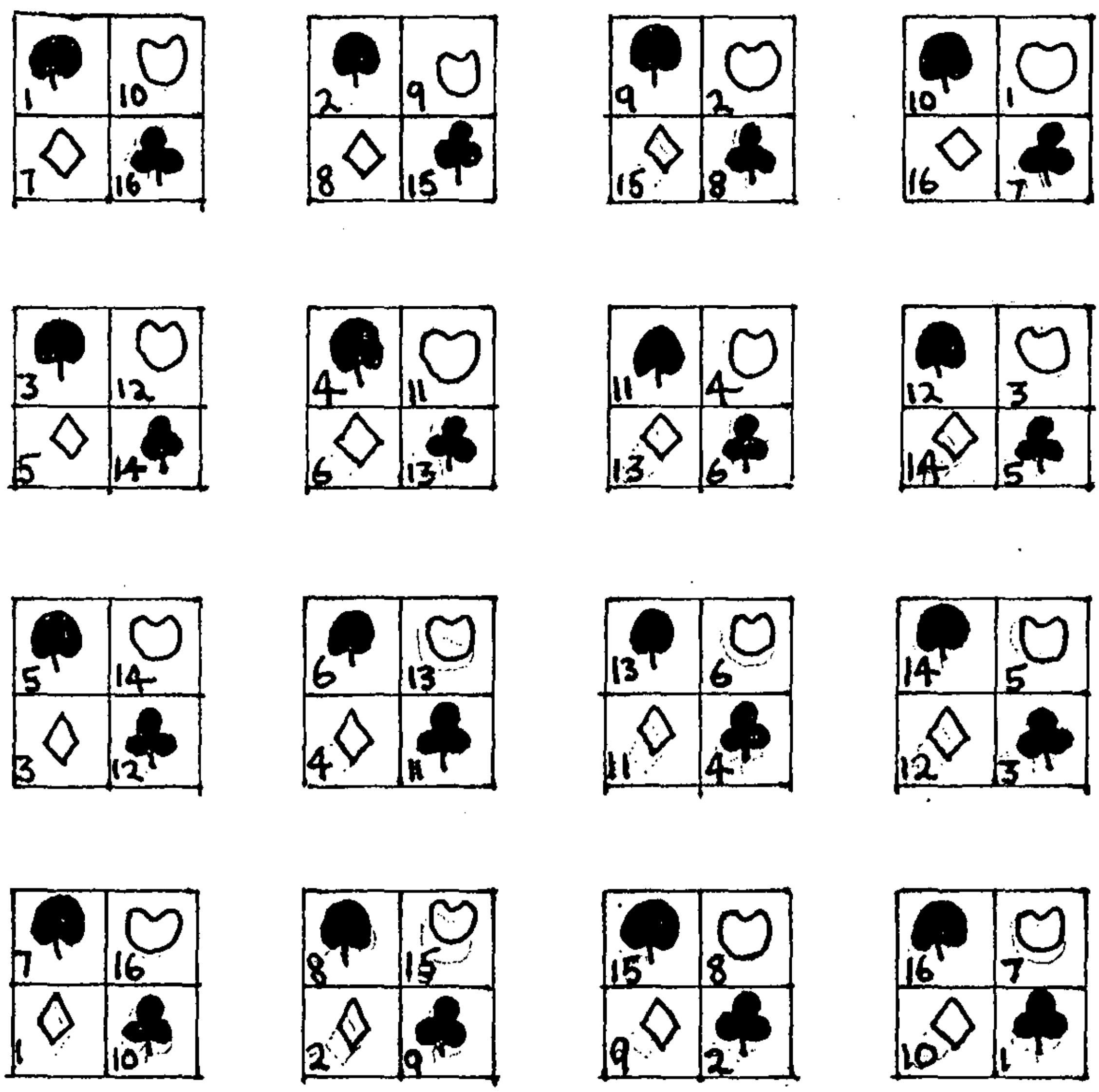


DIAGRAM 7.

Each array position is associated, in a given order of precedence, with a number and a suit. The number enables tool in each quadrant to be dealt with in sequence.

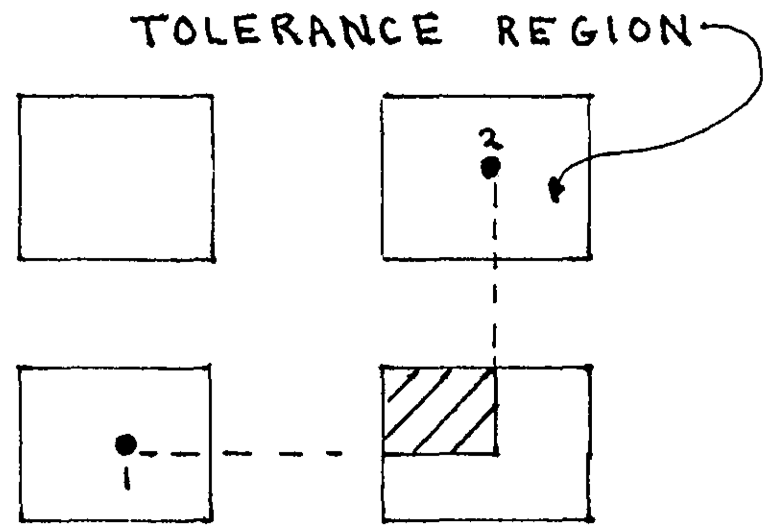


DIAGRAM 8.
The shaded region is the plantable area defined by tools 1 and 2.

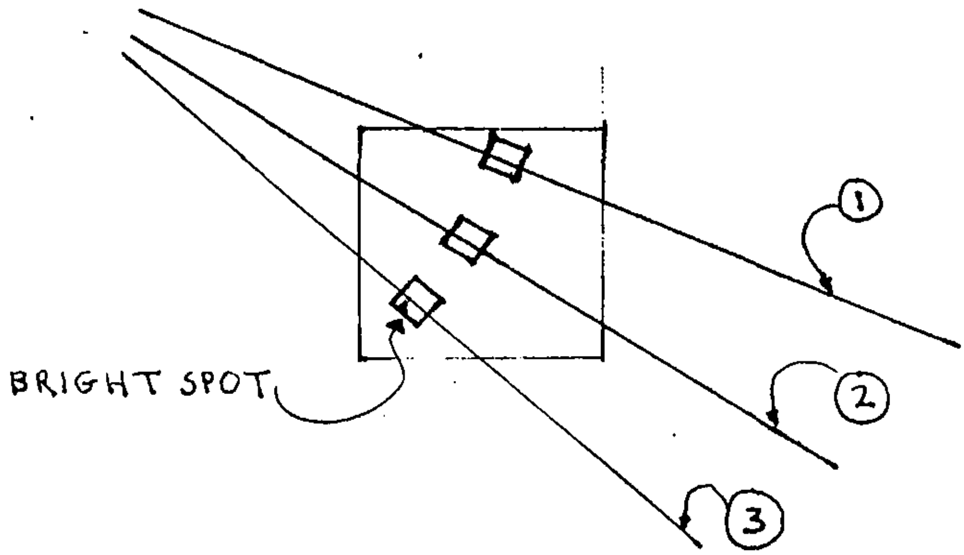


DIAGRAM 9.

①, ② and ③ are different positions of the pointer discontinuity. If the bright spot image is rectangular there may be difficulty in getting balance and accuracy of placement of a sensory array over the image if it has also a rectangular shape.

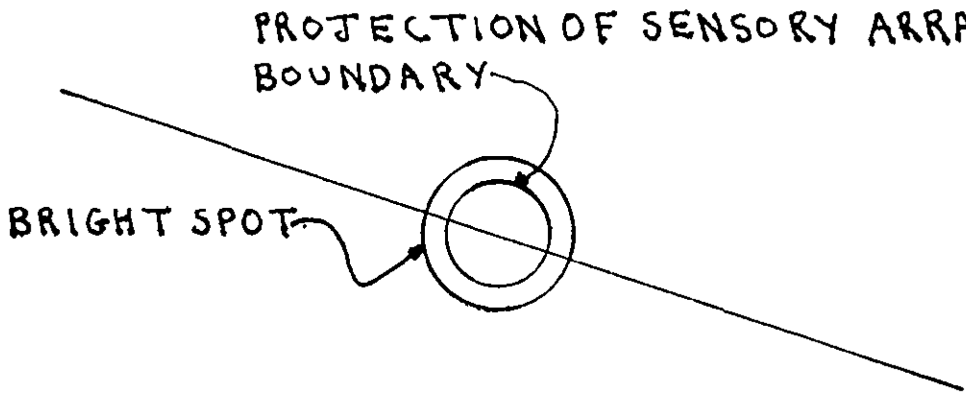


DIAGRAM 10.

If the bright spot image is circular and also the sensory array image a fit can be achieved in any position.

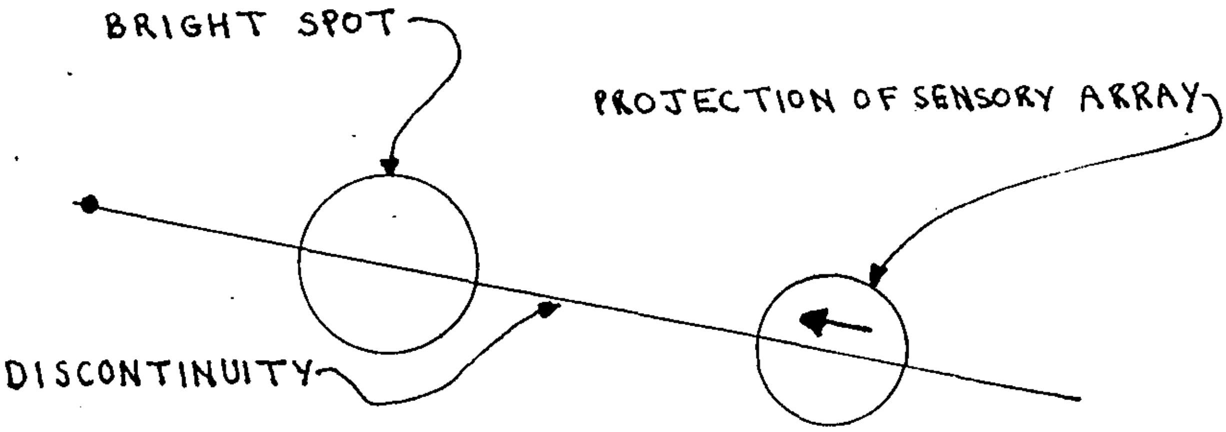


DIAGRAM 11.

"←" = DIRECTION OF MOTION.

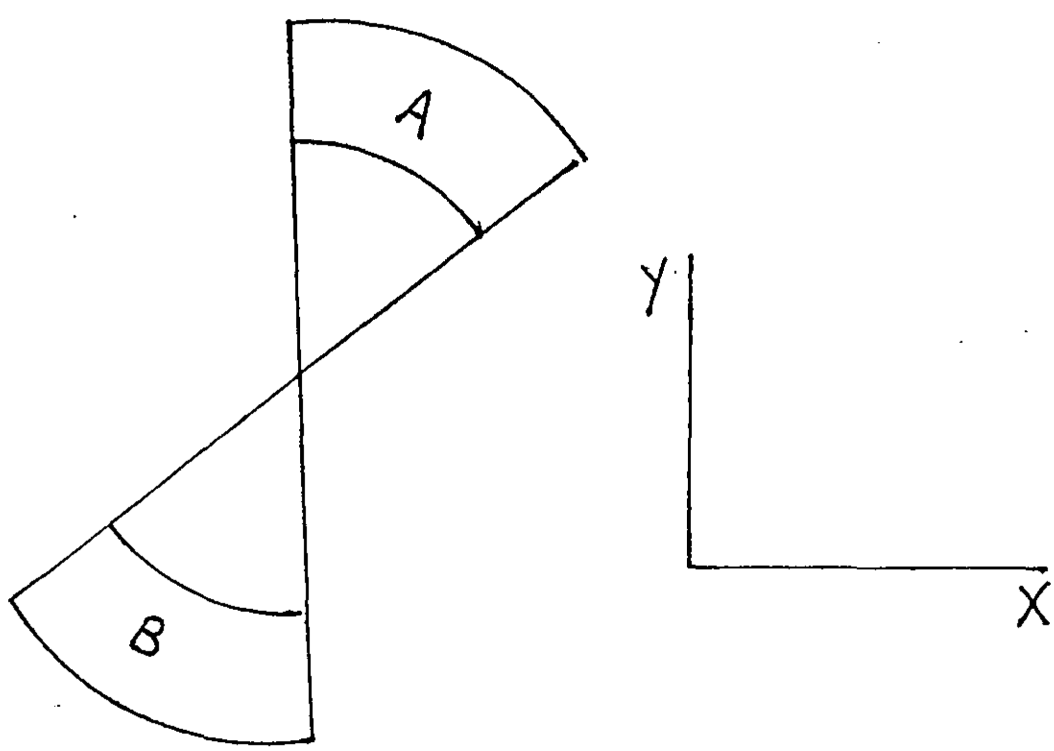


DIAGRAM 12.

Sensory array basic structure. XY a horizontal plane.

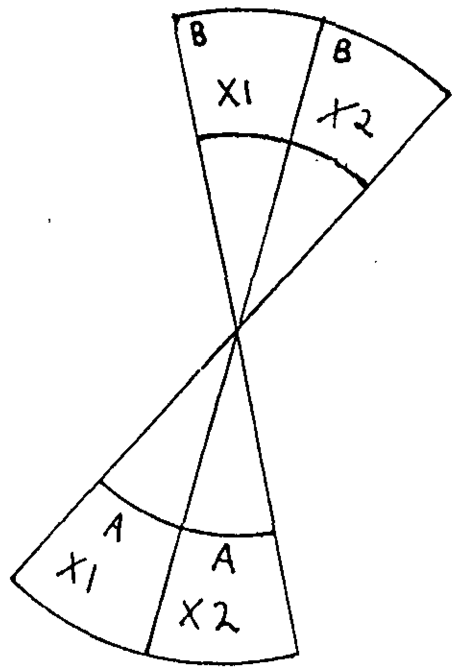


DIAGRAM 13.

Arrays A & B are made up of sub-arrays A (X1) and A (X2), B(X1) and B(X2) respectively.

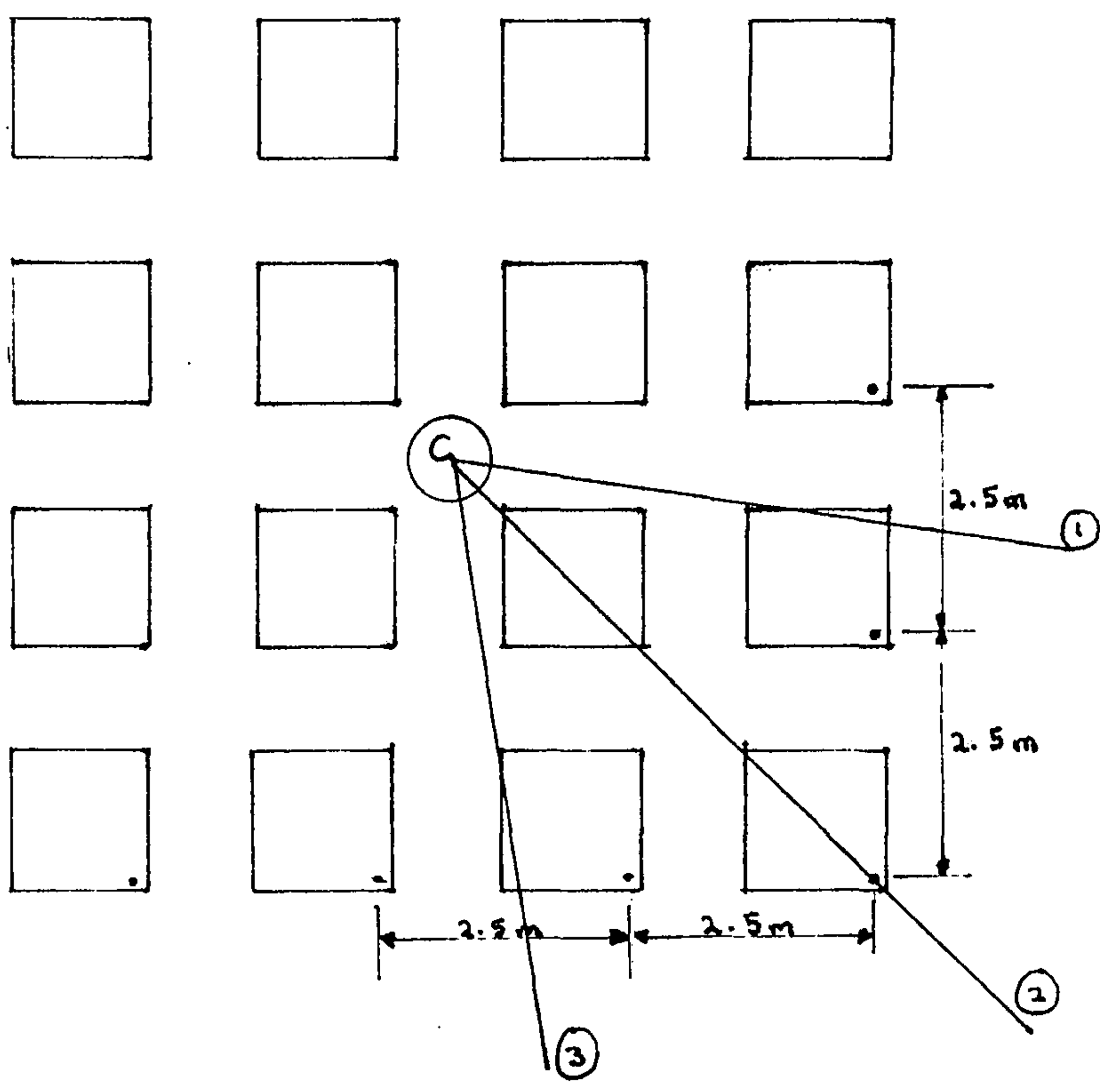


DIAGRAM 14.

"C" is the vehicle cab. ①, ② & ③ are pointer discontinuities. 2.5m spacing is illustrated. Maximum pointer to tool distance occurs on discontinuity ②.

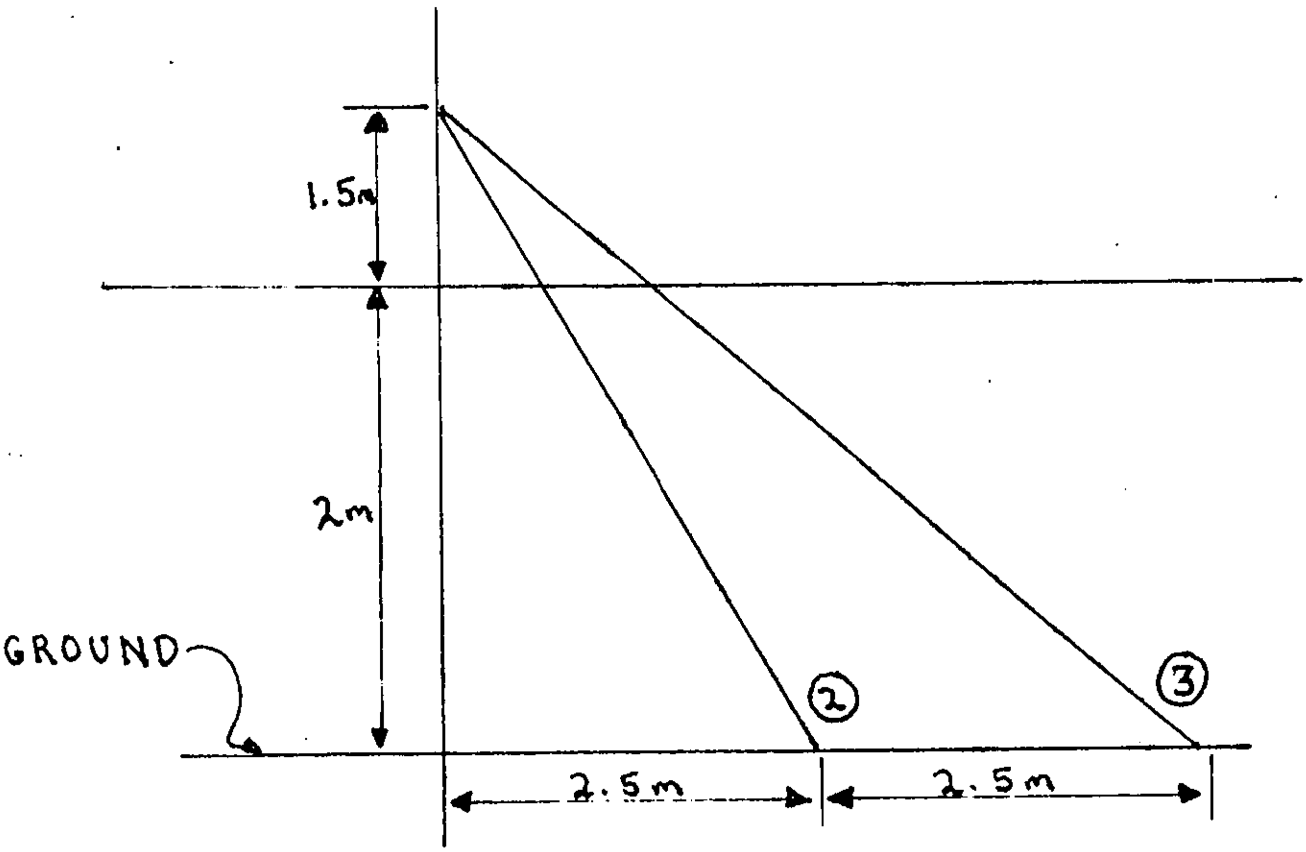


DIAGRAM 15.

Vertical angles of the bright spot projector at positions ② and ③ of diagram 14.
Pointer height is assumed to be 3.5m.

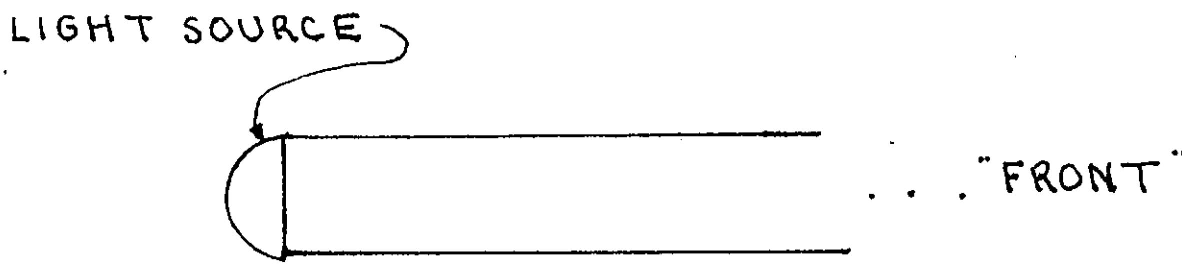


DIAGRAM 16.

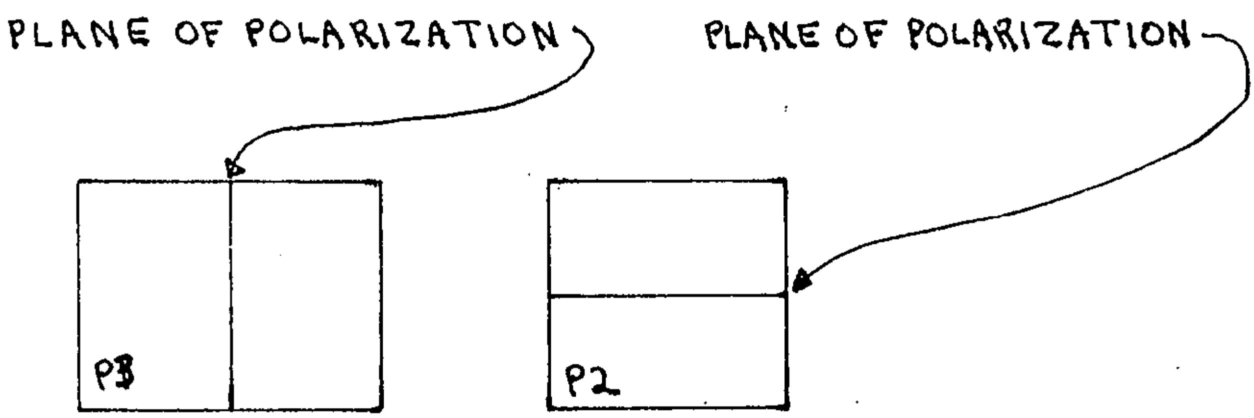


DIAGRAM 17. P1 and P2 polarizing filters.

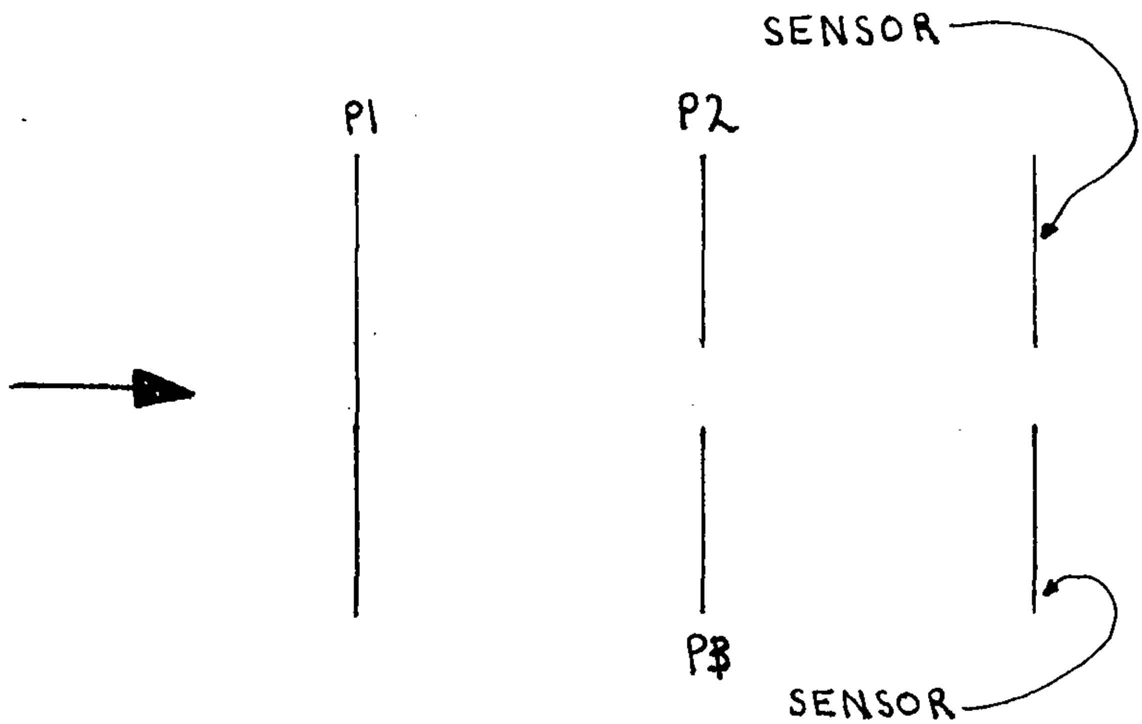


DIAGRAM 18. P3 and P2 as in diagram 17.

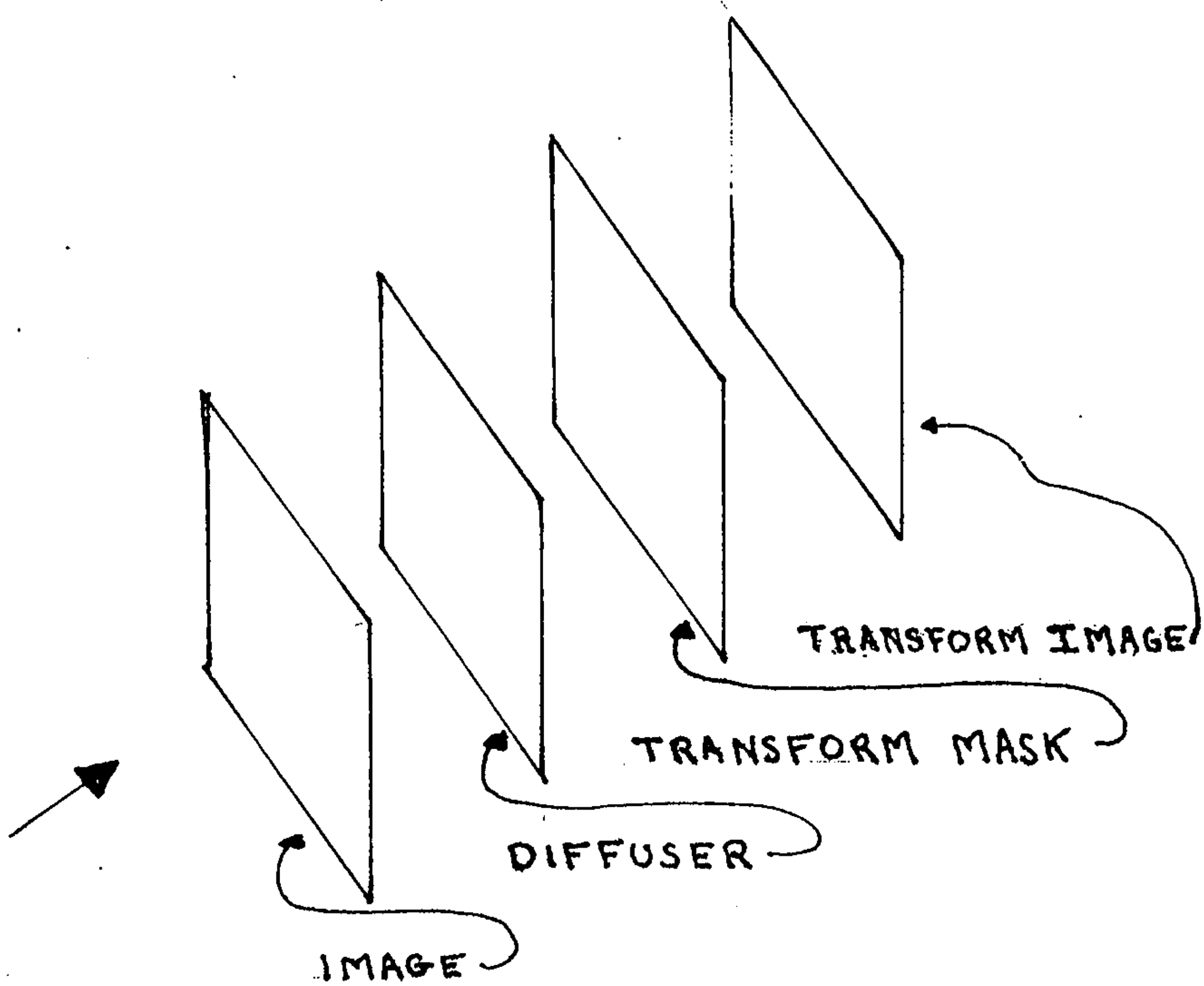


DIAGRAM 19.

Klimeras( ) experimental arrangement. A photo-sensitive screen records the transformed image. "→" = direction of illumination. Lighting is incoherent.

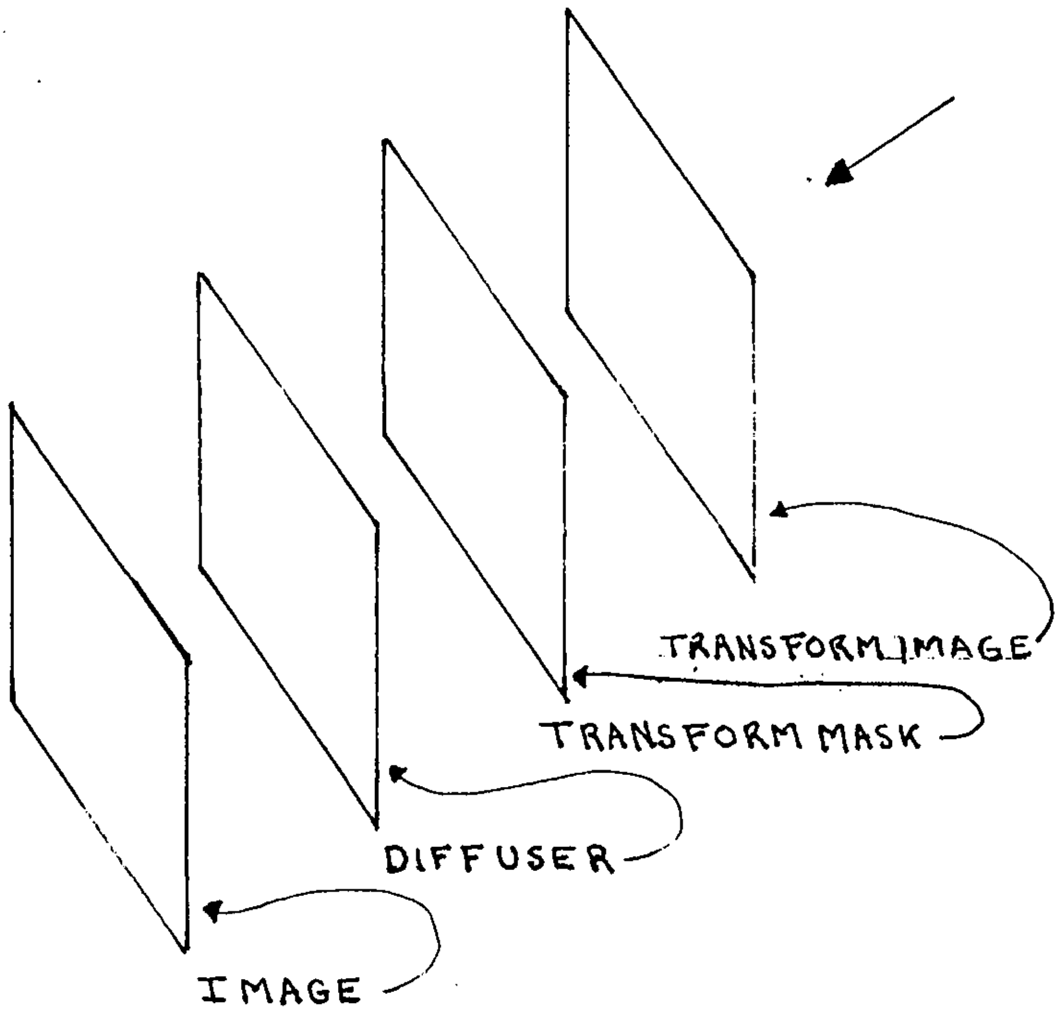


DIAGRAM 20. "←" direction of illumination. Lighting incoherent.

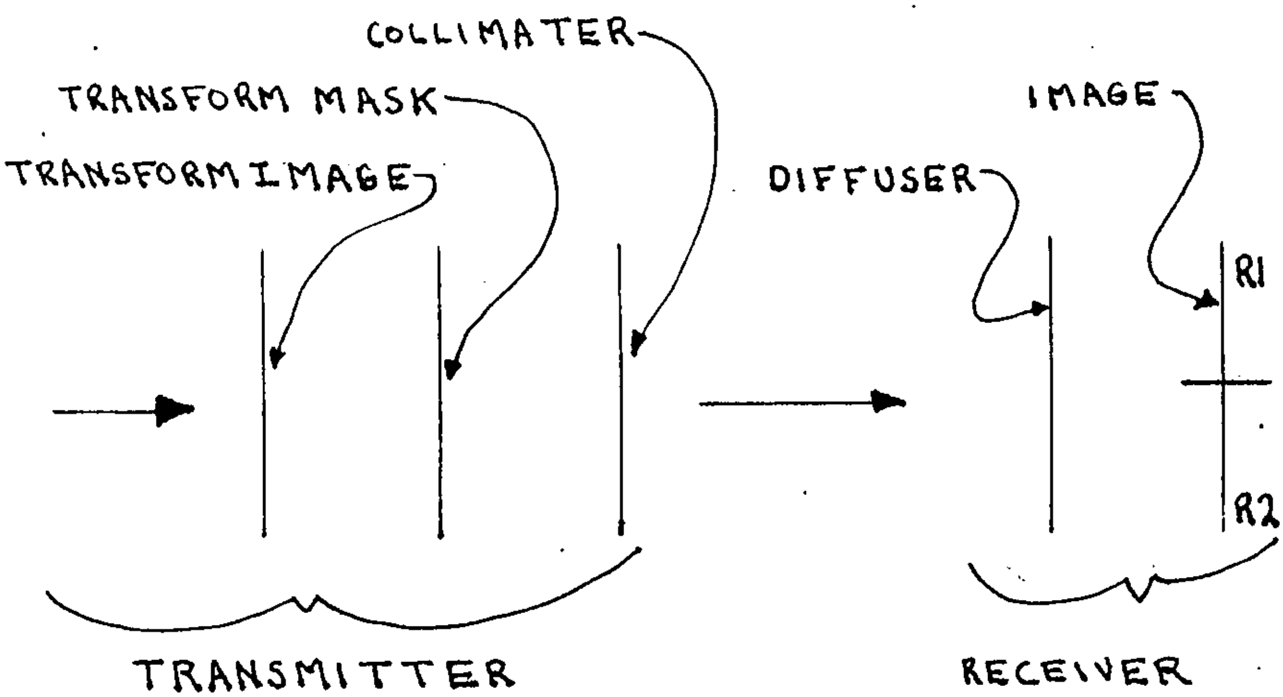


DIAGRAM 21.

R1 and R2 electronic photosensitive screens.
"→" = Direction of illumination.

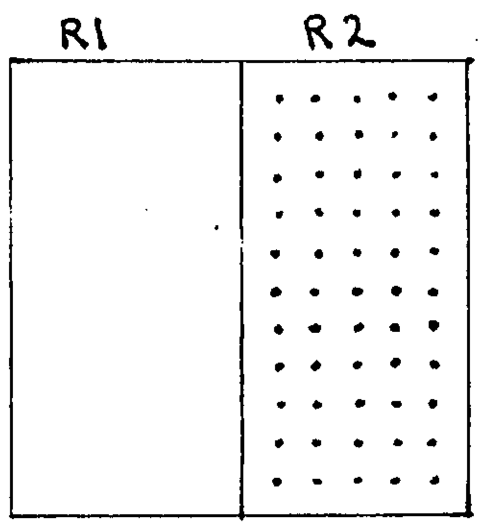


DIAGRAM 22. If the original image is that shown then R1 will receive no illumination from the transmitter. "R1" and "R2" denote the regions of the image received by R1 and R2 of Diagram 21.

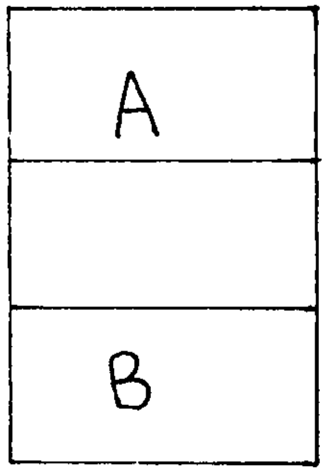


DIAGRAM 23. A, B sensory arrays.

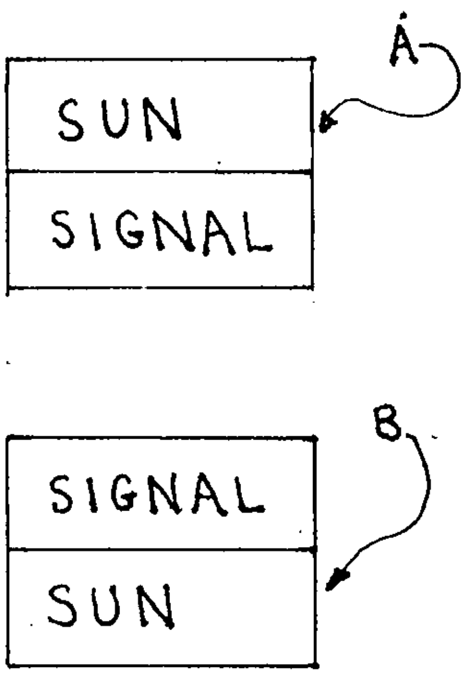


DIAGRAM 24. A, B as diagram 23. A and B are both made up of sunlight detecting and signal detecting sub-arrays.

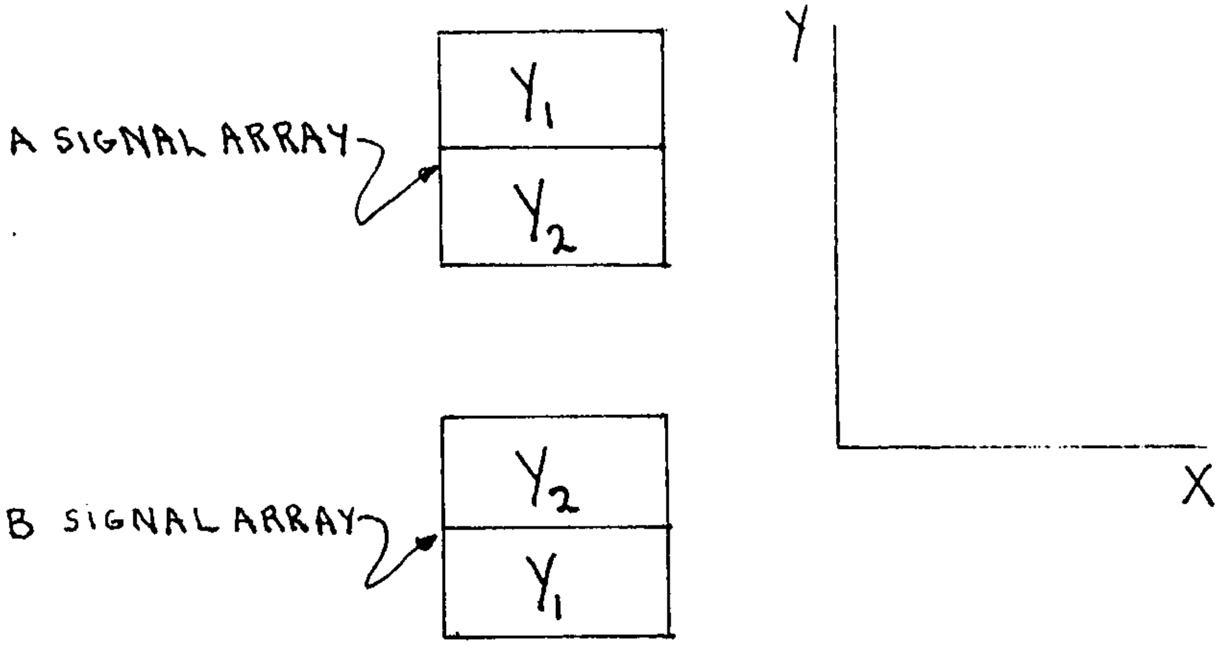
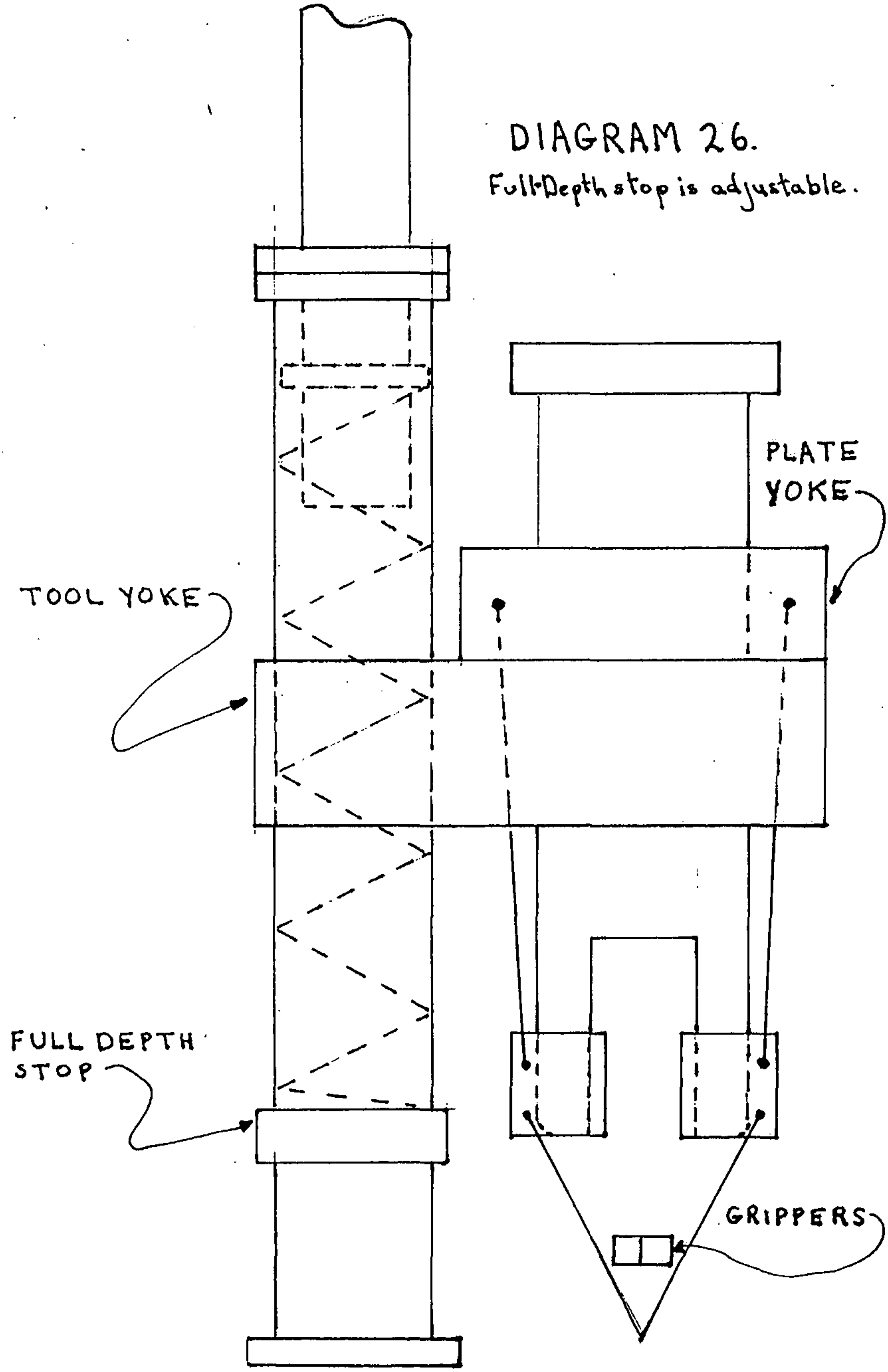


DIAGRAM 25. A and B as diagram 24

Y_2 and Y_1 are sub-arrays. Y_2 arrays are motion limiters. If a Y_2 array meets a discontinuity then "Y" motion is reversed. Spacing sensors have an identical structure to pointer sensors. Bright-spot "Y" motion is limited by the pointer limiters. Bright-spot sensory structure is shown in diagrams 12 and 13.

DIAGRAM 26.

Full-Depth stop is adjustable.



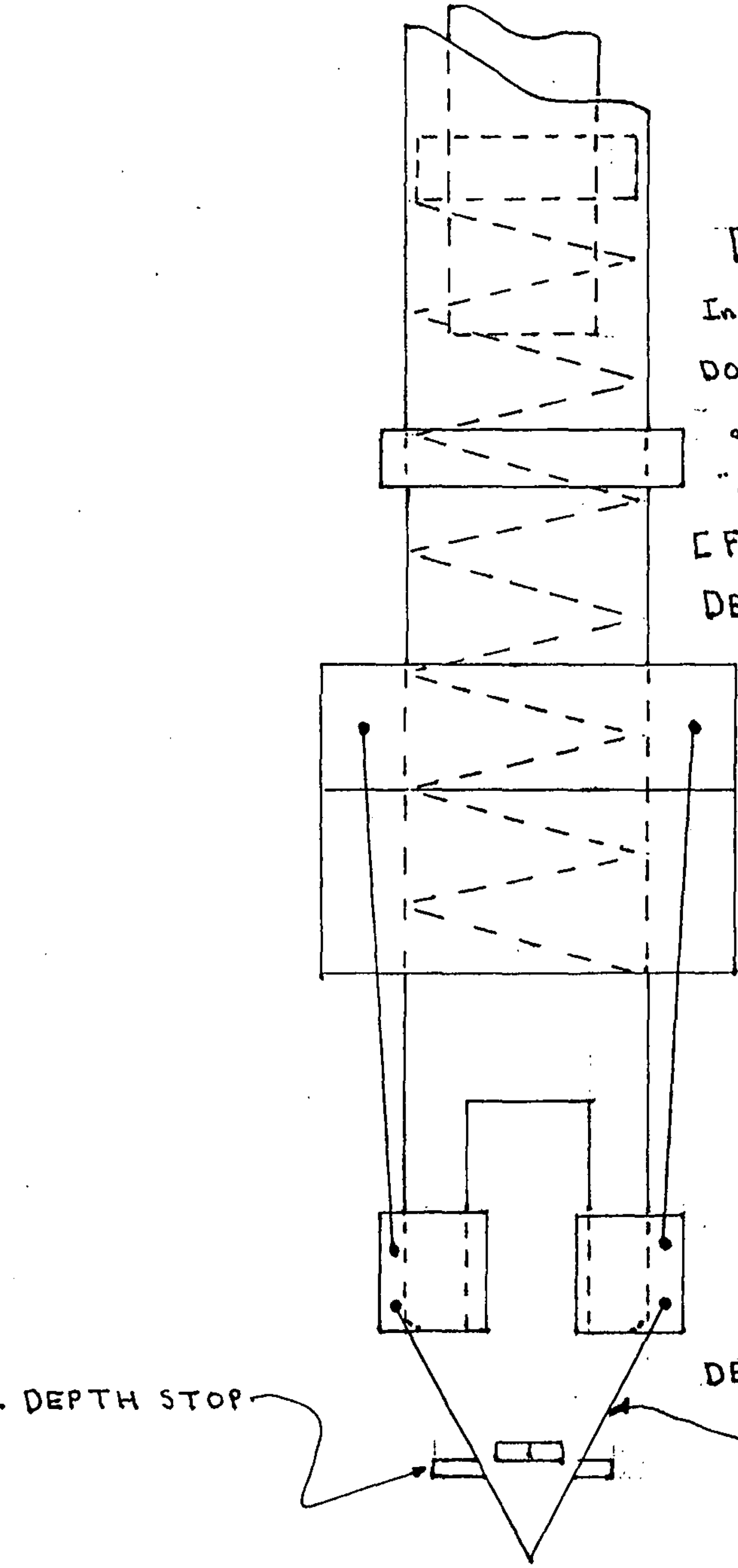


DIAGRAM 27.

In this scheme "FRAME DOWN" and "FULL-DEPTH" are interconnected. "OBSTACLE" = [FRAME DOWN ∧ ~FULL DEPTH] etc. The depth stop could be mounted on the magazine frame (not shown).

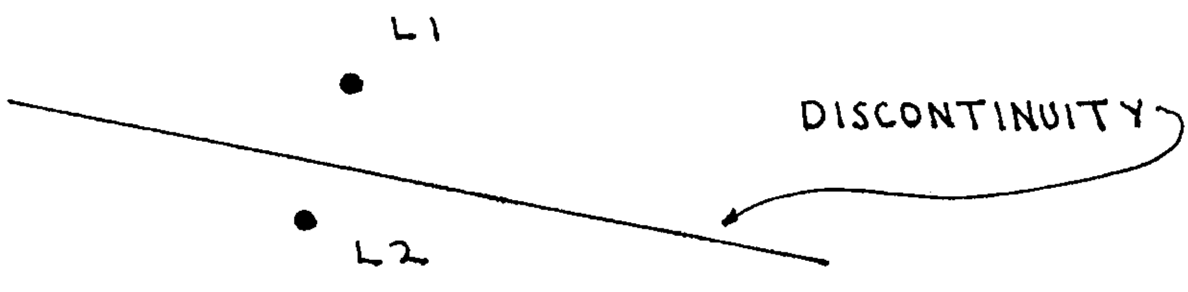


DIAGRAM 28.

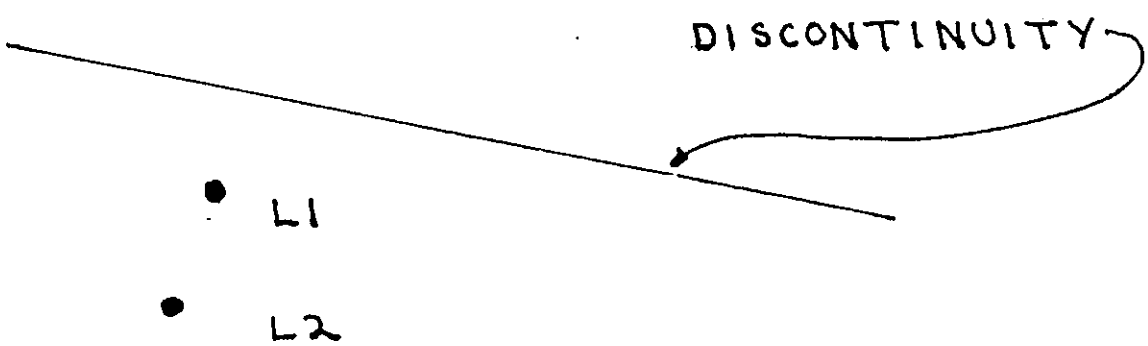


DIAGRAM 29.

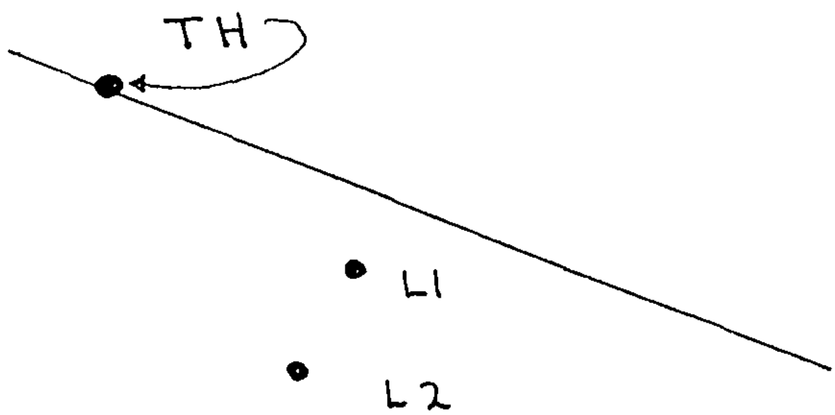


DIAGRAM 30. L1 is "LOW".

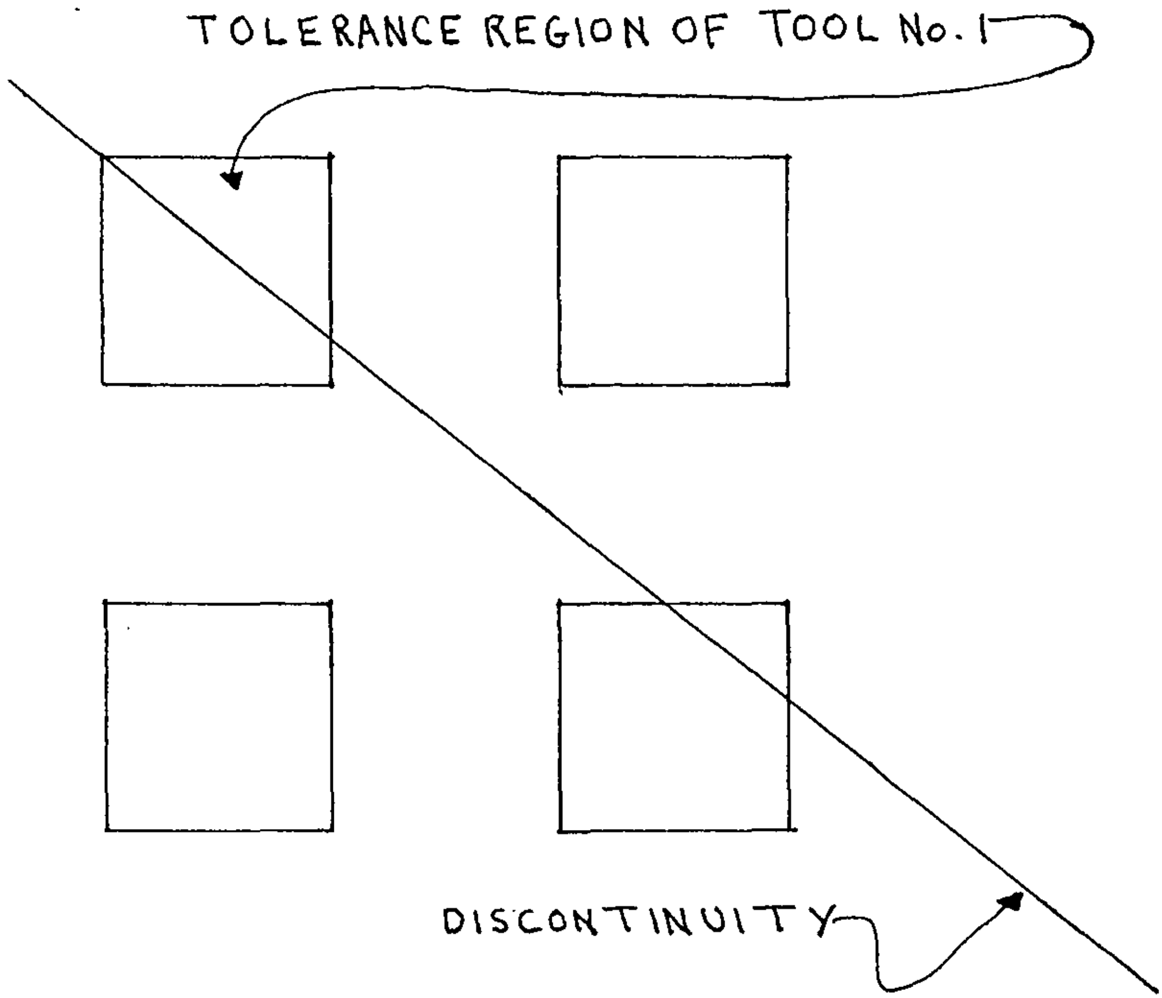


DIAGRAM 31. Position of the Pointer discontinuity in the No.1 Tool's quadrant.

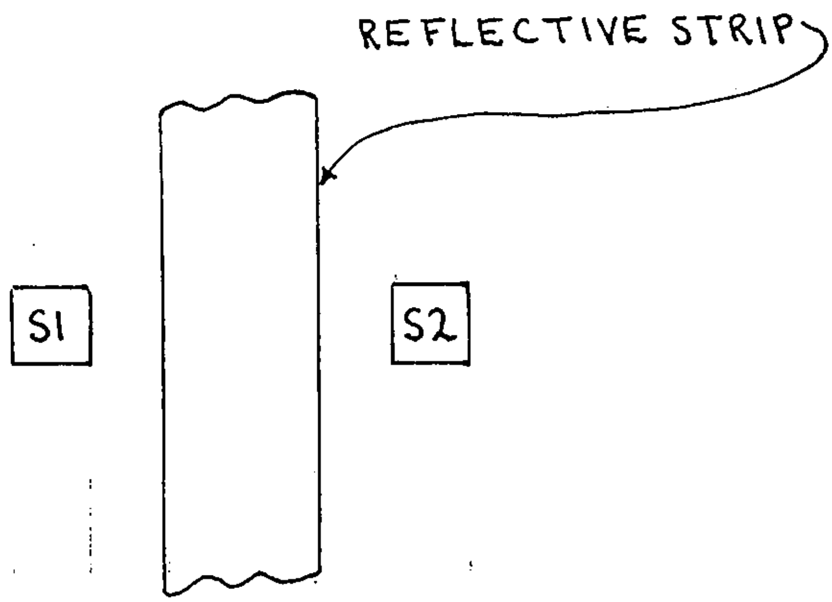


DIAGRAM 32

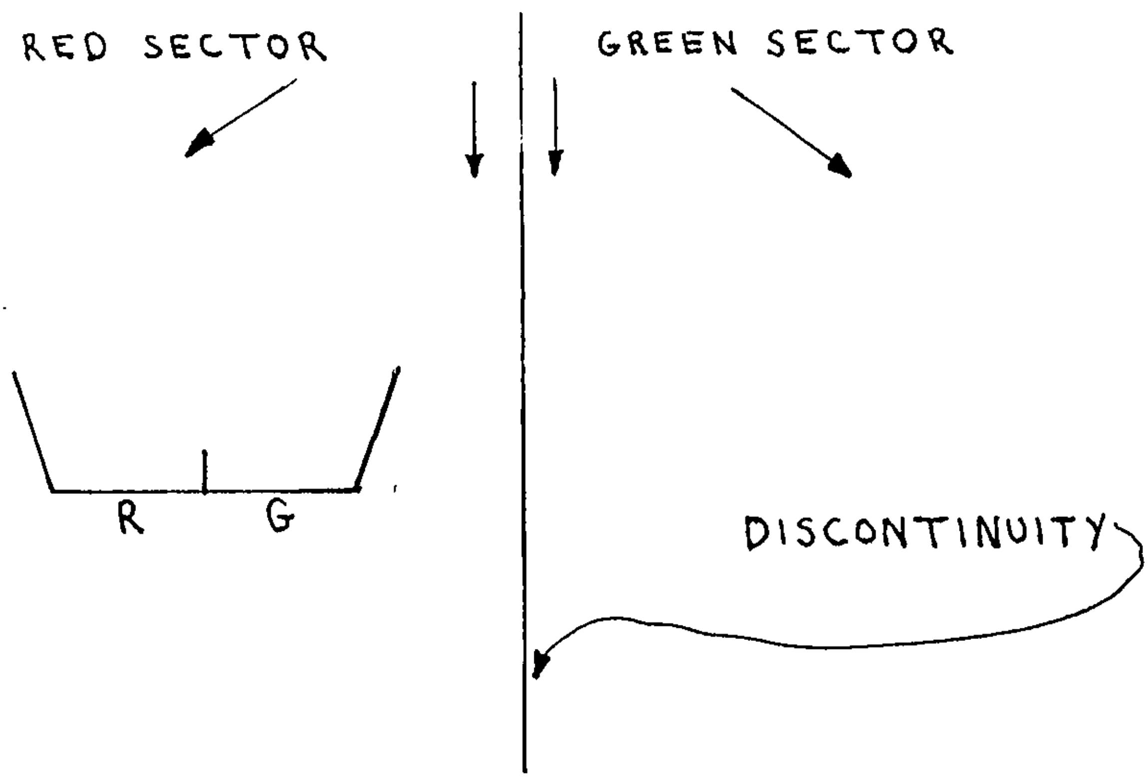


DIAGRAM 33. R = red : G = green.

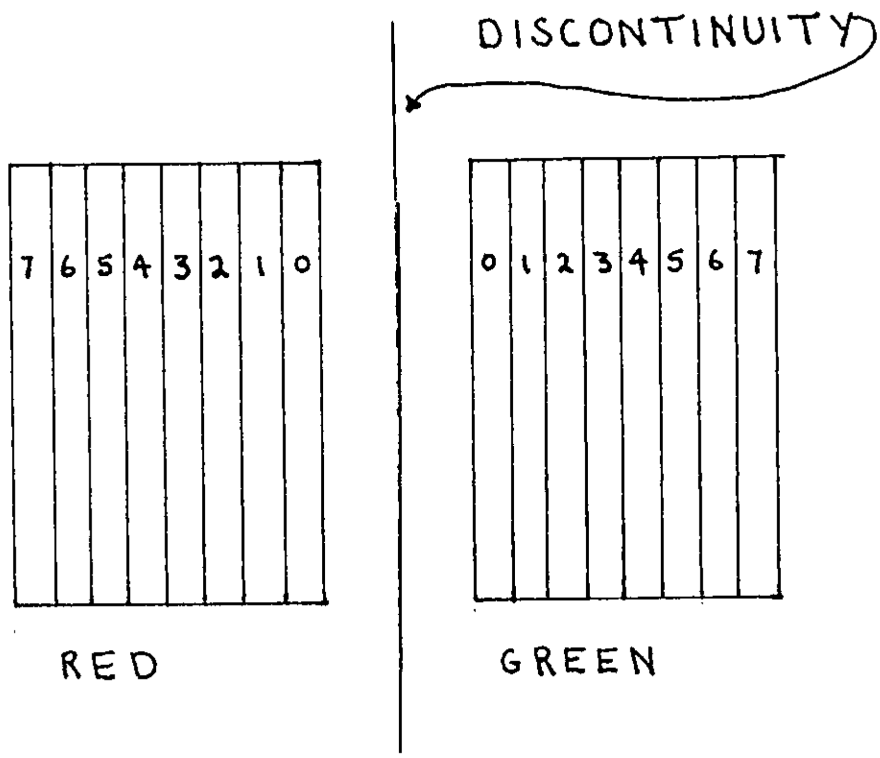


DIAGRAM 34. An array of density filters placed in front of each light source. Filter K is less dense than filter K+j (j positive integer). This arrangement produces a gradient which approximates to a linear step-function.

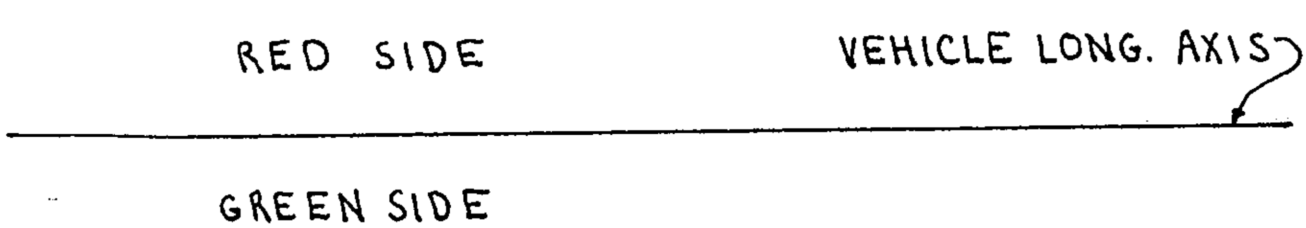


DIAGRAM 35.

D (m)	T (m) 1	d_1 $\sqrt{(D^2+T^2)}$	d_2 $2D-T$
2		2.2	3
3		3.2	5
4		4.1	7
5		5.1	9
6		6.1	11

FIGURE 1.

D (m)	T (m) 0.5	d_1 $\sqrt{(D^2+T^2)}$	d_2 $2D-T$
2		2.0	3.5
3		3.0	5.5
4		4.0	7.5
5		5.0	9.5
6		6.0	11.0

FIGURE 2

D (m)	T (m) 1	d_1 $\sqrt{(T^2+(D+T)^2)}$	d_2 2D
2		3.0	4
3		4.0	6
4		5.0	8
5		6.0	10
6		7.0	12

FIGURE 3.

D (m)	T (m) 0.5	d_1 $\sqrt{(T^2+(D+T)^2)}$	d_2 2D
2		2.5	4
3		3.5	6
4		4.5	8
5		5.5	10
6		6.5	12

FIGURE 4.

D (m)	T (m) 0.5	d_1 $\sqrt{(T^2+(D+T)^2)}$	d_2 $2D-T$
2		2.5	3.5
3		3.5	5.5
4		4.5	7.5
5		5.5	9.5
6		6.5	11.0

FIGURE 5.

$$d_1 = \sqrt{(D^2 + T^2)}$$

$$d_2 = \sqrt{(D^2+T^2) - 2DT)}$$

$d_1 > d_2$ for the range of values of D and T considered.

FIGURE 6

D (m)	T (m) 1	d_1 $\sqrt{(T^2+(D+T)^2}$	d_2 $2D-T$
2		3.0	3.0
2.5		3.6	4.0
3		4.0	5.0
4		5.0	7.0
5		6.0	9.0
6		7.0	11.0

FIGURE 7.

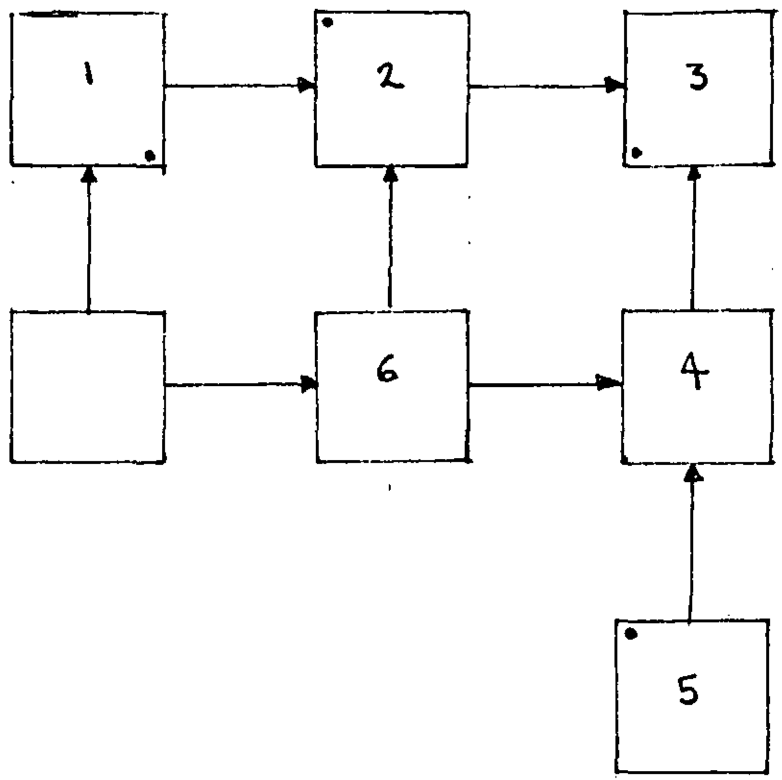


DIAGRAM 36. Lighting of tool 3 by 1, 2, 4, 6.

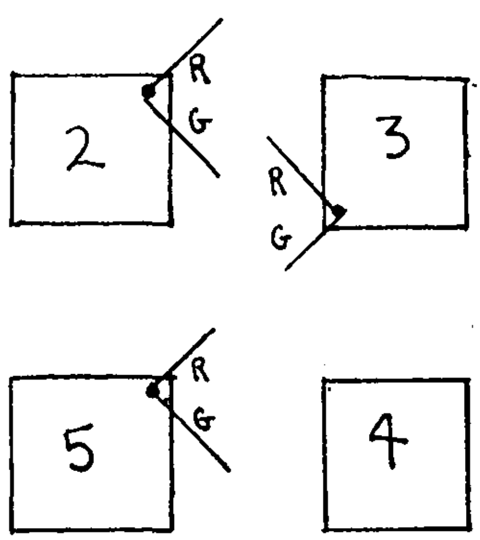


DIAGRAM 37. Interaction between 3 and 5 may be a problem.

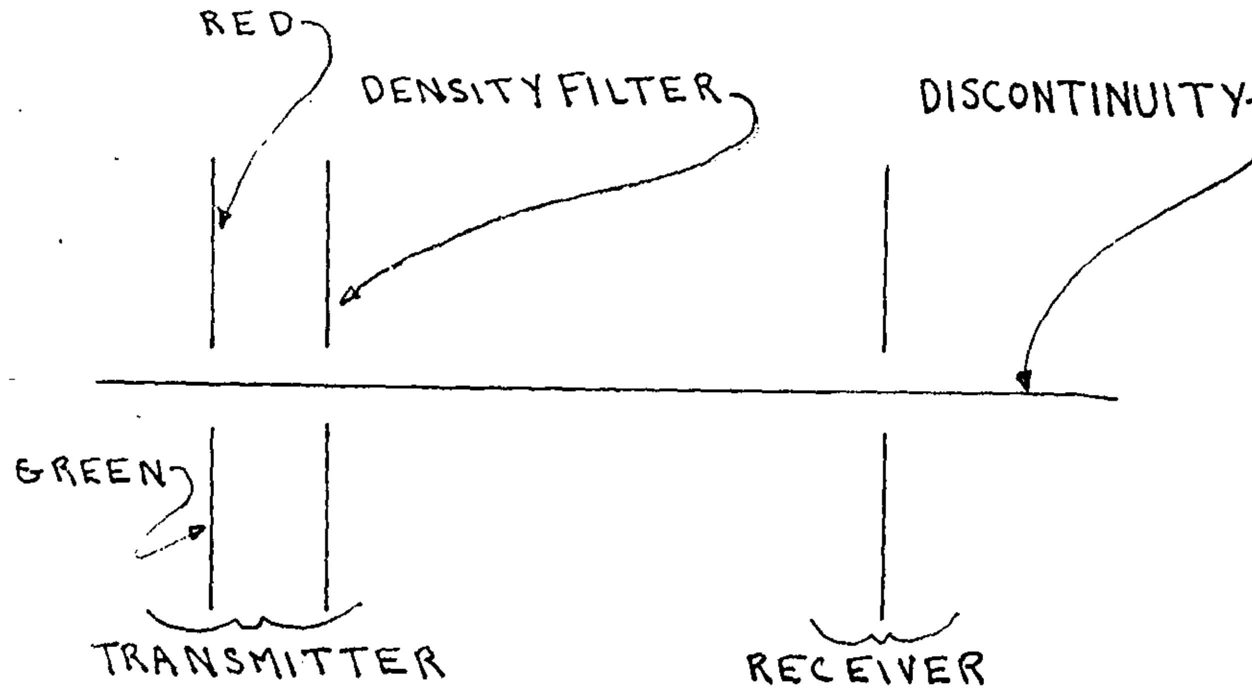


DIAGRAM 37.

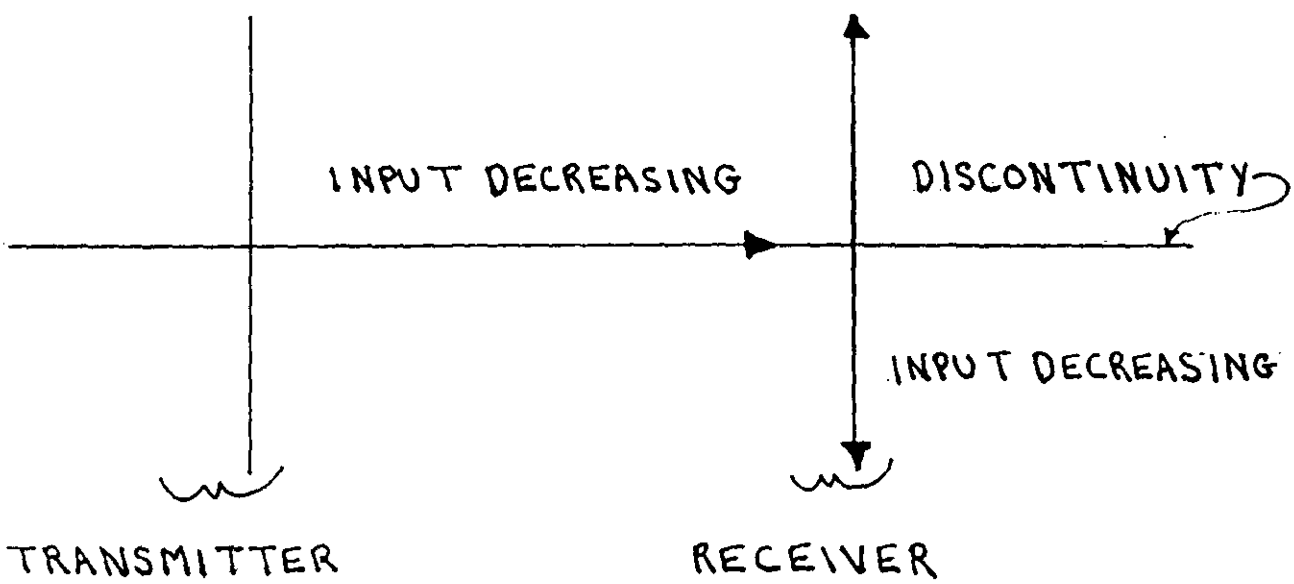


DIAGRAM 38.

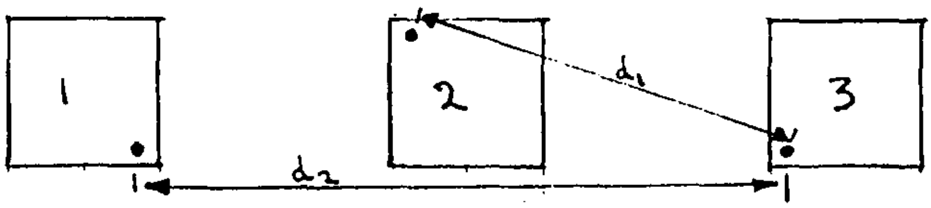


DIAGRAM 39. $d_1 = \sqrt{D^2 + T^2}$, $d_2 = (2D) - T$

Because no endstops are used other than for the No. 1. tool, it is possible in the situation shown for tool 3 to move beyond its tolerance region in moving towards tool No. 1.

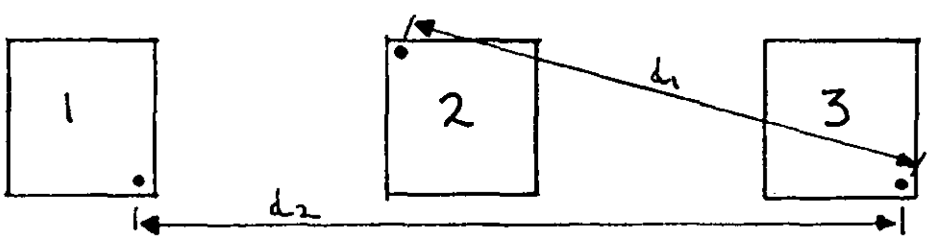


DIAGRAM 40. $d_1 = \sqrt{((D+T)^2 + T^2)}$, $d_2 = 2D$

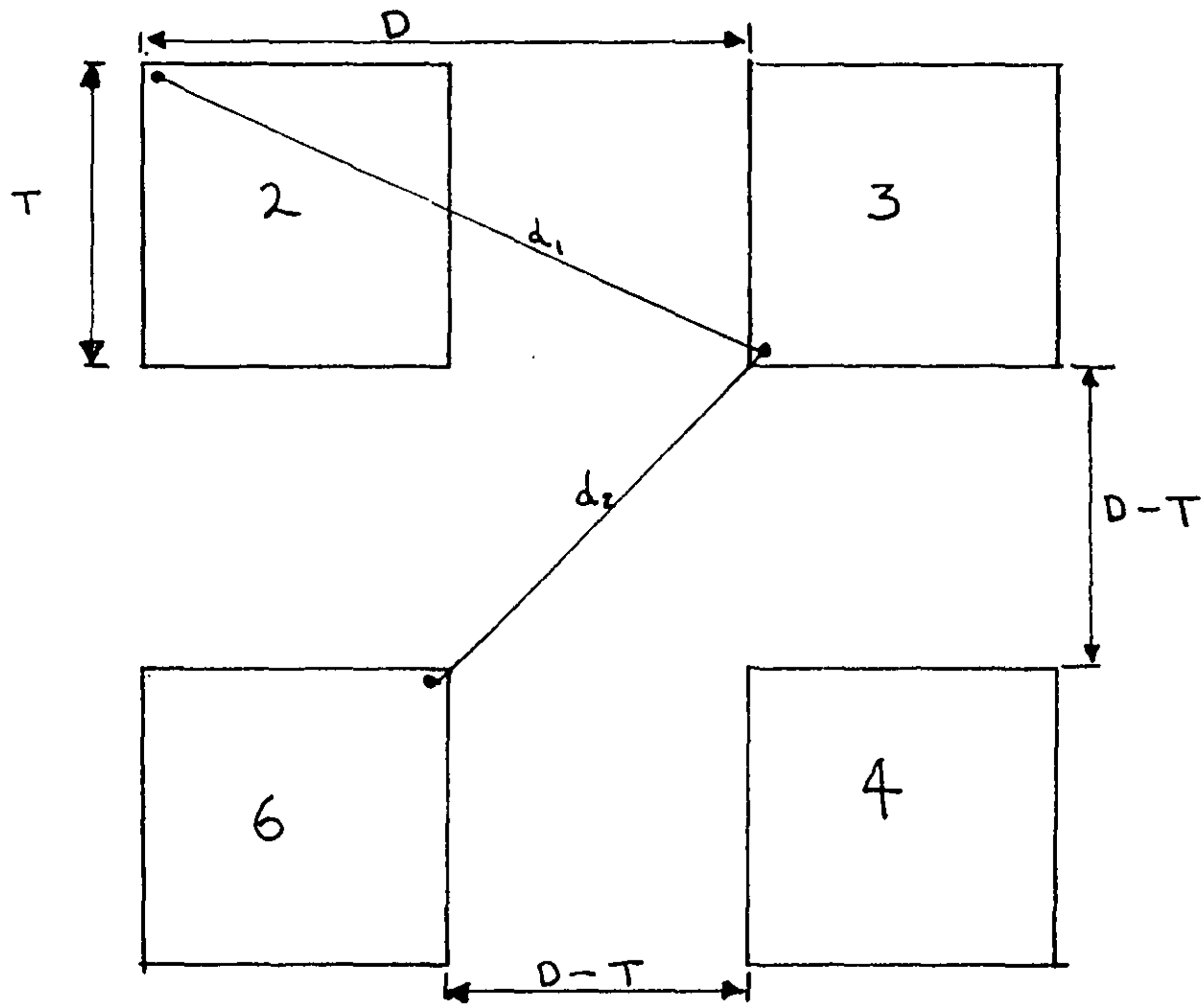


DIAGRAM 41.

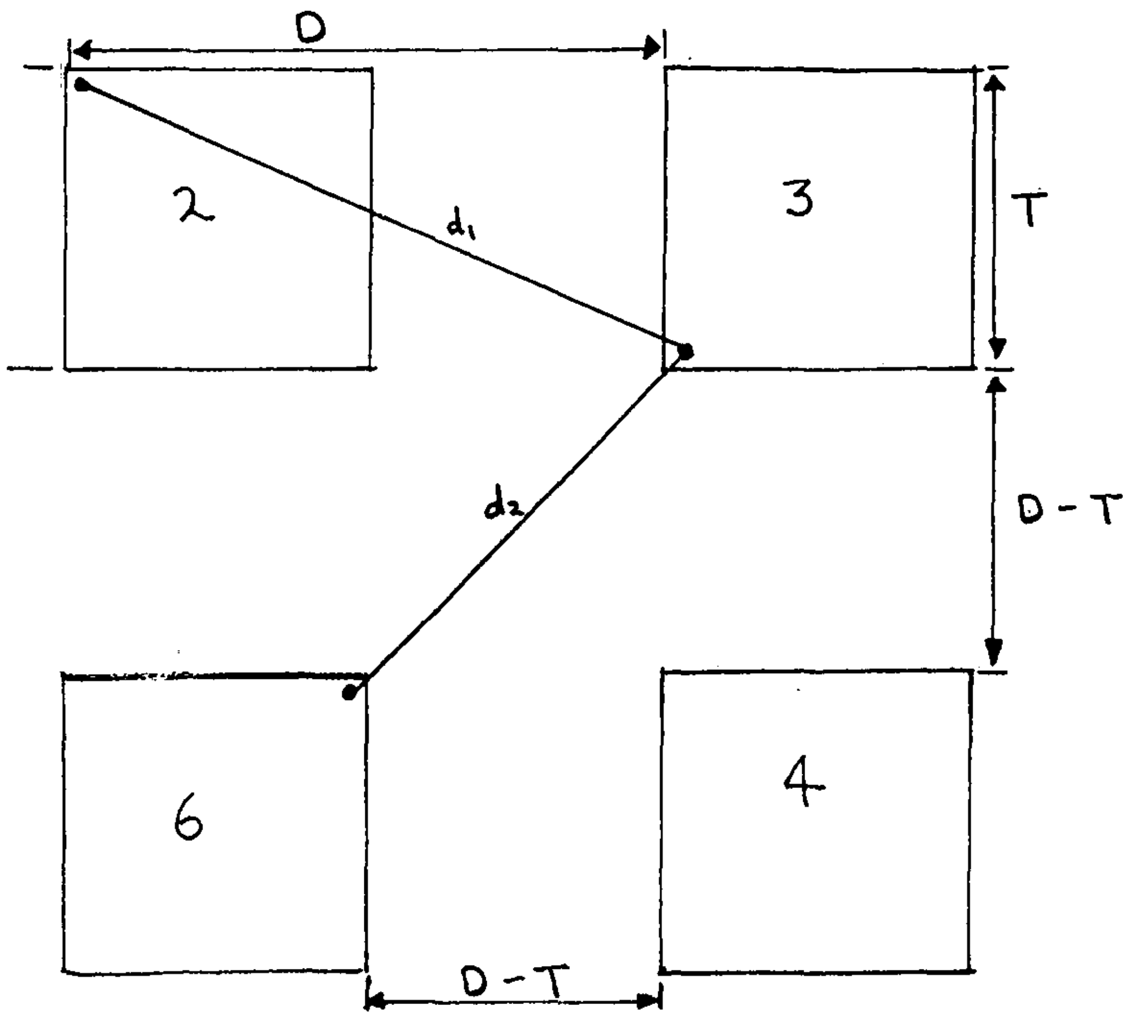


DIAGRAM 42.

Let the distance between two points be defined arithmetically, e.g. distance $d_1 = D + T$ and distance $d_2 = 2(D - T)$. Figures 3 and 4 show d_1 and d_2 for the range of spacing distances (2 – 6) m and for T of 1m and 0.5m.

D(m)	T(m) 1	d_1 (D + T)	d_2 2(D − T)
2		3	2*
3		4	4*
4		5	6
5		6	8
6		7	10

FIGURE 3.

D(m)	T(m) 0.5	d_1 (D + T)	d_2 2(D − T)
2		2.5	3
3		3.5	5
4		4.5	7
5		5.5	9
6		6.5	11

FIGURE 4.

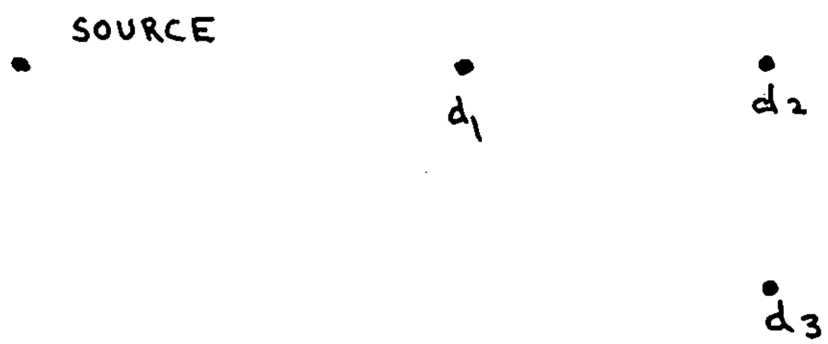


DIAGRAM 43. d_1 is a given position of a tool. d_2 is a subsequent position. d_3 is a position taken after d_2

In diagram 43 let the input at d_2 be $In(d_1) - (\frac{d_2 - d_1}{d_1}) In(d_1)$. Suppose that the tool is moved from d_2 to d_3.

Let the input at d_3 be,

$$In(d_2) - (\frac{d_3 - d_2}{d_2}) In(d_2).$$

Figure 5.

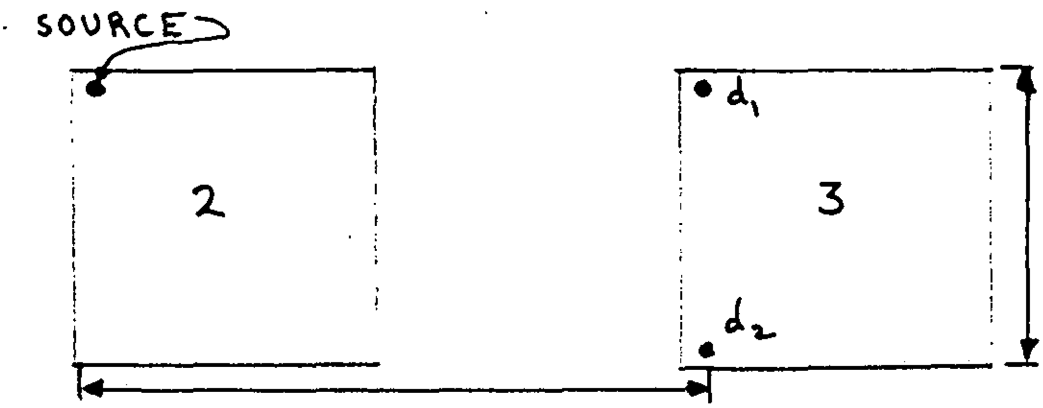


DIAGRAM 44.

d_2 is a tool position taken subsequent to position d_1

In diagram 44,

$$In(d_2) = In(d_1) - \left(\frac{d_2 - d_1}{d_1}\right) In(d_1)$$

$$= In(D) - \left(\frac{T}{D}\right) In(D)$$

$$= In(D) - \left(\frac{1}{D}\right) In(D) \quad \text{(1m tolerance)}$$

$$\text{or} = In(D) - \left(\frac{0.5}{D}\right) In(D) \quad \text{(0.5 m tolerance)}$$

FIGURE 6.

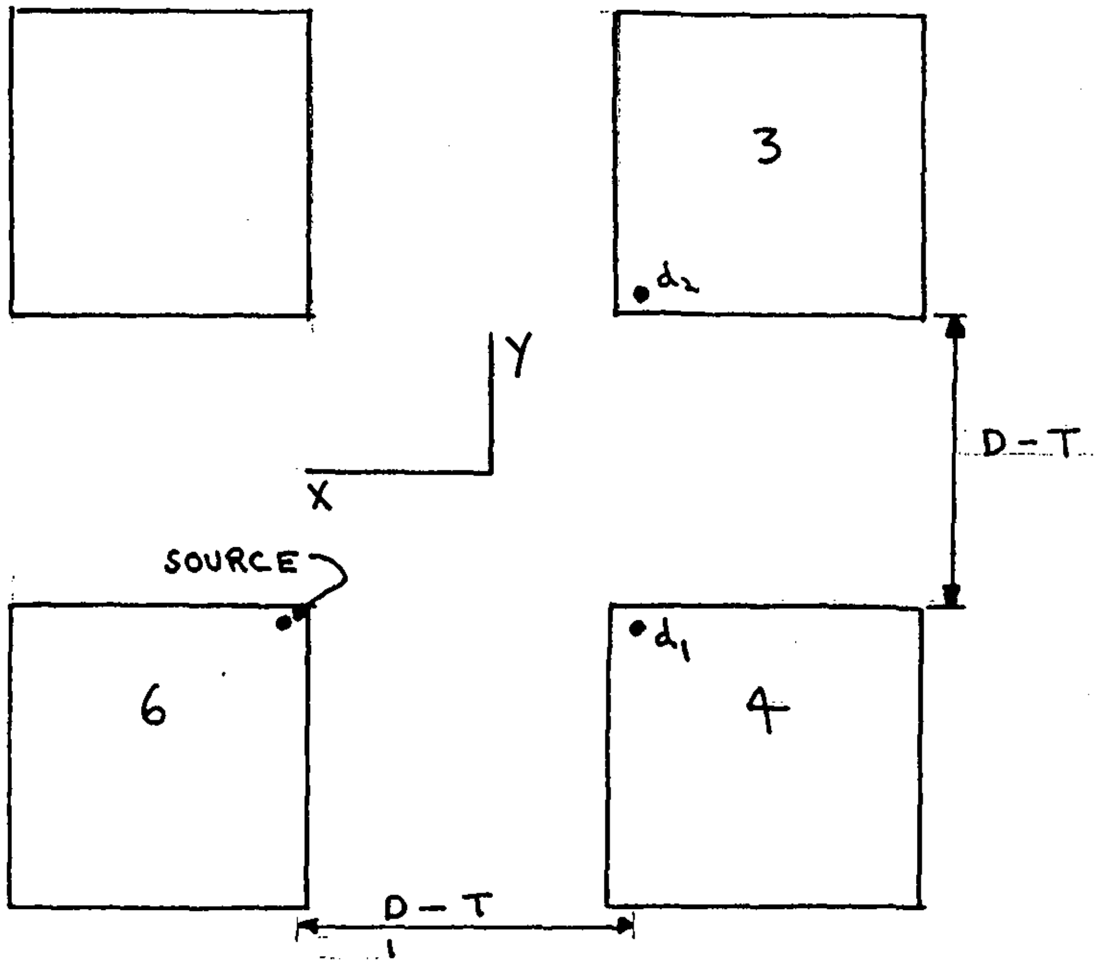


DIAGRAM 45.

In diagram 45, $I(d_2) = In(d_1) - \left(\frac{d_2 - d_1}{d_1}\right) In(d$

$$= In(d_1) - \left(\frac{D-T}{D-T}\right) In(d_1)$$

$$= In(d_1) - In(d_1) = 0$$

An interpretation of the "0" here is that an extreme "Y" position extinguishes input.

FIGURE 7.

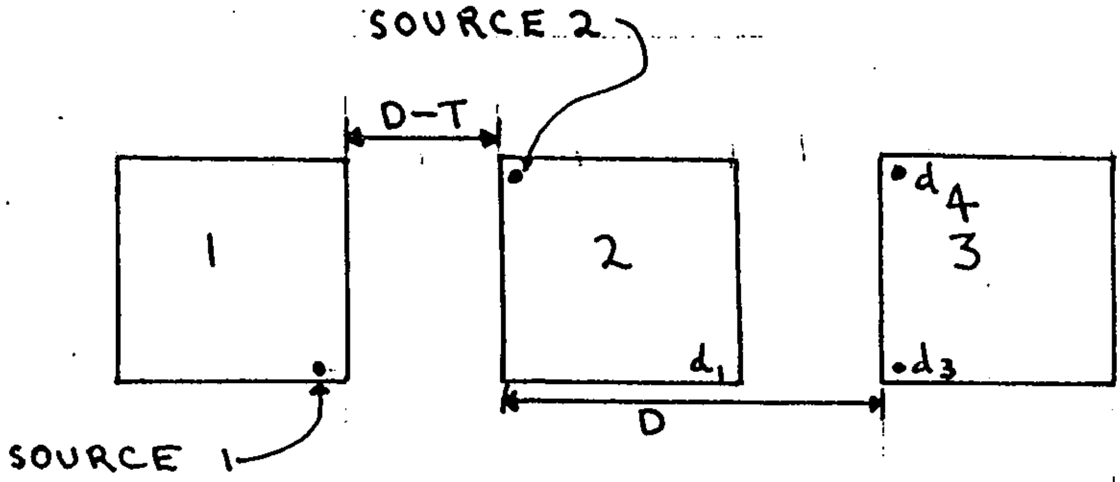


DIAGRAM 46. Least distance SOURCE1 to d_3 vectorially. Relative maximum SOURCE 2 to d_3 vectorially.

In diagram 46,

$$In(d_3) = In(d_1) - \left(\frac{d_3 - d_1}{d_1}\right) I(d_1) =$$

$$In(D) - \left(\frac{D-T}{D}\right) In\ D \quad . \quad (\text{SOURCE1 to } d_3)$$

AND,

$$In(d_3) = In(d_4) - \left(\frac{d_3 - d_4}{d_4}\right) In(d_4) =$$

$$In(D) - \left(\frac{T}{D}\right) In\ D.$$

FIGURE 8. (Diagram 46 and Figure 8 check the SOURCE1 and SOURCE2 case for theory applicability.)

If T = 1 then, (in diagram 46)

Input (Source 1 to d_3) =

$$In(D) - \left(\frac{D-1}{D}\right) In(D)$$

Input (Source 2 to d_3) =

$$In(D) - \left(\frac{1}{D}\right) In(D)$$

FIGURE 9.

D(m)	T(m) 1	(SOURCE 2 to d_3) (1/D)	(SOURCE 1 to d_3) $\left(\frac{D-T}{D}\right)$
2		1/2	1/2
3		1/3	2/3
4		1/4	3/4
5		1/5	4/5
6		1/6	5/6

For the theory adopted, input (SOURCE 2 to d_3) is greater than input (SOURCE 1 to d_3) except in the case D = 2.

FIGURE 10.

D (m)	T (m) 0.5	(SOURCE 2 to d_3) $\left(\frac{T}{D}\right)$	(SOURCE 1 to d_3) $\left(\frac{D-T}{D}\right)$
2		(0.5/2)	(1.5/2)
3		(0.5/3)	(2.5/3)
4		(0.5/4	(3.5/4)
5		(0.5/5)	(4.5/5)
6		(0.5/6)	(5.5/6)

FIGURE 11. Input (SOURCE 2 to d_3) is greater than input (SOURCE 1 to d_3).

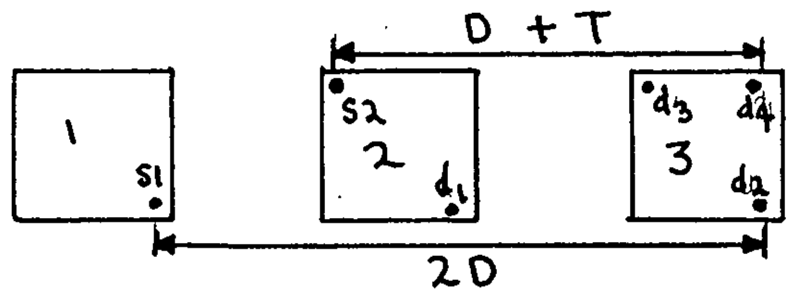


DIAGRAM 47.

In diagram 47,

$$\text{In}(S1 \text{ to } d_2) = \text{In}(d_1) - \left(\frac{d_2 - d_1}{d_1}\right)\text{In}\,d_1$$

$$= \text{In}\,D - \left(\frac{D}{D}\right)\text{In}\,D = 0$$

An interpretation of the "0" is that the input falls below a threshold of sensitivity at this distance.

FIGURE 12.

In diagram 47,

$$\text{In (S2 to } d_2) = \text{In}(d_4 - \left(\frac{d_2 - d_4}{d_4}\right)\text{In}(d_4)$$

$$= \underbrace{\text{In}(d_3) - \left(\frac{d_4 - d_3}{d_3}\right)\text{In}(d_3)}_{\text{In}(d_4)} - \left(\frac{d_2 - d_4}{d_4}\right)\text{In}(d_4)$$

$$= \text{In}(D) - \left(\frac{T}{D}\right)\text{In } D - \left(\frac{T}{D+T}\right)\left(\text{In}(D) - \left(\frac{T}{D}\right)\text{In}(D)\right)$$

= (a) $\text{In}(D) - \left(\frac{1}{2}\right)\text{In } D - \frac{1}{3}\text{In } D - \frac{1}{6}\text{In } D$ (with $D = 2$ and $T = 1$)

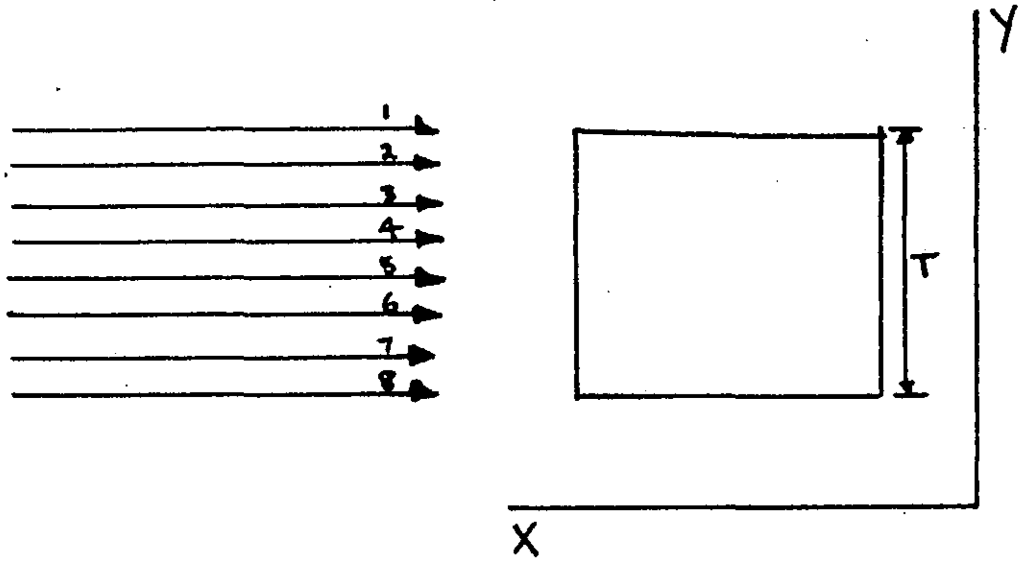
= $\text{In}(D) - 0.83\ \text{In}(D)$.

= (b) $\text{In}(D) - 0.455\ \text{In}(D)$ with $D = 2$ and $T = 0.5$.

= (c) $\text{In}(D) - 0.3\ \text{In}(D)$ with $D = 6$ and $T = 1$.

These results show that with a system of illumination which follows the theory which has been illustrated, Input (S2 to d_2) is greater than Input (S1 to d_2). A threshold at (D+T) would eliminate interference from S1.

FIGURE 13



In a field of illumination like that shown (numbered arrows) an appropriate step-wise linear decrease on the "Y" axis ($1 \to > 1+k$) and an appropriate linear "X" gradient could give a concrete embodiment of a theory such as the one explored.

DIAGRAM 48.

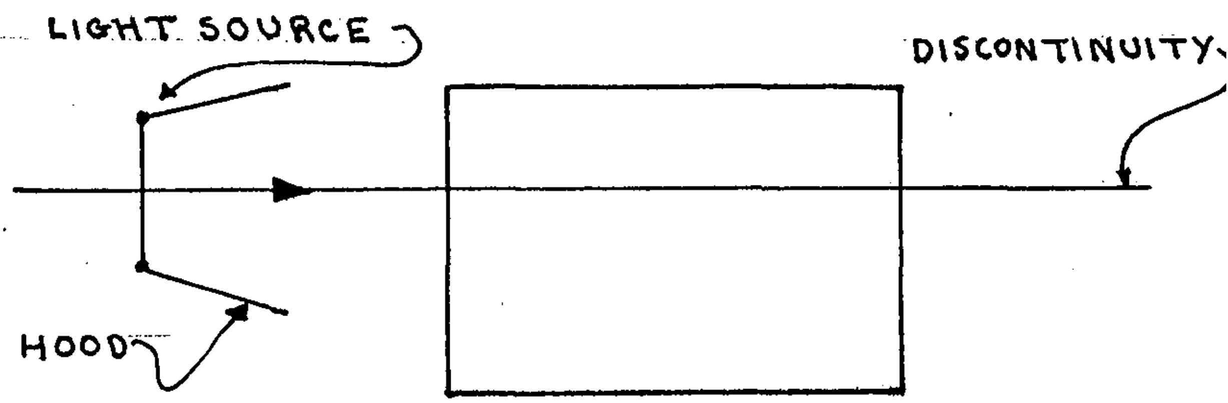


DIAGRAM 49. In a practical system the tolerance region must be illuminated but the step-wise linear decrease shown in diagram 48 will only be approximated. A hood sharpens the cut-off.

Chapter XIII.

SYSTEM REVIEW 2

An attempt is made in this chapter to extract the maximum number of inputs, outputs and interrupts which might be needed to drive the motor system of a tool. An exploration is then made of the interface design and some options exposed. The main integrated circuit which is to be used in the interface is the TMS 9901 PSI (programmable systems interface). An outline at a high level of a program is then given. If a development system were available this program would be worked in a microcomputer "Pascal" (in this case a Texas Instruments version; versions by Intel, Motorola, etc. are available). Without the use of these tools the target language is 9900 assembly language. Assembly is to be done by the SBC "monitor".

The following major functional sub-areas are distinguished:

1. Gantry motion.
2. Planting.
3. Response to the Pointer.
4. Response to Spacing input.
5. Response to Bright Spot input.
6. Set-up.
7. Level Tool.

Figures 1 to 4 show the maximum number of inputs, outputs, and interrupts which are needed to drive these responses. These numbers are an estimate at this point. Once further detail is entered into changes in the numbers may be needed. It is judged that future changes will not be great and that the figures extracted here are a useful guide on which to rough out an interface design.

Sub-routine	Input	Destination	Output	Destination
"Gantry"	=X, =Y end-stops	4 interrupts to 9901	Move =X Move =Y	4 output bits to 9901 (thence to actuators)
"Plant"	Spacing bit Tool frame up and down Plates raised Plates lowered Plates free Tool lowered (= Full depth and Obstacle end-stops) Tree fed Tree released Fill empty Magazine empty Pointer input	12 interrupts 1 input	Raise frame Lower frame Raise plates Lower plates Feed tree Lower tool Raise tool Feed fill Release tree Mag. Empty (a signal to operator) Fill empty (signal to operator) Lock levelling device Reverse spacing lights	13 output bits

Comments: The "Plant" sub-routine follows a fixed sequence. Only "Obstacle" causes a true context switch. This implies that five interrupt ports on a 9901 could suffice to deal with "Plant":

1. Normal sequence with accompanying initialization of interrupt mask and vectors.
2. Obstacle.
3. Fill.
4. Magazine.
5. Pointer (Pointer is needed here to interrupt the "plant" sub-routine if necessary. The "Pointer" sub-routine is discussed in Figure 2.)

FIGURE 1

Sub-routine	Input	Destination	Output	Destination
"Pointer"	Four pairs	12 interrupts	Move =X	(Gantry sub-
	of receptors	2 inputs	Move =Y	routine)
	one pair active			
	at one time.			
	Y- < Y+			
	Y+ < Y-			
	Wide limit Y- extinguished			
	Wide limit Y+ extinguished			
	Inner limit Y- extinguished			
	Inner limit Y+ extinguished			
	Sample X- input			
	Sample Y- input			
	< TH			
	> TH			
	Pointer on			
	Pointer off			

Comments: If input is balanced then no Y-motor action is required. It is possible to use less interrupts. Given that the system is in the Pointer sub-routine an interrupt from a designated source could bring about a sequential software driven testing of a sub-collection of input bits which are associated with the Pointer sensory system. The inputs "Sample X" and Sample Y" are needed for the more minor sub-routine "Find Direction" (see below).

FIGURE 2

Sub-routine	Input	Destination	Output	Destination
Space (Four pairs of receptors. Four pairs of transmitters. Two pairs of receptors operating simultaneously except when special inter-tool communication occurs. Two pairs of transmitters operating simultaneously with particular exceptions.)				
	>T 2 sides	16 interrupts	Pair 1 On/off	5 9901 ports
	<D	8 in/out	Pair 2 On/off	
	Y- < Y+		Pair 3 On/off	
	Y+ < Y-		Pair 4 On/off	
	Sample X Two sides			
	Sample Y Two sides		Move =X	Gantry
	Spacing light on	2 sides	Move =Y	
	Spacing light off	or 4 sides	Signal to operator	Sub-routine
	Input received	2 sides		
	Input ceased	or 4 sides		

Comments: Some sub-routines which occur in Space are needed in Pointer and in Brightspot. In an extreme software solution polling of sub-collections of input could be used to ascertain the condition of the system. In a more hardware oriented solution separate devices could be used for each functional sub-area with as many inputs as possible being treated as interrupts. A middle ground solution could use shared hardware (feature detectors: Marr, 1982) with software controlled switching of the input of different functional sub-areas to the feature detectors. There is further discussion below.

FIGURE 3

Sub-routine	Input	Destination	Output	Destination
Brightspot				
	Input received	6 interrupts	Move +X	(Gantry sub-routine)
	A < B		Move +Y	
	B < A			
	X2 < X1			
	X2 < X1			
	Input off			

Comments: The Brightspot sub-routine shares input with the Pointer sub-routine. The sub-routines "Set-up" and "Levelling do not introduce any further inputs, outputs or interrupts. Levelling is to be treated as an autonomous function which is not under the control of the tool SBC except possibly for locking the levelling system (light on equals lock, light off equals no lock).

FIGURE 4

Figures 1 to 4 show that the following numbers of interrupts, inputs and outputs are needed.

Interrupts	Inputs	Outputs
50	19	36

These numbers of interrupts would be needed for a hardware oriented solution. The 50 distinguishable interrupts can be handled by less than 16 concrete interrupt ports on a 9901 since some collections of interrupts do not occur simultaneously with others. For example, when "Plant" is entered "Space" "Brightspot" and all "Pointer" directives except those carried by Pointer off/on become inactive. This reduces the count of interrupt ports needed at that time to 18. The comments under Plant (Figure 1) suggest that the number can be reduced further. It has been suggested that Space, Pointer and Brightspot could share Feature Detectors (Hardware sources of interrupts), with input from each functional sub-area being under software control. This organization would reduce the number of concrete interrupt ports needed also.

The speed of response needed for the planting application are not great when compared to the speed of a machine cycle (seconds compared to nanoseconds). Neither is the depth of computation which is needed great; the number of machine cycles needed to bring about a perceptual/motor sequence is not great; the exact number cannot be ascertained until the program need has been worked down to assembly language. It seems likely that the speed of data processing in this application will be considerably greater than the speed of physical response which is needed.

A balance between software and hardware must be found. The number of interrupts can be reduced to a point where two 9901's can deal with input, output and interrupt communication. This means that a standard 9900 SBC configuration can be used.

The use of a 9900 based SBC for every tool accompanied by the use of communication between the tools, tool sub-parts, operator and tools by means of light signals (sound could also be used) simplifies the design. The SBC is underused. This suggests that an extreme hardware solution to sensor to SBC communication is not appropriate.

Figures 5A and B shows the features which need to be detected. Some possible solutions to the problem of sensor to SBC communication (interface organization) are then described.

<u>"Features" needing to be detected</u>

1.	+Y < -Y	Used in Pointer. Brightspot and Space.
2.	-Y < +Y	
3.	Inner limit -Y extinguished	Used in Pointer and Brightspot.
4.	Inner limit +Y extinguished	
5.	Outer limit -Y extinguished	
6.	Outer limit +Y extinguished	
7.	X gradient increasing	Used in "Find Direction"
8.	X gradient decreasing	
9.	Y gradient increasing	
10.	Y gradient decreasing	
11.	<TH	Pointer threshold
12.	>TH	
13.	<D	Spacing thresholds
14.	>T	
15.	Brightspot input	Brightspot
16.	X1 < X2	
17.	X2 > X1	
18.	A < B	
19.	B > A	
20.	Brightspot Off	
21.	Pointer on	Returns control to Pointer.
22.	Pointer off	Causes a tool to halt at TH without planting.
23.	Spacing Light on	Signalling between tools
24.	Spacing Light off	
25.	End-stop +X	Grantry travel limits
26.	End-stop -X	
27.	End-stop +Y	

28. End-stop -Y

29. Tool-frame up | Plant sub-routine

FIGURE 5A

30. Tool frame down

31. Plates raised

32. Plates down

33. Plates free

34. Tool lowered to "Full Depth"

35. Tool on obstacle

36. Tree fed

37. Tree released

38. Fill empty

39. Magazine empty

FIGURE 5B

An Extreme Hardware Solution

Hardware detectors of the features are used. Each functional sub-area has its own detectors. Each detector is routed to a distinct 9901 interrupt port. For this solution ADC is functionally superfluous as input (with an exception) is either the presence or the absence of a signal. Opto-couples could be used to interface the input from each sensor and detector. This interface would bring the input to the level required by the family of digital components being used for the detection (most likely a family of TTL or CMOS). Designs for such an interface already exist. Diagram shows one example.

A more software oriented solution

The input from each source of input is conditioned and brought to a distinct port of "K to 1" analog multiplexer. The output of the multiplexer passes to a 9901 (or more than one 9901) via opto-couples or via ADC. The input from each source is read in from the multiplexer at regular intervals in a fixed sequence (via software controlled addressing of the multiplexer). Each input from a given source is stored in a fixed location. Once input sequence is completed a fixed sequence of computation is performed on the data which has been collected. This sequence need not be fixed but could involve Status Register controlled context switches, in effect software interrupts. The computation results in motor action if this is required.

A hardware/software solution

The first solution can be modified to bring about a decrease in the number of hardware detectors of identical features, such as "A less than B", which need to be detected in different functional sub-areas. Diagram 1 shows the main organization. The switching from functional sub-area to functional sub-area is to be done at regular time intervals and in a regular sequence. In this solution each sub-area shares the detectors with the other sub-areas. The detectors could be constructed from PLA's (programmable logic arrays).

The only class of input which is not "1/0" is that where the direction of a gradient needs to be found (e.g. is input increasing with a given movement or is it decreasing?). Exact measurement of input is not needed. What requires to be known is whether a given sample of input is less than or greater than a subsequent sample. This judgment could be made by passing the samples through ADC (via an analog multiplexer) and thence to the CPU where a software routine will compare them (a standard operation). A "hardware" solution based on a potentiometer could also be used.

Program Outline

An interface between the sensors and the CPU is assumed to exist. Output is to pass from the CRU to solid state relays via the 9901 PSI. Long links (more than three inches) between the PSI and a relay will contain an incoherent light link. This link is similar to that by which the tools space from each other or by which the operator communicates with each tool. The signals on the link will be off/on. No further consideration of the organization of output is given is this work; it looks to be unproblematic.

An attempt is now begun to obtain a program which is a structure of sub-routines (modular). The program is to be presented in "top down by successive refinement" fashion. To get to assembles language it would be necessary to continue the process, expanding named sub-routines and extracting new sub-routines until a level is reached where all statements are in assembly language.

Hand Set-up.

Set main beams and sub-beams
Set the end-stops on the No. 1 tool
Set D
Set T

Power up

Initialization of parameter values
Initialization of Interrupt Mask
Initialization of Interrupt Vectors

(An interrupt driven system is assumed. Software switching of an analog multiplexer may be used.)

Set-up
If Pointer input occurs then,

Begin
"Number 1 Tool"
End

If Spacing input occurs then,

Begin
"Lower Order Tool"
End

Comment: "No. 1 Tool" can be interrupted by Spacing input. If spacing input is received and a tool is not receiving balanced Pointer input then a context switch is made to the "Lower Order Tool" sub-routine.

Number 1 Tool.

If input = TH then,

Begin
"Find Corner (+TH)"
End

Begin
"Spacing Lights"
End

If Spacing input k and spacing input K+1 then,

Begin
Find Corner (+TH)
End

Lower Order Tool

If Spacing input on one side then,

Begin
"Find Direction (+D)"
End

Begin
"Move to Corner (+D)"
End

Comment: A second spacing input causes a context switch to the sub-routine "Interior Tool".

If spacing lights on two sides then,

Begin
"Move to D (X)"
End

Begin
"Move to D (Y)"
End

Comment: The tool moves to the D threshold on the X side and the Y side. These sub-routines take the array to the position which is shown in Diagram 2.

Begin
"Signal Condition"
End

If one spacing input and unbalanced and have received a signal from two lower order tools then,

Begin
"Boundary Move to (+D)"
End

Else

If two spacing inputs and have received signals from two lower order tools then,

Begin
"Interior Move to (+D)"
End

Comment: This is the end of the sub-routine "set-up". The sub-routine "Interior Move to (+D) causes the array to follow the No. 1 tool back to a start position. The movement of the tools out from the start position and back is needed to prevent incorrect lighting of spacing lights and hence a confusion of orders of precedence. The named sub-routines are expanded after the whole program has been described in main form.

Semi-automatic operation.

The operator points at a planting spot. The Brightspot is turned on.

If Pointer input is received then,

Begin
"Move to (+TH)"
End

If at (+TH) and no Brightspot input has been received then,

Continue to move in the same direction.

Comment: This sequence can be interrupted by spacing signals. If these occur the result is that a light is turned on to alert the operator that the tool is wrongly spaced. In Semi-automatic operation once set-up is completed spacing signals do not result in a motor response. A tool will continue to respond to the pointer and to Brightspot input. The sub-routine "Plant" can in this condition be entered. The first sub-routine contained in "Plant" checks the status of the spacing signal bit. If a spacing signal is indicated then the system halts. A return is made to the sub-routine "Move to (+TH)".

Semi-automatic Spacing.

```
Begin
        If input > T then,

                Signal Condition

        If input < D then,

                Signal Condition
End
```

Brightspot.

Comment: If a tool is in the sub-routine "Semi-automatic Spacing" then receipt of Brightspot input causes a context switch to the sub-routine "Brightspot". The Pointer sensors and Brightspot sensors interact to guide the tool when it is in the sub-routine Brightspot. For the meanings of "A", "B", X1 and X2 see diagrams 12 and 13, Chapter 11. A further detail is dealt with on Page 21.

```
Begin
        If A < B then,

                Begin
                        Move to B
                        Until A = B
                End

        If B < A then,
```

```
        Begin
                Move to A
                Until A = B
        End

    If X1 > X2 then

        Begin
                Move to (X1)
        End

    If X1 < X2 then

        Begin
                Move to (X2)
        End
```

"Plant Tree"

```
    If receiving Brightspot input       And
        Balance (A, B)                  And
        Balance (X1, X2)                And
        No Spacing Signal On            then,
        Begin
                "Plant"
        End
```

Comment: If the conditions are not met then the tool will not enter "Plant". It will remain stationary until the Brightspot is turned off. Control is returned to the Pointer. When a tool ends "Plant" control is returned to the spacing response which occurs during set-up. The operator turns the Pointer for the No. 1 tool down. This causes it to move back to Start. The other tools follow it. (See Below)

The named sub-routines are now dealt with.

"Find Corner (+TH)".

```
        Begin
                "Find Direction (+TH)"
        End

        Begin
                "Move (X, +TH)"
```

End

Begin
"Move (Y, +TH)"
End

Comment: The sub-routines "Move (Param 1, Param 2)" are expanded below. The value of the parameter (+TH) is t be retrieved from storage with the address held in a Workspace Register which is used by the sub-routine. The other sub-routine parameters are handled similarly. Doing this enables a given sub-routine to be used for more than one purpose, for example, Find Direction (D) or (T) or (TH) or (-TH) or of a lower input sensor in the sub-routine "Balance (P)".

"No. 1 Spacing Lights".

Comment: "Find Corner (+TH)" brings the No. 1 tool to the position shown in Diagram 2. The No. 1 tool turns on all its spacing lights.

Begin
"Lights On (No. 1)"
End

Comment: This sub-routine will consist of the 9900 assembly language directive LDCR (Load Communication Register Unit) which outputs a sequence of bits to given addresses of the 9901. Simultaneous output occurs at these addresses. With a different parameter output will follow a different pattern (see below).

"Find Corner (-TH)".

Comments: This sub-routine has the effect of moving a tool in a direction opposite to that in which the pointer threshold TH lies. It has the same form as "Find Corner (-TH)".

Begin
"Find Direction (-TH)"
End

Begin
"Move (X, -TH)"
End

Begin
"Move (Y, -TH)"
End

"Find Direction (+D)".

The parameter +D indicates the input which is to be dealt with. The "+" sign indicates that movement which increases input is needed.

In the sub-routine "Find Direction" which is called when Pointer input is being dealt with there is a complication due to the fact that motion along the pointer discontinuity involves both "X" and "Y" motion. However there is a basic sub-routine "Find Direction" which is used with TH and the other parameters. "Find Direction" when used for a spacing response has one form. The parameters "X" and "Y" are recognized. For spacing X-motion is independent of Y-motion. The sub-routine which is described here could have the parameter "X" or the parameter "Y". "Param" is used here as a variable over "X" and "Y".

Begin Input (Param) Output (Param 1)	Comment: This is the first sample of input. A given output is produced which gives rise to motion in one direction on an axis.
Input (Param)	Comment: Second sample of input. Let the first be called "In1" and second "In2".

If (D-In1) > (D-In2) then,

Begin	
Halt (Param)	
Enter (Param 2)	The required output.
Output (Param 2)	
End	The motion of the tool is reversed.

Comment: The sub-routine "Move to (+TH)" is dealt with next and then "Find Direction (+TH)". The two sub-routines share motor responses.

"Move to (+TH)"

This sub-routine differs from the sub-routine "Move to Corner (+TH)" inasmuch as in the latter a direct X-motion is made to an X end-stop followed by a direct Y motion to a Y end-stop. In the "Move to (+TH){ sub-routine a tool moves to the Pointer discontinuity and then zig-zags along the discontinuity with the outer limits straddling the discontinuity. Once Brightspot input occurs the narrow (Inner) limits are used to limit Y motion. The tool continues to zig-zag along the discontinuity but in smaller steps. The zig-zag motion may occur in Find Direction with pointer input. It does not occur in Find Direction with spacing input.

The need for accurate movement towards the Brightspot and for accurate halting within the Brightspot points to the use of a lay-out in which the tool sensor and the tool are separated. The sensor finds the Brightspot. When the tool docks at the sensor it is correctly placed above a planting spot (Diagram 3).

Outline of Move to (+TH)

```
Begin
    Find Direction (+TH)
End

Begin
    Straddle Discontinuity
End
```

Straddle Discontinuity

If no outer limit extinguished and no inner limit extinguished then, (Diagram 7)

```
    Begin
        "Between Limits"
    End
```

If one inner limit extinguished and no outer limit extinguished then, (Diagram 6)

```
    Begin
        "Inner Limit Off"
    End
```

If one outer limit off then, (Diagram 5)

```
    Begin
        "Move to Discontinuity"
    End
```

```
        (End of "Straddle Discontinuity").


"Between Limits"

        Begin (Extinguish Inner Limit)

                If one inner limit is low then,

                        Move to low Until,

                                One inner limit is extinguished

                Else, Move (y) Until, (comment. any direction)

                        One inner limit is extinguished
        End

                If one inner limit is extinguished then,

                        Begin
                                Zig-Zag to (+TH Outer Limits)
                        End

                Else,
                        Begin
                                Extinguish Inner Limit
                        End

        (End of "Between Limits")


"Inner Limit Off"

        Find Direction (Y, Lower Inner)

                Begin
                        Extinguish Inner Limit
                End


"Move to Discontinuity"

        Find Direction (Y, Low Outer)

                Begin
```

Extinguish Inner Limit

End

"Zig-Zag to (+TH, Outer Limits)"

Begin

Move (+X) Until,

An Outer limit is extinguished

Move (Y) Until,

The other outer limit is extinguished

Begin

Zig-Zag to (+TH, Outer Limits)

End

End (Zig-Zag to (+TH, Outer Limits)

Comment: This sub-routine is halted by an end-stop or a Brightspot interrupt. Diagram 4 shows the pattern of motion.

Brightspot

The interaction of "Pointer" and "Brightspot".

When the tool moves forward along the discontinuity line under the influence of the Brightspot input it does so by using the "Zig-Zag to (-TH), Outer Limits)" sub-routine. This sub-routine is interrupted by "Brightspot". The Brightspot sensors command motion. The Pointer sensors and sub-routine direct motion between the Pointer limits according to the Brightspot commands. Once Brightspot input has been received the tool zig-zags between the inner pointer limits (Diagram 4). To do this a tool must pass through a transition from the wider zig-zag to the narrower zig-zag. Once a tool begins to move on the discontinuity under pointer influence it establishes a sequence of motion, Y X Y X Y ... . Before this cycle of movement is established a tool is either to one side of the discontinuity (Diagram 5), in which case an outer limit is extinguished, or both outer limits are lit and one inner limit is extinguished, or both outer limits are lit and one inner limit is extinguished, or both inner limits are lit (Diagrams 6 and 7). Two cases can be distinguished - cycle of pointer motion along the pointer discontinuity established - cycle of movement along the pointer discontinuity not established. Some sub-cases need to be distinguished in both these cases; they are explained below.

Case 1 Cycle established

In Y motion phase OR

In X motion phase

Case 2 Cycle not established

Solution to Case 2. If cycle 1 (Diagrams 8 and 9) is not completed then complete cycle 1. If one inner limit is unlit then, Move (Y) until the previously lit (non-extinguished) inner limit is extinguished (Diagrams 8 and 9). Start Inner Zig-Zag to (-TH). If both inner limits are lit (Diagram 10) then, establish cycle 1 start Inner Zig-Zag to (+TH). Solution to Case 1. Sub-case 1: Y motion not occurring or X motion occurring. Complete X motion (which is either in progress or about to occur). Move Y until the previously lit (non-extinguished) inner limit is extinguished (Diagram 11).

Sub-case 2. X motion not occurring or Y motion occurring. Complete Y motion (which is occurring or about to occur). Move (X) until the previously lit (non-extinguished) inner limit is extinguished (Diagram 12). Start Inner Zig-Zag to (-TH).

Depending on the amount of motion which the Outer and Inner limits allow, the size of the Brightspot relative to this motion and the accuracy required, these adjustments may cause the tool to overshoot the Brightspot. The receipt of Brightspot input will have been recorded. If the input ceases during adjustment then the zig-zag now having been established between the inner limits it is reversed until the input is received again.

The sub-routine "Straddle Discontinuity" and its sub-routines, "Between Limits", "Inner Limit Off" and "Move to Discontinuity", can be used here. A modified sub-routine (Parameter value change) "Zig-Zag to (-TH, Outer Limits)" can be used, namely, "Zig-Zag to (-TH, <u>Inner</u> Limits)".

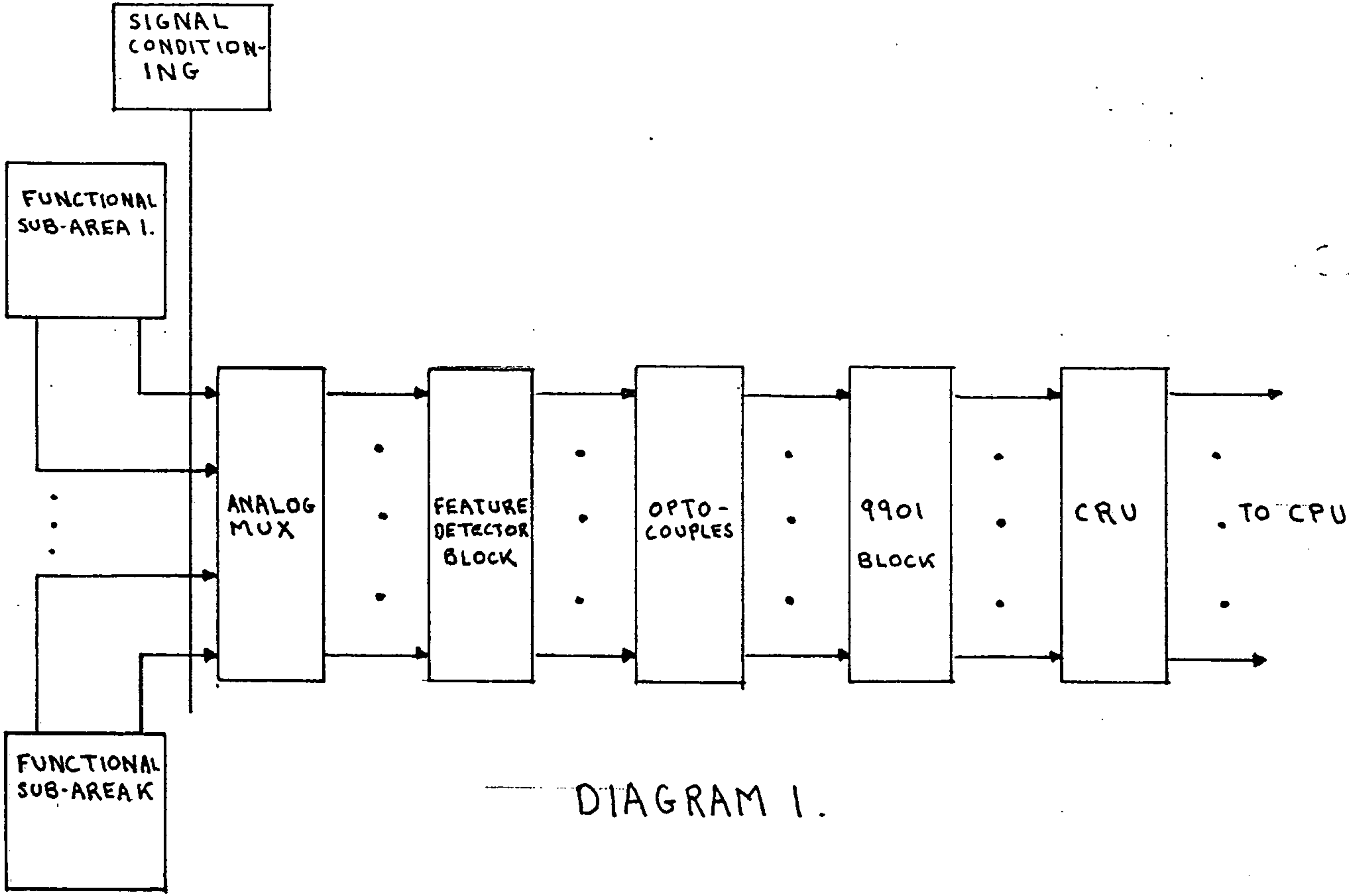

SIGNAL CONDITIONING
FUNCTIONAL SUB-AREA 1.
FUNCTIONAL SUB-AREA K
ANALOG MUX
FEATURE DETECTOR BLOCK
OPTO-COUPLES
9901 BLOCK
CRU
TO CPU

DIAGRAM 1.

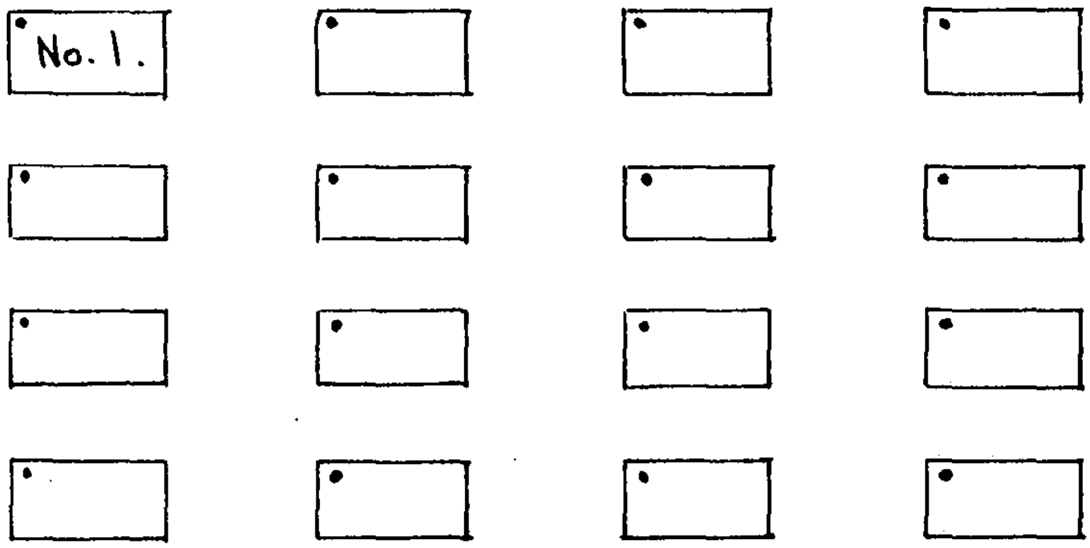


DIAGRAM 2 Dots are tools.

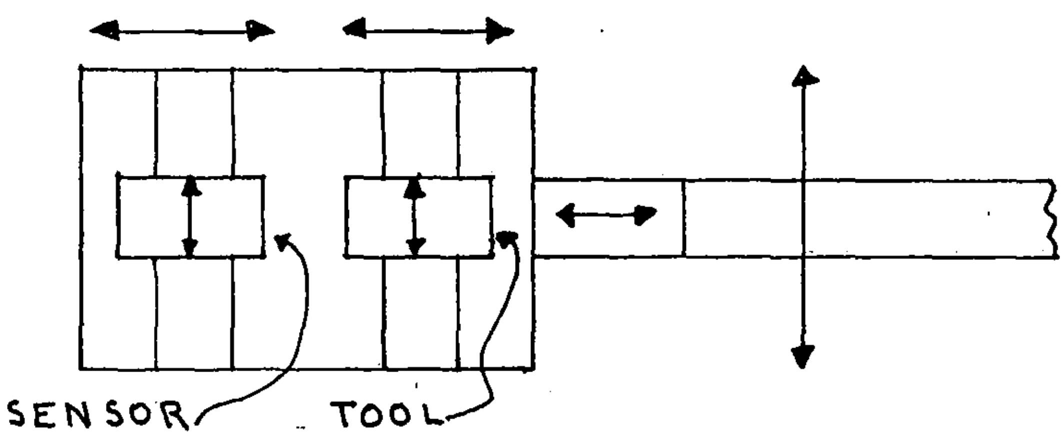


DIAGRAM 3.

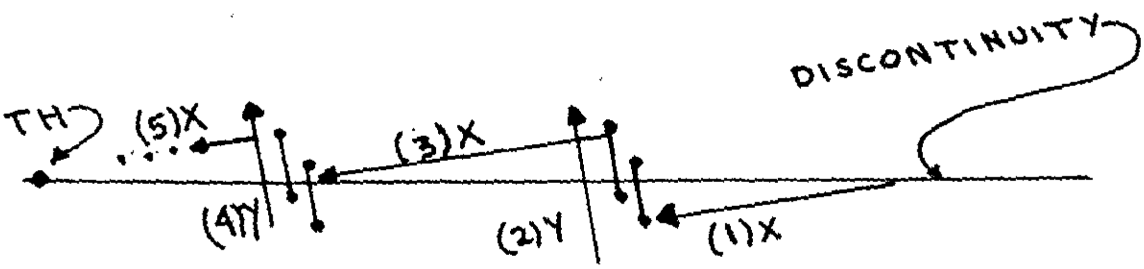


DIAGRAM 4. "I" = sensor plane
The dots are limits. The limits shown could be outer limits or inner limits.

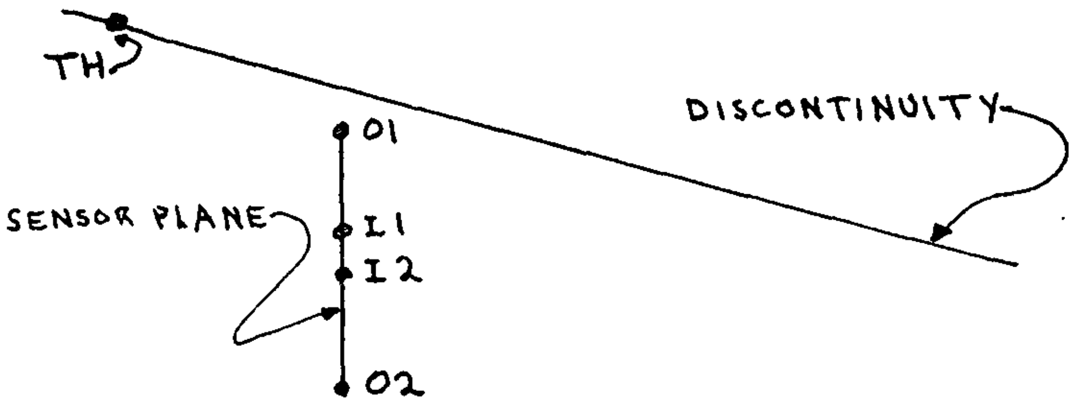


DIAGRAM 5. O1 and O2 are outer limits. I1 and I2 are inner limits.

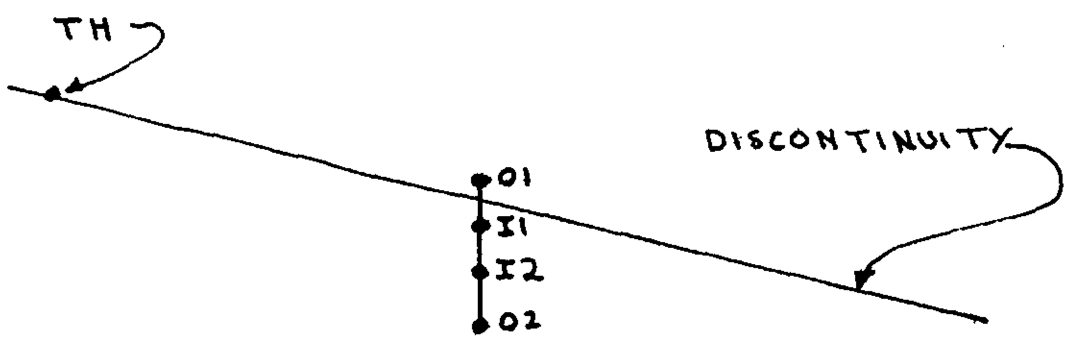


DIAGRAM 6. Legend as in diagram 5.

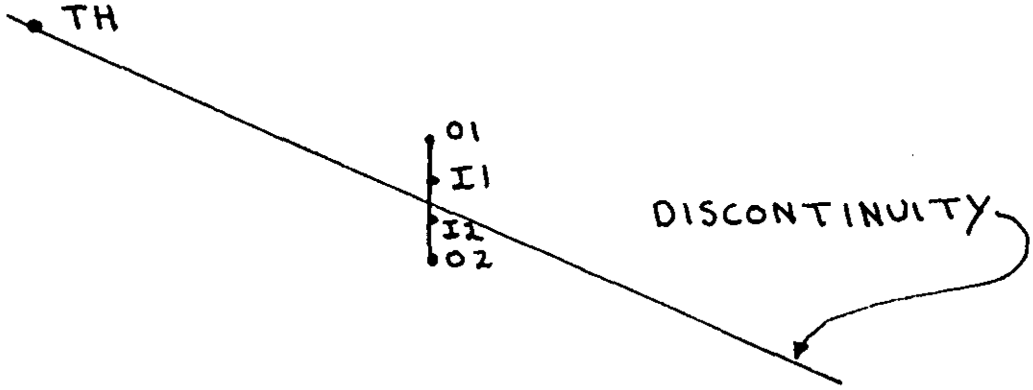


DIAGRAM 7.

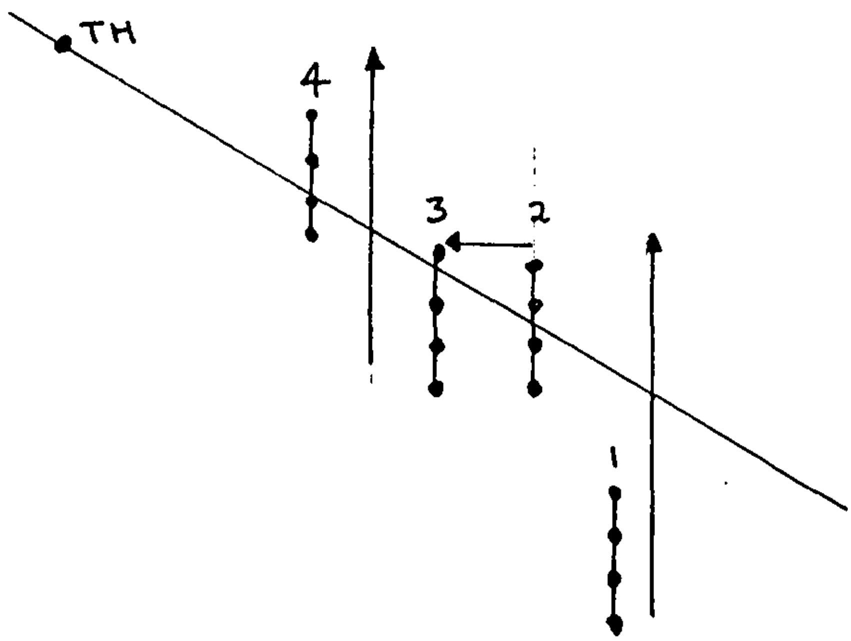


DIAGRAM 8. Inner cycle established at position 4.

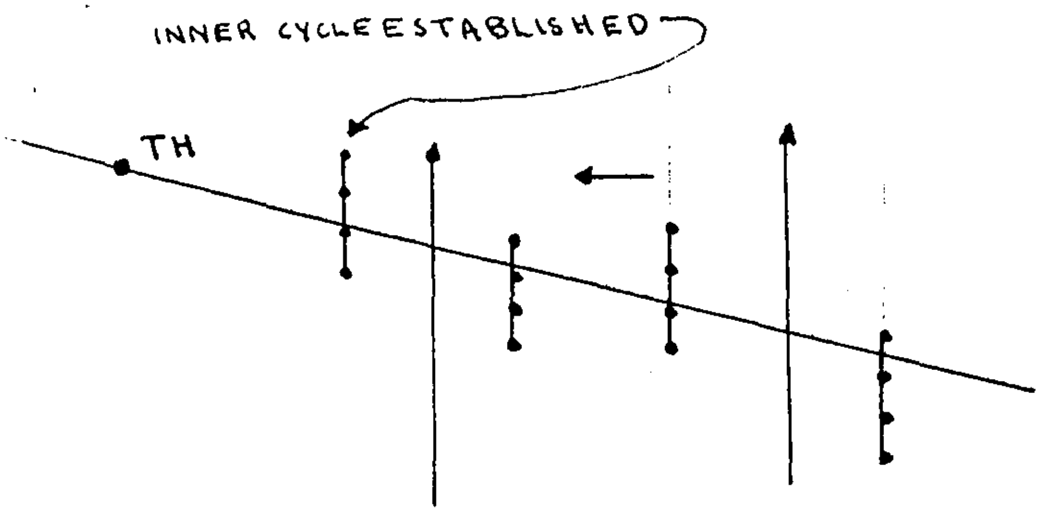


DIAGRAM 9.

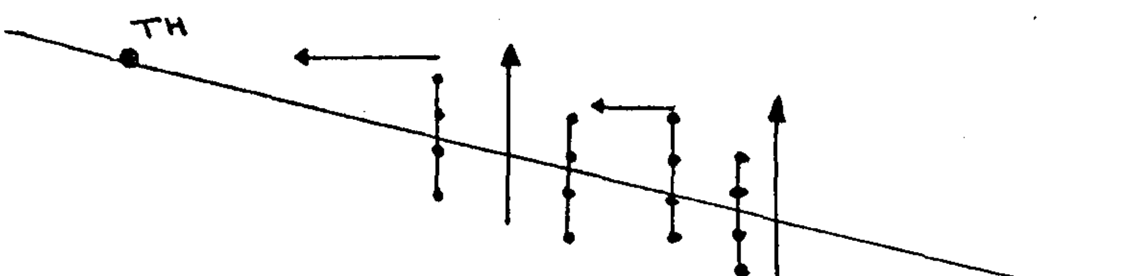


DIAGRAM 10.

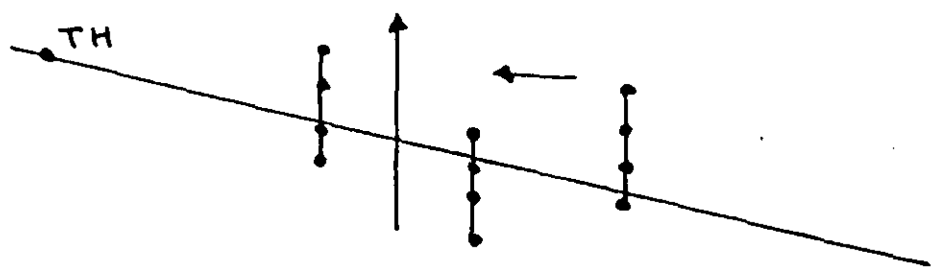


DIAGRAM 11.

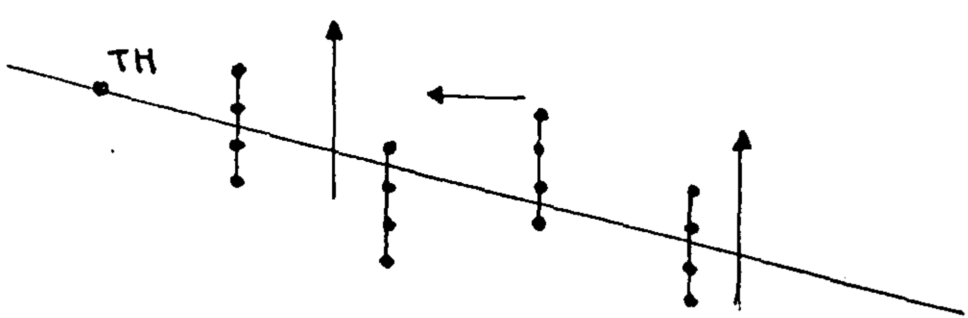


DIAGRAM 12.

Chapter XIV.

EXPERIMENTAL WORK RELEVANT TO SEMI-AUTOMATIC OPERATION

This chapter contains a report on some simple experiments on the detection of light and a discussion of an alternative to the detection of a planting spot by the detection of a maximum of diffusely reflected light which makes use of sound detection.

The aim of the experiments is to take a first look at the feasibility of using tool guidance based upon the detection of signals transmitted by incoherent light against a background of sunlight. Where polarized light is used the light source is incoherent. A rough indication of feasibility is sought. The light detector used is photographic exposure meter having a relatively insensitive needle movement and a relatively restricted range of sensitivity. If detection is shown to be possible with this device then it is concluded that detection will be possible with more sensitive devices and without the use of a mechanical movement.

A single light source is used throughout the experiments. It is a readily available vehicle spotlight the bulb of which has a tungsten filament (Diagram 1). Our preference is to use a system of detection which makes use of polarized light and the detection of the state of balance of a pair of receptors or pairs of reflectors. An indication of the feasibility of using polarized light has been looked into. If basic feasibility looks to be demonstratable then a more major investigation would need to be undertaken, one which makes use of more sensitive means of light collection, means which could involve the use of lenses, reflectors, more sensitive photo-reactive elements and so on. If, with the simple means used feasibility is not shown or is not clearly shown then the more careful investigation will need also to be undertaken and other investigations. Some possibilities based upon light detection are listed in Figure 1. An alternative using sound is discussed later. Its use will involve an investigation of erroneous signal detection of the sort which was discussed for light in Chapter 12.

The dimensions of a sixteen tool array with 2.5m intertool spacing have been assumed as dimensions with which to work. A maximum distance between a signal source and a receiver occurs for a tool in the positions shown in Diagrams 1 and 3. This case has been explored. A vertical distance above the ground of the light source of 3.5m has been assumed. This assumption is based on an estimate of a maximum height above the ground of the vehicle undercarriage of 1m, with 0.5m clearance between the beams (to avoid a dangerous scissor motion) and a height above the cab floor of less than 2m.

An attempt has been made to assess the following questions:

1. Can a useable fall-off of intensity with increasing distance from a source of specularly reflected light be detected?

   Answer: Yes (Figure 2).

2. Can a maximum of diffusely reflected radiation be detected in the presence of sunlight?

   Answer: Yes (Figures 3 and 4).

3. If the specularly reflected light is polarized can the difference of intensity be detected between two sensors one whose input passes through a polarizing filter having its plane in the same orientation as that of the source filter, the other having input passing through a polarizing filter whose plane of polarization is rotated 90° relative to the plane of polorization of the filter at the light source (i.e. the two filters are "crossed").

   Answer: Yes (Figure 2).

4. If the light source is polarized can two sensors having polarizing filters arranged as in "3." detect against sunlight an "artificial" maximum of diffusely reflected light? Can this maximum be distinguished from a natural maximum (e.g. such as that which occurs from a rock surrounded by soil).

   Answer: Uncertain. When the artificial source was polarized no difference of reading was observed between the sensor having the uncrossed filter and the sensor having the crossed filter. It is possible that the loss of intensity of the artificial source after having passed through two polarizing filters and after having been diffusely reflected is great enough that the increment over diffusely reflected sunlight through the uncrossed filter could not be detected. It is also possible that a rotation of the plane of polarization accompanied the diffuse reflection of the artificial light. It is further possible that the diffuse reflection destroyed the polarity of the artificial light. Figure 4 shows results with both filters on the sensor.

The question of the detection of diffusely reflected polarized light demands a more careful investigation. This is reserved until later. In case insurmountable difficulties arise guidance of a tool to a planting spot or work place using sound signals has been looked into.

Sonar integrated circuits can be bought off-the-shelf. They are used in such an application as the automatic focusing of cameras (Polaroid). With their use the distance from a pointer to the place pointed to can be found (Diagram 4). A method based upon the measurement of distances is described below. A second method is described, it is similar to the light based method, where a maximum of sound reflectance is sensed.

Our problem in the silvicultural application is to use the sonar IC's in a way which avoids as far as possible increasing the complexity of the pointer. There is a trade-off however, inasmuch as the Brightspot sensory mechanism would no longer be needed if sound is used.

Method 1

The method will solve the problem of bringing the tool to the position pointed to by its pointer by computing the distance (a,b) of Diagram 4.

The pointer is equipped with two sonar integrated circuits. One circuit is fired along the line (ac). The other circuit is fired along the line (ab). The firing is synchronized.

The tool comes to the light discontinuity and moves towards TH. (A tool depending on its position in an array will either reach TH before it reaches the point C' (ac' = ac) or it reaches C' before it reaches TH. Let it be assumed that it reaches TH first; the system is to be interrupt driven so that the eventual outcome of events whether TH is reached first or second is identical in either case.) When the tool reaches TH it halts. Input from a sound sensitive sensor is then attended to. The pointer sonar IC's each transmit signals repeatedly and receive an echo from each transmission. The receipt of the echo fires the transmitter (the transmitter could fire at fixed intervals or by some other pattern but the echo fired system is useful for our purpose). Upon receipt of a sound signal by the tool sensory system the clock circuit (of the 9901) begins a count which is halted upon the receipt of the next sound signal.

In this case the time which will have elapsed between the receipt of the first sonar transmission to the tool and the second transmission is the time during which the echo has traversed the path from the tool to the echo receiver (the distance {a, TH}) plus the time during which the signal transmission following the receipt of the tool echo has traversed the path from the transmitter to the tool (the distance {a, TH}). Thus half the elapsed time from the receipt of the first signal to the receipt of the second signal is the time needed for the signal to travel the distance (a, TH). The SBC can calculate this time from the clock count.

The tool, having calculated the count for (a, TH) in the case being considered moves forward until it reaches the position C'. From this position the echo from the tool at C' will return at the same time as the echo from the ground at C (Diagram 4). The simultaneous receipt of the two echoes gives rise to input which turns off the pointer (a hardware circuit could turn the pointer on again, for example the simultaneous receipt could cause the discharge of one or more capacitors. The input from the capacitors to an appropriate circuit could turn off the pointer. When the capacitor input discharges the input ceases and the pointer goes on again. The capacitor (or capacitors) would then be charged again. Upon receipt of the pointer signal the tool halts; it is at C'. The pointer sonar system fires. Receipt of a signal by the tool starts a clock count which is terminated by the receipt of the next signal. The count is the time needed for a sound signal to traverse the distance (2ac). Half this count is the time needed for the signal to traverse the distance (ac).

The time needed for the sound signal to travel (a, TH) and (a,c) are now known. The distance (a, TH) is associated with a <u>fixed</u> angle α (Diagram 4). A look up table entered with the "(a, TH)" count value (this value could be turned into a distance) will give (with interpolation to cut down the table size) the value of the angle α . With the angle known and with the count of (a, C') known, the distance (a,b) (Diagram 4, the point b is directly above the work spot) can be computed (i.e. {a,C'} cos α); in this case the computation can be done in terms of clock counts (Figure 5). From this point there is more than one way of taking the tool to the point b. One way is to subtract the a clock count computed for (a,b) from the count for (a,C'). The count which remains is the time for a signal to traverse the distance (b, C'). This count can be transformed into a distance and the distance transformed back into a clock count in terms of the velocity of the tool (Figure 5). The tool moves. A clock count is begun. When it terminates the tool will (in the ideal case) be at point b.

Another way is to use the count which has been computed for the distance (a,b). The tool moves upon receipt of a sound signal and begins to count either down from this value or up to this value. When it receives a second signal if the count has simultaneously halted the tool halts; it is at b. If it has not completed the count it begins a new count which continues until the receipt of the next sound signal. It is either at b or it is not at b. And so on. The Doppler effect arising from the motion of the tool should be negligible as the tool velocity is low relative to the signal velocity and the rate of computation.

Method 2

Detection of the planting spot may be possible by a method which uses sound in the same way that the Brightspot method uses light. No computation of angles and distances is needed.

A tool carried sound sensor is used having a directional hood whose aperture faces the ground. The tool travels along the light discontinuity until a maximum of sound input is recorded. If the point of aim of the pointer sonar system is not directly below the discontinuity then a pair of sensors or more than one pair will be needed to centre the tool at the maximum point.

This method involves less computation than the amounts based upon the measurement of distances and angles. Whether in all reasonable cases detection is possible by this method would have to be investigated experimentally.

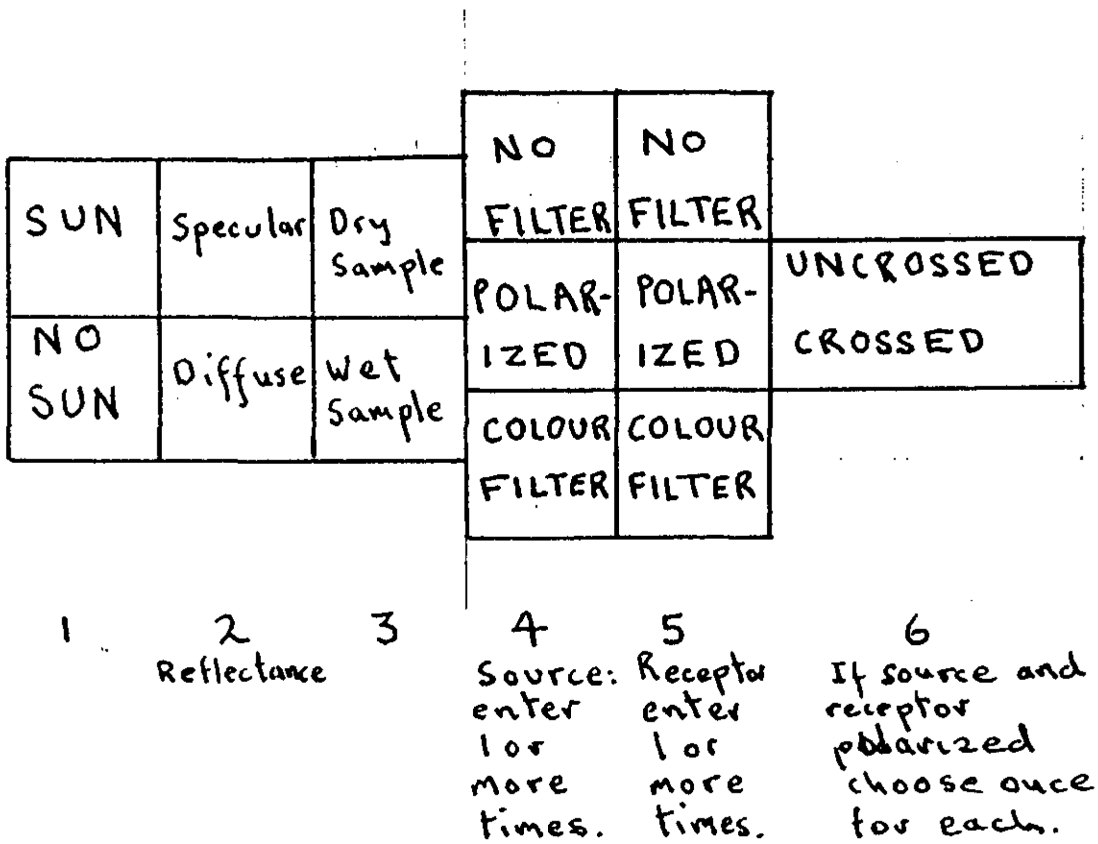


FIGURE 1. An implicit listing of experiments on light detection. The "decision" boxes are entered in numerical order.

Specular reflection in the presence of sunlight. Hooded sensor.

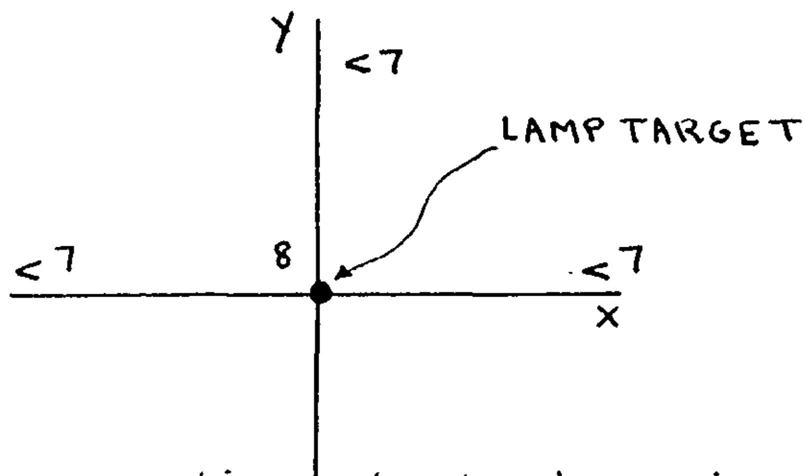
Filters	Distance from artificial light source.		
	0 m	3 m	6 m
None	FSD (>18)	17.5 < R < 18	15.5 < R < 16
Polarizing (1 on sensor)	17.5	15.5	14.0
Polarizing (2 on sensor)	16.0	14.0	12.0
Polarizing (1 on lamp)			11 < R < 12
Polarizing (1 on sensor 1 on lamp)			8 < R < 9
Polarizing (2 crossed one on sensor one on lamp)			< 5

FIGURE 2. Ambient radiation, 12 units towards the sun, < 8 away from the sun.

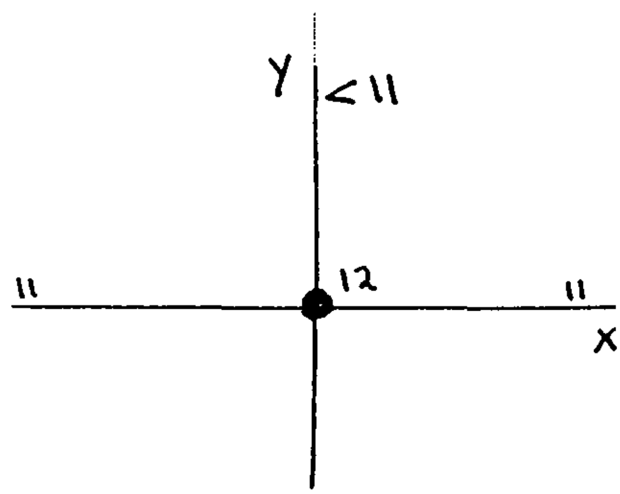
FILTERS	REFLECTOR	
	BLACK CARDBOARD	
	Max. at ground Level.	3.5m from ground
None	8	7
1 Polarizing (on sensor)		5 < R < 6
2 Polarizing (on sensor)		4 = R = 5
2 Polarizing (crossed on sensor)		R = 1

FIGURE 3.

Diffusely reflected radiation in the presence of sunlight. Hooded sensor.



(a) Detection of a local maximum: sensor at 3.5m above the target. When moved along both axes the sensor recorded a m



(b) Detection of a local maximum: sensor at 3.5m above the target. When moved along both axes a maximum was recorded.

FIGURE 4.

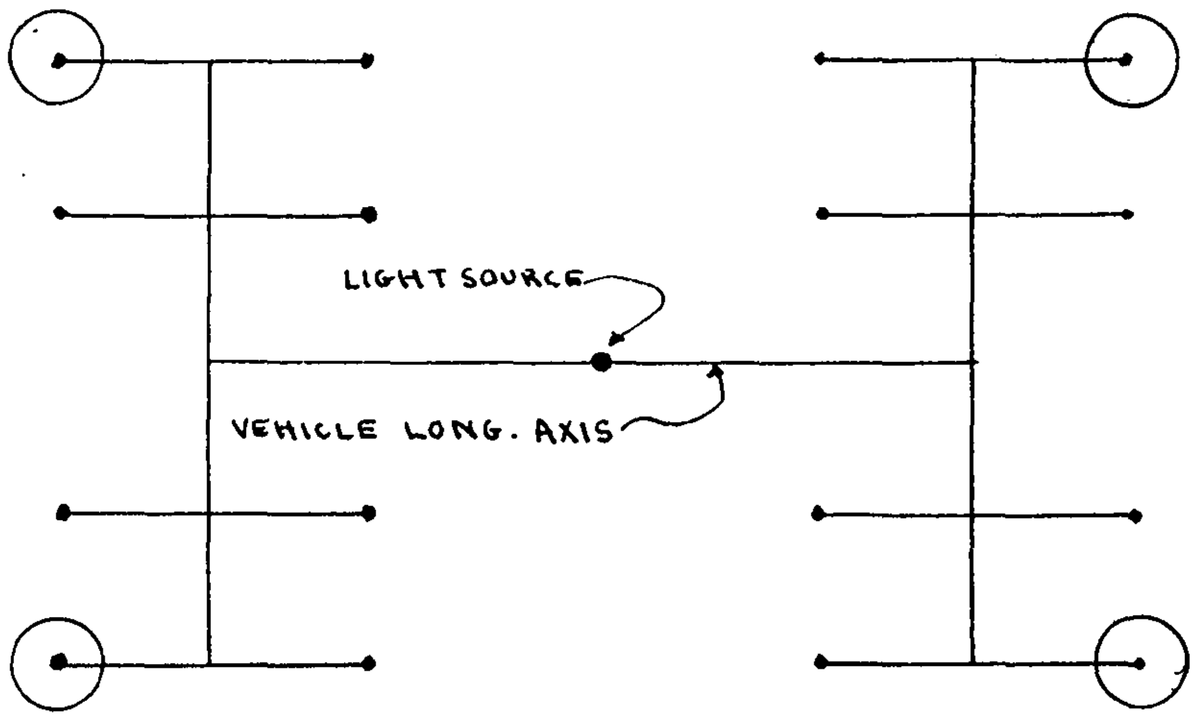


DIAGRAM 2. Circled tools at a maximum distance from the light source.

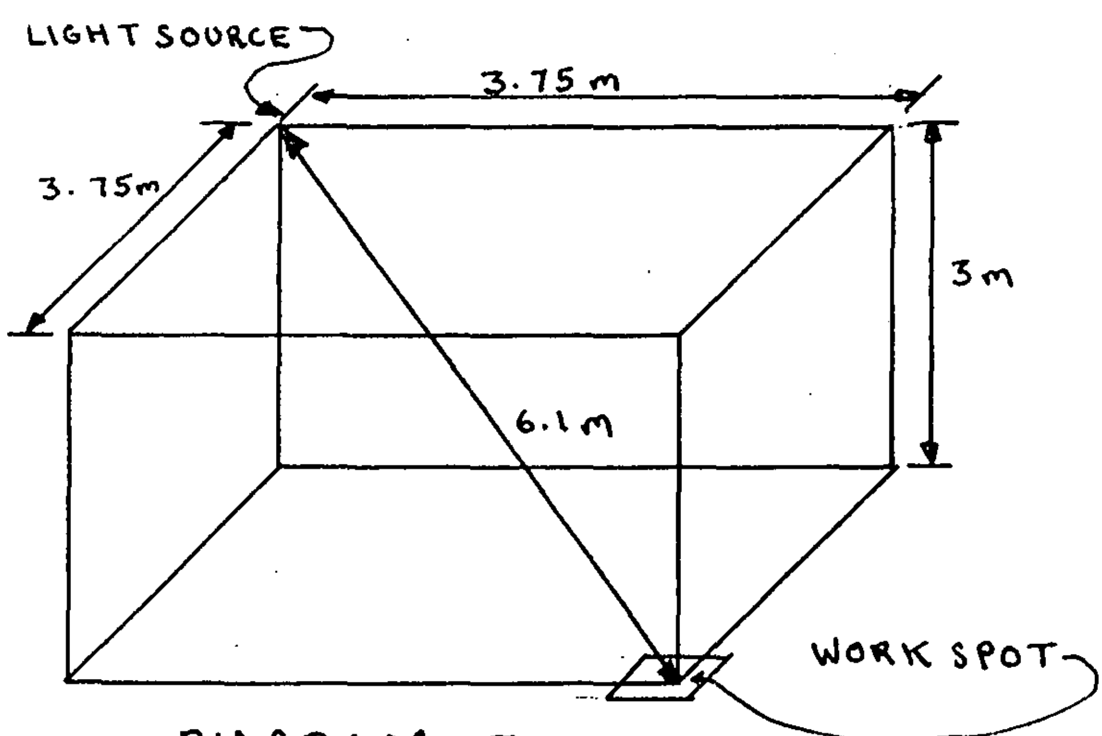


DIAGRAM 3.

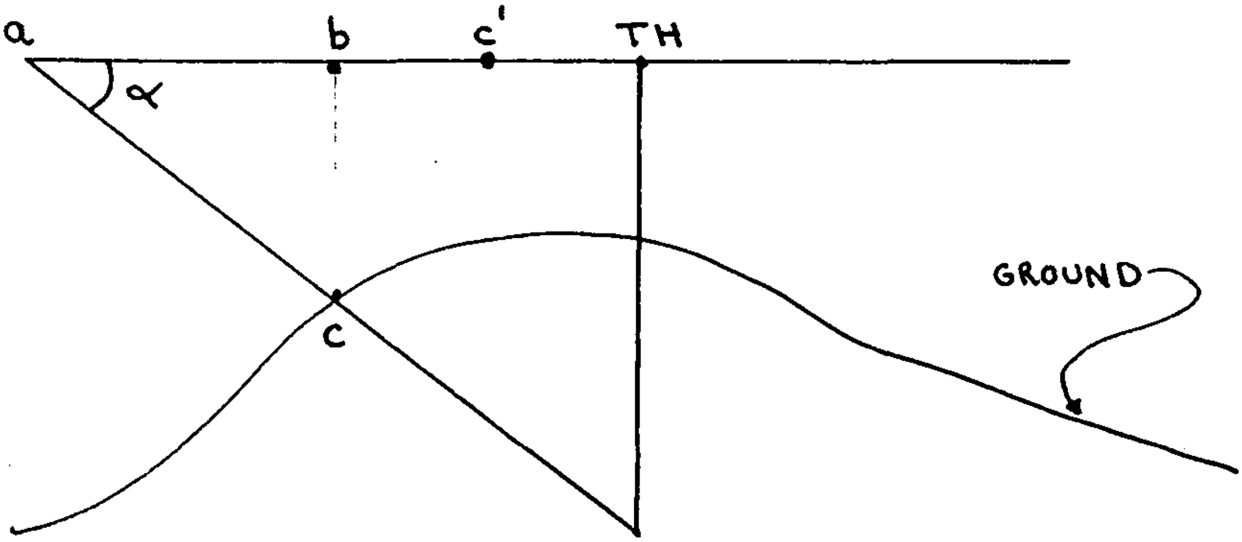


DIAGRAM 4. Light source at a.

1. Distance (ab) = (ac) cos α

2. (Time (ab) x velocity (sound))

= (Time (ac) x velocity (sound)) cos α

= distance (ab).

3. Time (ab) = Time ac Cos α .

FIGURE 5.

Chapter XV.
CONCLUSION

The work which has been presented falls into three parts -- strategical design, conceptual design and detail design.

At the end of the strategical work the following results had been achieved.

(1) A "commercial/technical" theory for a design had been constructed.

(2) An understanding of the order of magnitude of the production costs which might be borne by a design.

(3) An understanding of the commercial value of an embodiment of the theory had been attained; the order of magnitude of a retail price for a device and the number which might be sold were understood.

(4) A plan for the work to be undertaken had been set. It was based upon the degree of detail required for patenting purposes. This plan served to limit the work needing to be done to a manageable size.

(5) A decision had been made to proceed to the conceptual design stage.

If a design variation of an already existing product were being dealt with then a further outcome of the strategical work would have been a product design specification (PDS). In the present case there was demand but no existing device to fulfil it. The theory for a solution took the place of the PDS. The theory is, in effect, a specification but it is one that is stated in general terms. It is not as complete in detail as a normal PDS and it is of a more speculative nature than a PDS for a product in a better developed product area (Appendix 4).

Three major problem sub-areas emerged from the first phase of work:-

(1) Vehicle; the problem of tool carriage.

(2) Mechanical handling of seedling trees (silvicultural/mechanical problems).

(3) Tool guidance.

Conceptual design work was pursued on the three areas until what looked to be a workable and combinable collection of design schemes emerged. Patent specifications were drawn up for a vehicle, for a magazine and for a placemen device. Work was at that point halted on the vehicle and the handling problems. Further detail was pursued on the guidance problem. This was needed in order for the practical workability of the proposed tool design scheme to be able to be judged. A patent specification covering some aspects of the guidance work was drawn up.

The silvicultural statistics for British Columbia (Province of British Columbia, 1986-7) show that approximately the same area of land was prepared as was planted. If the average amount spent on land preparation per hectare is translated into a price per tree (via an assumption of a given average tree density per hectare: Province of British Columbia, 1984) then it is seen that site preparation costs are in the same cost range per tree as planting.

It was intended that some preparation be done at each planting spot if necessary. The spot preparation problem has been put aside so far. It is know that because of both the expense and the difficulty of doing so there is a wish to avoid heavy preparation. The cost of using a tractor suitable for doing clearing does not allow for an acceptable rate of return from planting (Province of British Columbia 1989).

The tractor rental cost used ignores the potential cost of haulage, the cost of further personnel who will be needed in addition to the tractor driver; at least one man in addition to the driver is needed.

At the moment mostly "two-pass" site preparation and planting is being done. The sites are firstly prepared (this may include burning or machine preparation) and then hand planted. There is a desire to perform "single pass" planting with one vehicle preparing the ground and planting in one operation. There are advantages to a device which could at the same time prepare a site spot style (Appendix 3) and plant. A machine which could do this could work at a bid price range which was at least double that which has been chosen for just planting if the rate of planting is still that which has been being explored (1000 trees/hour). Alternatively, if the rate of return for just planting is adequate then a device which both plants and prepares could when using the same bid price range as that for just planting perform planting at half the rate of a device which just plants.

The attractiveness of this "one-pass" solution is strengthened by the fact that a solution to the guidance problems in semi-automatic control would enable a single operator to guide a tool carrying an array of preparation tools and an array of planting tools.

It is strengthened further by the fact that the British Columbia Forest Service has used a bulldozer pulled furrow planter on some sites, clearing and planting in one pass. Their willingness to bear the expense of this operation suggests that the device being designed here will be acceptable on economic grounds.

Approximately 20% of Interior sites are suitable for furrow planting if clearing is done (B.C. Forest Service, personal communication).

The commercial licensing of patented devices has been explored and also the royalty rates associated with licensing. In the introductory section to this thesis four phases of development were distinguished for exploratory purposes. The likelihood of selling licenses before the end of phase II is low.

The implications of the funding situation and the competitive situation are:

(1) That our original appraisal of the funding situation is correct.

(2) That the financial environment assumed for the project is a reasonable one.

(3) That the overall solution chosen (vehicle plus tools) has considerable commercial potential and a decided advantage over the known competition.

(4) That one-pass site preparation and planting needs to be carefully considered. It may well be the most satisfactory way of approaching the planting problem and also commercialisation.

A one-pass system planting at half the rate which was initially explored, that is, 500 trees/hour compared to 1,000 trees/hour, looks to have greater commercial value than a system which purely plants at 1,000 trees/hour. The money "lost" by using the lower rate is made up by the income from site preparation. (The amount earned from planting and site preparation would be the least that would be earned. The vehicle has other uses.)

With this combination (500 trees/hour plus site preparation) the order of magnitude estimate for a lower boundary for the potential demand is increased from 4,000 units (planting tools plus vehicle) to 8,000 units (planting tools, site preparation tools, vehicle). The retail price for a unit (which plants and does site preparation) is in the region of \$120,000 (Can.) - \$150,000 (Can.).

It has already been said that the vehicle has multiple use in silviculture. This has been ignored in obtaining the estimates. The overseas potential (outside North America) has been ignored. The effect on the size of the demand of the backlog of sites needing to be planted has been ignored. The potential for wider application of the vehicle has been ignored. The figure of 8,000 units is an estimate in the region of a lower boundary for the potential demand.

(5) A one pass system could be conveniently controlled semi-automatically. This suggests that a semi-automatic solution to the problem of spot choice is particularly valuable.

(6) That patents are important; commercial companies rarely consider unpatented devices, nor do governmental agencies.

In retrospect a considerable saving of time and effort could have been achieved if the following areas had been understood at the outset.

(1) Strategical design for innovative products; there is a negligible literature.

(2) The requirements of the patent examiners.

(3) Licensing.

(4) The financing of product development: scattered data exists.

(5) The application of (electronic) large scale integration, particularly the use of microprocessor based single board computers.

(6) The programming design strategy of "top-down design with step-wise refinement" with a modular structure being achieved by the use of sub-routines.

Without the goal of halting at the patenting stage having been set and before the vehicle patent specification had been drawn up an attempt was being made to acquire the knowledge which would enable detail design to be undertaken in the three problem sub-areas (vehicle, handling, and guidance). Little progress was being made. After the vehicle specification had been drawn up an understanding of the degree of detail required for patenting was achieved. By this time an understanding also of licensing, of the financial climate for machine development, of the implications of the existence of single-board-computers (and their development systems) and of modularity (applied more widely than just to software) had been achieved. The goal of stopping at the patenting stage and of seeking licensees was formulated. Work then went forward comparatively rapidly. The detail needed in the remaining sub-areas could be rapidly assessed from the relevant prior art. The scope of knowledge needed was still wide but it was manageable.

Appendix 1

Competition

Guide: Handling and storage.

There are two major families of seedling trees which have to be handled - bare-root seedlings and packaged root seedling ("plugs").

A mechanical plug planter must handle the commonly used range of types and sizes.

A mechanical bare-root planter must handle the commonly used range of types and sizes.

A planter which plants only bare-root seedlings will miss the Canadian (and the Scandinavian) market but will meet the majority part of the American market.

A planter which plants only plugs will miss the American market - this is the major market.

There is no existing commercially operational spot-planter of bare-root seedlings.

There is no mechanical handling system for spot planting bare-root seedlings.

There is no existing planter which will handle the full range of plugs.

There is no mechanical handling system. The operational handling systems which (in Scandinavian experimental planters) use blowing or dropping as a handling method. This does not result in a high enough percentage of correctly placed trees.

There is no operational mechanical tree planting device for logging cutover. On such sites trees are placed by hand.

We have attempted to design a tool which will:

(1) Place all types of seedling both bare-root and packaged root.

(2) Store, mechanically retrieve from storage and transfer to the ground all types of seedling both bare-root and packaged.

Important features of the combined handling and placement system:

(1) Each is held vertical and not released until backfilling around its roots or pack has taken place.

(2) The roots or the root pack are placed into an excavation, not dropped.

(3) The placement into an excavation of the roots or root pack takes place simultaneously with the making of the excavation. This enables the excavation to be small and avoid difficulties which arise when an attempt is made to fit roots or a root pack into an excavation.

(4) Doing this ensures that the roots are not bunched or "J"-ed or in the case of plugs that the pack is not crushed or bent.

Guide: Tool transportation.

Scandinavian planter are mounted on forwarders (four wheel-drive lorry) or on skidders (wheeled logging tractor). Neither of these carriers is either functionally or economically viable on cutover.

Tracked tractors can be used in North America on a small proportion of sites. If they are used then heavy clearing has to be performed; at present they are used with furrow planters which to be used demand that the ground be clear of obstacles. On some sites it may be cheaper to clear and then furrow plant than to clear and then hand plant if furrowing planting can be done simultaneously with clearing, the planting device being pulled by the clearing machine.

Tracked tractors are neither economically suitable, logistically suitable nor functionally suitable on the majority of sites.

The evidence which is available points to the conclusion that no thought has been given to the problem of tool carriage by the competition.

We have attempted to design a carrier which is suitable for tree planting and also for a range of other silvicultural and forestry tasks.

Competition: Spot Planters.

(1) Armstrong Project (British Columbia). Skidder mounted "gun" type planter of hard cased plugs. Believed to be hand loaded. Hard cased plugs are not used commercially.

(2) Alan Moss and Associates (Vancouver, B.C.). May be same as Armstrong Project. Attempting to mechanise the planting of soft-walled plugs, that is the normal package. Believed to be hand loaded.

(3) Brinkman Project. Skidder mounted "gun" type planter of plugs. Hand loaded.

(4) "B.C. Technology" information. An officer of the organization gave information about the existence of another project. It may be one of those already mentioned. No further information.

(5) North Carolina planter. Experimental hand loaded planter of bare-root seedlings. Pulled by tracked tractor.

(6) G.A. Serlachius Corporation (Finland). This system may be a furrowing one. Plants a specific plug, paper pot type. Carried on forwarder.

(7) Modo Mekan (Sweden). Plants two parallel rows fixed spot fashion. Forwarder carried. Delivery of plugs looks to be pneumatic.

(8) Doroplanter (Sweden). Similar to Modo Mekan.

(9) Hiko (Sweden). Four row fixed spot planter. Skidder carried. Pneumatic delivery. Otherwise similar to Modo Mekan.

(10) FIAB/Forestema (Sweden). Forwarder carried system. Places a specially designed package onto the surface of the ground. Conveyor feed.

(11) Panth. Skidder or forwarder mounted. Places plug by gravity into excavation and simultaneously loose back-fills.

Furrow Planters.

(12) Timberland (U.S.A./Canada). Intermittant furrower. Hand loaded. Logging tractor pulled. Believed to plant both bare-root and plug seedlings.

(13) Hodag (U.S.A./Canada). Similar to Timerland.

(14) One-Shot (U.S.A./Canada). Similar to Timberland.

(15) Hedeslskabet (Denmark). Tractor pulled. Hand loaded. Continuous furrowing.

(16) C and H (U.S.A.). Continuous furrower like Danish one.

(17) Mining site reforestation and reclamation equipment. Hybrid fixed spot planter with closure method like that of a furrow planter.

Hand Devices.

(18) Potti Putki (Finland). Hand "gun" planter of plugs. Thought to operate in similar manner to the hand tobacco transplanter.

(19) B.C. Forest Service (Canada). Hand "gun" planter of hard cased plugs.

Other work.

(20) The U.S. Forest Service has undertaken assessment work (See the Appendix on the retail price of a planter). It is not known whether any particular concept has been fixed upon.

Appendix 2

Tree seedling types, sizes and weights

In the U.S.A. 66% of trees planted are bare-root.

Corresponding figures for Canada as a whole have not been obtained. In British Columbia the most important forestry region in Canada, only 5 to 7% of trees planted are bare-root.

In Scandinavia packaged trees are planted.

Weights: Trees are not usually weighed, but some information exists for the purposes of judging helicopter loads. The following information was given verbally by the B.C. Forest Service.

Normal range packages:

Packages containing 300 - 350 trees weight between 25 and 50 pounds.

300 - 350 plugs can be usefully taken to weigh 40 pounds.

Abnormal range packages:

Larger plugs exist where 75 trees weight 40 pounds. These trees, in the region of three feet in height, are unusual.

Normal range bare-root:

The weight of 1,000 bare-root trees can be taken to be 30 pounds.

The remainder of this Appendix is abstracted from British Columbia, Ministry of Forests, 1984.

SEEDLING STOCK TYPE CLASSIFICATION

An increasing diversity of seedling stock types are now being produced for outplanting in British Columbia's reforestation programme. At present, a variety of descriptions may be applied to the same stock types. Some standardization in nomenclature used in descriptions is essential for stock ordering, future performance assessment relative to stock types used and in general reference, whether verbal or written.

The description, now in use, is based on species, age, basic stock type (with additional sub-descriptions to more closely identify other significant factors), stock dimension and, where necessary, an additional symbol(s) to identify other treatments.

In addition to the stock type classifcation, nursery inventory reports now give a physical description of planting stock based on three criteria:

a) seedling top height
b) seedling stem caliper
c) seedling shoot-root ratio (by weight measure)

Descriptive Components in Classification

a) Species (Appendix 6-12 of the Silviculture Manual)

b) Age

First digit - growing season(s) or part growing season, in initial medium. + second digit - growing season(s) in subsequent medium. e.g. 2+1, 1+1, 1 1/2+1, etc. Emergent type seedlings will have a 1+0 designation with an additional symbol under special treatment.

c) Basic Stock Types

i) B - Bareroot - roots develop freely in beds.

ii) C - Containers - grown in a container and planted in the same container (e.g. bullet, paper pot).

iii) P - Plug - shaped root system, grown in container, extracted for planting (e.g. CFS/BCFS styro plug; Leach plug, etc.).

A sub-designation of the basic type indicates additional treatment or a derivative, a trade name or inventors name for a stock type.

e.g. Sub-designation of "B"

MP - Mudpacks Pelton System
NR - Nisula Roll

Sub-designation of "P"

SB - CFS/BCFS styro system
RL - Ray Leach system

Sub-designation of "C"

BW - Walters Bullet
PP - Paper Pots

Full Designation

BMP BNR BBR
CBW - Walters Bullet
CPP - Paper pots (present designation in use)
PRL - Ray Leach
PSL - Spencer Lemaire - Root Trainer
CSS - Structure soil

d) Stock Dimension

i) Bareroot - add suffix; average top height in cm, and average stem caliper in mm. (Nurseries provide this information in their morphological description of stock.)

e.g. F 2+0 BBR 25/6 Av. top height (25cm)
Av. stem caliper (6mm)

ii) Containers, Plug or Encased Bareroot

Top diameter or side dimension (square) to the nearest centimetre; length to the nearest centimetre. e.g. Mudpack 214; top diameter 2 cm, length 14 cm; Styroplug 211; top diameter 2 cm, length 11 cm.

Examples of full description using above 4 components:

1) F 2+0 BR 25/6

2) F 1+0 PSB 211 - CFS/BCFS styro block plug 2 cm x 11 cm

3) F 1+0 CBW 210 - Container Walters Bullet 2 cm x 10 cm

4) F 1+0 CPP 415 - Container Paper pot 4 cm x 15 cm

Silviculture

e) Additional designation to identify special treatments, additives, mixes, etc. where for future reference or assessment the extra information is significant.

This information will appear at end of the basic description following a (+) sign and a list of code letters will be developed as required. Some currently in use are designated below, under various headings:

i) Container Material

Wood (W); Plastic (Pl); Paper (Pa); Peat (Pe); Biodegradable (BD)

ii) Shape

Square (S); Round (R); Triangular (T)

iii) Foliar Treatment

Transpiration treatment (TR)
Browsing repellant (Br)
Top pruned (TP)

iv) Root Treatment

Pruned (PR)
Growth stimulant (GS)

v) Origin

Cuttings (Cu)

vi) Issued to Field as

Emergent seedlings
Heeled-in (H)
Stock sent for mudpacking, sorted not packed, returned as bare root - (UP)

Examples of full description:

a) Walters Bullet grown as 1+0 emergent type, in square plastic bullet with root hormone.

F 1+0 CBW 210+S (shape)/GS (root hormone)/E (emergent type).

Silviculture

TABLE OF DESCRIPTION

COMMON STOCK TYPES

STOCK TYPE		DIMENSIONS		DESIGNATION	
BASIC	SPECIFIC	BR-TOP LENGTH cm C, P, TOP DIA. cm	ROOT COLLAR DIA. mm LENGTH cm	PREVIOUS	CURRENT
Bareroot (B)	BR			BR	BR plus top length (cm) and root collar dia. (mm) e.g. BR 20/6
	Hudpack (HP)	Top Dia. of pack (cm) 1.6 2.2	Pack Length (cm) 14 18	or 14 cm 1-0 (5 1/2") HP 2-0 (7") HP or 18 cm	BHP 214 or B 15/3 HP 214 BHP 218 or B 20/4 HP 218
	Nisula Roll	Top Length cm	Root Collar	Nisula Roll	BNR 20/6
Plugs (P)	Styro Block (SB)	Top Dia. cm 2.5 3.0 2.8 3.9	Length cm 11 12.7 13.3 15	2A 4 4A 8	PSB 211 PSB 312 PSB 313 PSB 415
	Ray Leach Cells (RL)	2.5 2.5	12 16	Fir Cell Pine Cell	PRL 212 PRL 216
	Spencer Lemaire Root Trainers (SL)	2.2 x 1.9 2.8 x 2.0 3.8 x 3.7 4.6 x 4.0	10 10 12 20	Ferdinand Five Hillson Tinus	PSL 210 PSL 310 PSL 412 PSL 520
Containers (C)	Paperpots (PP)	3 3.8 4	15 7.5 15	FH 315 FH 408 FH 415	CPP 315 CPP 408 CPP 415
	Walters Bullets (BW)	1.9	10	4" square	CBW 210

Mechanical Silviculture

Appendix 2

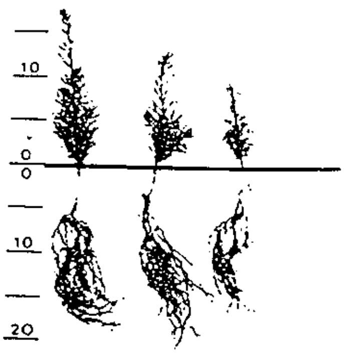
Silviculture

EXAMPLE OF COMPARISON OF ESTIMATED COSTS FOR VARIOUS SITE PREPARATION/PLANTING ALTERNATIVES BASED ON OBSERVED FIELD PERFORMANCE AND ESTIMATED COSTS AND PLANTING PRODUCTIVITY - Updated June '82*

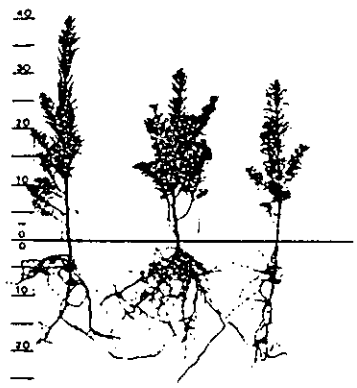
(original as per E. Van Eerden, Canadian Forestry Service, Nov. '76)

Stock Type	Nurs. Costs $/M	Site Preparation None $/hectare	Site Preparation Burn $/hectare	Site Preparation Scalp $/hectare	Debris Clear	Est. Plan Prod. Trees 8-hr. Day Nos.	Est. Plan Prod. Costs $/Day	Survival Percent	No. of trees for 1000 live trees/ hectare in 5 yrs. Nos.	Plant Costs $/ha	Nurs. Costs $	Total Establ. Costs $/ha
B.R. 2-0	45	0				1350	75	50	2000	428	88	516
	45		74			500	75	65	1538	230	70	374
	45			148		800	75	60	1667	156	74	378
	45				111	700	75	75	1333	143	59	313
B.R. 2-1	90	0				300	75	75	1333	333	119	452
	90		74			450	75	80	1350	208	111	393
	90			148		700	75	75	1333	143	119	416
	90				111	600	75	80	1250	156	117	379
Plug 2 (1-0)	60	0				700	75	75	1333	143	79	222
	60		74			900	75	80	1250	104	74	252
	60			148		1100	75	75	1333	91	79	318
	60				111	1100	75	80	1250	85	74	270
Plug 2 (2-0)	80	0				800	75	85	1176	110	94	204
	80		74			1000	75	85	1176	88	95	257
	80			148		1200	75	80	1250	78	99	325
	80				111	1200	75	85	1176	71	94	276
Plug 2/BR Transpl. (1-1)	90	0				300	75	65	1538	384	135	519
	90		74			450	75	70	1429	238	126	438
	90			148		700	75	65	1538	165	136	449
	90				111	600	75	70	1429	179	127	417
Plug 8 (1-0)	180	0				500	75	75	1333	200	237	437
	180		74			650	75	80	1250	144	223	441
	180			148		800	75	75	1333	125	237	510
	180				111	800	75	80	1250	117	223	451
Plug 8 (2-0)	200	0				600	75	85	1176	147	232	379
	200		74			750	75	80	1250	125	233	432
	200			148		900	75	85	1176	98	247	493
	200				111	900	75	85	1176	98	233	442
Walters 4 1/2" Bullets (1-0)	75	0				1000	75	70	1429	107	107	214
	75		74			1200	75	75	1333	83	99	256
	75			148		1600	75	70	1429	67	106	321
	75				111	1600	75	75	1333	62	99	272
Mudpack (2-0)	85	0				400	75	60	1667	312	141	453
	85		74			565	75	65	1538	204	128	406
	85			148		900	75	60	1667	139	141	428
	85				111	900	75	65	1538	128	114	353

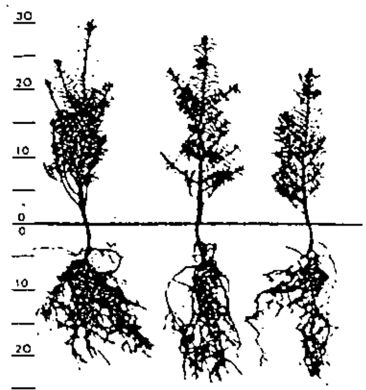
*To calculate standard costs for a specific operation or district, plug in relevant figures based on experience in that specific area.



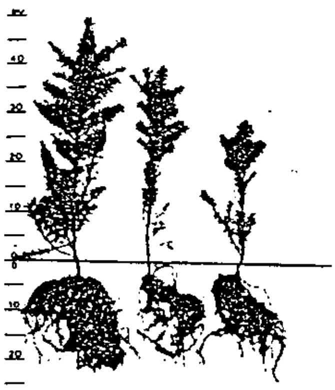
F(c) 1+0 BR 12/3 1.6



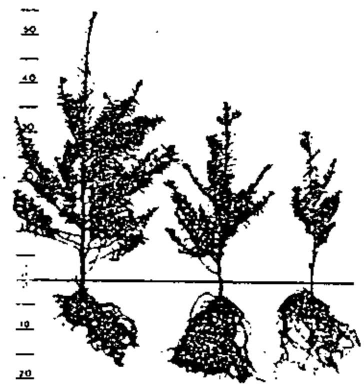
F(c) 2+0 BR 30/6 2.7



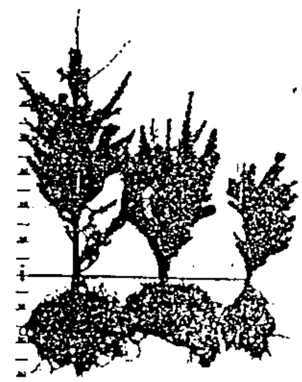
F(c) 1+1 BR 27/6 1.6



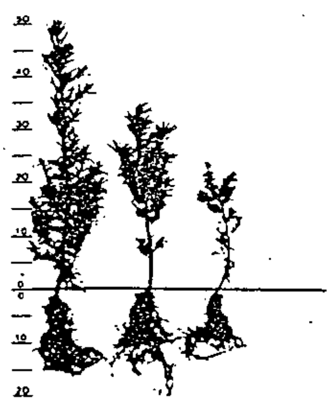
F(c) 2+1 BR 38/5 1.4



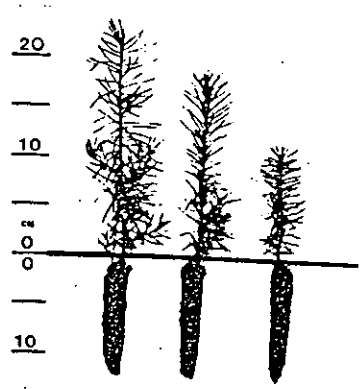
F(c) 1+2 BR 35/7 1.6



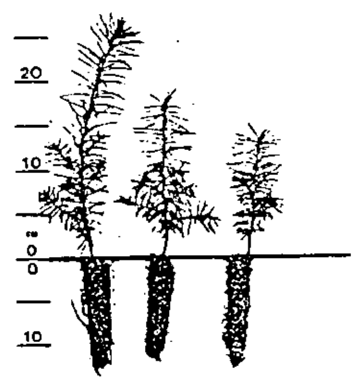
F(c) 2+2 BR 58/14 2.1



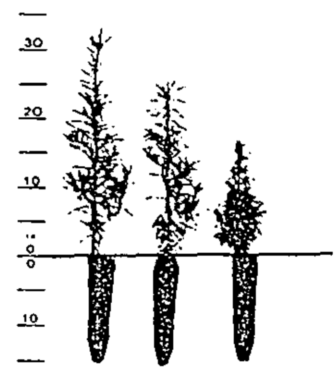
F(c) 1+1 PSB/BR 34/7 1.8



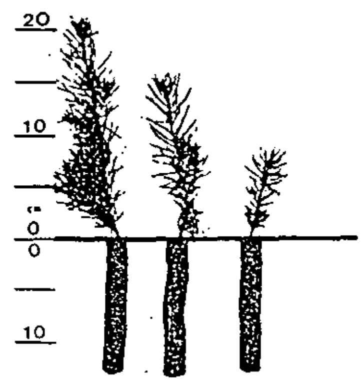
F(c) 1+0 PSB 211 17/2 1.7



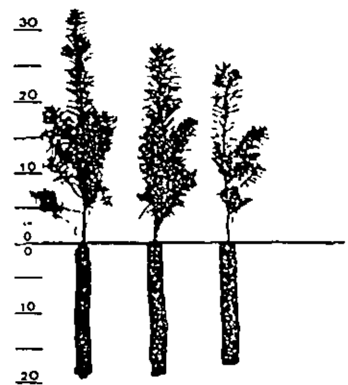
F(c) 1+0 PSB 313 17/3 1.8



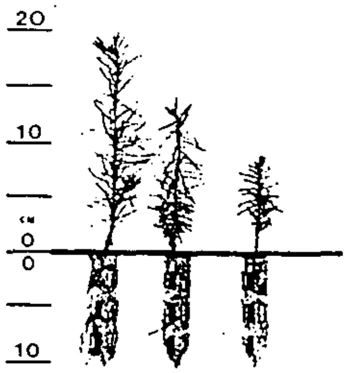
F(c) 1 + 0 PSB 415 24/4 1.5



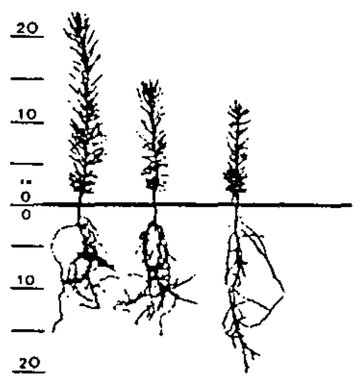
F(c) 1 + 0 MP 214 14/2 1.9



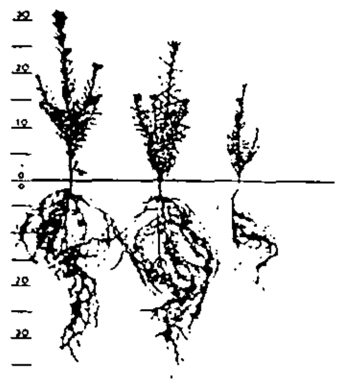
F(c) 2 + 0 MP 218 26/6 1.8



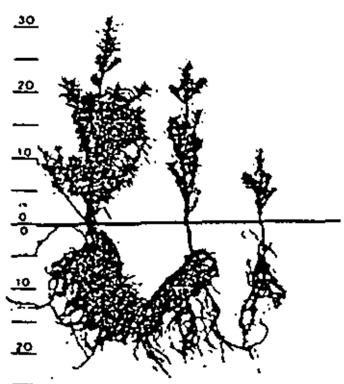
F(c) 1 + 0 CBW 210 14/2 2.2



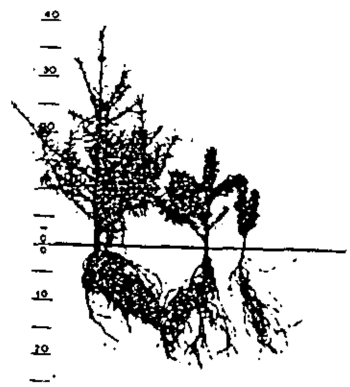
F(i) 1 + 0 BR 13/2 2.6



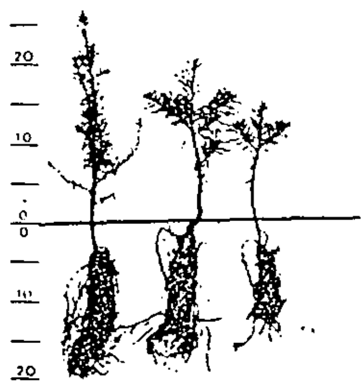
F(i) 2 + 0 BR 25/7 1.8



F(i) 1 + 1 BR 24/6 1.6



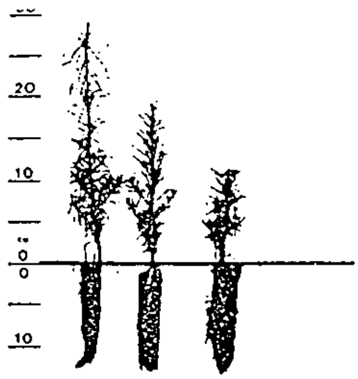
F(i) 2 + 1 BR 17/8 1.3



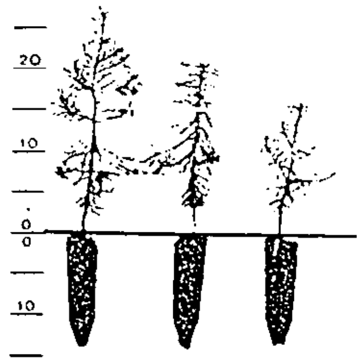
F(i) 1 + 1 PSB/BR 19/7 1.0

Appendix 2

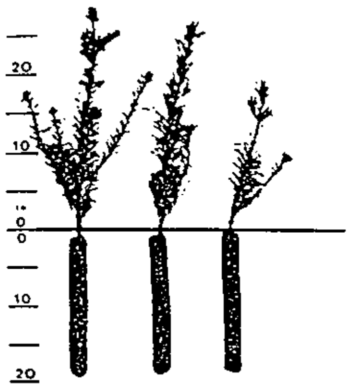
F(i) 1 + 0 PSB 211 17/2 1.6



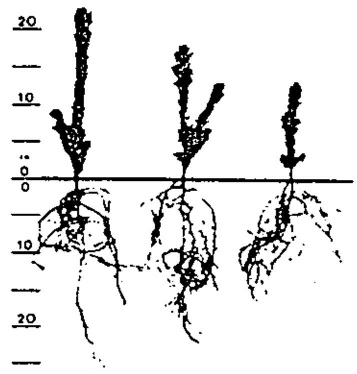
F(i) 1 + 0 PSB 313 18/3 1.9



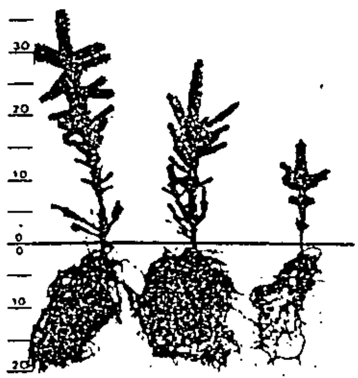
F(i) 1 + 0 PSB 415 20/4 1.5



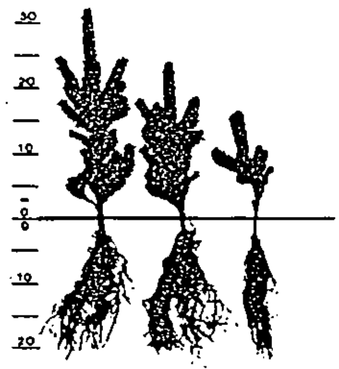
F(i) 2 + 0 MP 218 26/6 1.8



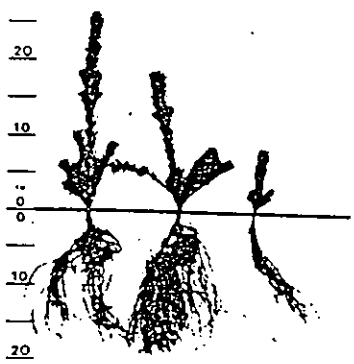
S(i) 2 + 0 BR 17/4 1.8



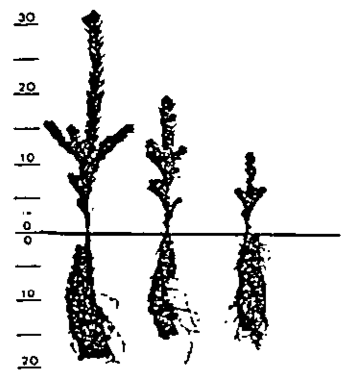
S(i) 2 + 1 BR 29/8 1.8



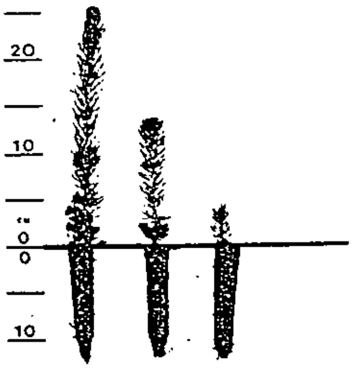
S(i) 1½ + 1½ BR 24/4 1.3



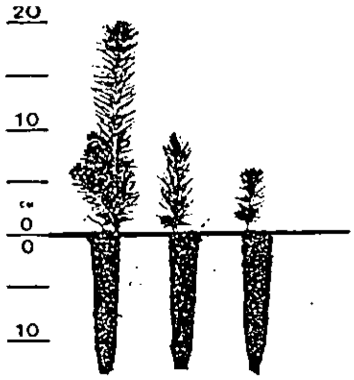
S(i) 1½ + ½ BR 20/4 1.4



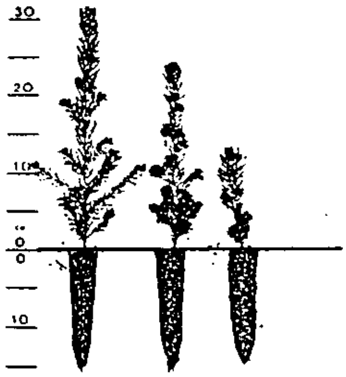
S(i) 1 + 1 PSB/BR 20/4 1.6



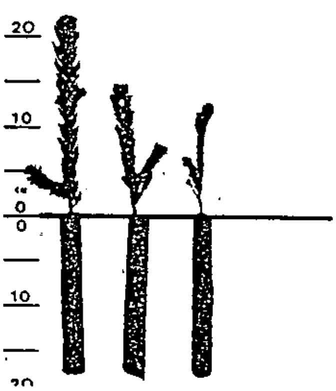
S(i) 1 + 0 PSB 211 13 2 2.0



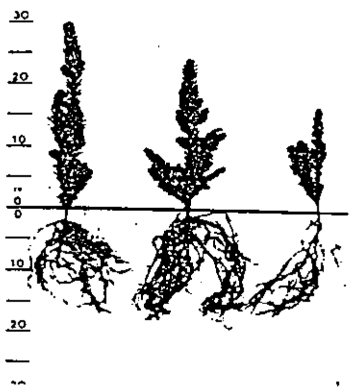
S(i) 1 + 0 PSB 313 8/2 1.3



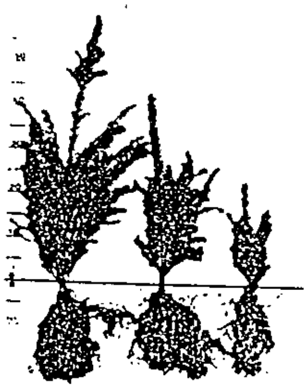
S(i) 1 + 0 PSB 415 24/4 3.3



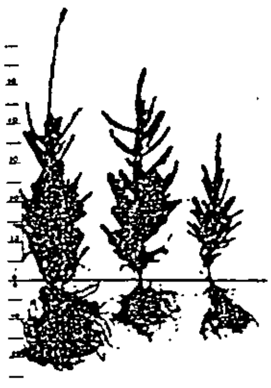
S(i) 2 + 0 MP 218 13 4 1.8



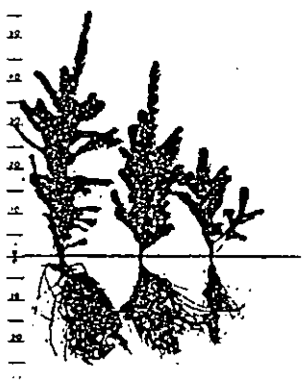
Ss 2 + 0 BR 23/6 2.1



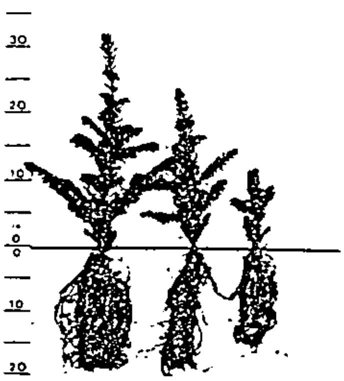
Ss 2 + 1 BR 41/12 2.3



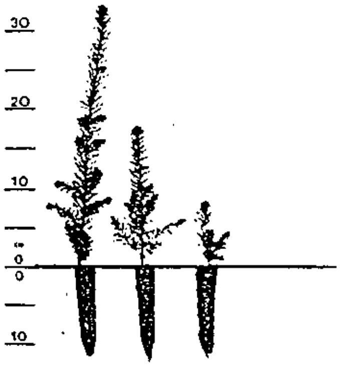
Ss 1 + 2 BR 55/11 2.3



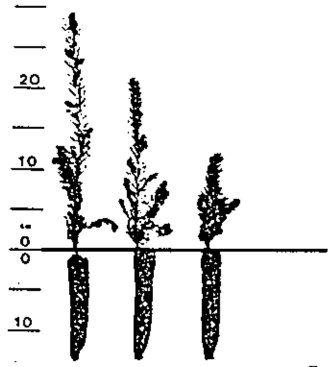
Ss 1½ + 1½ BR 43/9 2.3



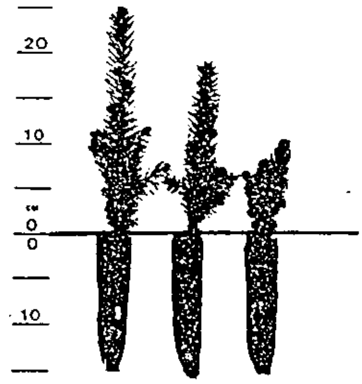
Ss 1 + 1 PSB·BR 23/6 1.4



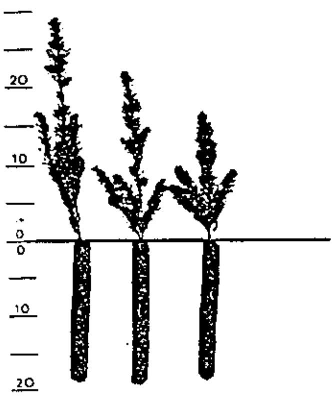
Ss 1 + 0 PSB 211 17 4 1.3



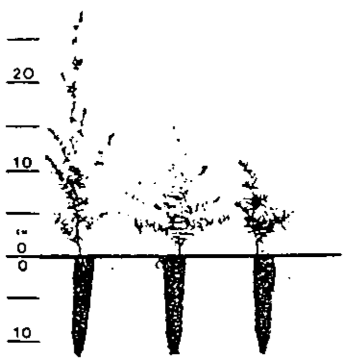
Ss 1 + 0 PSB 313 21/3 1.7



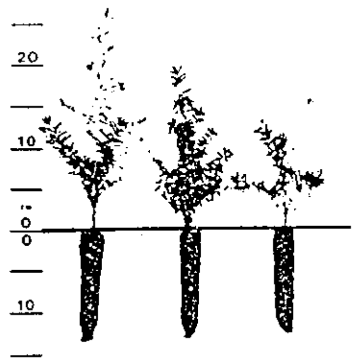
Ss 1 + 0 PSB 415 19/3 1.5



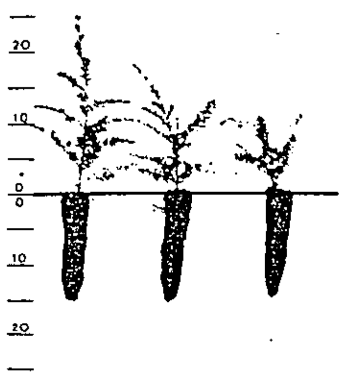
Ss 2 + 0 MP 218 23/4 2.1



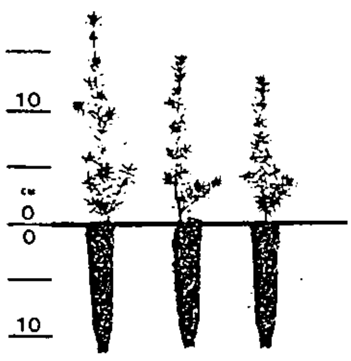
Hw 1 + 0 PSB 211 15/3 2.1



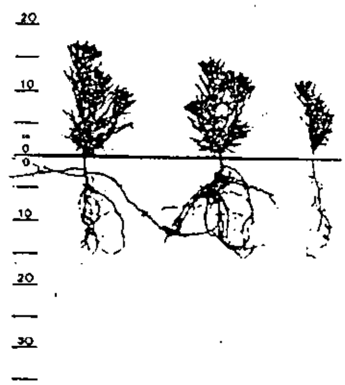
Hw 1 + 0 PSB 313 19/2 2.8



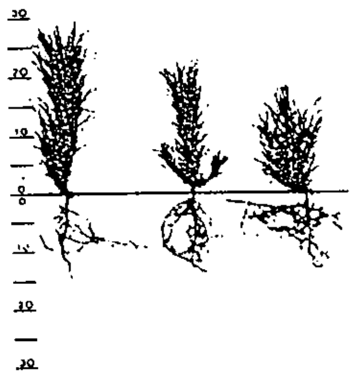
Hw 1 + 0 PSB 415 19/3 1.7



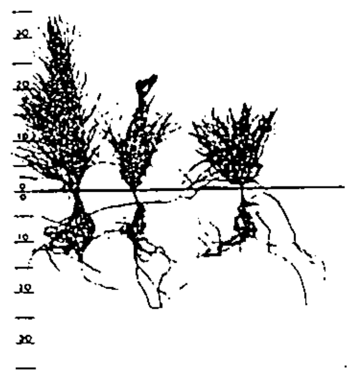
Hm 1 + 0 PSB 211 14/3 1.8



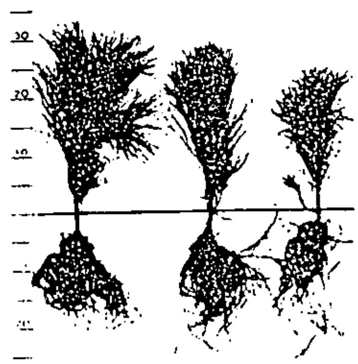
Pl 1 + 0 BR 14/4 2.6



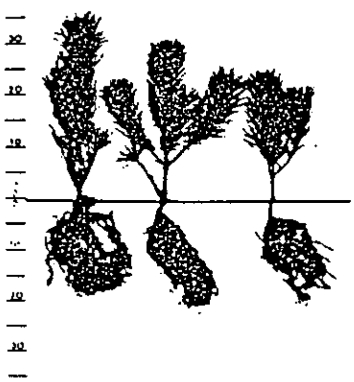
Pl 2 + 0 BR 16/4 3.7



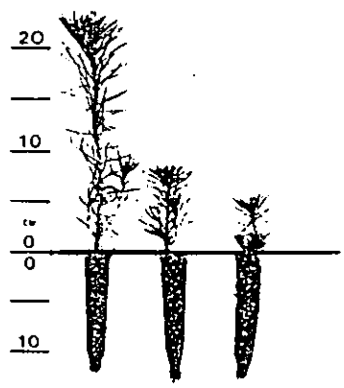
Pl 1 + 1 BR 20/5 4.3



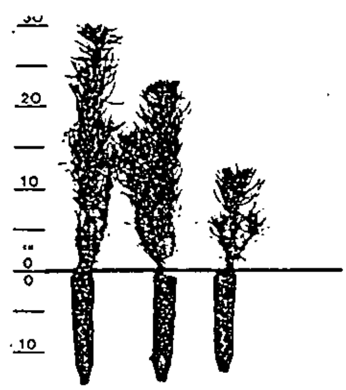
Pl 1½ + ½ BR 26/7 2.9



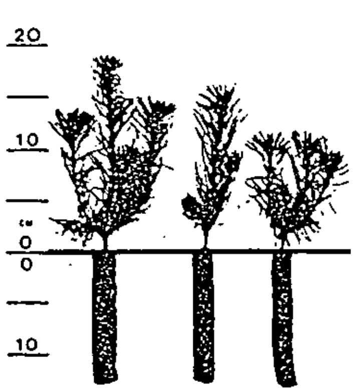
Pl 2 + 1 BR 29/10 2.7



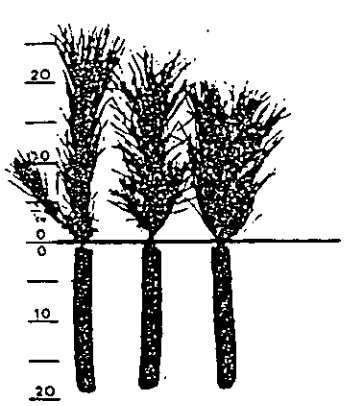
Pl 1 + 0 PSB 211 8/2 1.1



Pl 1 + 0 PSB 313 23/3 3.4



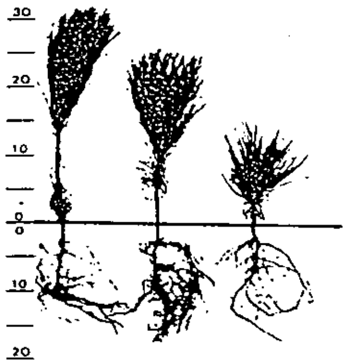
Pl 1 + 0 MP 214 14/2 2.6



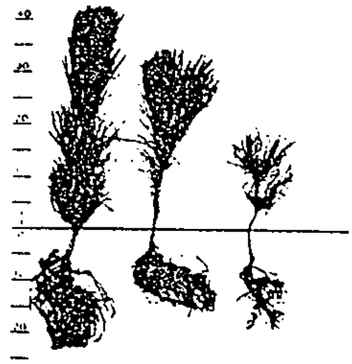
Pl 2 + 0 MP 218 18/4 3.7

Pl 1 + 0 CBW 210 18/3 2.1

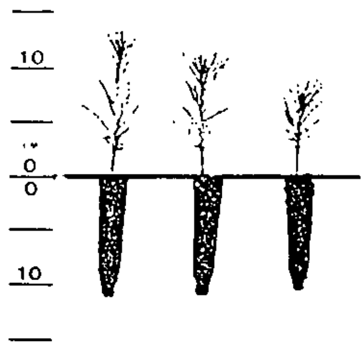
Appendix 2



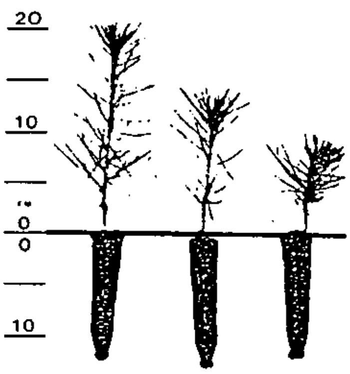
Py 2+0 BR 14/5 3.1



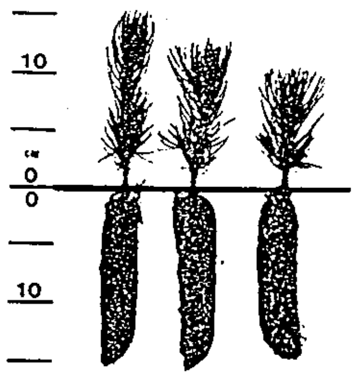
Py 2+1 BR 28/6 2.4



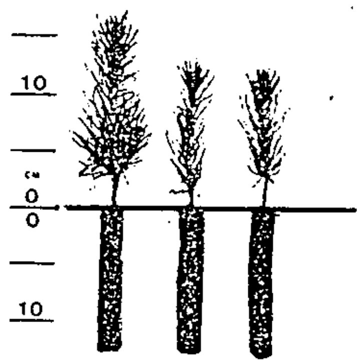
Py 1+0 PSB 211 10/3 1.0



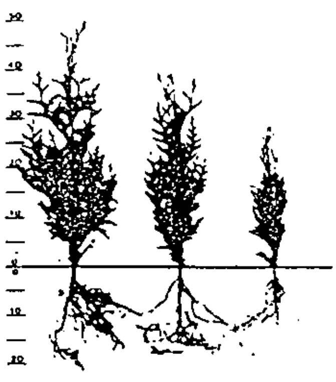
Py 1+0 PSB 313 12/3 1.2



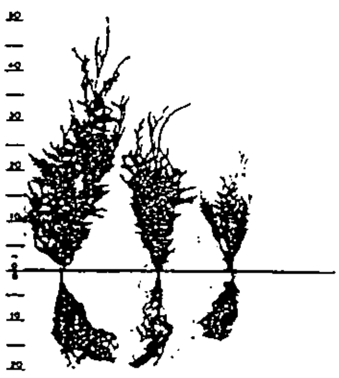
Py 1+0 PSB 415 10/3 1.1



Py 1+0 MP 214 12/3 3.0



C 2+0 BR 40/6 4.5



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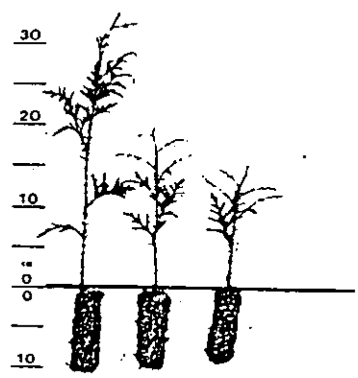

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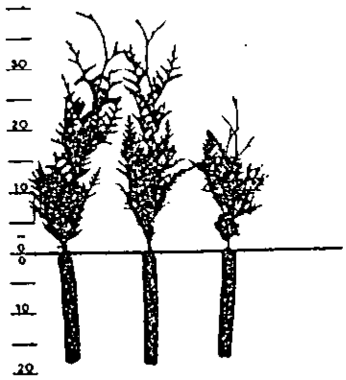
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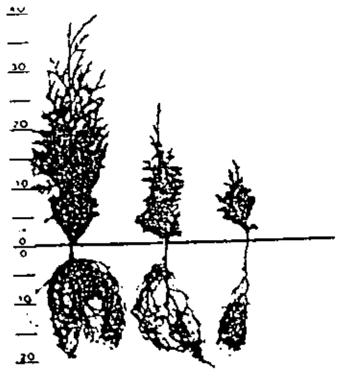
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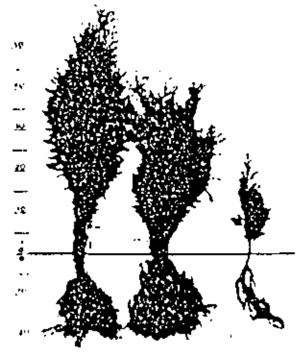
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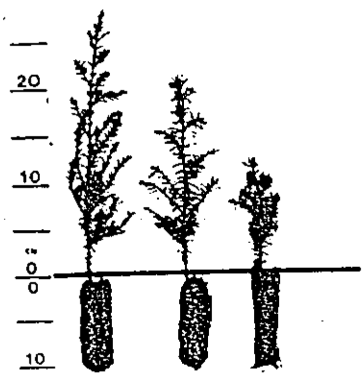
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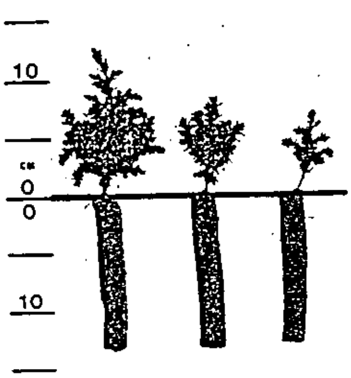
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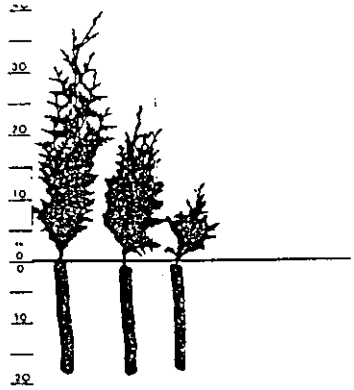
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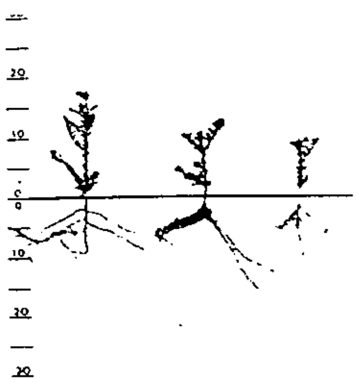
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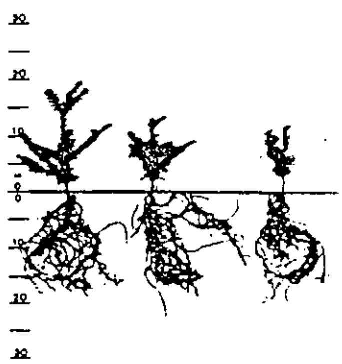
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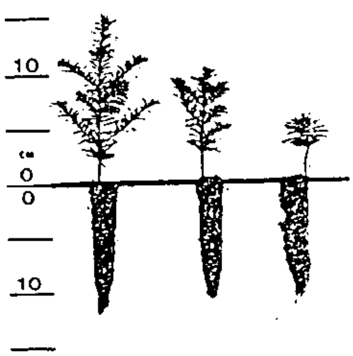
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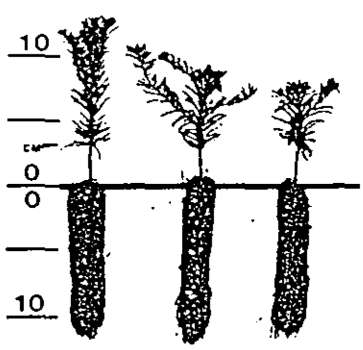

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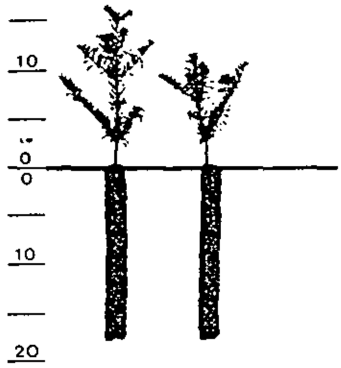

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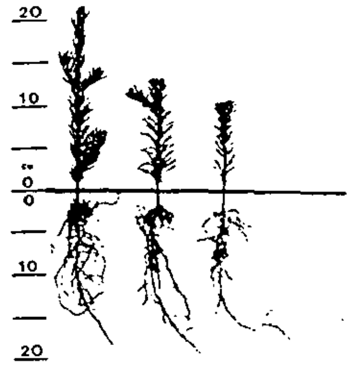

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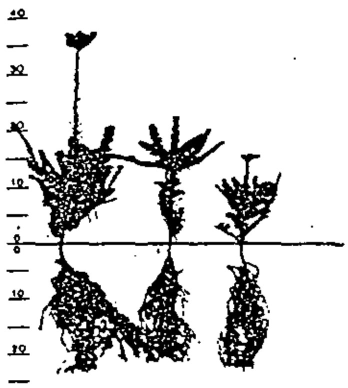

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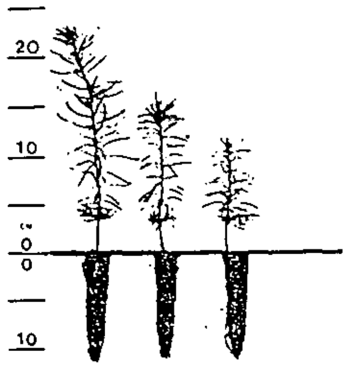

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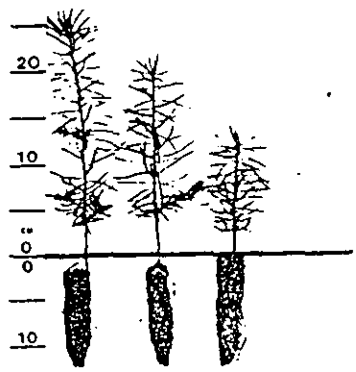

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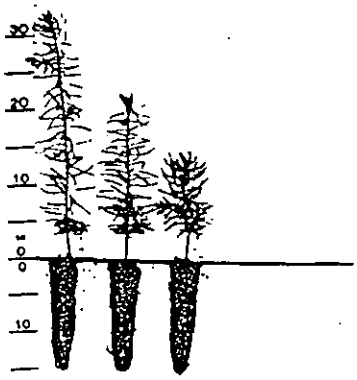

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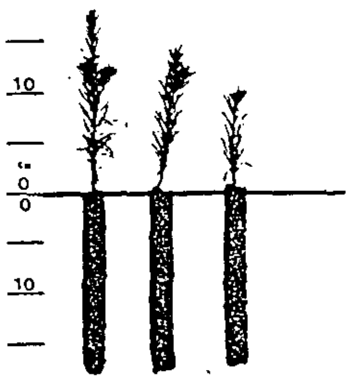

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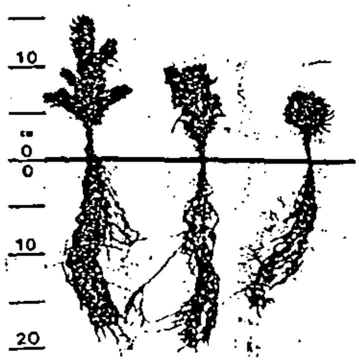

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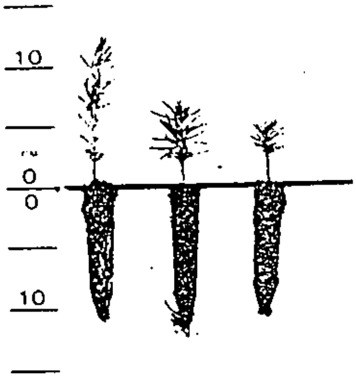

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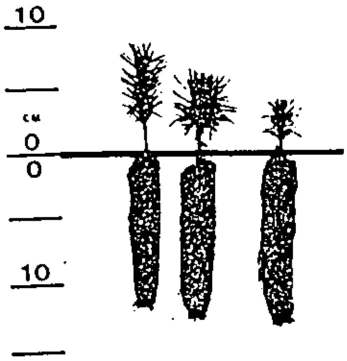

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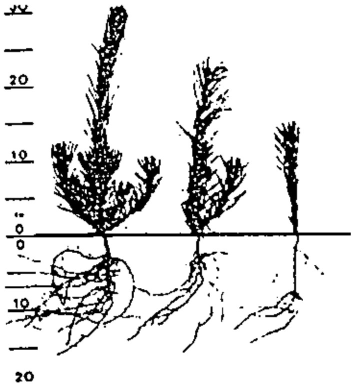

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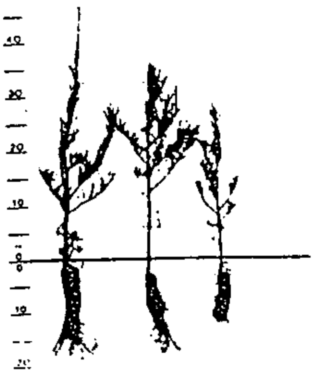

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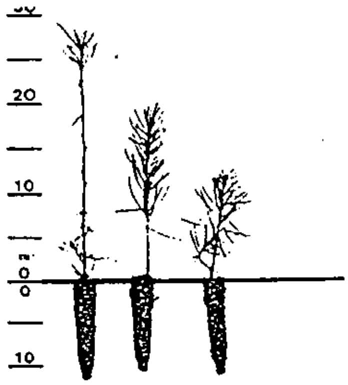

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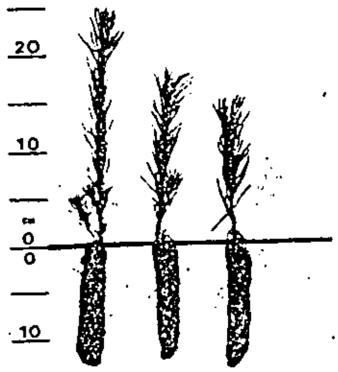

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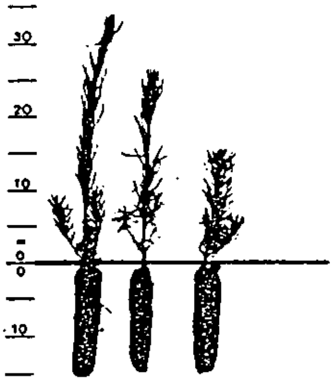

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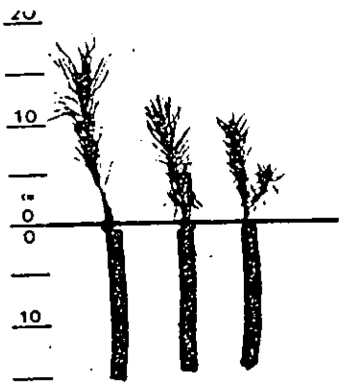

Lo 1 + 0 MP 214 10/2 1.7

Appendix 3

Planting Methods and the Work Sequence

Two basic planting methods can be distinguished:

(1) Furrow planting;

(2) Spot planting.

Furrow planting, a mechanical method, uses standard farm-field furrowing technique. Because of the presence of obstacles on logged sites the method is unsuitable for planting trees unless heavy clearing is performed. Because of the cost of clearing there is a demand for a method which avoids the need for it.

An attempt has been made to adopt furrow planting to sites where there are obstacles by intermittently furrowing. Short furrows with unfurrowed gaps between them are used. The method has not found acceptance. It is not suitable on logged sites unless considerable clearing has been performed.

In "spot" planting, each tree is individually placed in a "chosen" spot. No furrowing is performed. In standard methods an excavation is made, the tree placed in the excavation which then closed.

Two forms of spot planting can be distinguished:

(1) "Fixed" spot planting;

(2) "True" spot planting.

Fixed spot planting is performed by those Scandinavian planter which use more than one tool. The tools are arranged in fixed positions on a carrying frame. The operator causes each of the tools to plant intermittently with each position planted having as close as possible a fixed interval from the tree previously planted by the same tool. In effect the tool array plants two or more parallel rows with each tree in a row being at a fixed interval from any adjacent tree. Some fixed planters will recognize an obstacle to planting and miss a position in a row. (We are not sure of the form of this recognition but we believe that it works on some such principle as that of the unusual compression of a spring such as could occur if the excavating tool hit a rock.) Fixed spot planting is suitable for rougher ground conditions than furrowing but on North American logging cutover it will result in under planting.

True spot planting is performed by hand planters and by the mechanical system which is being developed in this thesis. Here the planter (man or machine) attempts to plant at an ideal inter-tree distance. If this is not possible (due to obstacles) the planter seeks to find a spot within a tolerance region adjacent to the ideal position. True spot planting can result in stands of the required density being planted in heavily obstructed ground. The site preparation needed is less than that for any other method provided that a carrier is available which can negotiate logging slash and naturally occurring ground obstacles. A man on foot can do this. The stepping vehicle is intended to do so.

It is expected that the work sequence for mechanised planting will, at least to begin with, be a modification of the presently used hand planting sequence.

Hand planting contracts are awarded to contractors who bid for them in competition with other contractors. A bid is for a cost per tree (say 25¢ Canadian).

In British Columbia the Forest Service advertises contracts and invites tenders. Commercial companies commonly send invitations to bid to selected contractors; an experienced contractor can ask to be considered.

Before tenders are accepted for a site it is viewed. Viewing is satisfactory; bids are not accepted from contractors who have not viewed a site.

Viewing commonly takes place in the fall of the year; some viewing is done in the spring.

Once a contract is awarded a fixed starting date is arranged.

The organization awarding a contract supplies the trees for the contract. The types of seedling to be planted are stated on the contract form. An arrangement is made for getting the trees to the worksite.

A contract is for a given number of days. Trees are expected to be planted at a given rate. With this established the rate of delivery of trees can be arranged.

Delivered trees are carefully stored. The method of storage may be stated in the contract but is commonly arranged by word of mouth - both parties understand what is needed. The leas that is needed is that the trees be stored in the shade with good air circulation around them.

Planting crews are, with few exceptions, paid a piece rate - a certain amount per tree which has been planted and where the samples of planting taken by the contractor's supervisors and the supervisors of the organization granting the contract are up to standard for density and quality of placement.

It is common in British Columbia for planting crews to camp on a planting site for the duration of a contract. The crews, assembled by a contractor, move around the country from contract site to contract site.

The trees are supplied to a planting crew from a nursery. Nurseries are now all commercial. Until recently there were both governmental and commercial nurseries. The trees to be planted, if they are bare-root are lifted from the ground, the earth is shaken off, they are rot trimmed, packed into counted bundles (say 50 to a bundle) and the bundles packed into cardboard boxes having a moisture proof inner bag (waxed paper), 1,000 or so to a box.

Trees to be planted out are lifted whilst dormant and cold stored prior to their being delivered for planting. The trees are planted whilst still dormant.

Packaged root trees are handled and stored similarly. No root trimming is needed.

Appendix 4

The specification is given by headings only. The full contents are retained as an exhibit.

"Commercial" and "technical" aspects of the design interact. Both are included in the specification.

At the beginning of this work the existence was recognized of a demand for means of speeding up tree planting, lowering the cost of tree planting and improving the quality of tree planting.

The demand (still unmet) is expressed two ways. One is for a logging tractor pulled or carried mechanical device. The other is for a hand-tool which will enhance the capability of the hand planter.

The majority demand is for a tractor based device.

There is to date no commercially operational tractor based device which will satisfy the majority demand. Neither is there a hand-held device which will replace the traditional hand-tools (shove, mattock, and dibble) and provide the hand planter with increased efficiency and quality.

The two solution types, tractor based and hand-held, are very different. The only operational solution at present is to plant by hand. In this position parametric analysis of existing products is not useful. At most it shows a gap which is already known to be there.

No straightforward way of drawing up a specification suggested itself. The procedure which was followed is described here. The problem of finding a procedure - one is dealing with the problem of problem definition - was the most difficult problem faced in dealing with this design.

It was decided that a hand-tool solution which was both functionally and commercially viable was unlikely to be obtainable.

Whether a tractor based solution was solvable was unknown, but one was forced either to drop the problem or go in that direction.

The restriction to existing types of carrying vehicle implicit in the demand was discarded. It was suspected that logging tractors, the only vehicles approaching adequacy, were unsuitable.

An attempt was made to make explicit leading attributes which vehicle/tool system would have to satisfy (e.g. speed range, clearance, spatial dimensions, mass, logistics, economics, slopes, planting rates, seasonal use, bid price range, rate of return, other uses, etc.).

Attributes were sought which were likely to "fix" a design, that is, form the main part of a specification which would confine a solution sufficiently for it to be conceptually workable.

At the same time, having decided to make a preliminary exploration of a vehicle/tool solution, the categories of a comprehensive specification were collected together and explored for content. No attempt was to be made to satisfy any but what appeared to be main attributes (initially) until a more detailed stage of work. At some time if the work progressed that far, each item in the whole collection would have to be considered. It was possible that some items might be found to take on significance at an earlier stage so that the collection was kept in mind and referred to from time to time.

With what appeared to be leading attributes for a vehicle having been made explicit it was found that the existing carriers did not satisfy them (economic, logistic, dimensional and functional factors). An examination of alternatives was made (e.g. helicopters, airships, balloons, hovercraft). The logistics, associated tasks needing a suitable vehicle for tool carriage, the end users, the existing pattern of employment and the existing financial organization associated with forestry undertakings suggested the appropriateness of a comparatively small, light, ground vehicle as a tool carrier. An attempt would have to be made to design such a vehicle from scratch. The attributes which appeared to be associated with it did not look to be satisfied by a conventional wheeled vehicle nor a tracked vehicle.

An examination was made of the potential use of a vehicle which satisfied the collection of attributes by which the tool carrier was at this point described. Such a vehicle was seen to have to have wide potential use both civil and military. The commercial potential associated with the vehicle was judged to be sufficient to justify further exploration of the problem of mechanising planting.

At this point a reasonable seeming solution seemed to be that of a ground vehicle, comparatively small and light which moved at comparatively slow speeds, which carried an array (initially eight or more tools was considered - it was seen later that a single-pass system could use less tools) of tools whose individual rate of operation was comparatively slow (i.e. comparable to that of a hand planter). Handling was to be automatic, placement into the ground was to be automatic, the full range of commonly used seedling types was to be handled, the vehicle/tool system was to be guided by one man. (In the text specific ranges of values are given.) These choices gave rise to two further problems - spacing and choice - which had to do with unloading the operator of the task of guiding each tool in detail; there was not enough time for him to do this.

From this exploration the main "technical" sub-problems needing to be solved emerged.

As work on each sub-problem progressed return was repeatedly made to an examination of the demands (i.e. the initially chosen attributes for a solution) which had been made upon a solution. Did they seem to be producing a "balanced" design? ("unbalance" - If a collection of attributes gave rise to a demand that a tool plant a tree in (½) seconds the collection would be judged to be "unbalanced". Planting at this rate in the conditions met with on logged ground does not look to be readily approachable. It might be possible. Since it is known that a man can plant at a rate which is in the region of one tree every 30 seconds it does not seem unreasonable to demand that a tool plant at this rate.)

Less general demands were revealed. They were added to the specification. Changes were made where necessary.

The work progressed in this way cycling between the specification and the sub-problems of the conceptual design. Cycling occurred also between sub-problems. A specification and a conceptual design solution emerged from this activity, at first with both tentative and then more firm as a balanced seeming solution to, at this stage, the main parts of the whole problem was developed.

Unless there is a radical change of technology, where a product area is well developed the greater part of the attributes for a specification and even the values of these attributes will be fixed. It seems to the writer that the same pattern of activity as that just described nonetheless takes place in working out a specification but the unknown portions are very much more confined with what is unknown usually being the value of an attribute rather than the attribute type itself.

1. **Specification Contents**

Abuse resistance
Acceptance by purchaser, conditions of
Access to work site as it affects the design
Aesthetics
After sales service
Alternative uses and potential development
Auxiliary attachments
Bid prices for planting
Cab roll-over protection
Capital, sources and costs
Codes and standards
Company constraints
Competition
Conditions in use
Consumer protection
Control of part size and part diversity
Control of planting devices
Cost of ownership
Cost of capital used in order of magnitude, calculations of price and cost
Costing
Costs - electronic
Costs - if capital borrowed
Customers
Developability
Disposal
Environment
Ergonomics
Expected pattern of sales
Fire Prevention
Forecast Market Size

Forecast Monopoly Time

Forward speed

Freightability

Guarantees

Hand (planting) prices

Hazards

Hazards and liability

Hours of operation per year

Information from supplier to user

Insurance

Language of Users

Machine cycle

Machine (seedling) preparation types

Machine facilities for operator

Maintenance

Manufacture - main methods

Manufacture - type

Market constraints

Market size

Materials

Mobility to and from planting site

Number to be produced

Obstacle height

Operating costs

Operator

Packing and protection

Parts

Patents

Performance

Pests

Planting conditions

Planting pattern

Planting method

Planting rate

Planting requirements

Planting spot choice

Planting spot cultivation

Planting tool

Political problems

Potential to do related tasks

Power source

Power source failure - contingency

Preferred sizes

Preparation of seedlings

Procurement of materials

Product life span

Product life span

Prospective markets

Quality

Rate of planting

Rate of return

Reaction (amount of capital required)

References

Reliability

Roadability

Safety

Service - conditions of

Service - after sales

Service - life between overhauls

Service - inspectability

Service - malfunction leading to stoppage in the bush

Serviceability

Shelf-life

Silviculture - density of planting

Silviculture - planting sites

Silviculture - transplant preparation

Silviculture - quality control
Silviculture - supporting organization
Silviculture - operational sequence
Silviculture - site preparation costs
Silviculture - spacing from planted margins
Silviculture - spacing from unplanted margins
Silviculture - spacing of trees
Silviculture - individual machine planting rate
Slope
Stability
Standard (see codes and standards)
Standard assessment procedure
Standardization
Statutory regulations, legal requirements
Storage (single use vehicle)
System, overall form
Terrain
Testing
Time scale
Time into market
Transportation to buyers
Tool Kit
Tree storage on machine
Tree storage - on site
Trees - packing and preparation
Tree placement
Tree sub-storage packs
Tree types and sizes
Units
User training
Vehicle - abuse resistance
Vehicle - aesthetics
Vehicle - area of use, silvicultural

Vehicle - assembly and disassembly
Vehicle - ground environment
Vehicle - ability over banks
Vehicle - construction
Vehicle - construction facility
Vehicle - control
Vehicle - flotation
Vehicle - ground clearance
Vehicle - electronic/electrical code
Vehicle - haulage and shipping
Vehicle - initial annual construction
Vehicle - first estimation of production cost
Vehicle - initial development
Vehicle - first estimation of selling price
Vehicle - marketing
Vehicle - materials
Vehicle - number of operators
Vehicle - power distribution
Vehicle - price use
Vehicle - probable location of construction facility
Vehicle - range of models
Vehicle - roll-over protection
Vehicle - safety
Vehicle - seating, driver position controls
Vehicle - maximum size envelope
Vehicle - speed
Vehicle - stability
Vehicle - codes and standards
Vehicle - stresses
Vehicle - terrain
Vehicle - terrain classification
Vehicle - type
Vehicle - underbody protection

Vehicle - private and potential use

Vehicle - weight laden

Vehicle - weight of load

Working life of planting system

Appendix 5 The Retail Price of a Hypothetical Planter (McKenzie, 1981)

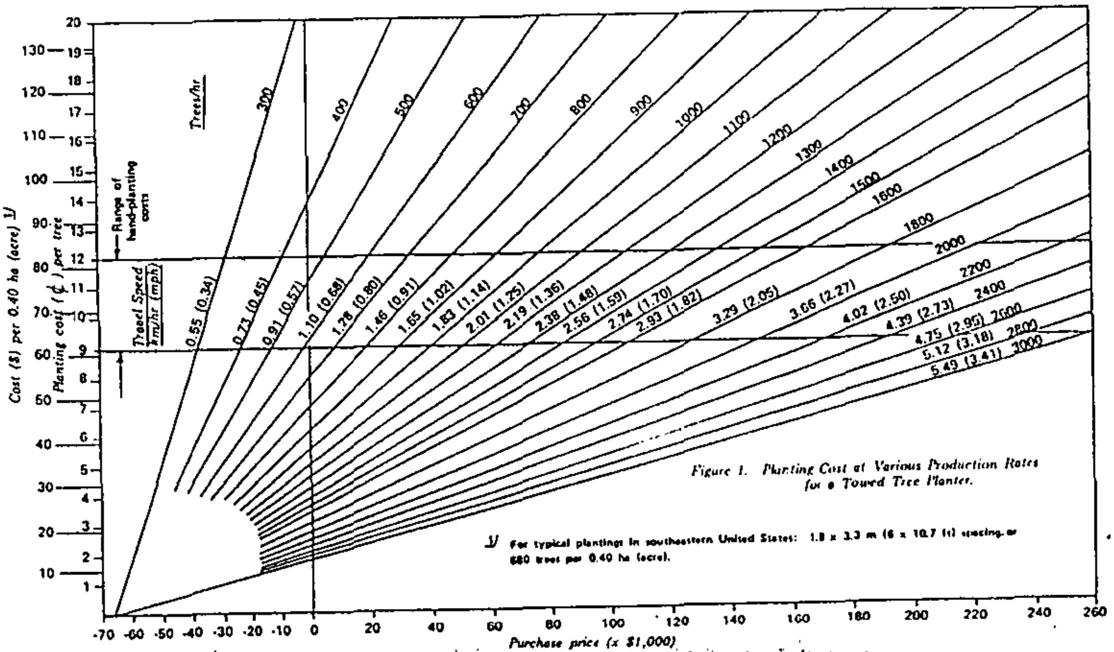

Figure 1. Planting Cost at Various Production Rates for a Towed Tree Planter.

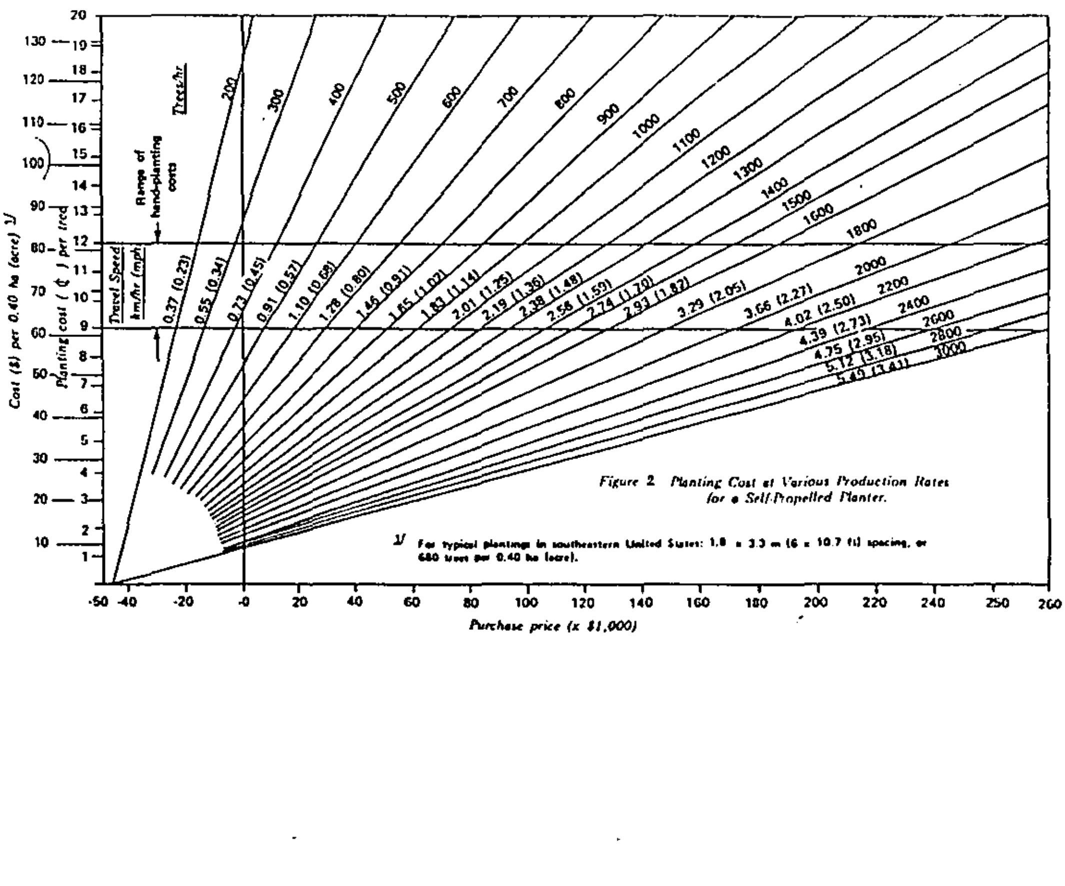

Figure 2. Planting Cost at Various Production Rates for a Self-Propelled Planter.

Appendix 6

Planting Statistics for the U.S.A. and Canada

The production of planting stock by the silviculturally most important states of the U.S.A. are listed for the year 1983 and for the Province of British Columbia for the year 1987.

State	Thousands of trees
Alabama	172,000
Arkansas	112,000
Florida	170,737
Georgia	248,478
Louisiana	96,500
Mississippi	122,107
North Carolina	95,000
Oregon	101,843
South Carolina	134,245
Texas	109,414
Washington	132,124
	1,494,448
British Columbia	137,208
	1,631,656

If the current amounts planted in the rest of Canada are added to this total the number of trees planted annually exceeds two thousand million. The trend has been for the annual plant to increase year by year.

Appendix 7

Planting as Part of a Larger Problem

Mechanising planting is a sub-part of the larger problem of achieving an adequate rate, quality and cost of re-afforestation.

The vehicle which we have patented is intended to fill the role for silviculture of the farm tractor its being intended as a carrier of tools for planting, thinning, plantation tending and fire fighting. It could be used for the carriage of ground survey personnel over rough ground.

The solution which we have attempted to obtain for mechanised planting is also aimed at the larger problem of the lifetime management of planted and naturally regenerated forests.

(Forest Engineering Research Institute of Canada, Technical Report {TR-80}, 1988)

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