# The research and development of an electronic gauging system

# ***The Research and Development of an Electronic Gauging System***

*by*

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*A DOCTORAL THESIS*

*Submitted in partial fulfilment of the requirements*
*for the award of*
***Doctor of Philosophy***
*to Loughborough University of Technology,*
*Department of Design and Technology.*

*November 1985*



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*This Thesis is the original work*
*of the above named author*
*with exceptions as detailed in 'Acknowledgements'.*

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## 1.0 ABSTRACT


*There is scarcely an engineering company in Britain which has not had to face radical changes in technology and world economic climate during the past decade. These companies have been forced to reorganise both their product policy and personnel, and have either foundered or emerged the stronger, as a result of these inevitable pressures from sources beyond their control.*

*This thesis tells the story of just such a well-established mechanical engineering company, which was forced out of its complacency of fifty years into a new, aggressive, and extremely competitive market, that of electronic gauging and measurement, and was able to recover from the brink of financial collapse because of its thrust into new technology and the resultant research, design and development of new and different products. For the first time in fifty years, British Indicators Ltd was forced to innovate in order to survive.*

## 2.0 BRITISH INDICATORS LTD AND THE NATURE OF THE ASSIGNMENT

### 2.1 The Company

*British Indicators Limited (BIL) is a traditional, mechanically based company which manufactures a range of gauging equipment for general use in the mechanical manufacturing industry. Their principal product for the past fifty years has been the* **Dial Test Indicator** *or DTI (see plate I) which has undergone little change in design, manufacture or application during the whole of its unusually prolonged marketplace life. To complement its range of DTIs, BIL also manufactures a range of accessories, which generally speaking, are designed to adapt the DTI to particular gauging or measurement applications.*

*The market for such instruments has been static for the period between c. 1935 to 1975, when latterly a decline in the order book was encountered not only by BIL, but also by the company's immediate competitors, J. Baty & Son, and E. Mercer Ltd. At first, the decline in orders was attributed to the onset of recession and increase in automated manufacture and measurement, which certainly have been responsible in measure for falling sales. Increasingly, though, BIL became aware of a new product entering the marketplace, which was replacing, in varying degrees, the 'traditional' method of measurement in the manufacturing industries, namely the inspector/machinist with a DTI on a comparator stand, or micrometer, used off line to measure a batch of components, for instance. The rising costs of labour and overheads dictate a need for more effective measurement, to achieve the following goals:*

1 *reduced measurement time*

2 *reduced human intervention and error*

3 *greater production control by feedback from measurement stages; some form of statistical analysis of results to eliminate scrap production due to dimension drift was required.*

## 2.0 BRITISH INDICATORS LTD AND THE NATURE OF THE ASSIGNMENT

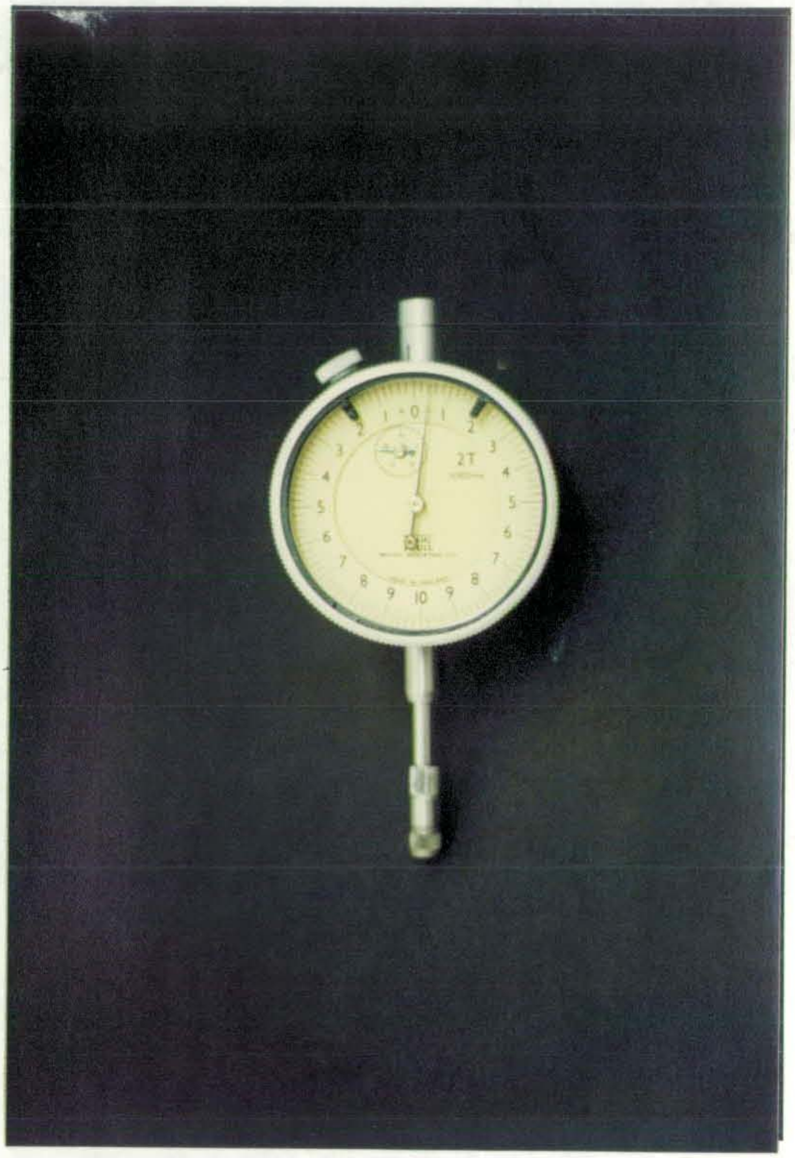


*Plate I - A D.T.I.*

## *2.0 BRITISH INDICATORS LTD AND THE NATURE OF THE ASSIGNMENT*

*While 3 above has been achieved by various elaborate means in the past and present, often the complexity and capital investment required has been prohibitive to all but the largest manufacturing establishments.*

*Thus, BIL became aware that their product mix was at best obsolescent; they had previously afforded complacency due to the unusually long lifecycle of their product, as a result of which they had long ago lost the ability to innovate in the marketplace. Furthermore, time was extremely tight because of increasing competition from new areas: it seemed that everyone had a headstart on BIL who had awakened too late to the changing business of measurement technology: their product had ceased to sell itself on its own merit and reputation, and the cashflow crisis was becoming a daily struggle for the company.*

*If BIL was to survive the change in its marketplace, and the recession, new products had to be developed which would offer performance and cost competitiveness. The time available between starting and investing in development, and bringing the new product to market, was minimal, the available funds were limited, and the company had already begun to contract - the number of employees fell from over 100 to less than 50 between 1980 and 1981.*

*The project was conceived in January 1978 as a result of previous negotiations between senior management of BIL and Professor K.W. Brittan, the Head of the Instrument Technology Postgraduate group, Loughborough University of Technology, when a vision of future possibilities was presented to BIL. At that time, BIL did not know what their new product would be, only that it would 'incoprorate the latest technology', and be competitive with current innovations and would secure a profitable product line once again for BIL; bold steps were required to introduce BIL to the electronic metrology industry.*

*The initial phase of the work thus undertaken by the author in January 1981 was investigation of the marketplace and current competitive products; areas of possible interest to BIL would be discovered. A decision would be made to actively pursue the design and development of*

## 2.0 *BRITISH INDICATORS LTD AND THE NATURE OF THE ASSIGNMENT*

*BIL's debut electronic measurement system, resulting in sales, recovery of investment, profit and perhaps most importantly at first, introducing BIL to the new technology which had hitherto passed them by, and providing them with the means to continue in the business which long ago they had helped establish.*

### *Points Arising From a Visit to BIL 22-23 January 1981*

*The most vital thing to do, as quickly as possible, was to identify what the market need would be in the next 2-3 years and to research and design an instrument to satisfy that need. During and following discussions with the BIL directors, notably Dave Neal, the Sales Director, certain salient points emerged.*

*The technology in manufacture and gauging (BIL's bread and butter at that moment) was changing rapidly. Automation and robots were doing away increasingly with personnel (as is the current recession). Therefore a product would be required which would be suited to and born of the new technology. Towards this end, it became increasingly clear that the new instrument was not simply going to be an electronic dial gauge (Baty Ltd, one of BIL's competitors, was to release onto the market just such an instrument in March 1981 at Inspex '81, NEC Birmingham). Rather, it should have the facilities of a computer interface, so that the instrument will take a reading or set of readings and do something with it - store it for future reference and recall, or more usefully, to perform in process corrections for machine malfunctions such as tool wear, setting up errors, etc. There is potential for a closed loop manufacturing system in which production of a large number of out of tolerance components is effectively eliminated.*

*Of course, the top end of the market is catered for by such instruments as 'Talyrond', 'Talysurf', etc. which interfaced to Data General minicomputers provide rapid measurements of complicated parameters of such items as engine pistons, bores and shafts. The minicomputer offers a detailed evaluation based on the measurement of many datum points which* *would previously have required literally hours of manual computation - during which time hundreds of wasted, out of tolerance components might have been produced.*

*There must exist a parallel in the middle cost sector of the market where not so precise, detailed evaluation is required. The capital investment involved in a 'Talycenta' type instrument involves thousands of pounds - the author was recently involved in developing a software package for a German company (Kolben-Schmidt) which alone cost £30,000 to complete.*

*What seemed to be required was a versatile basic instrument which would perhaps provide a simple, direct readout, but is also capable of being interfaced to a variety of equipment (which may already exist in the current product line) such as multi-gauge test rigs (see other examples below), with some kind of computing facilities for statistical analysis, trend analysis etc, for the more sophisticated systems.*

*After obtaining an internal view (ie. the views of the directors of the company - Eric Arnold, Technical Director - a senior member of BIL; David Neal, Sales Director; and Business Director Roger Greenfield) of what the future product might be, the logical next step was to visit existing BIL customers and see what their present and anticipated future requirements were.*

*The initial impressions gained and the responses of the relevant personnel (mainly technical/technical management - though shop floor staff were consulted where appropriate) obtained were recorded. A simple questionnaire was compiled to assist in finding out what the new product might be. The proposed plan of action was:-*

*a) To make preliminary visits to the larger customers to try to find out their needs for 1982/3 by means of the questionnaire, and by examining their present gauging systems and manufacturing plant, and by talking to the relevant personnel, paying due attention to cost, etc.*

*b) To amass information and try to formulate a preliminary specification for a tentative product, and to write it down in as concise yet detailed a form as possible at this stage.*

*c) To return to the people originally seen and obtain a definite response to the proposed specification for the tentative instrument. This specification would be a concept description containing as much detail as possible.*

*Hopefully, at this stage, it should be possible to arrive at a final specification and start the design process of the instrument.*

## *3.0 THE NATURE OF THE COMPETITION*

### *3.1 The Broad Spectrum of Electronic Gauging Products*

*At the time of the project's inception, there existed already a wide range of electronic metrology products. Electronic metrology is here defined as measurement using linear or digital electronics, or a hybrid of the two, to perform translation of a linear distance into a numerical output. Numerical manipulation of data thus obtained may or may not comprise part of the system.*

*Perhaps the simplest such system which can be envisaged is a simple analogue transducer driving via an amplifier an analogue panel meter graduated in units of distance. At the other end of the spectrum one can envisage many transducers connected to a system containing analogue to digital convertors, and a minicomputer to provide numerical/statistical data manipulation. Output in this case could be via a monitor, printer, 7 segment or dot matrix display; it may even be in the form of a closed loop back to the machine producing the part being measured (so called 'in process' gauging).*

*There must exist a whole possible range of products between these two extremes which represent capital investments between the orders of £100 and £100,000. A mid range product of this kind might be represented by the Sigma 'Sigmasam' costing in the region of £5,000 and providing some statistical analysis of data from several analogue transducers.*

*There now follows a brief summary of instruments available at the time which were considered to be in direct or indirect competition with BIL's existing, but obsolescent product range, and its possible new products.*

## 3.0 THE NATURE OF THE COMPETITION

### 3.2 *Saginomiya Electronic Linear Gauge c. 1977 (See Plate II)*

*This model, though now dated, was an obvious competitor for the standard D.T.I. The transducer is based on the Moiré fringe system, and has a digital output consisting of two square wave trains in quadrature to give directional displacement information to the remote readout unit, which provides BCD data output.*

*Applications of this unit are limited for the following reasons:*

- *Large size of remote display unit;*
- *10:1 cost ratio over mechanical D.T.I.;*
- *Need for mains power supply.*

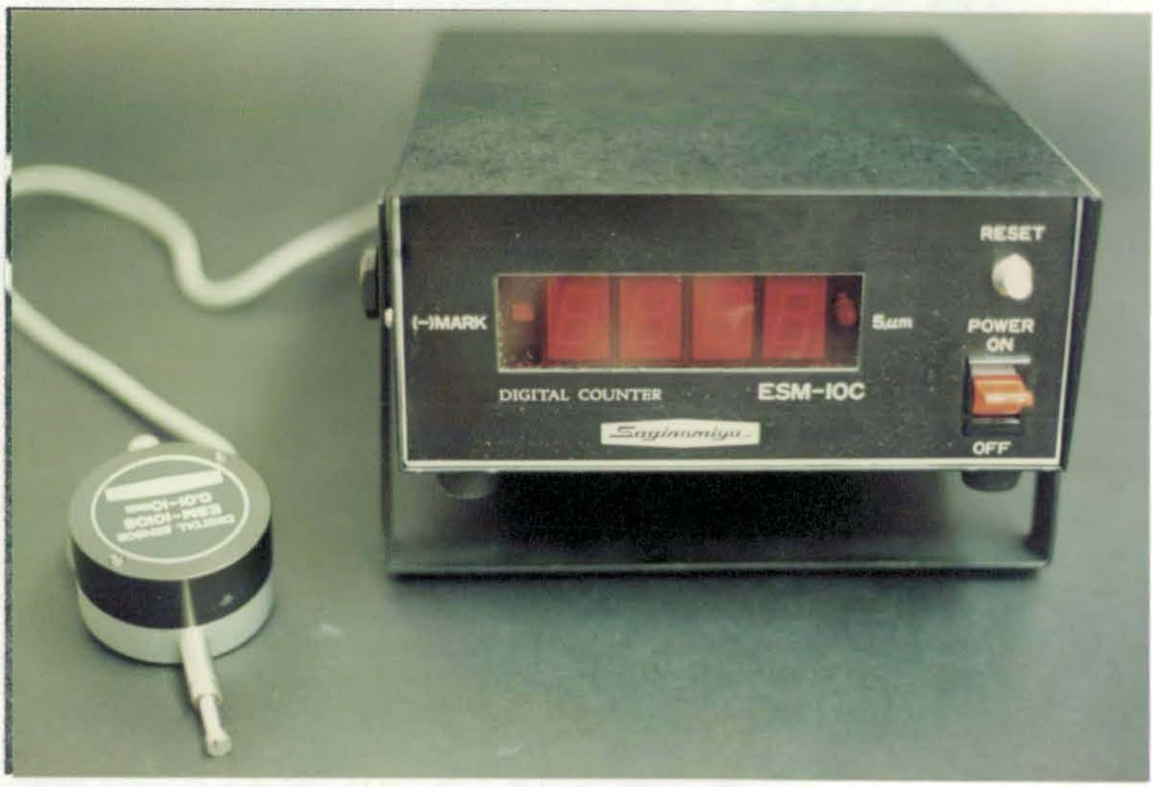



*Plate II. Saginomiya Electronic Linear Gauge*

## 3.0 *THE NATURE OF THE COMPETITION*

*May 1981 The Saginomiya Digital Sensor E.S.M. 1010S*

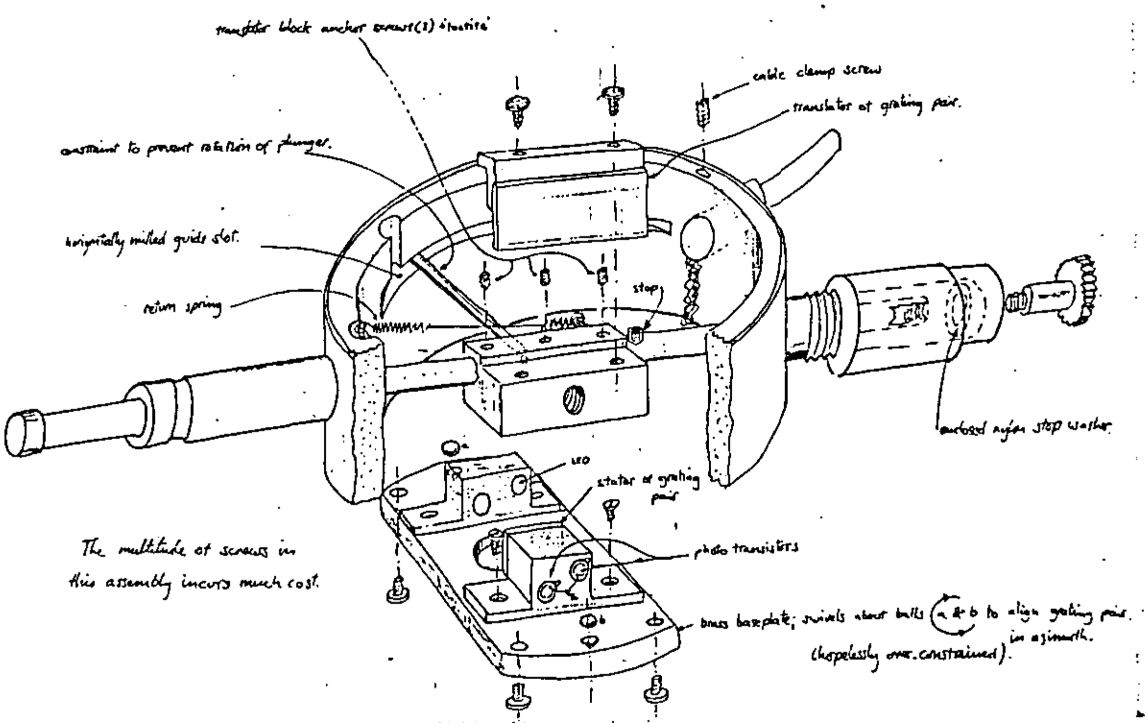
*A report was compiled which outlines the principles of operation, construction and production techniques associated with this Japanese electronic linear gauge, and its electronic circuitry was analysed in full. The gauge was taken apart and each component and main assembly was examined in detail.*


*Fig. 1 General Appearance of Sensor Unit*

*The main body of the unit is a machined die-casting with a steel bush force fitted at the operational end of the slide assembly and a fabricated, aluminium bush assembly diametrically opposite, also interference fitted. The unit is of roughly the same size and geometry as a mechanical gauge, though somewhat deeper.*

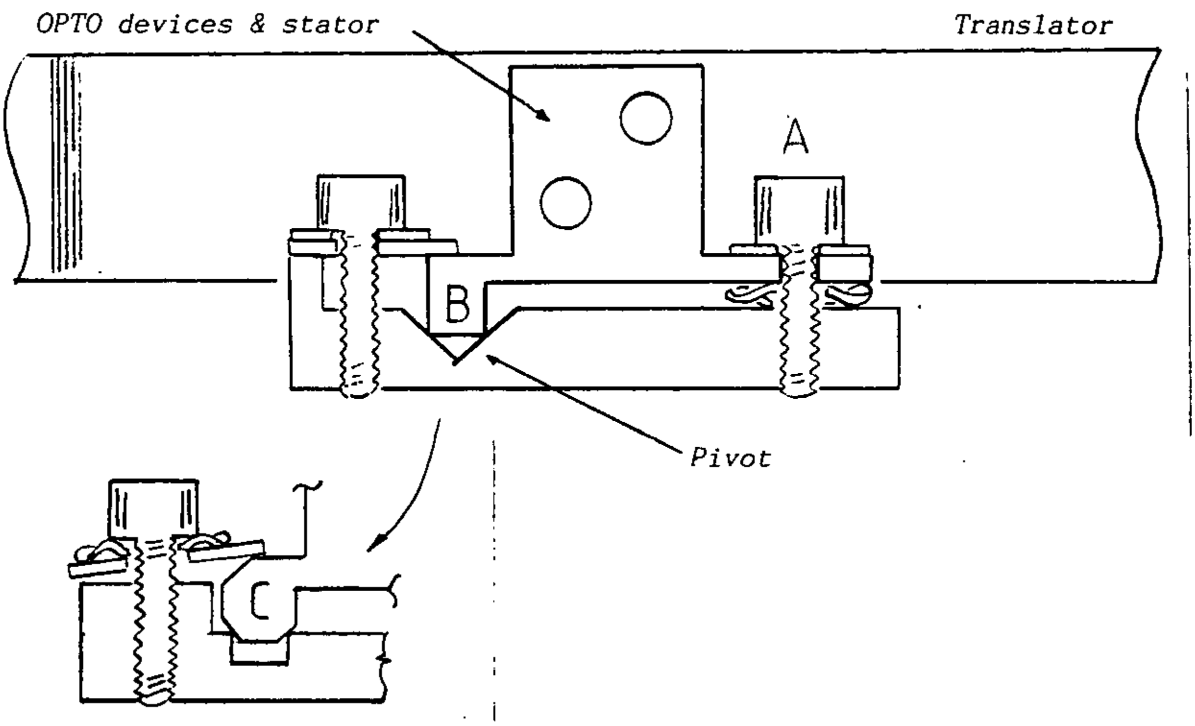
## 3.0 THE NATURE OF THE COMPETITION

*Fig 2 The slide assembly showing method of securing and aligning the pseudo-optics*



## 3.0 THE NATURE OF THE COMPETITION

*Some simple, cost effective ways of kinematically securing and adjusting the phototransistors in a Moiré fringe transducer system.*

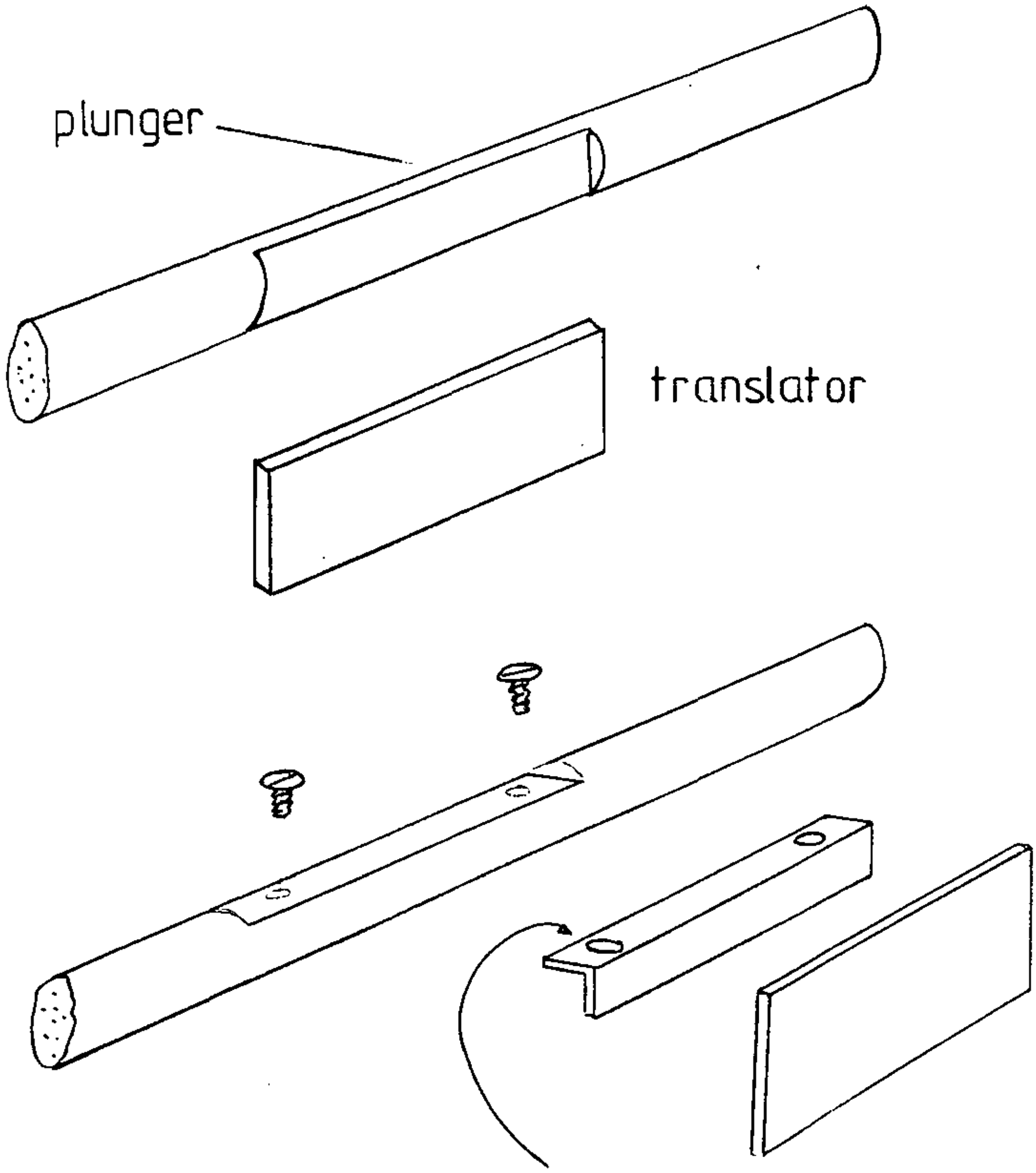



*Turning phase adjusting screw A causes stator assembly to pivot about kinematic pivot B or alternative C, thus adjusting relative phase of Moire fringes seen at OPTO device positions.*

## 3.0 THE NATURE OF THE COMPETITION

*A simple, cost effective method of securing the translator of a grating pair to the transducer shaft.*

*Grating translator glued directly to plunger. Problem: no adjustment is possible.*




*Oversized hole allows adjustment.*

## 3.0 THE NATURE OF THE COMPETITION

### 3.3 Moore and Wright Micro 2000 Micrometer (c. 1978). See Plate III.

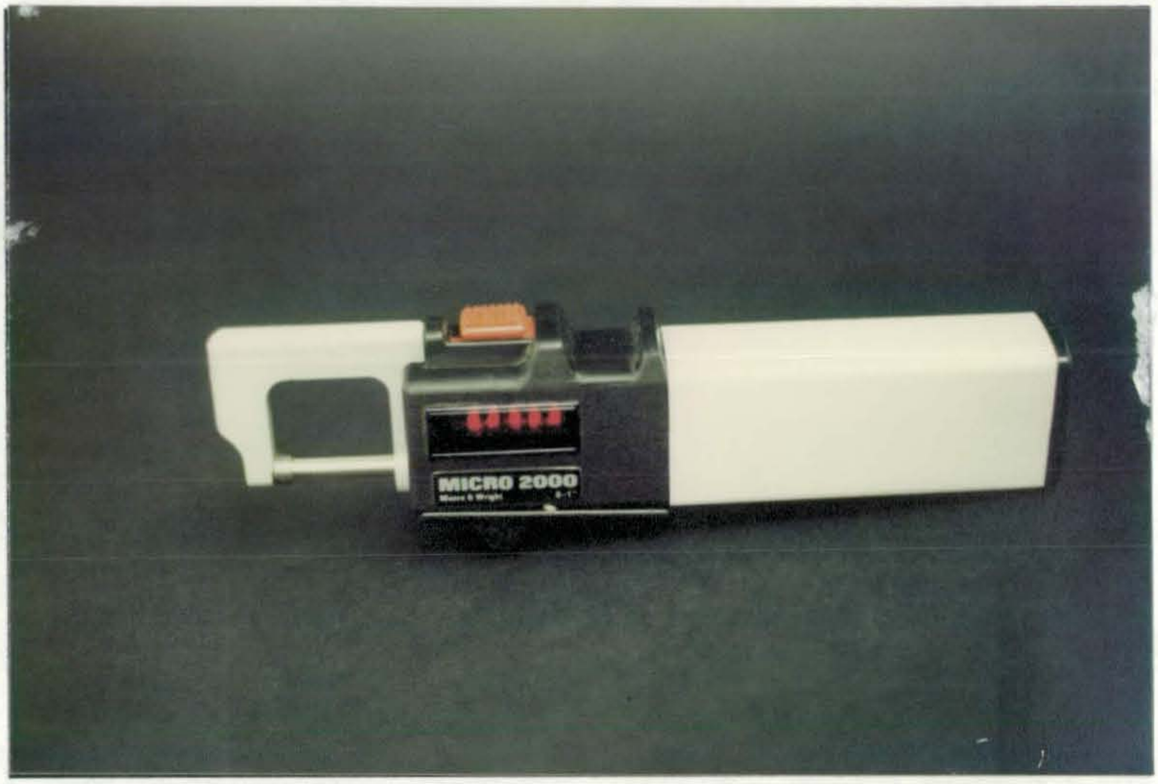



*Plate III. Moore & Wright Micro 2000*

*This was the first British made electronic micrometer, working on the Moire fringe principle and being self contained, providing LED readout to 2 microns resolution, but no facility for data output.*

*In many ways, the micro 2000 was a herald of the great forthcoming expansion of miniaturised electronic gauging and inspection equipment. It was a new venture for a traditional, mechanically based medium sized company; the development work for the micro 2000 was carried out by 'Patscentre' at a cost of around £500,000. The heart of the micro 2000 is a Ferranti custom chip in Bipolar technology which performs all counting, direction discrimination and display driving functions: the chip was a significant phase of the development task and sets the instrument apart from the previous example because of the miniaturisation thus obtained.*

## 3.0 THE NATURE OF THE COMPETITION

*The great savings in inspection time and error achieved by using digits instead of analog style calibrations was clearly demonstrated by the popularity of this type of instrument.*

### 3.4 Baty JB80 Electronic Linear Gauge (c. 1981) - See Plate IV

*Although the JB80 did not appear until the BI/LUT project was well under way, it is included here because it had some influence on development of the project. One major reason for this is that JE Baty is a direct competitor of BIL and the company was undoubtedly finding the same problems as BIL in terms of changing technology and marketplace.*

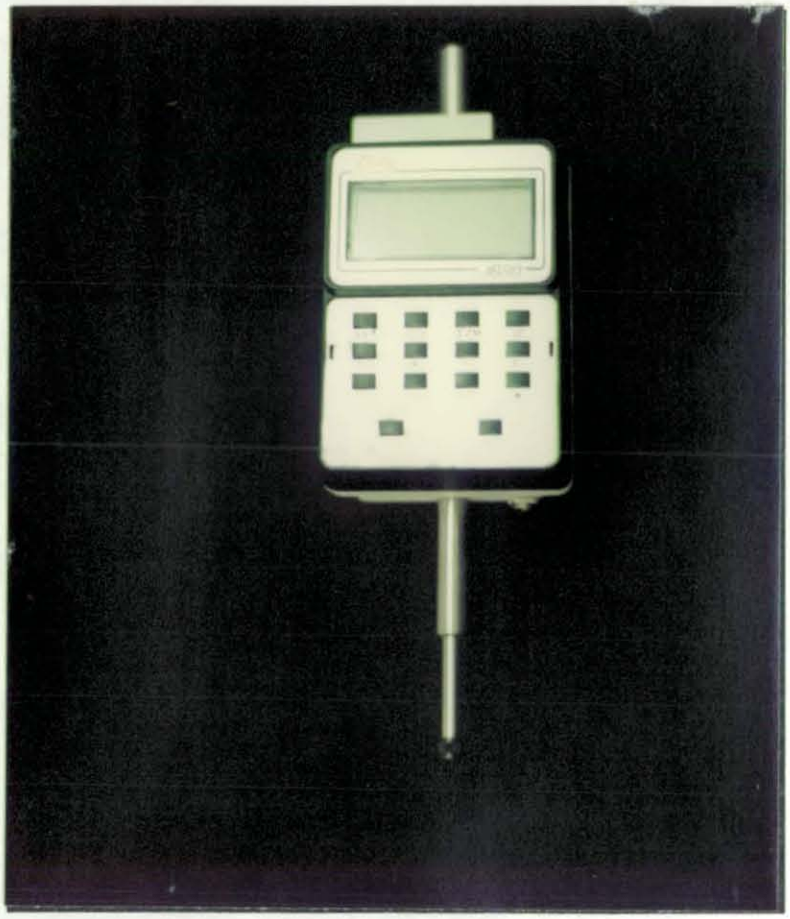


*Plate IV. JB 80*

## 3.0 *THE NATURE OF THE COMPETITION*

*Though the standard D.T.I. (see Plate I) has been and remains a staple product of J.E. Baty, it can be seen that the JB80 bears little resemblance to a standard D.T.I. either in appearance, size, function, applicaton or cost.*

*Internally, the JB80 is the most complex of the devices discussed so far. It contains in essence a custom mask-programmed memory single chip microprocessor, namely the I.T.T. SAA6000 which also provides LCD driving hardware; a custom chip counter driven by the ubiquitous Moiré fringe glass slides, and a 14 button keypad for implementing the various functions provided by the microprocessor. The salient functions are summarised here:*

- *inch/metric numerical conversion*
- *resolution adjustment 2/20 microns (1/10,000 or 1/1,000 inch)*
- *x2 display for diameter measurement along a radius*
- *recall maximum reading of a sample*
- *recall minimum reading of a sample*
- *recall mean reading of a sample*
- *preset maximum tolerance) for go/no go discrimination*
- *preset minimum tolerance)*
- *BCD output to printer*

*The unit is powered by a NiCd battery which has a working life of 3 hours between charges.*

*User reactions to the unit were obtained by BIL marketing and sales staff. They are summarised here:*

- *programming of JB80 is much too complicated, a fact illustrated by the manufacturer supplying a plastic cover for the keyboard, which users have been known to secure in place to prevent accidental or deliberate key presses.*

- *large physical size of the unit restricts its use, and often prevents its use on existing gauging equipment designed for the traditional D.T.I. The main causes of this cumbrous programming are:*

    - *multipurpose use of single buttons*
    - *time dependence of button function*
    - *unclear sequence of button presses*

- *battery life of 3 hours too short for working day.*

*It was generally found that the interfacing capability of the instrument was not being used beyond a simple printer facility offered by the manufacturer. The lesson learned here was that the typical mechanical engineer cannot be asked to perform what can be difficult interfacing between pieces of electronic apparatus.*

*Reliability problems are still apparent with the JB80.*

### *3.5 Sigma Gauging Ltd "SIGMASAM" (See Plate V)*

*The 'Sigmasam' presents perhaps the next step up from the JB80 in terms of processing of measurements and data manipulation. It consists of a customised steel case containing a multichannel Analog to Digital converter which interfaces between analog transducers and the internal microprocessor. The latter device then handles data manipulation and performs general 'housekeeping' functions - such as keyboard monitoring, integral display driving, transducer scanning etc. The final output is via the integral thermal printer, in the form of a fairly comprehensive statistical analysis. Information provided is in the form of tally chart (histogram), measurements out of tolerance, standard deviation, ±3 standard deviations etc.*

## 3.0 THE NATURE OF THE COMPETITION

*The 'sigmasam' then is a dedicated microprocessor controlled unit whose functional parameters could only be changed by a change in the custom program held in EPROM within the unit. Because of this and its customised keyboard interface to the operator the unit has sacrificed flexibility for the integrity of a dedicated system.*

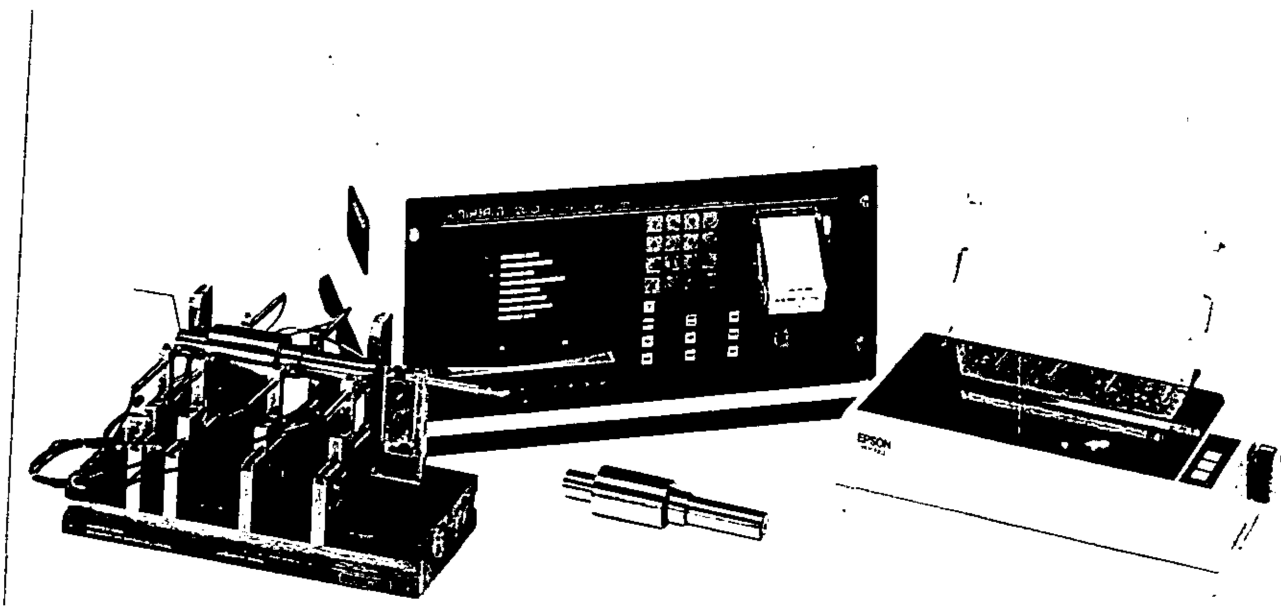



*Plate V. "Sigmasam"*

### *3.6 Metrology Exhibition - INSPEX '81*

*This bi-annual exhibition is a rich source of information to the product designer. Much can be learned about the activities of competitors in terms of level of technology, trends in marketing, and pricing policies. There now follows a transcript of notes taken at that time.*

## *INSPEX '81*

### *Introduction*

*Most of the week 16/3/81 - 21/3/81 was spent at the exhibition of metrological instruments and a large number of new electronic devices was on display from various manufacturers, notably Mitutoyo, Sony, Mercer, Sigma and Baty. A description of what might be regarded as competition for the new product now follows:*

### *A Baty's JB80 Electronic Microprocessor Based 'Dial' Gauge*

*1 a) General Impression My initial reaction to the instrument was that it incorporated many of the functions or facilities which initial enquiries had indicated to be desirable to certain dial gauge users. (The functions incorporated are detailed below).*

### *BATY JB80 (J BATY - J B EIGHTY)*

*Not ready for Inspex '81 - technical representative said they had a 'working prototype which went haywire just before the exhibition' - so they thought better of exhibiting.*

*The model I examined has virtually an empty plastics (ABS) case with the plunger and Moire fringe grating mounted in the die casting. The casting has a facility to mount a standard packplate.*

## *3.0 THE NATURE OF THE COMPETITION*

*Though no electronics was installed in the prototype, the following information was gleaned:*

1 *The instrument is based on a single chip micro, probably a CMOS chip.*

2 *Power requirements must be quite high since rechargeable cells are employed to supply 3 hours continuous operation on a 15 hour charge (approx).*

3 *Obviously the time required to develop the software has been underestimated by the software house/contractor - hence the delay in providing a working prototype.*

4 *There is some RAM in the unit which provides storage of some tens of readings and then can display the MAX or MIN reading of those in store - (a simple vector sort subroutine).*

5 *It was not clear whether the metric/inch (M/I) button provided a computed conversion or a counting type conversion usually encountered on* **non-computing** *type linear measuring devices eg. 2000, TESA DIGIT-CAL, etc.*

6 *The salesman disclosed that this was BATY's biggest ever venture and that they were taking quite a gamble.*

7 *Baty were originally fishing for response from potential customers - see final paragraph.*

8 *Design and development was embarked upon about 18 months ago.*

## 3.0 THE NATURE OF THE COMPETITION

*Summary*

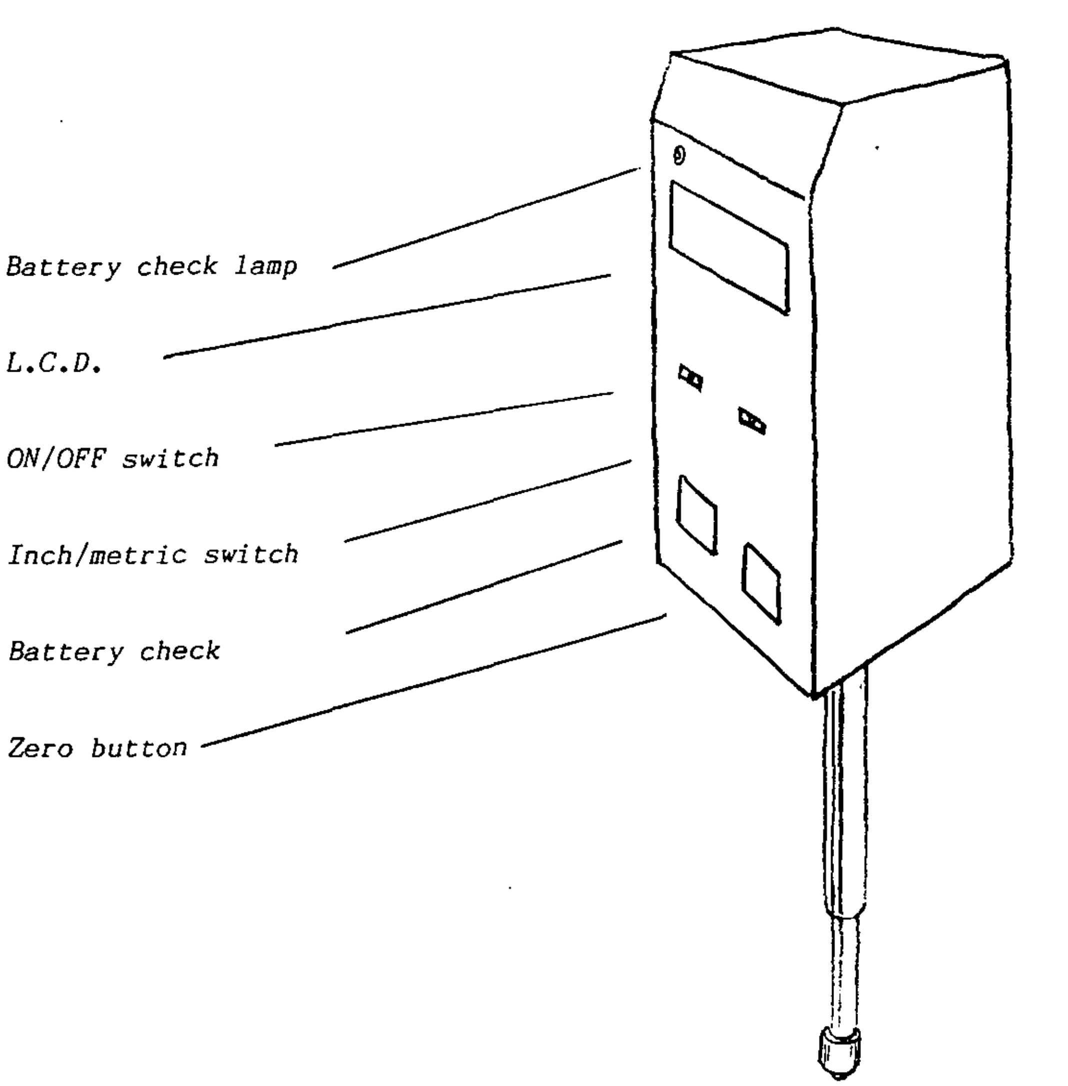
*It will be interesting to watch the market performance of the JB80. Although it is the first microprocessor based plunger gauge on the market, it is not necessarily going to be the most successful, competitive, nor satisfactory.*

*Should BIL develop its own micro-based dial gauge? Is there anything significantly lacking in or wrong with Baty's innovation?*

*The answers to these questions can only be answered by time and use in the hands of customers.*

## 3.0 THE NATURE OF THE COMPETITION

***MITUTOYO'S Digital Plunger Gauge***



## *3.0 THE NATURE OF THE COMPETITION*

*Mitutoyo were exhibiting a smart, rectangular shaped digital dial gauge (they called it a 'plunger' gauge) with an LCD readout reading to 0.01 mm/1 thou ". Unlike the BATY JB80, no sophisticated facility was incorporated - only direct readout, zero, inch/metric, battery check and on/off.*

*The operating principle is similar to an ordinary dial indicator with the pointer being replaced by a slotted disc, optics, a counting circuit and LCD.*

*According to a Mitutoyo representative, work was being done to increase the resolution 10 fold and production quantities would be available by Autumn 1981, selling for £40-£50 per item.*

*The appearance of the instrument was smart, in an anodised aluminium/plastics box, though the whole thing was on the bulky side compared to an ordinary dial gauge. In view of its competitive price, I expect it to sell well.*

*Many dial gauges are used in the comparator mode and for this basic application, mounted in a comparator stand, reading to 1 micron, the instrument is ideal.*

*It did not seem possible to exceed the slew rate of the electronics; the count returned to zero every time.*

*Mitutoyo were also marketing an electronic micrometer for about £90.00 with LCD readout, screw operation and 500 hour battery life from 2x AA alkaline cells.*

*Also offered by Mitutoyo was a range of height gauges, also with LCD readout, utilising glass scales as the primary measuring element.*

## 3.0 THE NATURE OF THE COMPETITION

### C E Johanssen "JOCAL"

*Also attracting considerable attention was the electronic 'vernier' style caliper from Johanssen of Sweden. Based on the linear inductosyn principle (no optics involved) it has a 'normal' operating life of 12 months from two watch-type cells.*

*According to the salesman, the instrument incorporates 5 integrated circuits though as usual, technical information was not readily forthcoming nor available.*

*The Jocal is a very compact instrument which has overcome two of the major problems associated previously with electronic 'pocket sized' instruments, namely (1) excessive bulk, (2) heavy current consumption necessitating overnight or daily recharging.*

## 4.0 *POSSIBLE DIRECTIONS OF THE RESEARCH AND DEVELOPMENT*

### 4.1 *General Appearance and Features of XX102A (Programmable Gauge)*

*This article intends to give a brief overview of the features and capabilities of the proposed John Bull programmable electronic gauge. The diagrams do not necessarily represent the final appearance of the instrument.*

### 4.2 *General*

*The XX102A is intended for general workshop use and can be mounted in most situations where a standard mechanical gauge might be used - snap gauges, bore gauges, comparator stands, etc. The greater ease of reading provided by the digital liquid crystal display will help eliminate operator error and relieve the tedium of repetitive measurements.*

### 4.3 *Programming Facilities*

*The gauge can be used in the ordinary way, or if so instructed by pressing the required keys, can perform the following tasks:*

- *Inch or metric readout.*
- *GO and NO GO testing, by means of entering pass tolerances, calculator fashion, on the keyboard.*
- *Storage of maximum, minimum and average of a series of measurements (recallable at any time).*
- *Diameter or radius measurement from a datum.*
- *Variable resolution (.001 mm or .01 mm).*
- *Positive reading for upward or for downward movement of plunger.*

## 4.0 POSSIBLE DIRECTIONS OF THE RESEARCH AND DEVELOPMENT

### 4.4 Other Features

- *Detachable display/keyboard, facilitating remote readout and programming, and minimising the size of the transducer for greatest convenience of mounting.*

- *Low power consumption enables long operating life from standard dry cells (2 x AAA size for example).*

- *Rugged, contaminant resistant casing for use in workshop environments..*

- *Cable for remote lifting of plunger.*

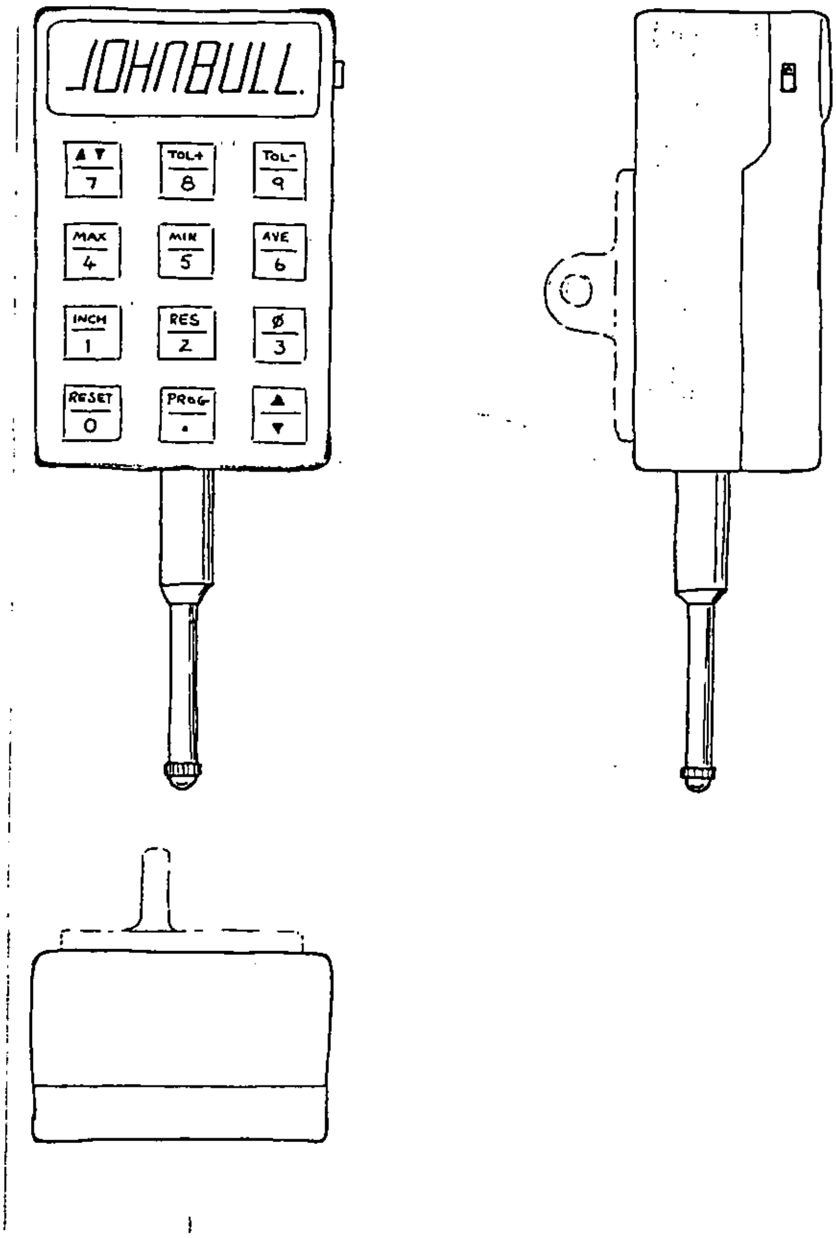
- *Plug for minicomputer interface for automated measurement analysis.*

#### 4.4.1 Expected Availability

*The John Bull electronic programmable gauge would be available by early 1983 at a price in the region of £100.*

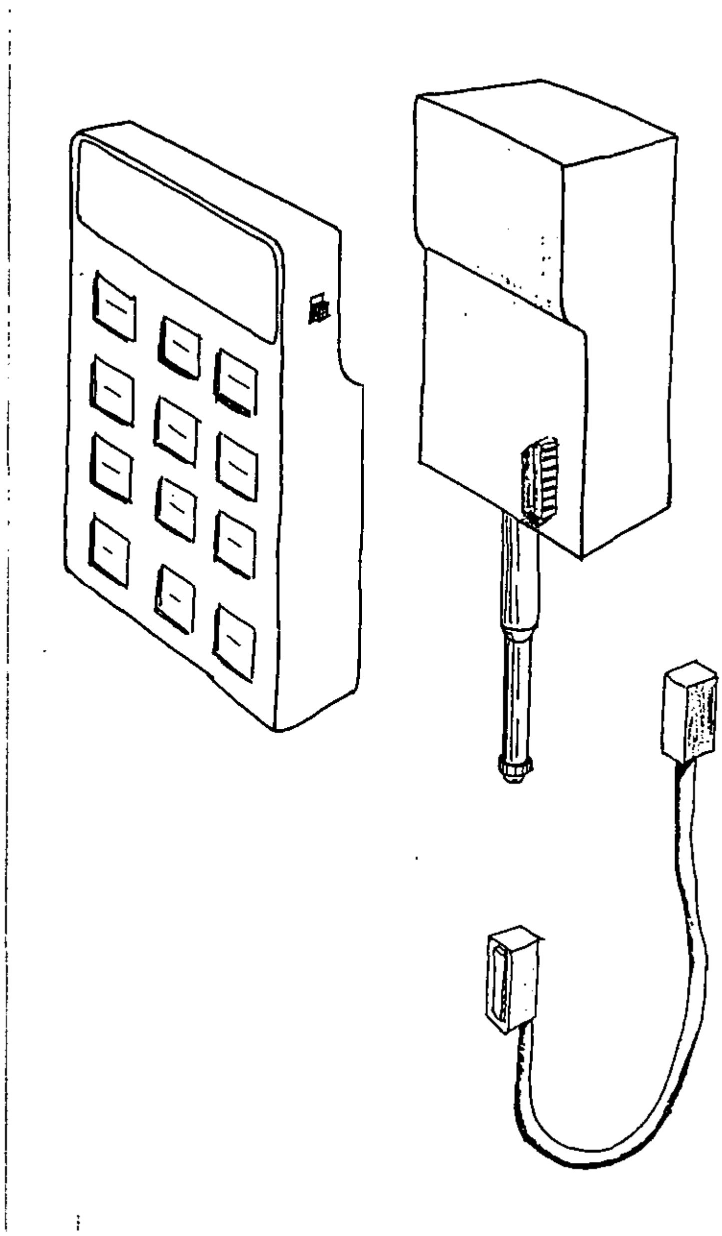
## 4.0 POSSIBLE DIRECTIONS OF THE RESEARCH AND DEVELOPMENT

*XX102A General Appearance (Fig. 4.1).*

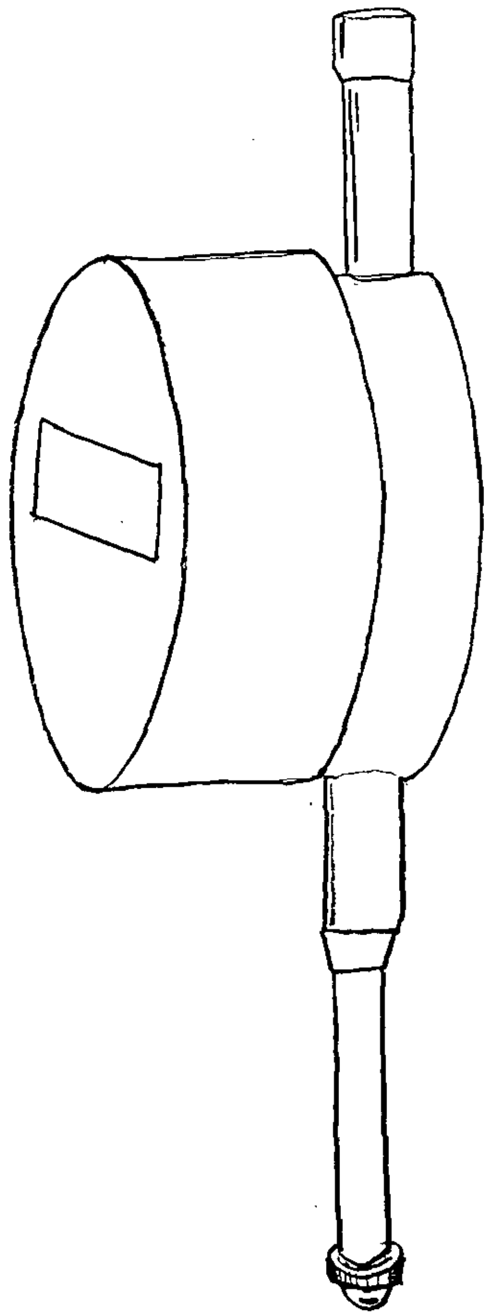


## 4.0 POSSIBLE DIRECTIONS OF THE RESEARCH AND DEVELOPMENT

*XX102A Remote Reading Facility (Fig. 4.2).*



*Simple Electronic Linear Gauge (Fig. 4.3).*



### 4.5 *Summary of Progress to Date* **(09/08/81)**

*After submitting the cost analysis of XX102A to B.I.L., the Directors arrived at a selling price, based on recovery of capital over three years and on selling at their usual 100% gross profit and at a rate of 100 per month, of about £100 each. It is no small coincidence that this is the anticipated selling price of the BATY JB80 gauge which is similar to the projected XX102A: thus indications are that the costing must be reasonably accurate.*

*The outcome of this assessment was that there was to be a board meeting in the near future of the B.I.L. Chairman, the Directors and project engineer, the author. At this meeting would be discussed the relative merits of two projects:*

*(1) XX102A, the 'processor based gauge;*
*(2) A simple digital gauge having no processor intended for higher volume sales of ca. 1,800 per month;*

*It would seem that there was some reluctance (understandably) on the part of B.I.L. to part with money for capital/tooling investment in a new product. In the face of changed and changing technology and a declining market for mechanical dial indicators, B.I.L. must decide what the shape of their business is to be in the immediate and longer term. In a world where men and women are increasingly less required to interface between analog style indicators and the production machine, was B.I.L. adopting the right attitude towards its product line?*

*It was clear to everyone that a new product was called for quickly and one which must be upwards compatible with future requirements in industry. Did B.I.L. want to be involved closely with the new technology? Surely it was vital that B.I.L. became involved with all aspects of the new technology and the only way to success was to* **do** *something quickly.*

## 4.0 POSSIBLE DIRECTIONS OF THE RESEARCH AND DEVELOPMENT

*Even if a new product such as XX102A were to yield nothing more than break-even after three years, the experience gained by all involved in getting something new (radically new for B.I.L.) from concept to market would be invaluable. Many mistakes would inevitably be made in a new venture such as this, as the company comes to deal in totally new (to it) areas - things like electronics purchasing and storage, stock control, electronic assembly and testing, servicing, quality control and inspection. One thing is certain: the sooner these teething troubles are overcome and experience is gained as a result, the more chance there is of gaining some product leadership in the future.*

*The history and marketing books show that product leadership rarely comes with a first new venture, though great successes have arisen with development and marketing of third generation products. Also, it is not necessarily the first product in the marketplace of a kind which is the 'best-seller'.*

*The market situation for dial gauge type products is changing rapidly as a result of new technology, new trends in automation in the workshop, and as a result of the economic climate. People are less and less being required to look at dial indicator style readouts and it is vital therefore that B.I.L. take a long look at its product range, present and future.*

*There are three types of product which might be considered in this light:*

### 4.5.1 High Volume, Low Net Margin, Many Competitors

*This heading accurately describes the company's present range of product (dial gauges). It also describes an electronic version which in effect simply replaces the rack and pinion and pointer with a digital electronic system. We know that there is existing competition and at the MACH81 exhibition in March, MITUTOYO were exhibiting just such an instrument with a projected selling price of £40.00 - £50.00.*

## *4.0 POSSIBLE DIRECTIONS OF THE RESEARCH AND DEVELOPMENT*

*Is the company wise to enter the market with such a gauge in the face of such strong competition? There are many instances in the toolroom where an analog, conventional readout is definitely preferable to a digital readout. These instances are typically where it is necessary to look for a maximum (eg. a diameter when rolling a component under a comparator stand mounted gauge) or a minimum reading (eg. when a gauge is fitted as a bore gauge).*

*My feeling is that to compete head-on with a giant such as MITUTOYO with a low net margin, non-revolutionary product (Saginomiya and ONO-SOKKI electronic gauges have been around for years) may be disastrous, since it is unlikely that in this country we can beat Japanese production skills, in terms of labour cost, available capital, and product experience.*

*In other words, in looking for a new product to lift itself from the doldrums, if this project were to be pursued by B.I.L., I fear that it may merely land itself in another similar situation as currently exists: just one of the (now electronic) dial gauge manufacturers fighting for its slice of the market. It is not enough merely to incorporate electronics into a 'new' product - electronics may be new and revolutionary to B.I.L. and some of its customers but it is everyday to many others.*

### *4.5.2 A More Sophisticated Electronic Gauge - XX102A*

*In the author's opinion this project would be a bigger step in the right direction. In a world which now responds to computer type instruments and devices and is moving more and more toward semi and full automation in measurement and inspection, the XX102A could be the product to establish B.I.L. in the electronic gauging scene, if this is what they want.*

*A as far as we know there is only one direct competitor, - J BATY with their JB80 processor based gauge.*

*The cost analysis has shown that for the estimated saleable quanity over a three year period, B.I.L. might only 'break even'. If this were the case though, at least B.I.L. would be in the marketplace with a new product and would have had the experience of designing and developing in an entirely new field. The next generation would then be primed for success.*

### *4.5.3 Summary*

1. *High volume, low net margin, new product may serve only to perpetuate the present market situation as far as B.I.L. is concerned.*

2. *It is vital to get into a new or existing market with a **significantly novel** type of product. In the face of rapidly advancing technolgy it will not be enough merely to incorporate electronics, to effectively adopt present products to involve electronics of an already dated nature.*

### *4.6 Deciding on the Development Task*

*At this time, September 1981, some 8 months into the project, there were enough ideas to present to the company chairman and senior executives of B.I.L., in order to arrive at a decision of what project should be developed to bring maximum profit in as short a time possible, with a minimal development cost and risk.*

*A board meeting was held and the decision was made to research, design and develop the system described in the following chapter.*

## 5.0 THE RESEARCH & DEVELOPMENT TASK

### 5.1 Emergence of a Specification for the New Instrument

*A board meeting was held where the author, marketing and sales staff, and financial management presented their findings during the preceding nine months to each other and to the group chairman. The following salient points emerged:*

5.1.1

*Development must now proceed at all speed so as to ensure a marketable product with minimum delay.*

5.1.2

*B.I.L. should utilise all its available expertise and traditional manufacturing facility as far as possible in the new instrument so as to expedite design and production and, importantly, to utilise existing labour and minimise design effort - ie. to avoid as far as possible 're-invention of the wheel'.*

5.1.3

*The product should be aimed at existing B.I.L. customers and should be as SIMPLE AS POSSIBLE to operate from an inspector's or a mechanical engineer's viewpoint.*

5.1.4

*The product should incorporate a microprocessor and/or custom chip for marketing reasons and to qualify for a government MAP grant, apart from the obvious requirement of miniaturisation.*

## 5.0 *THE RESEARCH & DEVELOPMENT TASK*

*5.1.5*

*The mistakes of Baty Limited should not be repeated, namely:*

- *producing an instrument forbiddingly complicated to operate;*
- *announcing the product 12 months before being able to supply it.*

*5.1.6*

*The product should* ***support*** *as far as possible existing B.I.L. products, rather than suddenly superseding them.*

*In the light of the above matters, a specification for a prototype electronic gauge emerged.*

### *5.2 'Bolt On Gauge' System Description (18/11/81)*

*Introduction*

*The concept of the 'bolt on' gauge is essentially to provide an add-on conversion system which will replace the conventional analogue pointer and dial system with a four or five digit liquid crystal display, with a minimal increase in size. The John Bull series II dial gauge (2" diameter, 1" travel or metric equivalent) has been selected as the most suitable for the conversion.*

*General Specification*

1. *Range of travel - 0 to 1" or 0 to 26mm. (nom)*
2. *Resolution of reading - .0004" or 0.01mm.*
3. *Liquid Crystal Display - min. digit height approximately 5mm.*
4. *Inch/metric switching.*
5. *Asynchronous reset.*
6. *Change from down count to up count at zero and display minus sign.*

## 5.0 THE RESEARCH & DEVELOPMENT TASK

7 Internal power source, to have life of several working days between recharge cycles.

8 Electronics response time must be small enough to prevent missed counts due to high speed plunger travel.

9 Operating temperature range 0 - 40° C.

10 Compact size - not greatly larger than standard size Series II indicator.

11 'Power down' mode after certain period of non-use to further extend battery life (this will be a programming task and will depend on available battery life).

12 Humidity - 0-85% RH.

13 Life expectancy - 3 years under normal use.

14 Maintenance - no greater than standard Series II gauge except for battery recharging.

15 Operating environments - toolroom, workshop . . . anywhere a standard indicator can be used.

16 Hazards: shock, moisture, dirt, oil, solvents, electrical noise and EM radiation; sunlight **resistant.**

17 Aesthetics of appearance - should be compatible with existing B.I.L. product range.

18 Quantity of manufacture - the electronics of the system necessitate a minimum batch of 1000 units per annum. 5000 units per annum might be anticipated.

19 Production deadline - March/April 1982.

20 Target selling price - £40-£50.

21 Assembly - no overly specialised methods of machining, testing etc. should be required.

22 Servicing - performable by relatively unskilled personnel.

23 Shelf-life - equal to standard Series II gauge.

24 Standard - to BS907.

25 Ergonomics - switches, display and buttons should be in the correct place.

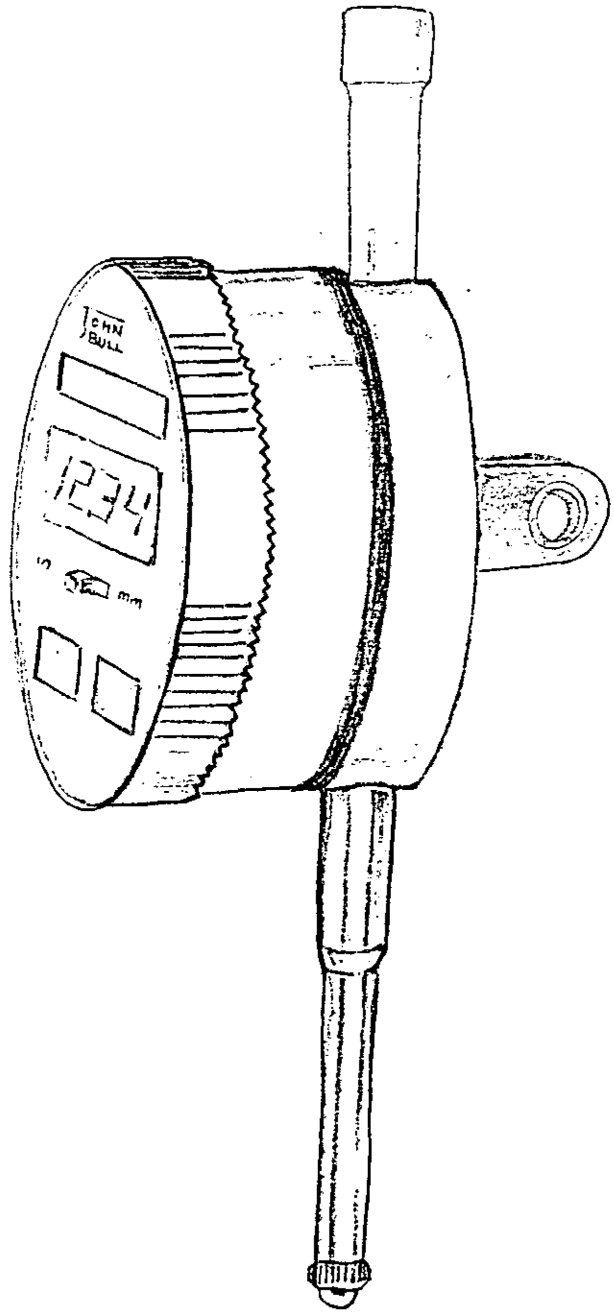
26 Interface socket to serial device - printer, computer etc.

27 Display to be rotatable to facilitate reading in any attitude.

28 Memory mode, where 'M' in display shows that the reading is frozen.

## 5.0 *THE RESEARCH & DEVELOPMENT TASK*

*Fig. 1a - General Appearance of Stage I (Bolt-on gauge).*



## 5.3 Alternative Means of Meeting the Specification

It should be pointed out that the specification (above) is by no means rigid at this stage as the whole research, design and development process is by nature iterative, so that each stage in the chain of problem definition, specification, concept design, detail design prototype and test, is capable of being modified as a result of progression to a following stage. However, for the purposes of description a sequential progression is here assumed to have occurred.

### 5.3.1 The Overall System Description Detail

As mentioned briefly above, the idea was to retain in the gauge the geared mechanical system. The analogue pointer and graduated scale would then be replaced by some kind of electronic system to count fractions of a revolution of the centre pinion to which the pointer had been attached.

Also a means of discriminating the direction of rotation was required so that an up/down count could be provided for the electronics.

Over the travel of 25 mm of the plunger using the Series II indicator mechanism, the centre pinion and pointer rotate 25 times. For this reason an absolute method of encoding is ruled out. In an incremental system however, there must be 100 counts per revolution, one count corresponding to ±0.01 mm. Over the total plunger travel of 25 mm there must be 100 x 25 = 2500 counts (nominally). If the minimum travel time over this distance is about 0.5 seconds (a realistic figure - see mechanical analysis later) then the typical count frequency is of the order of 5 KHz; thus we are dealing with a low bandwidth system.

It was necessary to obtain approximate figures such as these in order to facilitate initial selection of electronic devices which would perform the counting function fast enough to ensure that point (8) in the specification could be met; ie. that no count pulse should be missed under any circumstance.

## 5.0 THE RESEARCH & DEVELOPMENT TASK

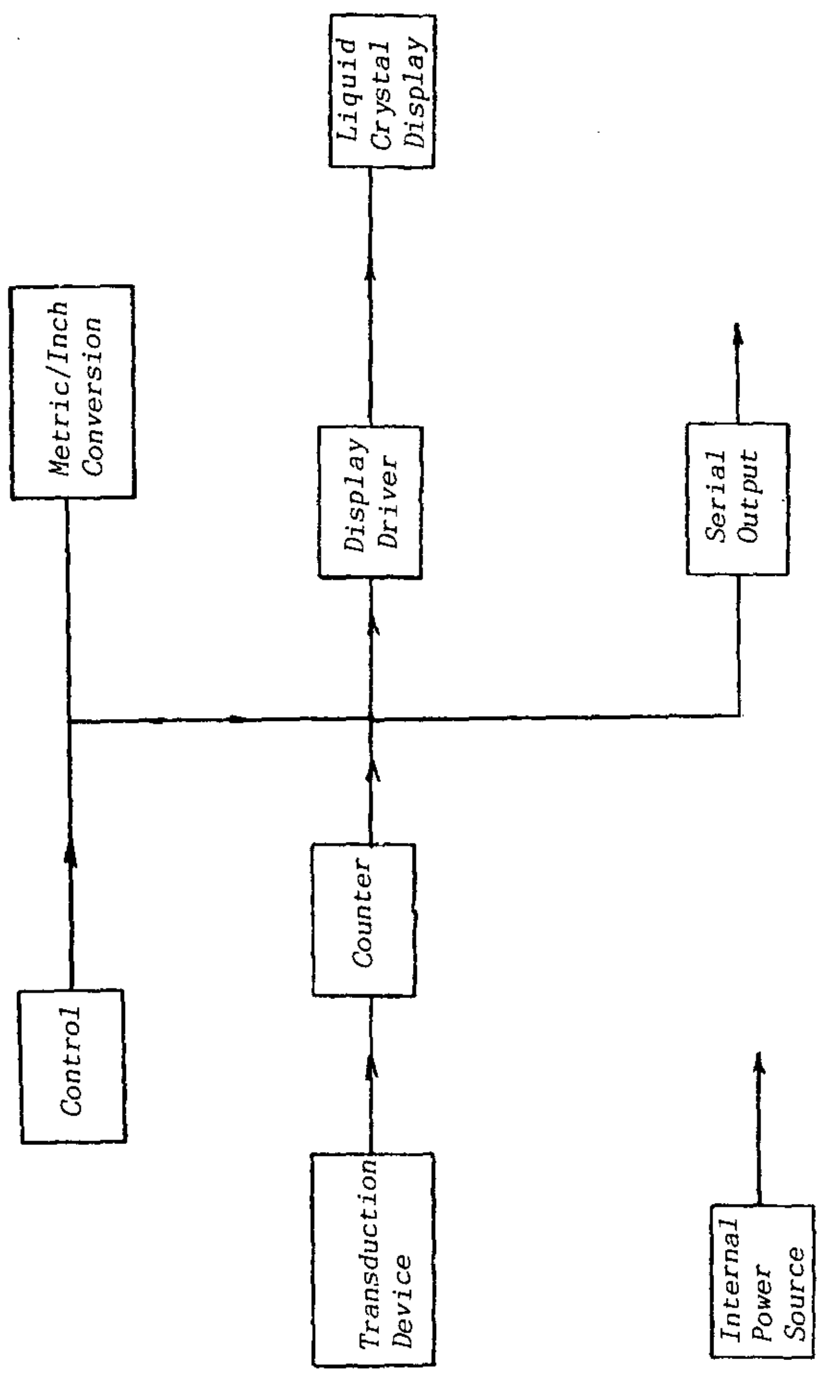
*Having, in some way, converted rotation of the centre pinion of the indicator into a numerical value in a counter, the remaining functional points of the specification must be met. These are the conversion between metric and imperial units, the driving of a display (due to low power requirements an LCD (Liquid Crystal Display) was chosen early in the design process), and general 'housekeeping' functions such as the monitoring of pushbuttons, timing, and driving the serial output port. At this point it is pertinent to consider the amount of current available from the internal power source. In the space available rechargeable cells could be used having a capacity of the order of 60 mAh. Therefore, if a working life between charges of 1 week (40 hours) is acceptable, the total current consumption of 1.5 mA maximum is allowable.*

*This figure was to be borne in mind in the selection of devices and transducer operating principle.*

*A block diagram of the basic elements in the electronic indicator is shown in Fig. 5.1*

# 5.0 THE RESEARCH & DEVELOPMENT TASK

Fig. 5.1



## *5.0 THE RESEARCH & DEVELOPMENT TASK*

*The numerical output from the device was chosen at this point to be of serial ASCII format for two overruling reasons: firstly, only 3 wires are needed to implement a serial link (in this case DATA, (TXD), Request to Send (RTS) and ground); secondly, by adopting the RS423 format it would be possible to connect a wide range of peripheral devices to the indicator. A parallel output would require many more wires and connector size must be kept to a minimum; in addition, few microcomputers have a parallel input port with any standard protocol of data transmission format.*

### *5.3.2 Alternative Transduction Means*

#### *5.3.2.1 Inductive System*

*A ferro-magnetic disc attached to the centre pinion of the indicator could be sensed for its position using the radial slots to complete a magnetic circuit forming part of a transformer core, in a similar means to the 'Inductosyn' principle.*

*The method was not persued for these reasons: firstly, that it would be necessary to manufacture small (expensive to produce) coils which would have to be mounted in close and accurate proximity to the rotating disc which would in turn need to be manufactured to high accuracy. There must be no risk of physical contact between disc and sensor coils otherwise undue hysteresis would arise in the measurement system. Also, the coils would need to be energised by A.C. of much higher frequency than the maximum count frequency in order to ensure that no count pulse could be missed. The coils would necessarily be of low 'Q' due to the large air gap between disc and pole pieces and so could be expected to dissipate some energy.*

*There would also be complication in demodulating the amplitude modulated signals thus produced, consuming power, space and design effort.*

5.2.3.2 *Capacitive System*

*Although no coils would be involved in such a system, all the other comments in 5.3.2.1 above apply to the capacitive method of detection, except that appreciably lower power levels would be involved. Both the inductive and capacitive systems were discarded in favour of an optical system described below.*

## 5.4 Infra-red Optical System

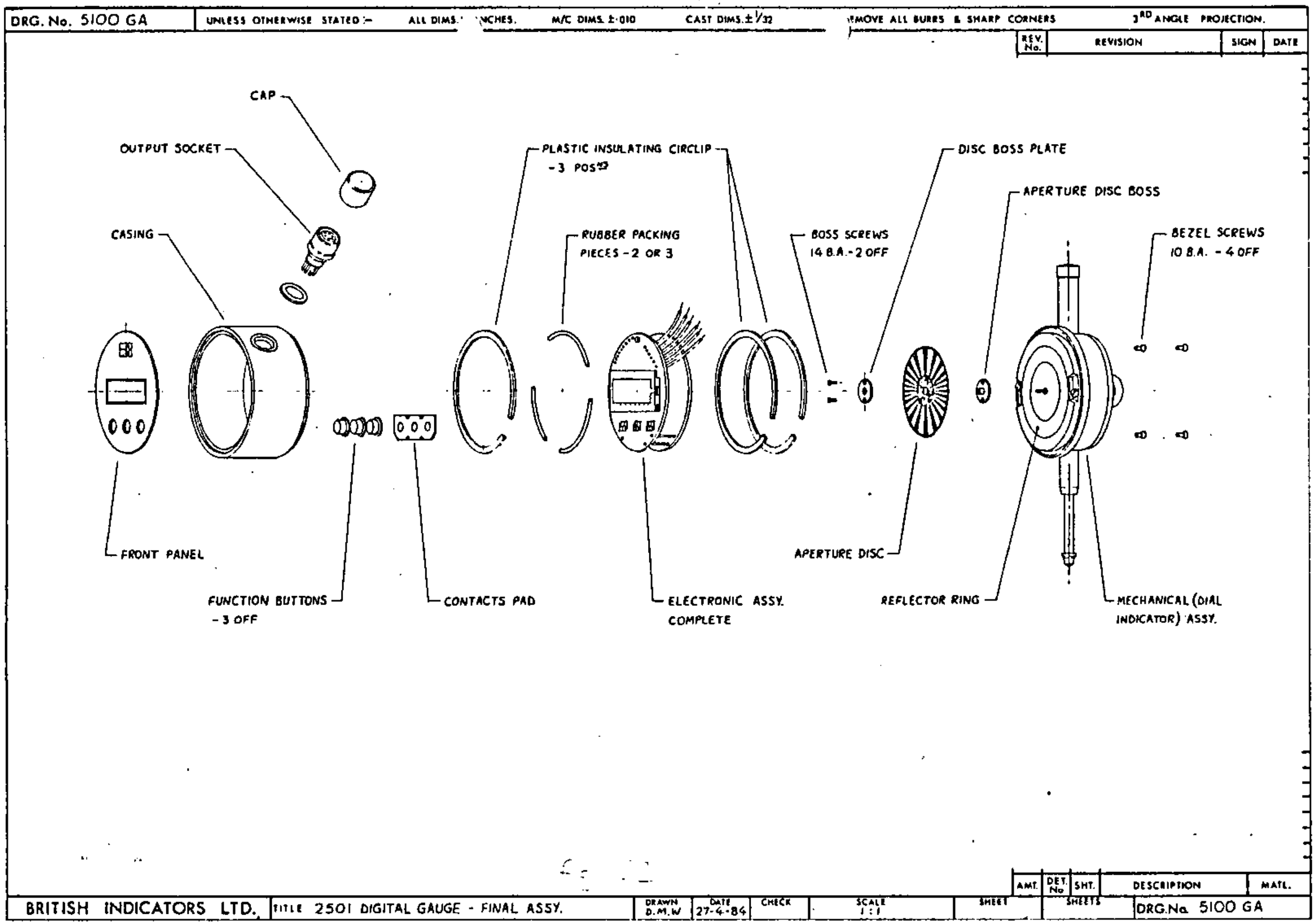
### 5.4.1 Physical Arrangement

*A significant selling point of the indicator is that the display can rotate through any angle relative to the body of the unit. By arranging for the optical devices to 'look at' the slotted disc (see Fig 5.2) from one side only, ie. the emitter's beam is reflected from the disc back to the receiver, at an appropriate angle. Thus, there is no electrical nor mechanical contact between the mechanical section and the electro-optical section. The whole electronics casing can thus be rotated freely and indefinitely about the central axis.*

*The disc attached to the centre pinion has a very different geometrical nature to that of the pointer which it replaces. The main difference is in the increased moment of inertia, and so it was very important to establish that this increase would not cause problems in operation such as sheared or distorted gear teeth, shearing of centre pinion shaft, or slip of the disc boss on the centre pinion shaft (see Fig 5.2), when the mechanism is suddenly accelerated or brought to rest, before proceeding further with a design on this basis.*

*The method adopted here will be to calculate the increase in the moment of inertia at the centre pinion due to the addition of the disc. Then, the effective linear mass equivalent of all the rotating parts referred to the RACK will be deduced, enabling* ***linear*** *force, mass acceleration, and momentum equations to be solved in a very straightforward manner.*

Fig. 5.2


DRG. No. 5100 GA
UNLESS OTHERWISE STATED :- ALL DIMS. INCHES. M/C DIMS ±·010 CAST DIMS. ±1/32
REMOVE ALL BURRS & SHARP CORNERS
3RD ANGLE PROJECTION.
REV. No.
REVISION
SIGN
DATE
CAP
OUTPUT SOCKET
CASING
PLASTIC INSULATING CIRCLIP -3 POS
RUBBER PACKING PIECES - 2 OR 3
DISC BOSS PLATE
APERTURE DISC BOSS
BOSS SCREWS 14 B.A. - 2 OFF
BEZEL SCREWS 10 B.A. - 4 OFF
FRONT PANEL
FUNCTION BUTTONS - 3 OFF
CONTACTS PAD
ELECTRONIC ASSY. COMPLETE
APERTURE DISC
REFLECTOR RING
MECHANICAL (DIAL INDICATOR) ASSY.
AMT.
DET. No
SHT.
DESCRIPTION
MATL.
BRITISH INDICATORS LTD.
TITLE 2501 DIGITAL GAUGE - FINAL ASSY.
DRAWN D.M.W
DATE 27-4-84
CHECK
SCALE 1:1
SHEET
SHEETS
DRG. No. 5100 GA

# 5.0 THE RESEARCH & DEVELOPMENT TASK

## 5.5 Analysis of the Mechanical System

### 5.5.1

*Comparison of moments of inertia of centre pinion and pointer, with centre pinion and disc assembly.*

*Centre pinion*

*Approximating the centre pinion to a cylinder the moment of inertia of mass of a cylinder Jmc is given by*

$J_{MA} = \frac{1}{2}M_C R_C{}^2$ (a) [13] ($J_{MA}$ = moment of inertia of Mass of an anulus).

*Centre pinion pointer boss*

*Approximating the centre pinion boss to a hollow cylinder, or anulus, its* $J_M$ *value is given by*

$$J_{MA} = \tfrac{1}{2}M_A(R^2 + r^2) \qquad [13]$$

and

$$M = p_A \pi L_A(R^2 - r^2)$$

yielding

$$J_{MA} = \tfrac{1}{2}\pi p_A L_A(R_A{}^2 + r_A{}^2)(R_A{}^2 - r_A{}^2) \qquad (b)$$

*Slotted disc boss*

*This part is a simple cylinder so (a) above applies :*

$J_{MB} = \frac{1}{2}M_B R_B{}^2$ ($J_{MB}$ - moment of inertia of Mass of the boss).

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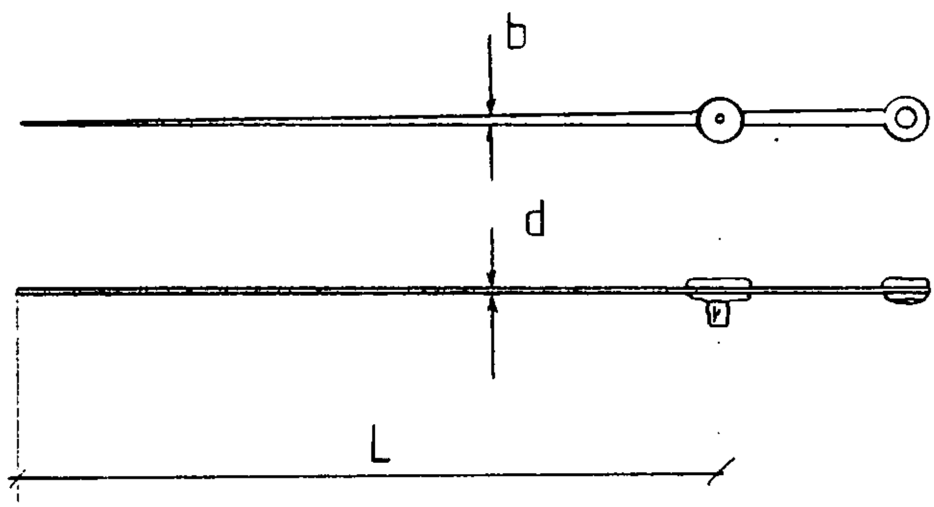
*Pointer*

*The pointer can be regarded as a cantilver (see Fig 5.3).*

*The amount of taper is regarded as negligible.*

*Fig. 5.3 The Pointer*




*The counter weight must have the same effective moment of inertia and so*

$J_{MP} = 2MK_o^2$ [13] (where $J_{MP}$ moment of inertia of Mass of the pointer).

*and*

$K_o = .577L$ [13]

*yielding*

$J_{MP} = .666pbd.\ \underline{L}^2$ (c)

## 5.0 THE RESEARCH & DEVELOPMENT TASK

*Slotted disc*

*The disc can be regarded as a cylinder with half its mass removed, since the slots have an equal mark/space ratio. Therefore from (a) above*

$$J_{MD} = \tfrac{1}{4}MR^2 \qquad (d)$$

*In all the above the symbols have the following meanings:*

| | | |
|---|---|---|
| $J_M$ | = | Moment of inertia of mass |
| $M$ | = | Mass of body |
| $P$ | = | Density of body |
| $R$ | = | Major radius of body |
| $r$ | = | Minor radius of body |
| $L$ | = | Length of body |
| $b$ | = | Breadth of body |
| $d$ | = | Depth of body |
| $K_o$ | = | Radius of gyration of body |

*Suffixes*

| | | |
|---|---|---|
| C | = | Centre pinion |
| A | = | Annulus (pointer boss) |
| B | = | Disc boss |
| P | = | Pointer |
| D | = | Disc |

*Similar formula and variants were used to compute the $J_M$ values for all the other gears in the train (see Fig. 5.4).*

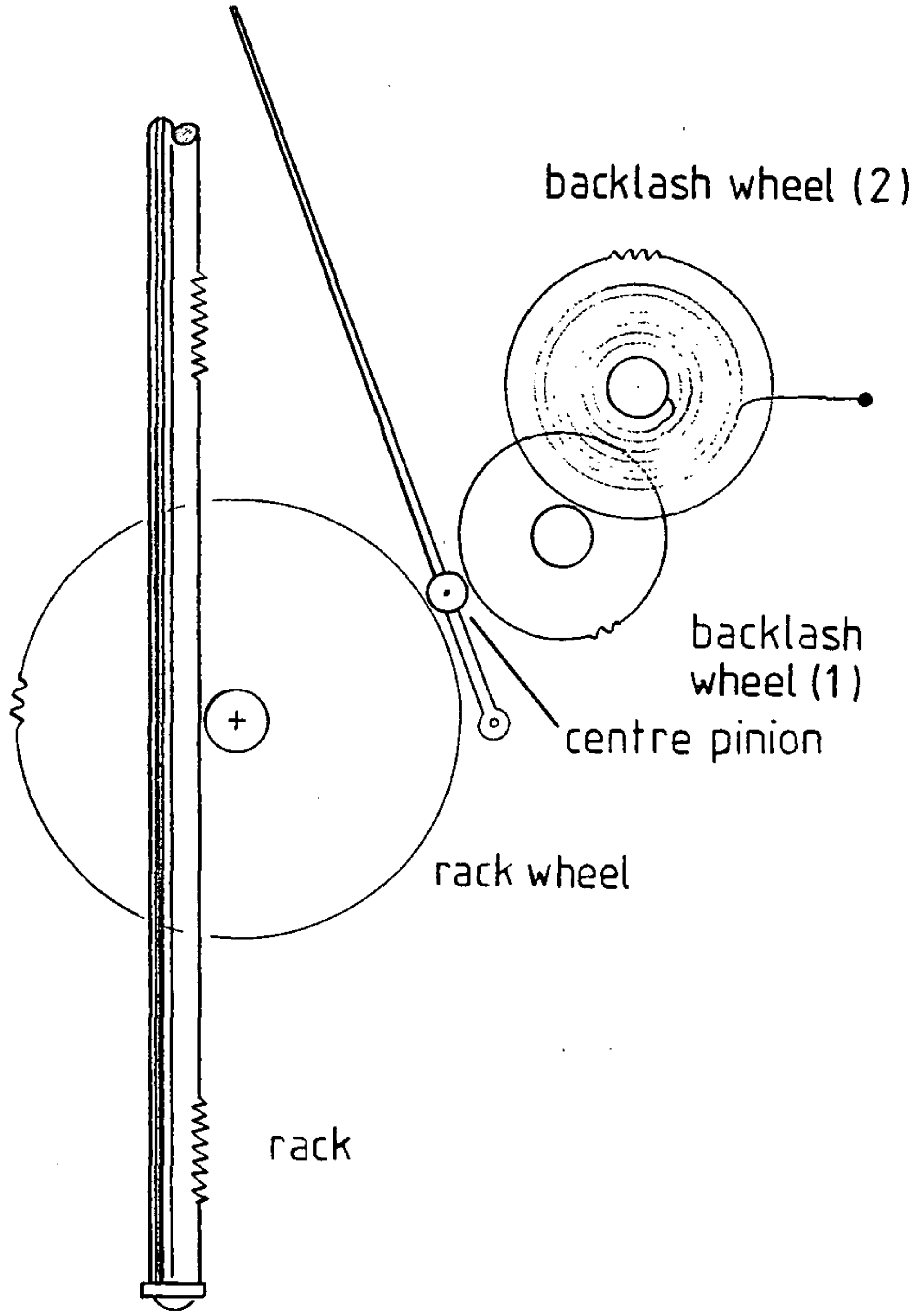



*Fig. 5.4 Geartrain*

## 5.5.2 Translation of $J_M$ Values into Equivalent Linear Mass

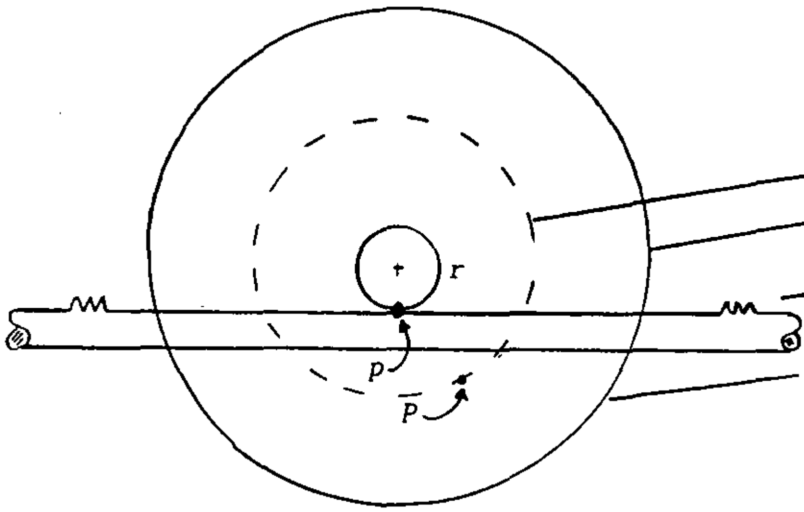



Fig. 5.5

*The Radius of Gyration of a body is that distance at which the entire mass may be considered to be concentrated.* $K_o = J_M/M$ m

*Therefore a force acting tangentially at p 'sees' the mass of the gear wheel multiplied by the factor Ko/r*

*(See Fig. 5.5).*

*Thus the translation of the inertia* $J_M$ *of a rotating gear wheel of mass M in mesh with a rack to an equivalent linear mass* $M_E$ *is:*

$$M_E = MK_o/r$$

$$= M\,(J_M/M)^{\frac{1}{2}}$$

$$M_E = (J_M \cdot M)^{\frac{1}{2}}/r \quad \text{Kg and for a disc}$$

$$M_E = (\tfrac{1}{2}M^2R^2)^{\frac{1}{2}}/r$$

$$M_E = .71MR/r \quad \text{kg}$$

*A similar technique was adopted for each wheel in the train, taking into account the different gear ratios present below in table 5.6.*

*Table 5.6*

| VALUE | RACK | RACK WHEEL | CENTRE POINTER | PINION WITH: DISC | BACKLASH (1) | WHEELS (2) | UNIT |
|---|---|---|---|---|---|---|---|
| $M$ | 14 | 2.40 | .16 | .48 | .57 | 1.37 | g |
| $J_M$ | - | .1200 | .0094 | .0425 | .0070 | .0430 | $10^{-6}Kgm^2$ |
| $K_o$ | - | 7.1 | 7.6 | 9.4 | 3.5 | 5.6 | mm |
| $M_E$ | 14 | 11.0 | 7.2 | 26.5 | 6.1 | 3.2 | g |

$M$ = Mass

$J_M$ = polar moment of inertia of mass

$K_o$ = radius of gyration

$M_E$ = Effective mass seen at the rack

### 5.5.3 Some comments on the results above

*Note that the moment of inertia of the disc assembly is approximately 4.5 times greater than that of the pointer assembly (the disc is made from 1 thou" stainless steel shim which is chemically milled to a high accuracy). The equivalent mass referred to the rack translation is some 3.7 times greater, but when all the other gearwheels' mass is taken into account, only a 40% increase in total equivalent mass is imposed. It now remains to be shown that under normal conditions of use that no damage to the mechanism will result at the most critical points, namely the points of reversal.*

### 5.5.4 Acceleration Under the Return Spring

*If the plunger is depressed to its maximum travel of 25mm (nom.) and released, temporarily neglecting air damping and the bearing friction, there will be uniform acceleration according to*

$$F = M_E a$$

where $F$ = spring force, a constant 1.5N

$M_E$ = equivalent mass of the rack

$a$ = resultant acceleration

thus $$a = \frac{1.5}{0.068} = 22 \text{ ms}^{-2}$$

*Using Newton's equations of motion:*

final velocity $$V_f = (2as)^{\frac{1}{2}}$$
$$V_f = 1 \text{ ms}^{-1}$$

*and the time taken is:*

$$t = 2s/V_f$$
$$t = 50 \text{ ms}$$

*In practice the mechanism moves more slowly than predicted by these figures, by a measured time factor of approximately 10, due to air damping and bearing losses.*

*Measurement has shown that a terminal velocity of approximately 0.1 $ms^{-1}$ is attained over this interval. Calculating through the gear train reveals that a frequency of approximately 2 KHz is produced by the slots of the disc passing a fixed point, which as mentioned previously, is a low frequency which will cause no count speed problem in practise.*

*The impulse exerted at the plunger stop is given by Ft where*

$$F = M_E/(V_f - V_o) \qquad [13]$$

where $M_E$ = effective mass
$t$ = time over which impulse acts
$V_f$ = final velocity
$V_o$ = initial velocity before impact
$F$ = force exerted as a result of momentum change

*The plunger comes to rest in a short time of 12 ms as found by measurement. (In practice, there is considerable elastic deformation throughout the gear train. The force exerted for this time is then 6 N or about 0.6 Kg.)*

*Most of this impulse is concentrated on a single rack tooth/rack tooth wheel due to the mounted angular momentum of the disc and other gear wheels (the momentum of the plunger accounting for nothing here).*

*A correctly formed gear tooth is stressed mainly in tension and it can be shown that the yield strength of a rack tooth is approximately 230 N (within the limit of elastic deformation). Thus there is a safety factor of at least 38 on the strength of the rack tooth, under this impact condition.*

### 5.5.5 Acceleration in the Upward Direction

*When the plunger is moved upwards, clearly an arbitrarily large force can be applied resulting in eventual destruction of a gear tooth, when the plunger suddenly comes to rest at the extent of its travel. This is a misuse condition which is protected against in the following way.*

*The rack wheel was redesigned to incorporate a spring loaded shock absorbing mechanism, which allows the gear wheel to rotate independently of the shaft when the plunger comes to rest, as just described. The* *effect of this is to increase the impulse time to several milliseconds, thus reducing the impulse force on the gear teeth.*

*In practise, it takes a great deal of abuse to damage a rack or gear tooth.*

### 5.5.6 Mounting the Disc on its Boss and the Centre Pinion

*Due to the increased angular momentum of the disc assembly over the pointer, there is significant instantaneous Torque present at the small diameter of the centre pinion. The pointer had previously been fitted to the spindle by means of a shallow round taper, but this no longer proved adequate to retain the boss. Any slip results in repeatability errors which are totally unacceptable. The solution was to form a spline on the spindle, and the aluminium boss, when driven over the spline with an interference fit, never changes its position.*

*The disc is bonded to the boss using Epoxy Resin adhesive.*

### 5.5.7 Tests to Destruction

*By accelerating the plunger extremely hard, it is possible eventually to deform a rack tooth or a gear tooth, when the rack comes to rest, and the shockproof wheel moves to the extreme of its travel.*

*However, the worst shock mode is to apply impulses to the plunger causing it to suddenly accelerate upwards (as in a drop test). The shockproofing cannot protect the mechanism in this direction, and it would be difficult to incorporate a two-way shockproofing mechanism in the available space without introducing unpredictable repeatability. However, the mechanism has been tested to the point of destruction, and can withstand an applied shock force in excess of some 3 Kg before signs of tooth deformation occur. No other failure mode than tooth deformation has been observed.*

# 5.0 *THE RESEARCH & DEVELOPMENT TASK*

## 5.6 *Accuracy and Calibration*

*It is here assumed that the electronic circuitry can be designed so as to introduce a negligible error as compared to those introduced by the gear train. For an indicator of resolution 0.01 mm it is usual to calibrate to a resolution of 1/10th of this figure, namely 1 micron. The specification calls for a repeatability of ± 1 count or 10 microns: a static electronic hysteresis of approximately 1% is therefore representative of 1/10 of 1 micron, which is fairly insignificant compared to the short range error allowed by BS907. For an indicator of this class it is 5um, ie. 2% of the allowable short range error.*

*Thus it was judged reasonable to calibrate the indicator to the nearest micron using an electronic drum micrometer with a traceable calibration certificate.*

*The indicator is in fact marketed in four principal areas, namely North America, U.K., Europe and Japan. Thus four separate and different standards must be catered for which are the A.G.D. (American Gage Design), BS907 for mechanical indicators, D.I.N. standard for mechanical indicators, and the J.I.S. (Japanese Industrial Standard).*

*Previously in the company, this calibration had been done manually using a drum micrometer, and a table of allowable differences for the relevant standard.*

*The method was antiquated and extremely slow, and so a microcomputer system was configured to speed up the task, eliminate virtually all operator errors, de-skill the job and provide a printed calibration chart for each indicator.*

### 5.6.1 *Calibration Using the Acorn Model B Microcomputer and the Sylvac D25 Electronic Micrometer*

*The Sylvac D25 micrometer has an inherent accuracy of ± 1 micron over 26 mm travel and a resolution of 1/10 micron. It has a BCD (Binary Coded Decimal) serial output which was interfaced to the 'BBC' microcomputer's user port using an interrupt driven machine coded subroutine.*

*A BASIC program was then written to guide the operator through the calibration sequence of the indicator according to the relevant standard.*

*Not only the new electronic indicator but the whole of B.I.L.'s range of indicators are now calibrated using this system.*

### 5.6.2 *Calibration Results*

*The basic shortcomings of the indicator gear train become instantly apparent on examination of Fig 5.7, which is a sample of an indicator which passed calibration tests.*

*Referring again to Fig 5.4 which shows the gear train configuration, it can be seen that there are three principal elements which comprise the magnification system. They are the rack, the rack wheel and the centre pinion. (The backlash wheels would only contribute second or third order effects since they are not directly in the gear train, and exert only the hairspring backlash force). Taking these in order and referring to Fig 5.7:*

#### 5.6.2.1 *The Rack*

*The rack, being a linear component, might be expected to contribute a long term progressive error due either to a pitch error or a parallelity error. The latter causes a long term progressive error by virtue of a steadily increasing or decreasing depth of mesh with the rack wheel.*

*The error is illustrated by the chain dotted line superimposed on the graph. Because racks are all cut on one machine, this error tends to be a batch error and is quite consistent. The cutting tool was checked for pitch accuracy and it was found that in fact the rack teeth effective height was not parallel to the axis of the plunger. In production the remedy is easily effected by more careful setting up of the machine.*

5.6.2.2 *The Rack Wheel*

*This component rotates 2.5 times over the full travel of 25 mm and so any eccentricity of the effective PCD (Pitch Circle Diameter) of either the pinion (the portion in mesh with the rack) or the outer section, or a combination of both, would result in 2.5 cycles of a sinusoidal nature on the calibration chart. This is indeed seen to be the case in Fig. 5.7 where the cycles are highlighted by the dotted line.*

*The major eccentric on this wheel was found to be the larger brass part which also incoprorates the shockproofing spring. Eccentricity was reduced by improving the drilling and reaming accuracy, and tightening the clearance fit of shaft and gear wheel.*

*Fig. 5.7*

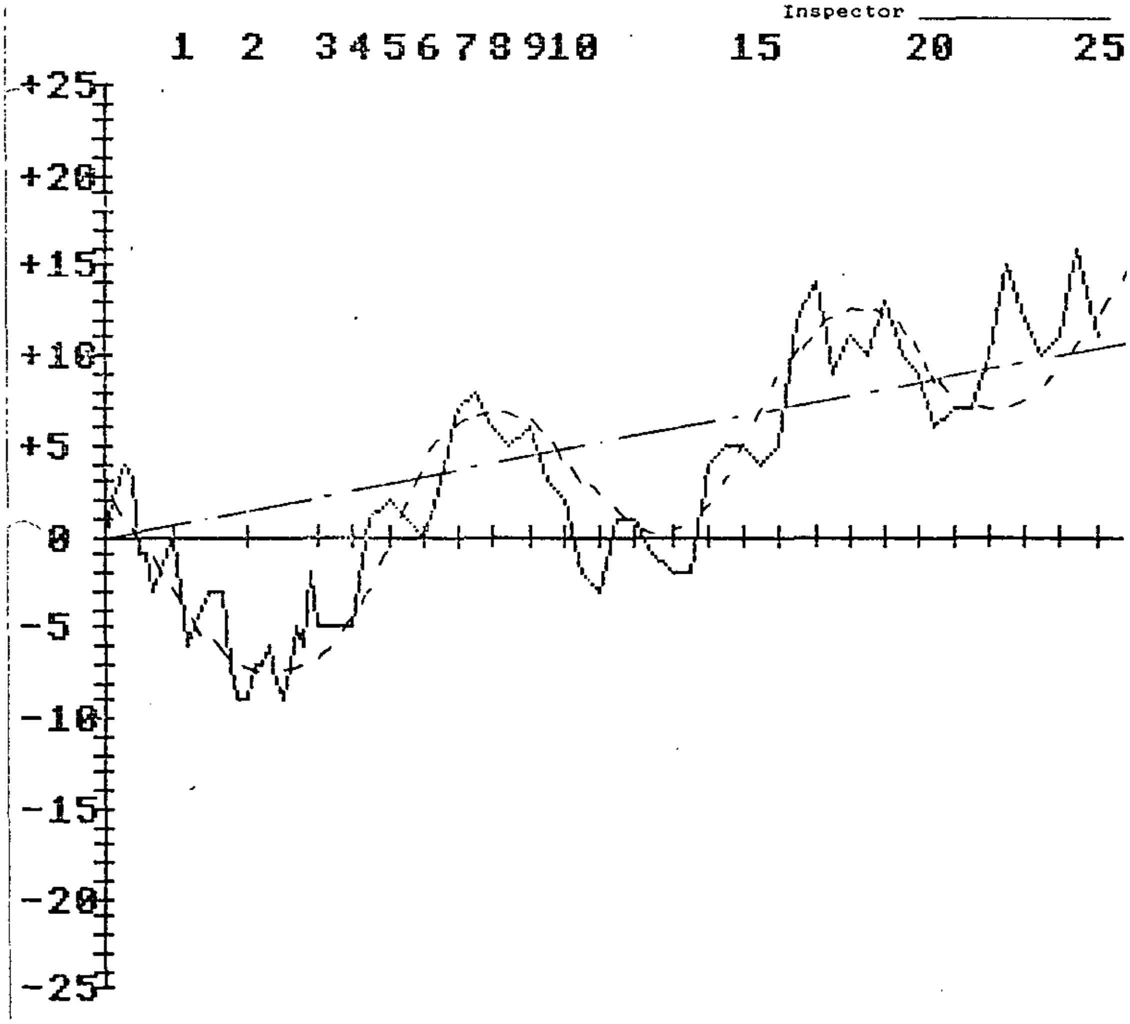
Fowler Ultra-Digit Indicator

Resolution 0.0004 inch/.01 mm
Gage Number 23
Date 21.2.1985

| A.G.D. Specification | ALLOWED | ACTUAL | |
|---|---|---|---|
| | | High + | High - |
| 1st 2.3 Revolutions | ± 0.010 | +0.004 | -0.009 |
| 1st 10 Revolutions | ± 0.030 | +0.008 | -0.009 |
| 1st 20 Revolutions | ± 0.040 | +0.014 | -0.009 |
| 1st 25 Revolutions | ± 0.040 | +0.016 | -0.009 |

Result Accepted

Inspector ______________



5.6.2.3 *Centre Pinion*

*This component rotates once per revolution, obviously, and so any eccentricity of the effective PCD in mesh with the rack wheel would show as 25 perturbations over the full travel of the plunger, as exemplified in Fig 5.7. Normally the centre pinion is the least troublesome part contributing ± 2 microns cyclic error.*

5.6.3 *Curing a Rejected Gauge*

*In almost all cases the indicator fails at the extreme of travel where the progessive rack error is added to the cyclic error of the rack wheel, and sometimes of the centre pinion too.*

*There are three ways to solve this cumulative problem:*

- *replace the rack wheel with a less eccentric part;*
- *replace the rack with a more parallel part, or*
- *re-mesh the rack wheel at a position one half turn from its present position, thus* ***subtracting*** *the cyclic rack wheel error from the progressive rack error at the end of travel.*

*The latter method can result in causing failure lower down the rack in the case of a marginally acceptable short range calibration.*

5.7 *Description of the Infra Red Pseudo Optical System*

*The mechanical properties of the aperture disc have been described previously. Its size was chosen such that the width of the slots near the circumference would be compatible with the beam diameter produced by the infra-red emitters, nominally 3 mm. Thus, the need for any lens was avoided and the full efficiency of the opto pairs could be utilised.*

## 5.0 *THE RESEARCH & DEVELOPMENT TASK*

*There are two pairs of devices, comprising two infra-red LEDS. and two photo-transistors of matched spectral and optical characteristics.*

*Beam divergence was chosen to be minimal at approximately 12° included angle thus minimising light loss. The two pairs are mounted radially an angular distance apart corresponding to an odd number of half pitches of the apertures of the disc. Thus as the disc rotates the light beams are alternately reflected and interupted, and there is a corresponding photoelectric current of a pseudo-sinusoidal waveform in the phototransistors, in quadrature, or 90° apart in phase.*

*It was initially attempted to reflect the light beams from the disc itself, but because of the extreme thinness of the disc, the flatness was found to be insufficient to maintain a constant distance from the opto devices. The disc was therefore made matt black, and behind it was fixed a stainless steel anulus to reflect the light.*

*The absolute location of the disc on the spindle was now non critical as the light beam was only interrupted by it, not reflected.*

*A test assembly was made and the typical current transfer ratio between the opto devices was measured. Using the highest sensitivity grades of opto devices, a transfer ratio of 0.2% was typically achievable at an excitation current of 0.5 mA, with a spread of 3:1. This large uncertainty of transfer ratio was due to an accumulation of tolerances in the devices themselves, their physical location accuracy and, to the second order, the quality of the reflector.*

*Since the gauge was to be battery powered by rechargeable cells, there would be a large variation in supply voltage to be expected, from a minimum of 4.2 V (cells near exhaustion) to a maximum of 5.6 V (cells on trickle charge). Thus it was necessary to design a constant current supply for the LEDS, which were connected in series to minimise current drain.*

## 5.0 THE RESEARCH & DEVELOPMENT TASK

*The circuit shown in Fig 5.8 has excellent supply voltage rejection characteristics, provides temperature compensation, and generates drive voltages for the triplexed LCD.*

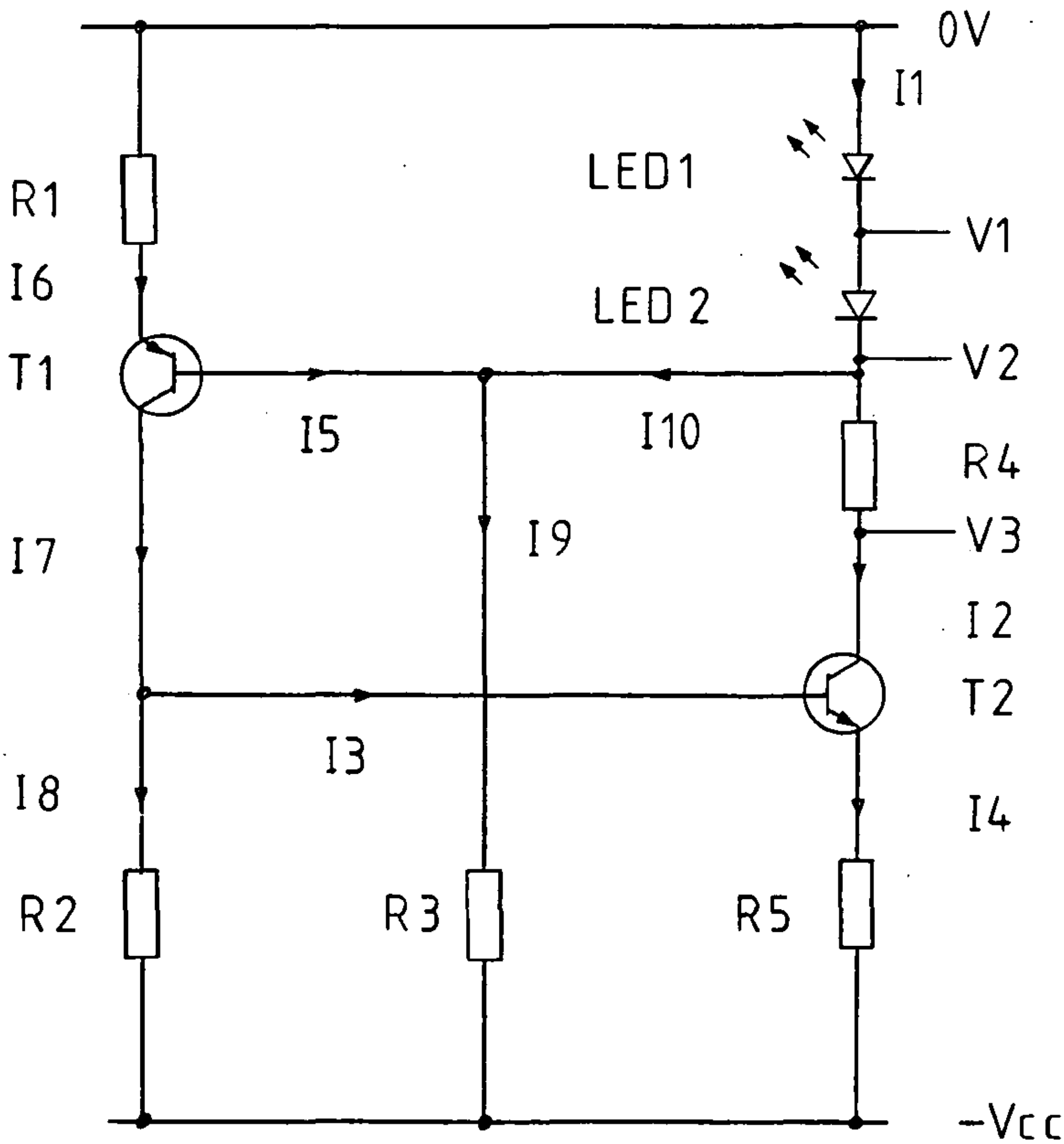



*Fig 5.8. Constant Current Source.*

### 5.7.1 Constant Current Generator for LEDS - Circuit Operation

*The two LEDS themselves are used as voltage references. Since they are to be driven by a constant current, it will be shown that they provide a very stable reference indeed against supply voltage variations. The base of T1 is thus held at a constant voltage and at constant temperature generates a constant emitter current through R1. Therefore T1's collector current is constant leading to a constant voltage being established at the base of T2. In a similar way, T2 generates a constant collector current through LED1, LED2 and R4.*

*R3 is necessary to provide initial turn-on current for T1 which otherwise might not begin to conduct depending on supply voltage rise time and gain. Once conduction is started the circuit switches on by positve feedback. R3 is connected to the node with the lowest impedance so as not to degrade the supply voltage rejection ratio excessively.*

### 5.7.2 Nominal Circuit Design

**For $I_1 = 0.5$ mA and $V_3 = -3.03$ V**

$R_4 = V_{R4}/I_1 = 2K2$ (NPV)

$I_3 = I_2/H_{FE} = 2.5$ uA

Let $V_{CE2} = 1.2$ V

$V_{E2} = V_{CC} - V_3 - V_{CE2} = 0.6$ V (see 5.7.3)

$R_5 = V_{R5}/I_4 = 1K2$

Let $I_8 \gg I_3$ say 20 uA

$R_2 = V_{B2}/I_8 = 62K$ (NPV)

$I_7 \;=\; I_3 + I_8 \;=\; 22.0\ uA$

$I_5 \;=\; I_7/H_{FE} \;=\; 0.1\ uA$

$I_6 \;=\; I_5 + I_7 \;=\; 22.1\ uA$

$V_{BE1} \;=\; 0.50\ V$ (see 5.7.3)

$V_{E1} \;=\; -2.02 + 0.50 \;=\; -1.52\ V$

$R_1 \;=\; V_{E1}/I_6 \;=\; 68K$ (NPV)

$R_3 \quad (V_2 - V_{CC})/I_5 \;=\; 1$ Megohm (largest practical value)

*Section 5.7.4 describes an iterative technique used to establish the working point of the circuit, both for nominal component values and for upper and lower* ***worst case*** *values.*

*Before this, however, it is necessary to be able to calculate junction voltages for the transistors and LEDS for a given junction current.*

### 5.7.3 Practical Semiconductor Junction Voltage Calculation

*In general the relationship between current and voltage for a forward biased junction is given by:*

$$I \;=\; I_o(e^{eV/KT} - 1) \qquad [2]$$

where

$I$ = junction current/A

$I_o$ = reverse saturation current/A

$e$ = charge of one electron/C

$V$ = junction voltage/V

$K$ = Boltzmann's constant/$JK^{-1}$

$T$ = junction temperature/K

The term $e/KT$ evaluates to approximately 40 at room temperature, thus:

$$I = I_o(e^{40V}-1)$$

and for forward biased junction where $V > .2$ V, $e^{40V} \gg 1$

thus $I = I_o e^{40V}$ to a close approximation.

To take two specific examples:

$$I_1 = I_o e^{40V_1} \text{ and } I_2 = I_o e^{40V_2}$$

thus $I_1/I_2 = e^{40V_1}/e^{40V_2}$

$$= e^{40V_1} . e^{-40V_2}$$

$$= e^{40(V_1-V_2)}$$

and $\log_e I_1/I_2 = 40(V_1 - V_2)$

$$\log_e I_1 - \log_e I_2 = 40V_1 - 40V_2$$

*This approximation holds good over several decades of junction current. Rearranging the equation*

$$40V_2 - \log_e I_2 = 40V_1 - \log_e I_1$$

*Either side can be determined by measurement of a real device (at room temperature) at a particular current. The term $40V_1 - \log_e I_1$ then yields a constant A which is particular to that type of junction (material of manufacture, geometry, doping levels) and substituting the constant A yields*

$$A = 40V - \log_e I$$

$$\text{or} \quad V = (A + \log_e I)/40 \qquad (a)$$

*The formula has been used with diode and transistor junctions.*

*For a silicon junction $A_S = 25$*
*For a Gallium Arsenide junction $A_G = 41$*
*Where I is in mA, V in volts*
*In a bipolar transistor junction I refers to the emitter current.*

*The use of this formula will be demonstrated shortly.*

### 5.7.3.1 Temperature Dependence

*It is well known that the temperature coefficient of forward voltage of a semiconductor junction is linear at constant current. Thus (a) above can be modified to take temperature into acount:*

$$V = (A + \log_e I)/40 + (20 - T)dV/dT \quad (5.7.3.1)$$

where $dV/dT$ is the temperature coefficient of voltage, and $T$, the junction temperature in °C.

for silicon $dV_S/dT = -2.3\ mV°C^{-1}$

for GaAs $dV_G/dT = -2.1\ mV°C^{-1}$

### 5.7.4 An Iterative Technique to Find the Working Point of a Circuit

The circuit of Fig 5.8 has been nominally designed using the required $I_1$ and $V_3$ as starting points. However, inevitably as the design progresses around the circuit, Nearest Preferred Values of components must be chosen. Thus, currents and voltages become adjusted and due to feedback action, the initially designed values inevitably change. A circuit of this type is sensitve to $V_{BE}$ values and so the equation (5.7.3.1) will be used extensively in calculations.

The approach adopted here will be to perform the following constant temperature analyses:

- find working point ($I_1$ and $V_1 \rightarrow V_3$) for nominal component values;
- find worst case maximum $I_1$ and $V_1 \rightarrow V_3$ taking component tolerances and $H_{FE}$ spreads into account;
- find worst case minimum $I_1$ and $V_1 \rightarrow V_3$ taking component tolerances and $H_{FE}$ spreads into account.

Then the temperature dependence of the circuit will be analysed using the results of the nominal analysis above.

From these results the temperature performance of the entire circuit will be deduced.

### 5.7.5 Iteration to find nominal working point at room temperature

*Refer to Fig 5.8 for the circuit diagram. The general technique is illustrated by this example. Firstly, a seed value or estimation for one of the values of voltage or current must be made in order to provide a starting point for the analysis. It is largely unimportant what value is chosen, but the closer it is to the final result, the fewer iterations will be required. It makes sense to start with the value which is of most interest in the circuit, and to use the number which the nominal design was produced for. Thus for this circuit let* $I_1 = 0.5$ *mA.*

*From this 'seed' value, all other voltages and currents in each branch of the circuit can be calculated, finishing with a calculation of* $I_1$*. This new value of* $I_1$ *will be closer to the 'true' value. Iteration then produces a converging series of values; when the same result is obtained twice the iteration is complete. In the first pass it is necessary to estimate some values (such as* $V_{be1}$*) since they depend on values not yet calculated. However, they are calculated with increasing accuracy in subsequent passes.*

*Iterations such as these are ideally performed by computers, and a program was written to iterate around the circuit until convergence is achieved.*

## 5.0 THE RESEARCH AND DEVELOPMENT TASK

*A segment of the program is shown here to illustrate the steps in the iteration. It should be noted that many possible iterations can be chosen, some of which will be divergent rather than convergent.*

```
195 CT=1
200 V2=2*(41+LOG(I(1)))/40+(20-t)*4.2/10
00
210 I(9)=(VC-V2)/R3
215 VR(1)=V2-VB(1)
220 I(6) =VR(1)/R1
225 VB(1)=(25+LOG(I(6)))/40+(20-t)*2.3/1
000
230 I(5)=I(6)/(HF-1)
235 I(10)=I(9)-I(5)
240 I(7)=I(6)-I(5)
250 I(8)=I(7)-I(3)
260 VR(2)=I(8)*R2
270 VR(5)=VR(2)-VB(2)
280 I(4)=VR(5)/R5
290 VB(2)=(25+LOG(I(4)))/40+(20-t)*2.3/1
000
300 I(3)=I(4)/(HF-1)
310 I(2)=I(4)-I(3)
320 V3=V2+I(2)*R4
330 I(1)=I(2)+I(10)
350 V3(CT)=INT(10000*V3)
370 REM GOSUB 380
375 IFV3(CT-1)=V3(CT)GOSUB380:?#pc:?#pc,
"ITERATION COMPLETE.":?#pc,"------------
-------":FORi=0TO Pc/2:?#pc:NEXTi:LIST12
0-180:END
376 CT=CT+1
377 GOTO 200
```

*To illustrate the convergence of the values, the results of three iterations with widely different 'seed' values are shown below in Figs. 5.9 - 5.11*

*Fig 5.9*

```
Nominal Iteration 1
===================

R1  =      68 k
R2  =      62 k
R3  =      1000 k
R4  =      2.2 k
R5  =      1.2 k
HFE =      200
VCC =      4.8 V
TEMP =     20 C
SEED: I1 =  .5 mA

RESULTS OF ITERATION
--------------------

ITERATION  1      V1= - 1.0077 V
                  V2= - 2.0153 V
                  V3= - 3.2630 V
                  I1=     .5698 mA

ITERATION  2      V1= - 1.0109 V
                  V2= - 2.0219 V
                  V3= - 3.0553 V
                  I1=     .4724 mA

ITERATION  3      V1= - 1.0063 V
                  V2= - 2.0125 V
                  V3= - 3.0924 V
                  I1=     .4935 mA

ITERATION  4      V1= - 1.0073 V
                  V2= - 2.0147 V
                  V3= - 3.0844 V
                  I1=     .4889 mA

ITERATION  5      V1= - 1.0071 V
                  V2= - 2.0142 V
                  V3= - 3.0862 V
                  I1=     .4899 mA

ITERATION  6      V1= - 1.0072 V
                  V2= - 2.0143 V
                  V3= - 3.0858 V
                  I1=     .4897 mA

ITERATION  7      V1= - 1.0072 V
                  V2= - 2.0143 V
                  V3= - 3.0859 V
                  I1=     .4897 mA

ITERATION  8      V1= - 1.0072 V
                  V2= - 2.0143 V
                  V3= - 3.0858 V
                  I1=     .4897 mA

ITERATION COMPLETE.
-------------------
```

*Fig 5.10*

```
Nominal Iteration 2
===================

R1 =      68 k
R2 =      62 k
R3 =      1000 k
R4 =      2.2 k
R5 =      1.2 k
HFE =     200
VCC =     4.8 V
TEMP =    20 C
SEED: I1 =  1E-06 mA

RESULTS OF ITERATION
--------------------

ITERATION  1     V1= -   .6796 V
                 V2= - 1.3592 V
                 V3= - 1.5211 V
                 I1=     .0770 mA

ITERATION  2     V1= -   .9609 V
                 V2= - 1.9218 V
                 V3= - 3.1903 V
                 I1=     .5794 mA

ITERATION  3     V1= - 1.0114 V
                 V2= - 2.0227 V
                 V3= - 3.0515 V
                 I1=     .4703 mA

ITERATION  4     V1= - 1.0061 V
                 V2= - 2.0123 V
                 V3= - 3.0932 V
                 I1=     .4940 mA

ITERATION  5     V1= - 1.0074 V
                 V2= - 2.0147 V
                 V3= - 3.0842 V
                 I1=     .4888 mA

ITERATION  6     V1= - 1.0071 V
                 V2= - 2.0142 V
                 V3= - 3.0862 V
                 I1=     .4899 mA

ITERATION  7     V1= - 1.0072 V
                 V2= - 2.0143 V
                 V3= - 3.0858 V
                 I1=     .4897 mA

ITERATION  8     V1= - 1.0072 V
                 V2= - 2.0143 V
                 V3= - 3.0859 V
                 I1=     .4897 mA

ITERATION  9     V1= - 1.0072 V
                 V2= - 2.0143 V
                 V3= - 3.0858 V
                 I1=     .4897 mA

ITERATION COMPLETE.
-------------------
```

*Fig 5.11*

```
Nominal Iteration 3
===================

R1 =      68 k
R2 =      62 k
R3 =      1000 k
R4 =      2.2 k
R5 =      1.2 k
HFE =     200
VCC =     4.8 V
TEMP =    20 C
SEED: I1 =   100000 mA

RESULTS OF ITERATION
--------------------

ITERATION  1     V1= - 1.3128 V
                 V2= - 2.6256 V
                 V3= - 4.8832 V
                 I1=   1.0282 mA

ITERATION  2     V1= - 1.0257 V
                 V2= - 2.0514 V
                 V3= - 2.8295 V
                 I1=    .3563 mA

ITERATION  3     V1= -  .9992 V
                 V2= - 1.9984 V
                 V3= - 3.1336 V
                 I1=    .5187 mA

ITERATION  4     V1= - 1.0086 V
                 V2= - 2.0172 V
                 V3= - 3.0748 V
                 I1=    .4834 mA

ITERATION  5     V1= - 1.0068 V
                 V2= - 2.0137 V
                 V3= - 3.0882 V
                 I1=    .4911 mA

ITERATION  6     V1= - 1.0072 V
                 V2= - 2.0144 V
                 V3= - 3.0853 V
                 I1=    .4894 mA

ITERATION  7     V1= - 1.0071 V
                 V2= - 2.0143 V
                 V3= - 3.0860 V
                 I1=    .4898 mA

ITERATION  8     V1= - 1.0072 V
                 V2= - 2.0143 V
                 V3= - 3.0858 V
                 I1=    .4897 mA

ITERATION  9     V1= - 1.0072 V
                 V2= - 2.0143 V
                 V3= - 3.0859 V
                 I1=    .4897 mA

ITERATION COMPLETE.
-------------------
```

*In future illustrations, only the final result will be reproduced to save space. It is demonstrated that the final result of the iteration is* ***independent*** *of the seed value chosen.*

### 5.7.6 Dependence of Constant Current on Supply Voltage

*Two iterations are shown here, for the extremes of supply voltage, in Fig 5.12 (see over).*

*From these results, the voltage coefficient of current is*

$$(dI/dT)/(dV/dT) = 1.06\ uAv^{-1} \text{ or } .02\%V^{-1}$$

*The LCD drive voltages and reference voltages V1 - V3 are virtually independent of supply voltage change over the specified range.*

### 5.7.6 Worst Case Analysis

*Referring again to the circuit in Fig. 5.8; a little thought will show that for $I_1$ min the following values apply:*

| | | | | | |
|---|---|---|---|---|---|
| | (MIN: | R2, | $H_{FE}$, | T, | $V_{CC}$ |
| $I_1$ min: | ( | | | | |
| | (MAX: | R1, | R3, | R4, | R5 |
| | (MIN: | R1, | R3, | R4, | R5 |
| $I_1$ max: | ( | | | | |
| | (MAX: | R2, | $H_{FE}$, | T, | $V_{CC}$ |

*(If it is ever uncertain in a circuit in which direction a component will influence the working point, the program can be run for confirmation).*

*Using 1% (except for non-critical R3) tolerance resistors and an $H_{FE}$ spread of 3:1 (100 - 300), the results of these iterations are shown in Fig. 5.13. (Note that decreased $H_{FE}$ ie. gain, results in a larger number of iterations).*

*Fig 5.12*

```
Minimum Supply Voltage
======================

R1 =      68 k
R2 =      62 k
R3 =      1000 k
R4 =      2.2 k
R5 =      1.2 k
HFE =     200
VCC =     4 V
TEMP =    20 C
SEED: I1 =  .5 mA

RESULTS OF ITERATION
--------------------

ITERATION  8     V1= - 1.0071 V
                 V2= - 2.0142 V
                 V3= - 3.0856 V
                 I1=     .4889 mA

ITERATION COMPLETE.
-------------------
```

```
Maximum Supply Voltage
======================

R1 =      68 k
R2 =      62 k
R3 =      1000 k
R4 =      2.2 k
R5 =      1.2 k
HFE =     200
VCC =     5.6 V
TEMP =    20 C
SEED: I1 =  .5 mA

RESULTS OF ITERATION
--------------------

ITERATION  8     V1= - 1.0072 V
                 V2= - 2.0144 V
                 V3= - 3.0860 V
                 I1=     .4906 mA

ITERATION COMPLETE.
-------------------
```

*Fig 5.13*

```
Worst Case Maximum I1
=====================

R1  =      67.32 k
R2  =      62.62 k
R3  =      950 k
R4  =      2.178 k
R5  =      1.188 k
HFE =      300
VCC =      5.6 V
TEMP =     40 C
SEED: I1 =   .5 mA

RESULTS OF ITERATION
--------------------

ITERATION  6      V1= -   .9686 V
                  V2= - 1.9372 V
                  V3= - 3.1544 V
                  I1=     .5626 mA

ITERATION COMPLETE.
-------------------
```

```
Worst Case Minimum I1
=====================

R1  =      68.68 k
R2  =      61.38 k
R3  =      1050 k
R4  =      2.222 k
R5  =      1.212 k
HFE =      100
VCC =      4.2 V
TEMP =     0 C
SEED: I1 =   .5 mA

RESULTS OF ITERATION
--------------------

ITERATION  15     V1= - 1.0424 V
                  V2= - 2.0848 V
                  V3= - 2.9117 V
                  I1=     .3739 mA

ITERATION COMPLETE.
-------------------
```

These are the absolute worst possible case extremes of working point. It is worth noting that the most critical parameter at these extremes is $V_3$ which is used as an LCD drive voltage. For a triplexed LCD, a maximum DC offset of 150 mV (compared to the other drive voltages V1 and V2) is allowable. We have

| | $VD_1$ | $VD_2$ | $V_{R4}$ | OFFSET/mV |
|---|---|---|---|---|
| $I_1$ max: | -0.9686 | -0.9686 | -1.2172 | + 249 |
| $I_1$ min: | -1.0424 | -1.0424 | -0.8269 | - 215 |

which is unacceptably large.

There now follows an investigation into the chances of these extremes being reached in a practical circuit. Statistical analysis will be used to determine the confidence level achievable in the working point of a nominally designed circuit such as the one under analysis.

### 5.7.7 Statistical Analysis of Component Tolerances and Confidence Level of Circuit Working Point

The factors which are considered to be the major influences on determining the working point of a circuit such as Fig 5.8 are

- spread in d.c. transistor gain, $H_{FE}$
- resistor tolerances
- temperature

The effect of the latter of these is dictated by the specification of 0-40°C, and the circuit configuration itself.

However the tolerances of $H_{FE}$ and resistor values will lend themselves to a statistical treatment. Using the 'stat-an' program described later, samples of transistors and resistors were measured. The results are displayed below, in Figs. 5.14 - 5.15.

*Fig. 5.14 $H_{FE}$ values (ZTX502)*

```
CHANNEL 0
-----------
METRIC SYSTEM
ACTUAL MODE
MAX.SIZE            300.0000
MIN.SIZE            100.0000
LOT SIZE            130
LOT  NO.              1
------------------------------------
FLIERS                0
OUTOF TOL             0
ABOVE TOL             0.0 %
BELOW TOL             0.0 %
TOL. USED            27.5 %
MAX READ.           259.0000
MIN READ.           204.0000
RANGE                55.0000
AVERAGE             217.8846
S.D.                  9.9951
+3 S.D.             247.8698
-3 S.D.             187.8994
+4 S.D.             257.8649
-4 S.D.             177.9044

   30.0000
   50.0000
   70.0000
   90.0000
MIN.TOL ---------------------------
  110.0000
  130.0000
  150.0000
  170.0000
  190.0000
  210.0000 XXXXXXXXXXXXXXXXXXXX
  230.0000 XXXXXXXXXX
  250.0000 X
  270.0000
  290.0000
MAX.TOL ---------------------------
  310.0000
  330.0000
  350.0000
  370.0000

        'X'= 4 READING
```

*Fig. 5.15: 1% metal film resistor values*

```
CHANNEL 0
-----------
METRIC SYSTEM
NOMINAL MODE
NOM.SIZE              150.0000
MAX.TOL               151.5000
MIN.TOL               148.5000
LOT SIZE              200
LOT  NO.                1

FLIERS                  0
OUTOF TOL               0
ABOVE TOL               0.0 %
BELOW TOL               0.0 %
TOL. USED              65.7 %
MAX READ.             150.9900
MIN READ.             149.0200
RANGE                   1.9700
AVERAGE               149.9814
S.D.                     .3375
+3 S.D.               150.9939
-3 S.D.               148.9688
+4 S.D.               151.3314
-4 S.D.               148.6313

  147.4500
  147.7500
  148.0500
  148.3500
 MIN.TOL ---------------------------
  148.6500
  148.9500
  149.2500 XX
  149.5500 XXXXX
  149.8500 XXXXXXXXXXXXXXXXXXX
  150.1500 XXXXXXXXXXXXXXXX
  150.4500 XXXXX
  150.7500 X
  151.0500
  151.3500
 MAX.TOL ---------------------------
  151.6500
  151.9500
  152.2500
  152.5500

          'X'= 4 READING
```

*Fig. 5.16: 2% metal film resistor values*

```
CHANNEL 0
-----------
METRIC SYSTEM
NOMINAL MODE
NOM.SIZE              150.0000
MAX.TOL               153.0000
MIN.TOL               147.0000
LOT SIZE              200
LOT  NO.                1

FLIERS                  0
OUTOF TOL               0
ABOVE TOL               0.0 %
BELOW TOL               0.0 %
TOL. USED              32.3 %
MAX READ.             150.6300
MIN READ.             148.6900
RANGE                   1.9400
AVERAGE               149.2962
S.D.                     .2415
+3 S.D.               150.0208
-3 S.D.               148.5715
+4 S.D.               150.2623
-4 S.D.               148.3300

   144.9000
   145.5000
   146.1000
   146.7000
  MIN.TOL ---------------------------
   147.3000
   147.9000
   148.5000
   149.1000 XXXXXXXXXXXXXXXXXXXXX
   149.7000 XXXXXXXXXX
   150.3000
   150.9000
   151.5000
   152.1000
   152.7000
  MAX.TOL ---------------------------
   153.3000
   153.9000
   154.5000
   155.1000

        'X'= 6 READING
```

*Fig. 5.17: 5% carbon film resistor values*

```
CHANNEL 0
-----------
METRIC SYSTEM
NOMINAL MODE
NOM.SIZE            150.0000
MAX.TOL             157.5000
MIN.TOL             142.5000
LOT SIZE            200
LOT  NO.              1
------------------------------------------
FLIERS                0
OUTOF TOL             0
ABOVE TOL             0.0 %
BELOW TOL             0.0 %
TOL. USED            41.3 %
MAX READ.           153.0000
MIN READ.           146.8000
RANGE                 6.2000
AVERAGE             148.7010
S.D.                   .8595
+3 S.D.             151.2794
-3 S.D.             146.1226
+4 S.D.             152.1389
-4 S.D.             145.2631

 137.2500
 138.7500
 140.2500
 141.7500
MIN.TOL ---------------------------
 143.2500
 144.7500
 146.2500
 147.7500 XXXXXXXXXXXXXXXXXXXXXX
 149.2500 XXXXXXXXXXXXXXXXXXXXXXXXX
 150.7500 XXX
 152.2500
 153.7500
 155.2500
 156.7500
MAX.TOL ---------------------------
 158.2500
 159.7500
 161.2500
 162.7500

          'X'= 4 READING
```

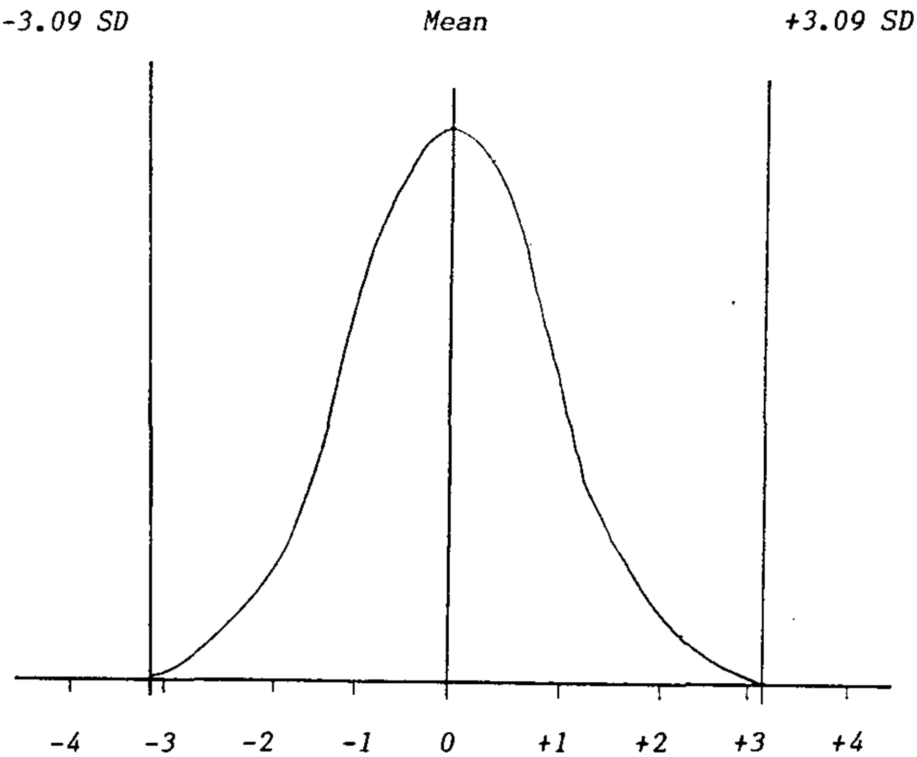
# 5.0 THE RESEARCH AND DEVELOPMENT TASK

*In each case, the tally chart (histogram) for each sample shows that the distribution is fairly normal, and the sample mean lies close to the nominal value of the component ($H_{FE}$ = 200, R = 150 kOhm). It is reasonable to assume that for very large samples, the sample mean would approach the population mean, ie. the population mean is the same as the nominal value of the component. ('Population' here means, for instance, all 150 kOhm ± 1% metal film resistors regardless of manufacturer).*

*To take a specific case, that of the 1% film resistors measured, which has the greatest 'tolerance used' (ie. 100 x (tolerance band - range measured)/tolerance band) of all the samples, and a standard deviation of .3375 kOhm.*

*Since we are justified in assuming that the sample mean would be equal to the nominal value of the resistor, the distribution of values can be shown as in Fig. 5.18.*

*Fig. 5.18: Normal distribution of resistor values*




*It can be shown that the probability of a value lying within the mean plus or minus 3.09 standard deviations (S.D.) is 99.9%.* [25]

*In other words, only one part in 10,000 will be outside the range of mean ± 3.09 S.D. (In fact this figure is widely used as a control limit on process control charts in many S.P.C. (Statistical Process Control) systems, stat-an included).*

*In this case, subtracting 2 x 3.09 S.D. from the tolerance band we find that 0.1% of all resistors can be expected to be within 100(3 - (2 x 3.09 x 0.3375))/3 = 30% of the tolerance band, ie. outside the mean ± 3.09 S.D.*

*This calculation was repeated for each sample taken:*

| | S.D. | Tolerance band | % in ± 3.09 S.D. | Tol used % |
|---|---|---|---|---|
| $H_{FE}$ | 9.9951 | 200 | 35 | 28 |
| 1% resistor | .3375 k | 3 k | 70 | 66 |
| 2% resistor | .2415 k | 6 k | 25 | 41 |
| 5% resistor | .8595 k | 15 k | 35 | 32 |

*Note that the largest value for the % within ± 3.09 S.D. for each sample is 70% of the range. In each case the actual tolerance used was less than 70%, which indicates that the reasoning is not overly optimistic for these samples.*

*To summarise: when calculating the extremes of performance of a circuit using a component tolerance of ± X%, if a tolerance of ± 0.7X% is used, only one component in 10,000 will have a value outside this range.*

*Note that in the case of the 1% resistor, in this particular set of samples, the larger percentage of the tolerance band is occupied by 99.9% of resistors, compared to the other samples. This is because as the tolerance band becomes smaller, the process becomes harder to control and so the control limits are more closely approached. One would expect to see a normal distribution like that of Fig. 5.18 with little variation from batch to batch.*

*However, in the other three cases where tolerance bands are larger, batch variations can be expected to shift the sample means one way or the* other. So, even though the scatter within a batch might be small (as in these instances), from batch to batch much larger overall variations should be expected.

Thus, the figure of 0.7 X tolerance band is here taken to be the 'most probable error' (ie. 99.9% reliable).

### 5.7.8 Statistical Tolerances

There are 7 components in the circuit with tolerances which have a direct influence on the working point, namely R1 - R5, T1 and T2. The 'weighting' or relative influence of each component can readily be found from the iteration program. In doing this, R3 was found to have negligible effect on the working point compared to the other component tolerances which have a larger but unequal effect. Thus there is a total of 6 components, the tolerances of which, at their extremes, have an influence on the working point, in one direction or the other. The probablility that in a given circuit any one component tolerance value will influence the working point in the positive direction is $\frac{1}{2}$, assuming a normal distribution about the mean. Thus, since there are 6 such tolerance values, the probability of them **all** influencing the working point in the same direction is $^1/2^6$ = 1/64 or 1.6%.

Furthermore, even if tolerances act in the same direction, the chance that they will all be towards the extreme of the distribution is also small. Statisticians have shown that [25], overall standard deviation, O.S.D., is related to individual S.D.s by

$$OSD^2 = SD_A{}^2 + SD_B{}^2 + \ldots \quad (5.7.8.1)$$

In other words, the overall variance is given by the sum of individual variances, since $SD^2$ = variance.

*For a normal distribution where the tolerance of a part is approximately equal to 6 x S.D. (as for all our samples above), then from 5.7.8.1:*

$$(T_o/6)^2 = (T_A/6)^2 + (T_B/6)^2 + \ldots$$

or $$T_o^2 = T_A^2 + T_B^2 + \ldots$$

and $$T_o = (T_A^2 + T_B^2 + )^{\frac{1}{2}} \quad \ldots (5.7.8.2)$$

*In other words, the overall tolerance or 'effective tolerance' of the working point in our circuit is equal to the R.M.S. value of the individual tolerances.*

*Thus in the circuit of Fig 5.8 we have the following tolerance weightings referred to R4 which has unity weighting influence on $V_{R3}$:*

| Component | Tolerance % | 99.9% Confidence Tolerance | Weighting | Effective Tolerance % |
|---|---|---|---|---|
| R1 | 1 | 0.7 | 1.82 | 1.27 |
| R2 | 1 | 0.7 | 1.66 | 1.16 |
| R4 | 1 | 0.7 | 1.00 | 0.70 |
| R5 | 1 | 0.7 | 0.81 | 0.57 |
| $H_{FE1}$ | 50 | 35.0 | 1.36 | 0.95 |
| $H_{FE2}$ | 50 | 35.0 | 0.30 | 0.21 |

*So the total effective tolerance in $V_{R3}$ is given by*

$$T_o = (1.27^2 + 1.16^2 + .7^2 + .57^2 + 0.95^2 + .21^2)^{\frac{1}{2}}$$

$$T_o = 2.17\%$$

*So we can expect, with 99.9% confidence, that $V_{R3}$ will vary by no more than ± 2.17% or approximately ± 22 mV as a result of component tolerance variations.*

*Nominal @ room temperature* $V_{R3} = +64$ mV

*Nominal @ min temperature* $V_{R3} = +5$ mV

*Nominal @ max temperature* $V_{R3} = +124$ mV

*These figures are within the tolerances quoted earlier by a margin of 17%, worst case, with a reliability of 999 in 10,000.*

### 5.8 Temperature Compensation

*The light output of a Light Emitting Diode (L.E.D.) is known to be inversely proportional to the junction temperature. Referring to Fig. 5.8.1, the iteration reveals the changes in* $V_2$, $V_3$ *and* $I_1$, *over the temperature range of 0 - 40 °C.*

*Firstly, it should be noted that the current generator circuit provides increasing* $I_1$ *with increasing temperature which tends to offset the negative temperature coefficient of light intensity, at a rate of* $+0.1\%°C^{-1}$.

*An opto coupled pair consisting of an L.E.D. driven at constant current and a phototransistor driven by a constant voltage source was tested over the temperature range of 0 - 40°C for current transfer ratio,* $I_T$. *The ratio* $dI_T/dT$ *is found to be* $-1\%\ °C^{-1}$ *and is quite linear over the range 0 - 40°C.*

*Referring to the circuit depicted in Fig. 5.8.2, the two differential amplifiers take their reference voltages from* $V_2$ *and* $V_3$ *in circuit 5.8. Iteration (Fig. 5.8.1) reveals that*

$$dI_1/dT = (-1\% + 0.1\%) = -0.9\%°C^{-1}$$
$$dV_2/dT = +4.2 \text{ mV } °C^{-1}$$
$$dV_3/dT = +3.3 \text{ mV } °C^{-1}$$

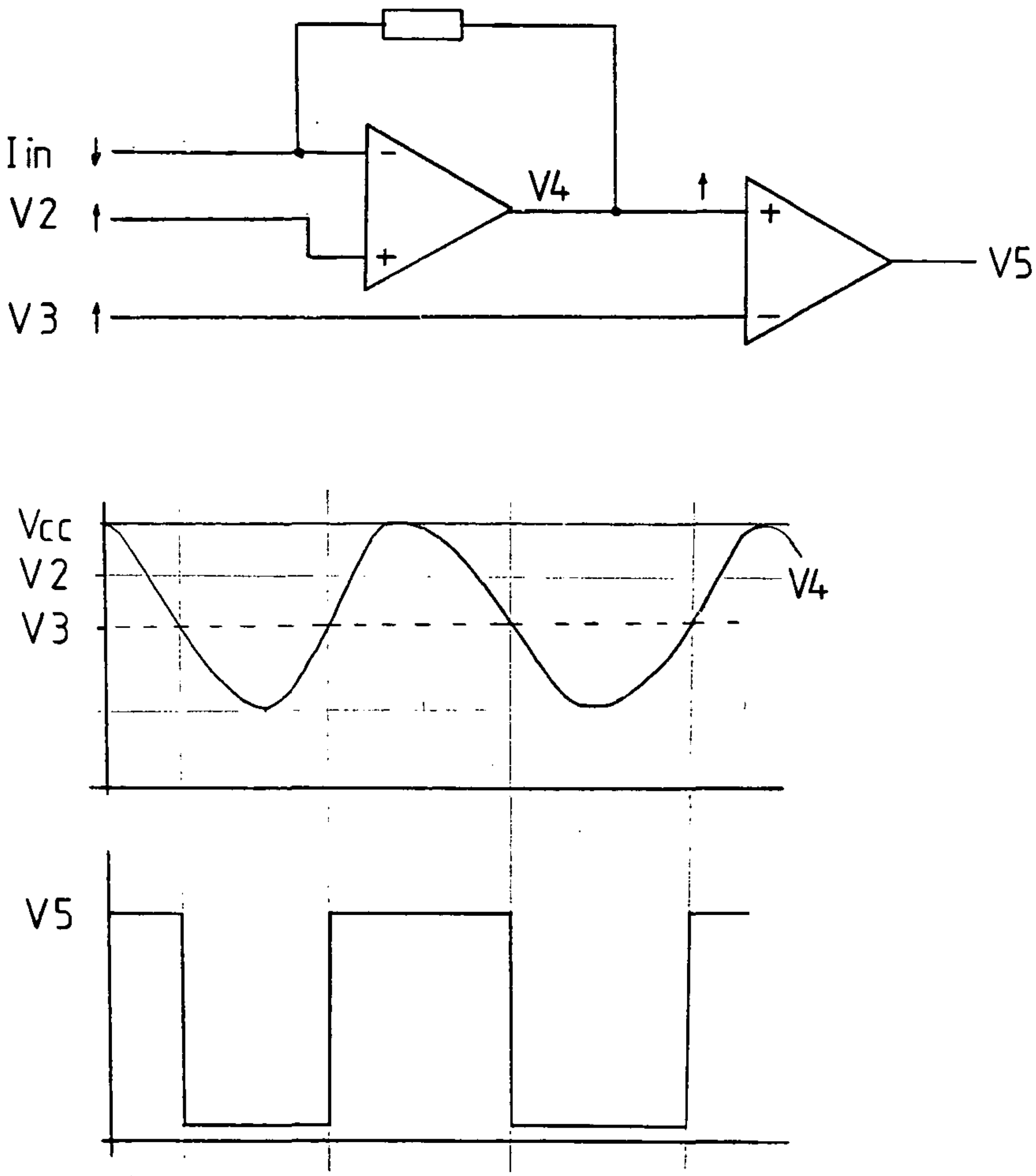
*and the average level of* $V_4$,

$$dV_4/dT = +(.5 \times .9\%) = +.45\%\ °C^{-1} = +2.2 \text{ mV } °C^{-1}$$

*Fig. 5.8.1 Temperature Variation Results*

```
Minimum Temperature
===================

R1  =      68 k
R2  =      62 k
R3  =      1000 k
R4  =      2.2 k
R5  =      1.2 k
HFE =      200
VCC =      5.6 V
TEMP =     0 C
SEED: I1  =   .5 mA

RESULTS OF ITERATION
--------------------

ITERATION  9      V1= - 1.0488 V
                  V2= - 2.0975 V
                  V3= - 3.1512 V
                  I1=     .4823 mA

ITERATION COMPLETE.
-------------------


Maximum Temperature
===================

R1  =      68 k
R2  =      62 k
R3  =      1000 k
R4  =      2.2 k
R5  =      1.2 k
HFE =      200
VCC =      5.6 V
TEMP =     40 C
SEED: I1  =   .5 mA

RESULTS OF ITERATION
--------------------

ITERATION  3      V1= -   .9656 V
                  V2= - 1.9312 V
                  V3= - 3.0209 V
                  I1=     .4989 mA

ITERATION COMPLETE.
-------------------
```

*Fig. 5.8.2 Differential Amplifiers and Voltage Levels*



## 5.0 THE RESEARCH AND DEVELOPMENT TASK

*The aim of the temperature compensation is to produce a square wave output $V_5$ which has a mark space ratio of 50% which is appreciably constant over the 0 - 40°C temperature range. To achieve this, $V_2$, $V_3$ and the average level of $V_4$, should track each other in directions such as to cancel the falling efficiency of the opto-coupled pair as temperature increases.*

*The total variation in* **effective** *threshold voltage*

$$dV_T/dT = dV_4/dT + dV_2/dT - dV_3/dT$$

*(where $DV_4/dT$ does not include the offset due to $dV_2/dT$)*

$$= (+2.2 - 4.2 + 3.3)\ mV\ °C^{-1}$$

$$dV_T/dT = +1.3\ mV\ °C^{-1} = .13\%\ °C^{-1}$$ *for a 1V p-p sinusoid.*

*The waveform of voltage $V_4$ is pseudo sinusoidal. The maximum gradient of a sinusoid is ± 1 and so for small changes in threshold voltage there will be twice the change in % duty cycle, D.*

$$\text{Thus } dD/dT = -2dV_T/dT$$

$$dD/dT = -.26\%\ °C^{-1}$$

*which represents a change of -5% over the range 20 - 40°C and +5% over the range 20 - 0°C, which is well within the allowable range of ± 25%$°C^{-1}$. This result was found to agree closely with measured results for several specimens.*

### 5.8.1 L.C.D. Temperature Compensation

*As mentioned previously the L.C.D. drive voltages are derived from the chain L.E.D.1, L.E.D.2 and R4. A triplexed L.C.D. has a negative temperature coefficient of threshold voltage of about -6 $mV°C^{-1}$. Partial compensation is provided by the negative temperature coefficient of* *voltage of L.E.D.1 and L.E.D.2, and with this partial compensation the constrast ratio of the display is improved at extremes of temperature beyond 0 - 40°C.*

## 5.9 General Description of the Analog Circuit

*Refer to Fig. 5.9.1.*

*$T_1$ and $T_2$ form a constant current source for the L.E.D.S. which are in series to minimise current consumption. By using high gain phototransistors it was possible to utilise an excitation current of only 0.5 mA. At such a low current noise and ageing effects are kept to an amount far below those expected at 'normal' excitation current some fifty times greater than this. (See Fig. 5.9.2)[12].*

*The constant current source provides constant current for the L.E.D.S. versus supply voltage variations, so that falling supply voltage (ie. battery discharging) does not cause a problem, as detailed earlier.*

*The photocurrent of each phototransistor is amplified by the transconductance amplifiers in IC1 which perform a current to voltage conversion according to the relation $V_o = -iR$.*

*The virtual earth at the inverting input ensures that minimal bandwidth loss occurs due to charge/discharge of junction capacitance of the phototransistors and op-amps. Boltzmann noise is minimised also since there is no resistor in the current path before the op-amp input.*

*The gain of this stage is variable to compensate for large (3:1) spreads in L.E.D. output, phototransistor sensitivity and physical alignment variation of the opto-electronic system.*

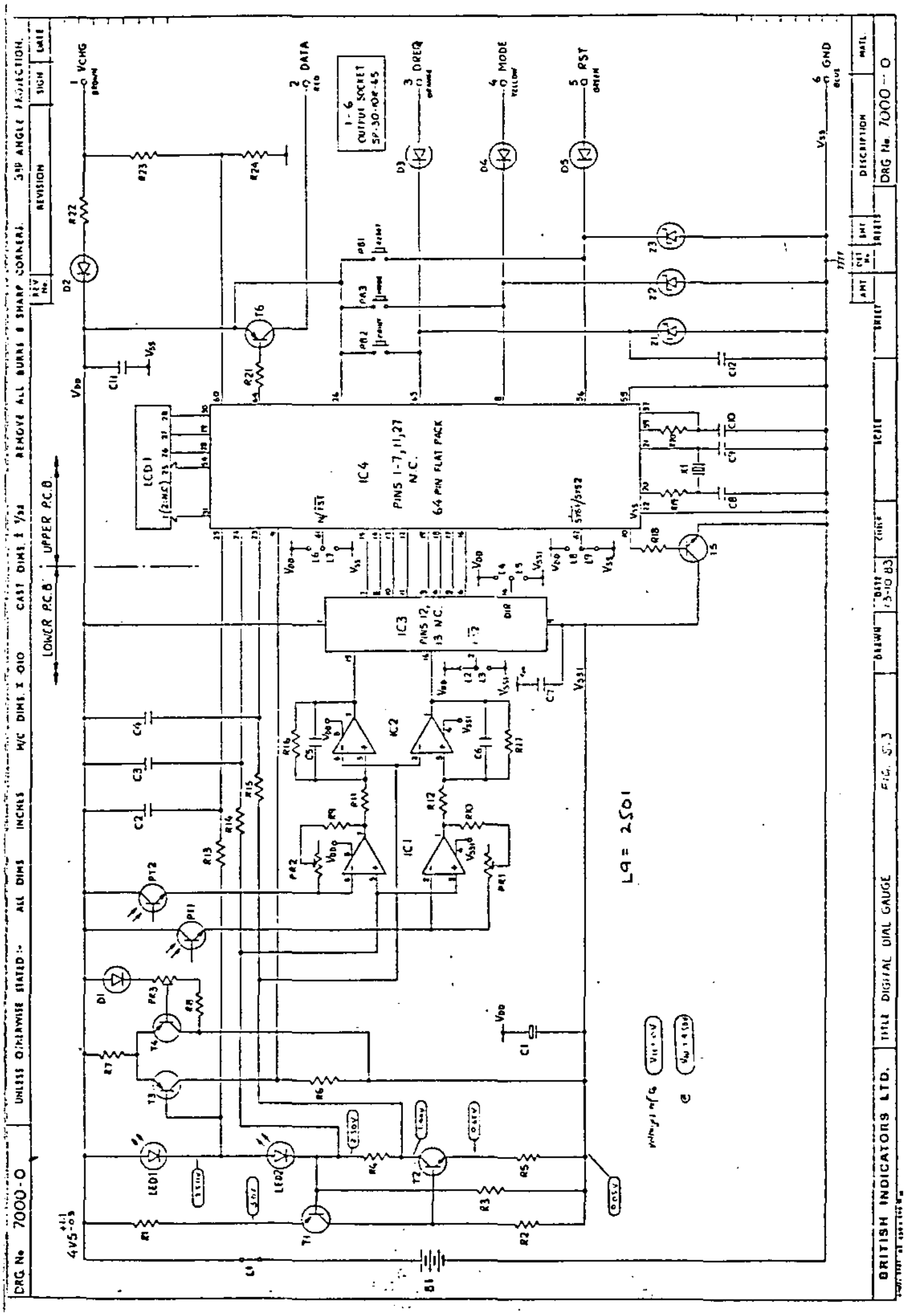



*Fig 5.9.1. Circuit Diagram of the Gauge*

## 5.0 THE RESEARCH AND DEVELOPMENT TASK

*The positioning of the opto-pairs on the PCB is maintained during assembly by means of a special jig. In this way the 90° phasing of the current generated in each pair is maintained within ±5°.*

*At the outputs of these two op-amps there exist two pseudo-sinewaves 90° apart in phase (nominally) of approximately 1 volt p.p. amplitude. These voltages drive the differential comparators IC2 which have positive feedback to provide hysteresis comfortably larger than the noise present at TP1 and TP2.*

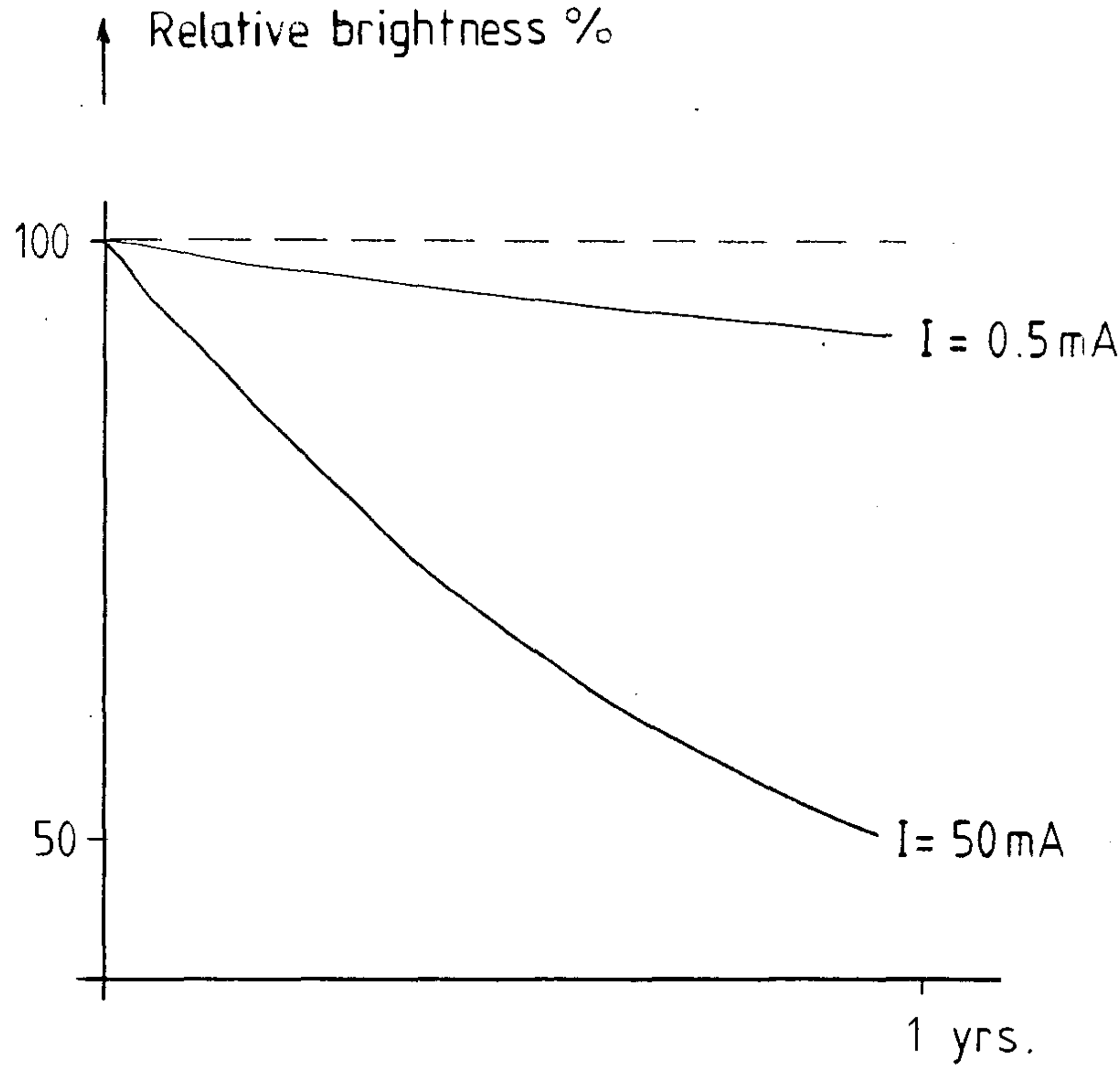



*Fig 5.9.2. L.E.D. Ageing Characteristics.* [12]

The two small 'speed up' capacitors are vital to ensure that as the switching threshold is reached, the rise and fall times of the square waves produced during switching are fast and clean enough to drive the following logic circuitry.

The 90° phase difference of these square waves is necessary to provide directional information to the ensuing counting system; therefore it is necessary for the 50% duty cycle to be maintained versus supply voltage drift and temperature variation (over the range 0 - 40°C).

In fact ± 25% drift can be tolerated: as the edges of the two square waves approach each other (due to changing duty cycle) the chance of miscounting increases, particularly at increasing frequencies. Thus, some form of compensation is required to keep the duty cycle sufficiently stable.

Referring again to Fig 5.9.1 it can be seen that the reference voltages for the transconductance amplifiers and comparator circuits are taken from two points in the circuit. These points are judiciously selected because of their voltage temperature coefficient. Assuming the whole circuit to be at the same temperature (a reasonable assumption since the whole is encased in an aluminium housing; negligible self-heating takes place since the entire circuit dissipates only 4.5 mW), component values have been calculated to ensure that the mean DC level of the pseudo-sine waves at TP1 and 2 moves in the same direction and by approximately the same amount as the comparator reference voltage for a given change in temperature. In fact, over the temperature range of 0 to 40°C a duty cycle change of ±5% was observed: the theoretical maximum allowable before miscounting can occur is 25% for each rectangular wave. The analysis of this circuit has already been presented.

The transistors T3 and T4 provide a low power voltage comparator to provide indication of falling battery voltage. Sufficient temperature compensation is provided by the temperature coefficients of voltage of L.E.D.1, T3 and the NiCd battery itself.

## 5.0 THE RESEARCH AND DEVELOPMENT TASK

### 5.10 Implementation and Miniaturisation of the Circuit

*Having obtained the two square waves in quadrature, digital circuitry is required to obtain a directional count from an arbitrary zero. This is achieved in a semi custom CMOS ULA made by Smith's Industries Ltd. The entire design for this device is detailed in Appendix I.*

*It should be mentioned here that a fully custom chip, perhaps incorporating some or all of the analog circuitry as well as the counting circuitry was seriously considered as a solution. However, the numbers involved (approximately 1,200 per year) were simply far too low to make the proposition viable - at least 100,000 pieces are required to even gain the interest of a custom I.C. manufacturer. There is also a much greater financial and technical risk involved in terms of design commitment. Together with much longer lead time to production samples (1 year compared to approximately 3 months) the option of fully customised design was ruled out.*

### 5.11 The Remainder of the Circuit - The Microprocessor

*The microprocessor chosen was the N.E.C. 7502 four bit CMOS single chip device. Factors influencing the choice were:*

i *on chip L.C.D. (Liquid Crystal Display) driving hardware*

ii *custom masked ROM of 2K bytes*

iii *low power consumption stemming from CMOS fabrication and low power standby mode*

iv *low tooling and piece-part cost for relatively small number of approximately 1,000 p.a.*

v *ease of software development provided by MACRO-assembler and simulation system.*

vi other devices not available in quantites of less than 10,000 per year

The decision to use a microprocessor at all was influenced by the fact that a straightforward L.C.D. driver chip has a similar unit cost to the CMOS microprocessor which contains one. Incorporating the microprocessor opens up new possibilities and gives the system much greater flexibility than a purely hardware solution.

Functions performed by the microprocessor include:

a) driving the triplexed L.C.D.

b) driving the RS432 serial data output port

c) strobing the U.L.A.'s multiplexed output bus

d) handling system timing

e) handling power on/off feature

f) performing inch/metric conversion for readout

g) monitoring battery supply voltage to indicate recharge point (in conjunction with T3 and T4)

h) scanning the three control buttons

All these functions are handled adequately by the device and provide a significant reduction in hardware design, effort and space.

## 5.12 Some Features of the Microprocessor Program

### 5.12.1 The Microprocessor Software

*It should be noted that a low power CMOS microprocessor is by nature a slow device (the NEC 7502 has two clocks, an RC 100KHz system clock and a 32.768KHz crystal clock). The possiblity of using the microprocessor itself to count the pulses produced by the transducer system was investigated.*

*Firstly, the count pulses would have to drive edge sensitive interrupt inputs and in order to extract directional information, each square wave (there are two in quadrature) would have to feed both a positive and a negative edge sensitive interrupt.*

*Thus there is a requirement for 4 interrupt inputs, 2 of each polarity. No single chip CMOS microprocessor exists with 4 such interrupts. Secondly, even if such a device were obtainable, it would need to be very fast indeed if no count pulse were to be missed. There would have to be sufficient speed of operation to increment or decrement the present count. Indeed, even using a 2.5 MHz 8 bit device, the maximum count frequency possible was found by Smith to be 500Hz [18]. In this system a maximum frequency of several kHz is to be counted.*

*Thus a hardware counter was necessary between the transduction system and the microprocessor.*

### 5.12.2 Program Design

*A feature of the 7502 4 bit processor is its limited instruction set and very limited flag structure. There is in fact only one flag, the Carry, which is generally affected by any operation resulting in an overflow of some kind.*

*An overview of the program design is shown in the flowchart in Fig 5.12. There now follows a description of how the program works and the* *functions which it provides for the gauge unit.*

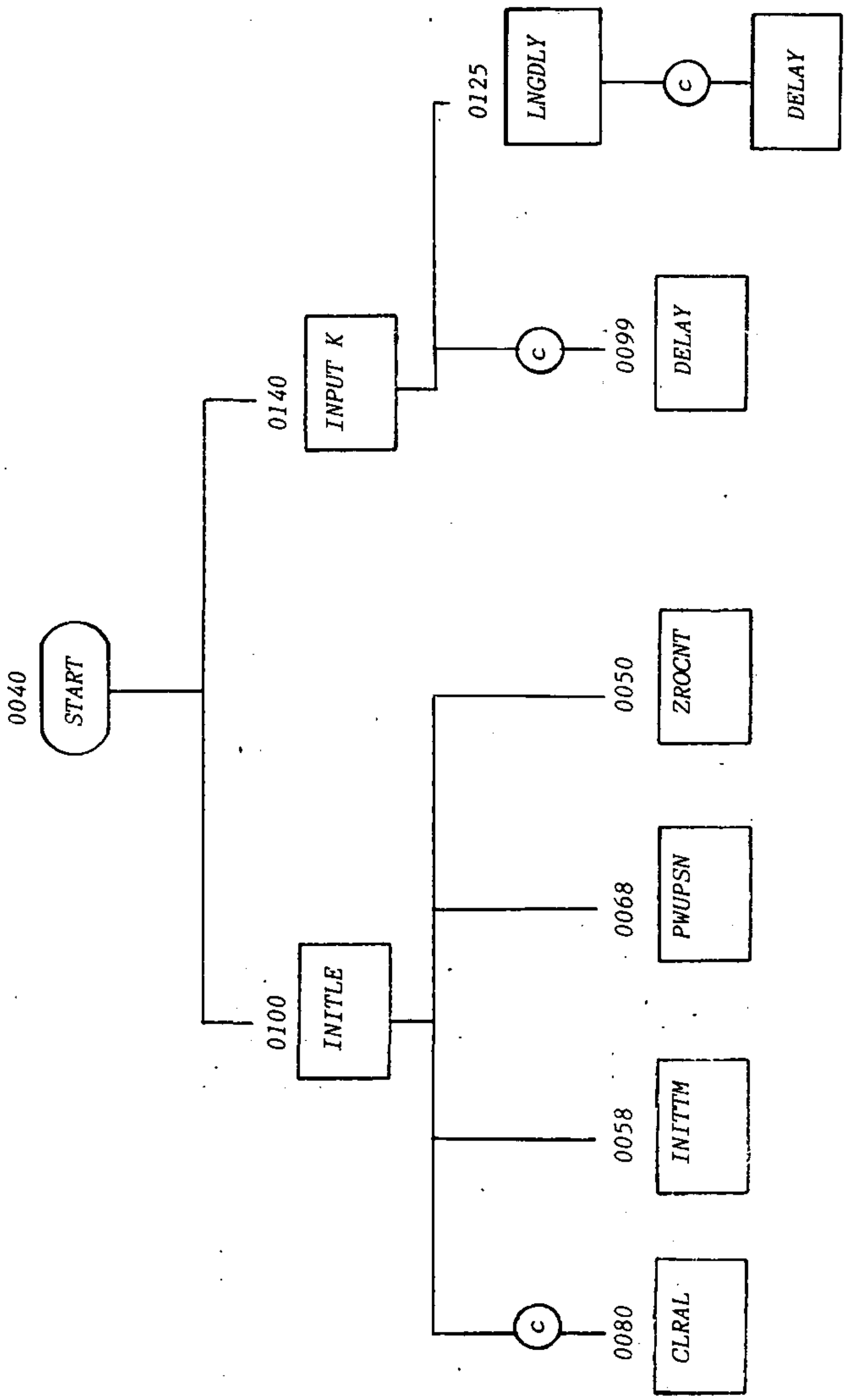
*Functions*

- *obtain value of measurement from ULA*
- *convert to inches if necessary (integer multiplication)*
- *scan 3 push buttons to see if pressed, and act accordingly*
- *update display and provide display test pattern*
- *check value to see if changed: if no change after 4 minutes, power down*
- *interrupt 1: on rising edge, transmit RS232 data from one port, at 300 baud*
- *interrupt 2: on level 1, freeze display as an error condition (count speed exceeded)*
- *check to see if external power is present: if it is do not power down*
- *monitor battery voltage and warn if low*

*Program Operation*

*Basically the program consists of an 'executive loop' which performs sequentially all those funtions listed above. It is desirable to update the display as quickly as possible and with the present design this is achieved, at a rate of 4 updates a second, provided that no interrupt occurs. Two of the more interesting sections of the program will be detailed here.*

*Fig. 5.12*


0040
START
0140
INPUT K
0125
LNGDLY
C
DELAY
0099
C
DELAY
0100
INITLE
0050
ZROCNT
0068
PWUPSN
0058
INITTM
0080
C
CLRAL

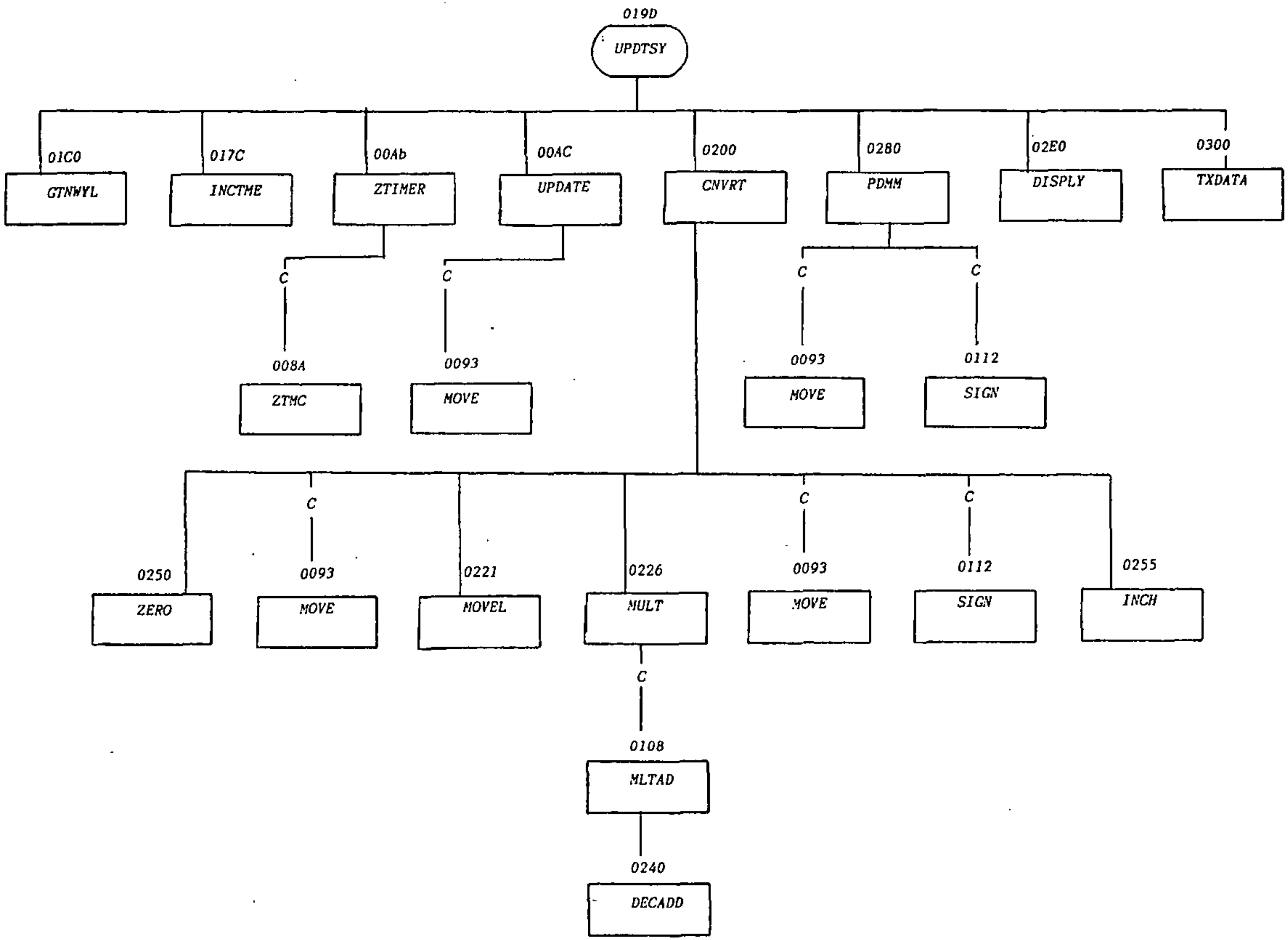
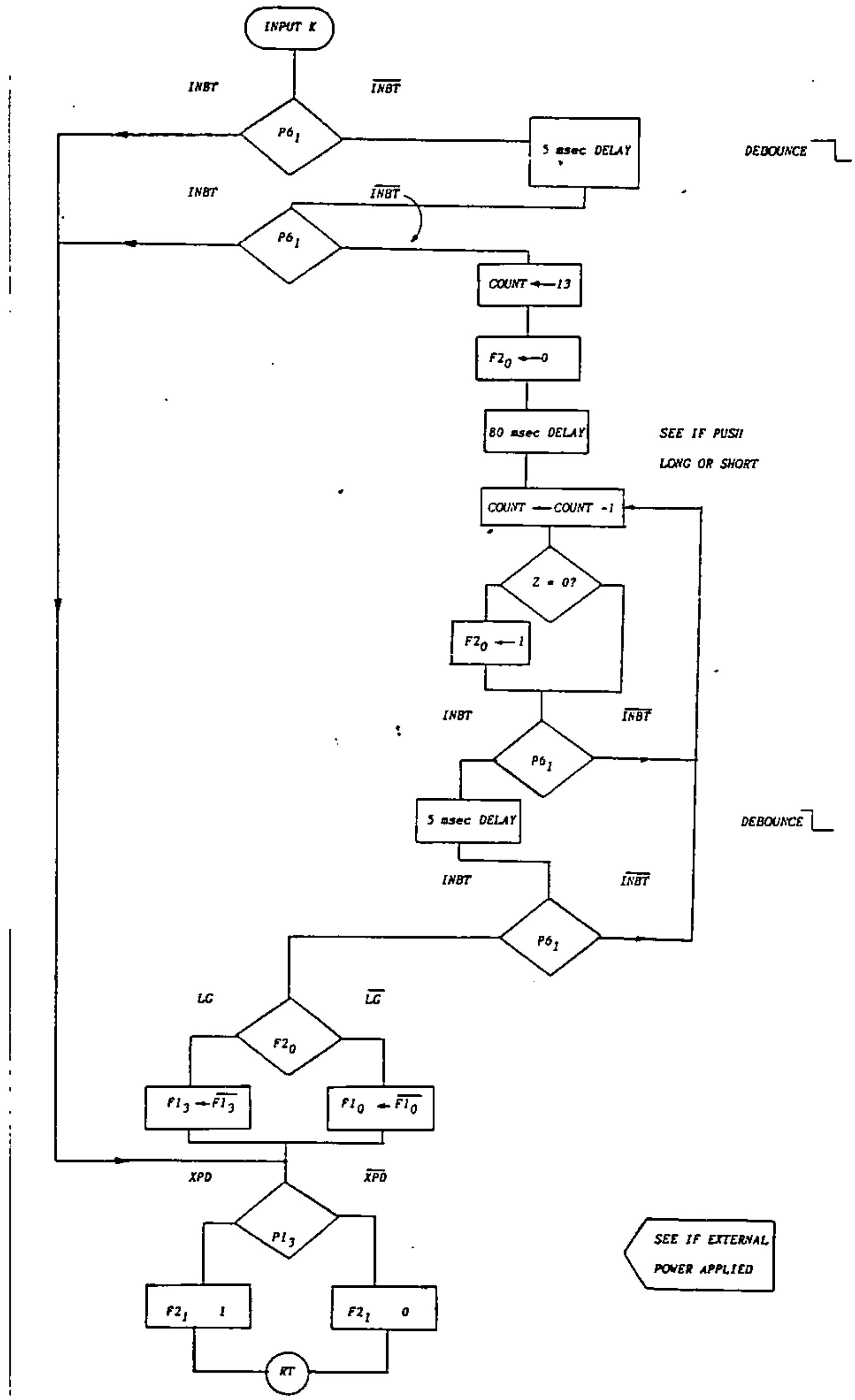



Fig. 5.12 (continued)

Fig. 5.12 (continued)



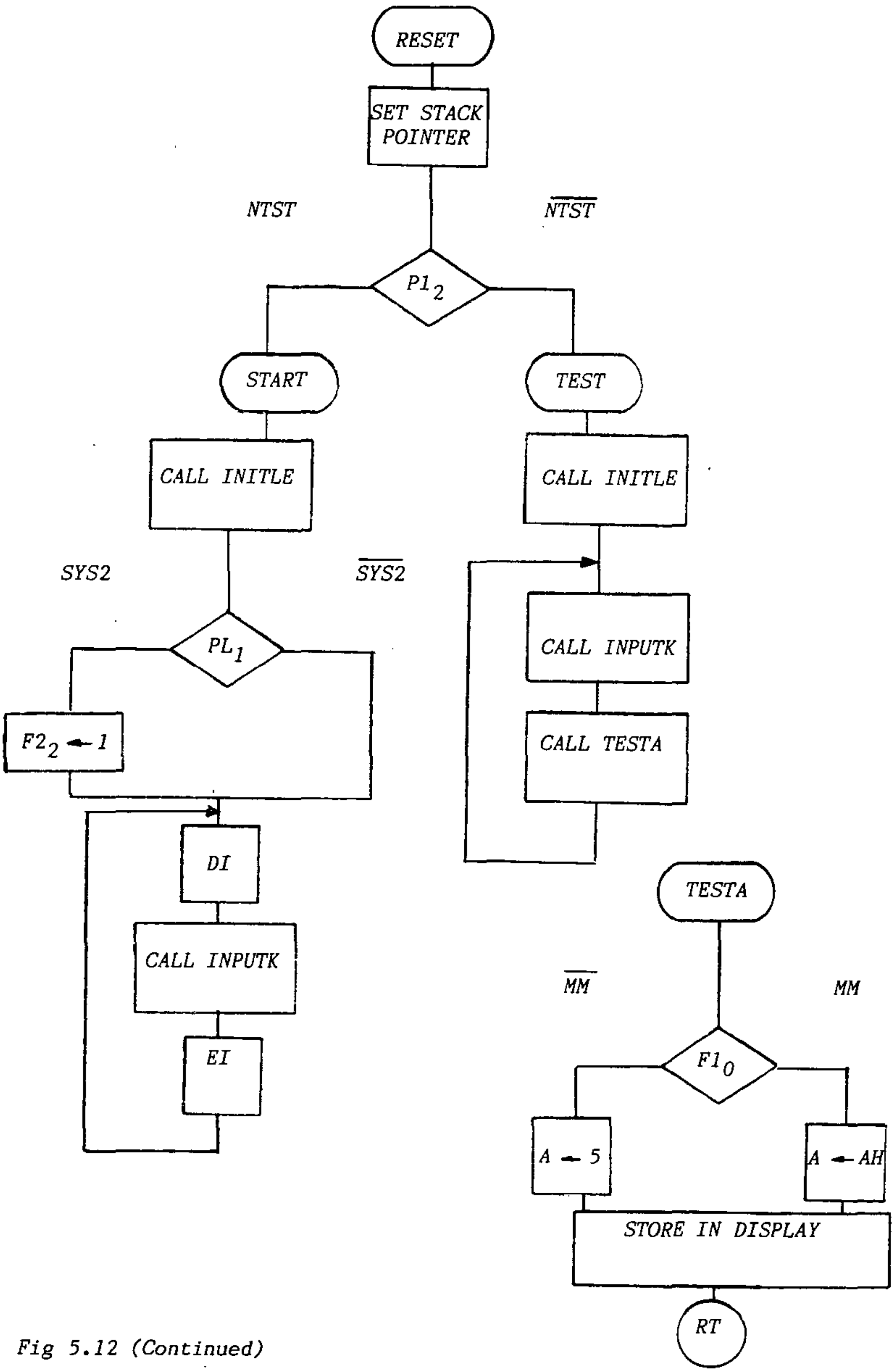



Fig 5.12 (Continued)

## 5.0 THE RESEARCH AND DEVELOPMENT TASK

### TESTS

*Flags*

| | | | |
|---|---|---|---|
| $F1_0$ | - | MM | Memory |
| $F1_1$ | - | VF | Value Fixed |
| $F1_2$ | - | VS | Value Same |
| $F1_3$ | - | IN | Inches |
| $F2_0$ | - | LG | Long |
| $F2_1$ | - | XP | External Power |
| $F2_2$ | - | S2 | System 2 |
| $F2_3$ | - | - | |

*Inputs*

| | | | |
|---|---|---|---|
| $P1_0$ | - | - | |
| $P1_1$ | - | STS2 | System 2 |
| $P1_2$ | - | NTST | Not Test |
| $P1_2$ | - | XPD | External Power |
| $P6_0$ | - | INBT | Button Not Pressed |
| $P6_1$ | - | - | |

```
                     ;*********************************************
                     ;ROUTINE TO CONVERT FROM MM TO INCHES
                     ;******************************************
0200 CB              CNVRT:  LHLT    LRESLT
0201 3250                    CALL    ZERO     ;ZERO MEMORY LOCATIONS AS VALUE ADDED TO THE
0203 15                      LAI     5        ;ROUND OFF 0.00005"
0204 4E4A                    LHLI    RESLT+3
0206 57                      ST
0207 CA                      LHLT    LMVALU   ;GET THE VALUE TO BE CONVERTED & REMOVE THE
0208 4F3A                    LDEI    VALU     ;                                        SIGN
020A D3                      CALT    CMOVE
020B 10                      LAI     0        ;SET SIGN POSITION TO ZERO
020C 4E1F                    LHLI    MVALU+5
```

```
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               (PD7502  -                          )

E STNO ADRS OBJECT   M   SOURCE STATEMENT

020E 57                      ST
020F C1                      LHLT    LFLG2
0210 66                      SKMBT   E2F
0211 321E                    CALL    MOVEL    ;SHIFT LEFT ONE NIBBLE IF SYSTEM 1
0213 3223                    CALL    MULT     ;CONVERSION
0215 4F4A                    LDEI    RESLT+3  ;SHIFT RIGHT 1 DIGIT TO MAKE ROOM FOR SIGN
0217 4E49                    LHLI    RESLT+2
0219 D3                      CALT    CMOVE
021A D5                      CALT    CSIGN    ;ADD SIGN & MEMORY INDICATOR
021B 3255                    CALL    INCH     ;ADD IN TO INDICATE INCHES
021D 5B                      RTS              ;SKIP ON RETURN
                     ;*******************************************************
                     ;
                     ;ROUTINE TO MOVE 1 NIBBLE LEFT MVALU
                     ;
                     ;**********************************
021E 10              MOVEL:  LAI     0
021F CA                      LHLT    LMVALU
0220 55              ML1:    XAM     HL+
0221 A0                      JCP     ML1
0222 53                      RT
                     ;**********************************************
                     ;ROUTINE TO MULTIPLY BY .3937 USING MULTIPLE ADDITION
                     ;******************************************
0223 CB              MULT:   LHLT    LRESLT
0224 17                      LAI     7
0225 D4                      CALT    CMLTAD   ;ADD 7 VALUES OF MVALU TO RESULT
0226 13                      LAI     3
0227 D4                      CALT    CMLTAD
0228 19                      LAI     9
0229 D4                      CALT    CMLTAD
022A 13                      LAI     3
022B D4                      CALT    CMLTAD
022C 53                      RT
                     ;************************************************
                     ;ROUTINE TO RESTORE UNITS TO IN/MM AFTER POWER UP
                     ;************************************************
022D 3852            RSTUNT: LADR    SAVEAD   ;GET SAVED VALUE OF IN/MM & PUT IN FLAG
022F C0                      LHLT    LFLG1
0230 57                      ST
0231 53                      RT
```

```
                     ;*********************************************
           0240            ORG     240H
                     ;******************************************
                     ;ROUTINE FOR DECIMAL INTEGER ADDITION
                     ;
                     ;***************************************
     0240 78         DECADD: RC                  ;CLEAR CARRY
     0241 41         D1:     LAM     DE          ;  A =(DE)
     0242 70                 ACSC                ;  A,C = A + (HL) + C
```

```
** UPD7502    ASSEMBLE LIST **          (16-AUGUST-1982-11AM )  PAGE   16

              (PD7502  -                          )

  STMT ADRS OBJECT   M   SOURCE STATEMENT

     0243 8C                 JCP     D5          ; JUMP IF<15
     0244 06                 AISC    6           ; A = A+6
     0245 57         D2:     ST                  ;NEVER SKIPPED (HL)=A
     0246 79                 SC                  ;SET CARRY
     0247 49         D3:     IES                 ,E=E-1 TO GET NEXT DATA
     0248 8A                 JCP     D4
     0249 5B                 RTS                 ;FINISH & SKIP ON RETURN
     024A 59         D4:     ILS                 ;L=L+1
     024B 81                 JCP     D1          ;ALWAYS TO HERE
     024C 57         D5:     ST                  ;STORE WHEN C?
     024D 06                 AISC    6
     024E 87                 JCP     D3          ;NO OVERFLOW VALUE STORED
     024F 85                 JCP     D2          ;NEW VALUE IN A TO BE STORED &CARRY SET
                     ;*********************************************
                     ;ROUTINE TO ZERO AREA -STOPS AT L=FH
                     ;***********************************
     0250 10         ZERO:   LAI     0
     0251 57         ZZ1:    ST
     0252 59                 ILS
     0253 91                 JCP     ZZ1
     0254 53                 RT
                     ;********************************************
                     ;ROUTINE TO ADD IN TO INDICATE INCHES
                     ;*********************************************
     0255 4E48       INCH:   LHLI    RESLT+1
     0257 1E                 LAI     0EH         ;CODE FOR I
     0258 55                 XAM     HL+
     0259 1D                 LAI     0DH         ;CODE FOR N
     025A 57                 ST
     025B 53                 RT
                     ;*******************************************
```

## 5.0 THE RESEARCH AND DEVELOPMENT TASK

```
                 ;***********************************
            0000         ORG      00H
                 ;***********************************
                 ;************* CALT  TABLE *************
                 ;***********************************

0000 39          CDELAY:  DCT      DELAY
0001 [illegible] CCLRAL   DET      CLRAL
0002 2A          CZTMC    DET      ZTMC
0003 [illegible] CMOVE:   DET      MOVE
0004 48          CMLTAD:  DET      MLTAD
0005 5A          CSIGN    DET      SIGN
0006 CC          CSNDNE:  DET      SNDNE
0007 C3          CSYNC:   DET      SYNC
0008 C0          CHGOUT   DET      NRGOUT
0009 C4          CLWOUT:  DET      LWOUT
000A DC          COUTCH:  DET      OUTCH
                 ;



                 ;

                 ;***********************************
            0100         ORG      100H
                 ;***********************************
                 ;CALL ROUTINES TO PERFORM INITIALIZATION
                 ;***********************************
0100 D1          INITLE:  CALT     CCLRAL  ;CLEAR ALL RAM INCLUDING DISPLAY
0101 3220                 CALL     RSTUNT  ;RESTORE UNITS (IN/MM)
0103 305D                 CALL     INITTM  ;INITIALIZE & START TIMER
0105 3056                 CALL     ZROCNT  ;SEND RESET PULSE TO ULA
0107 53                   RT
                 ;***********************************
```

*For more information see [21].*

### 5.12.3 Inch/Metric Conversion

*The mode of the indicator, imperial or metric, is determined by push-button 3 (PB3). If the button is held closed for more than 2 seconds, the status flag $F2_0$ is toggled.*

*The measuring system is based on the metric scale and so each incoming count pulse represents an increment or decrement of 0.01 mm. Thus, if flag $F2_0$ is set, the program flow is changed to incorporate the conversion factor. There are 25.4 mm in an inch, so the number obtained from the ULA must be divided by 25.4. This is the same as multiplying by 1/25.4 or 0.39370 and this is in fact the conversion factor used since it is faster and easier to perform integer multiplication than division. Integer arithmetic can be used even though decimal numbers are involved - all that is necessary is to ignore the decimal point in each number and place a decimal point in the right place in the final display. The program segment is well commented and thus self explanatory.*

*Note the reference to system 1 and system 2; this is to allow the 2 chip set (ULA and microprocessor) to be used for measurement systems of 1 or 2 um resolution.*

### 5.12.4 Serial Data Output

*The idea of the serial port was to provide standard ASCII output data on request at as high a speed as possible. Each number in the display is transmitted (MSD first) together with 'M' for memory and 'IN' for inches if appropriate, and a decimal point.*

*Before transmission each number must be converted to ASCII (by adding 48 to it) and for RS232 format, 1 start bit and 2 stop bits must be added. Because only 8 bit storage is available the start and stop bits are sent as appendices to the 8 bit data or character byte.*

```
1000                          ;*******************************
1001                          ;********************************
1002                          ;OUTPUT DATA AT 300 BAUD IN FORM OF DISPLAY EXCEPT NO
1003                          ;E FOR ERROR WILL BE GIVEN. WHEN TX USED IT WILL BE ON
1004                          ;EXTERNAL POWER. IF FMAX EXCEEDED NO TX
1005                          ; 1 EXTRA STOP BIT DURING THE UPDATE PERIOD
1006                          ;BUTTON CHECKED BETWEEN CHARACTERS & A HOLD OCCURS IF A BUTTON
1007                          ;IS DETECTED
1008                          ;*****************************************************
1009 0322 1F                  TXDATA: LAI     0FH     ;POINT TO MS DIGIT TO BE OUTPUT
1010 0323 3919                        XADR    OUTADR  ;STORE THIS TO ADDRESS CHARACTER
1011 0325 3E07                        LEI     07H     ;OUTPUT FROM 8 DATA POSITIONS
1012 0327 D7                          CALT    CSYNC   ;CLEAR WAITING TIMER INTERRUPT
1013 0328 3340               T1:      CALL    OUTNXT  ;OUTPUT THIS CHAR
1014 032A 313B                        CALL    INPUTK  ;CHECK IF BUTTON IS BEING PRESSED
1015 032C 3019                        DDRS    OUTADR  ;DECREMENT ADDRESS
1016 032E 48                          DES             ;SEE IF 6 CHAR OUTPUT
1017 032F A8                          JCP     T1      ;NOT COMPLETE GET NEXT CHAR
1018 0330 4E0D                        LHLI    0DH     ;CR
1019 0332 DA                          CALT    COUTCH
1020 0333 313B                        CALL    INPUTK
1021 0335 4E0A                        LHLI    0AH     ;LF
1022 0337 DA                          CALT    COUTCH
1023 0338 313B                        CALL    INPUTK
1024 033A 53                          RT
1025                          ;**************************************************
1026            0340                  ORG     340H
1027                          ;****************************
1028 0340 CC                  OUTNXT: LHLT    LOUTAD
1029 0341 1F                          LAI     0FH     ;SEE IF IT IS FIRST DISPLAY CHAR
1030 0342 5F                          SKAEM
1031 0343 2380                        JMP     OT1
1032 0345 7B                          XAL             ;ADDRESS FIRST CHAR WITH HL
1033 0346 3E24                        LHI     4
1034 0348 52                          LAM     HL      ;A NOW CONTAINS FIRST CHAR
1035 0349 3F6F                        SKAEI   0FH     ;IF F THEN NOT M & NOT -
1036 034B 95                          JCP     OT2
1037 034C 4E20                        LHLI    ' '     ;SEND SPACE FOLLOWED BY SPACE
1038 034E DA                 OT7:     CALT    COUTCH  ;SEND FIRST BLANK
1039 034F 313B                        CALL    INPUTK  ;CHECK BUTTON
1040 0351 4E20                        LHLI    ' '
```

```
** UPD7502    ASSEMBLE LIST **          (16-AUGUST-1982-11AM )   PAGE   21

                (PD7502  -                              )

E STNO ADRS OBJECT   M   SOURCE STATEMENT

   1041 0353 DA              OT4:     CALT    COUTCH  ;SEND SECOND BLANK
   1042 0354 53                       RT
   1043 0355 3F6C            OT2:     SKAEI   0CH     ;IF C THEN NOT M & -
   1044 0357 A0                       JCP     OT3
   1045 0358 4E20                     LHLI    ' '
   1046 035A DA              OT6:     CALT    COUTCH
   1047 035B 313B                     CALL    INPUTK
   1048 035D 4E2D                     LHLI    '-'
   1049 035F 93                       JCP     OT4
   1050 0360 3F6B            OT3:     SKAEI   0BH     ;IF B THEN M & -
   1051 0362 A6                       JCP     OT5
   1052 0363 4E4D                     LHLI    'M'
```

```
     0365 9A                          JCP      OT6
     0366 4E4D             OT5:       LHLI     'M'
     0368 8E                          JCP      OT7
                           ;****************************************
                           ;ROUTINE CONTINUES IN NEXT 64 BYTE BLOCK
                           ;*****************************************
               0380                   ORG      380H
                           ;*********************************
     0380 1D               OT1:       LAI      0DH      ;CHECK FOR DECIMAL POINT (DP) ON IN/MM
     0381 5F                          SKAEM
     0382 A9                          JCP      OT8      ;NOT D SO CHECK FOR C
     0383 4E48                        LHLI     048H     ;ADDRESS CONTAINING F FOR BLANK IF MM
     0385 60                          SKMBF    0        ; & E FOR N IF INCHES
     0386 8C                          JCP      OT14     ;NO DP NEEDED JUST SEND DATA
     0387 4E2E             OT9:       LHLI     '.'      ;IT IS INCHES SO NEED DP
     0389 DA                          CALT     COUTCH   ;SEND DP
     038A 313B                        CALL     INPUTK   ;CHECK BUTTON
     038C CC               OT14:      LHLT     LOUTAD   ;GET VALUE FROM RESULT ADDRESS
     038D 52                          LAM      HL       ;    & PLACE IN A
     038E 3E34                        LHI      4
     0390 7B                          XAL
     0391 52                          LAM      HL       ;VALUE IN A
     0392 3F6F                        SKAEI    0FH      ;NOW SEE IF IT IS BLANK,I,N,OR NUMBER
     0394 99                          JCP      OT10
     0395 4E20                        LHLI     ' '      ;SEND BLANK & RETURN
     0397 DA               OT11:      CALT     COUTCH
     0398 53                          RT
     0399 3F6E             OT10:      SKAEI    0EH
     039B 9F                          JCP      OT12
     039C 4E4E                        LHLI     'N'      ;SEND N & RETURN
     039E 97                          JCP      OT11
     039F 3F6D             OT12.      SKAEI    0DH
     03A1 A5                          JCP      OT13
     03A2 4E49                        LHLI     'I'      ;SEND I & RETURN
     03A4 97                          JCP      OT11
     03A5 7B               OT13:      XAL               ;MUST BE A NUMBER SO SEND IT
     03A6 3E33                        LHI      3        ;FIRST NIBBLE FOR ASCII NUMBER
     03A8 97                          JCP      OT11
     03A9 1C               OT8:       LAI      0CH      ;CHECK FOR DP ON IN/MM
     03AA 5F                          SKAEM
```

```
** UPD7502    ASSEMBLE LIST **          (16-AUGUST-1982-11AM )  PAGE   22

              (PD7502  -                              )

E STNO ADRS OBJECT   M   SOURCE STATEMENT

     03AB 8C                          JCP      OT14     ;NOT F,D,C SO A NUMBER-SEND IT
     03AC 4E48                        LHLI     048H
     03AE 60                          SKMBF    0
     03AF 87                          JCP      OT9      ;SEND DP FOR MM
     03B0 8C                          JCP      OT14     ;NO DP SO SEND DATA
                           ;********************************
                           ;
                           ;**********************************
               03C0                   ORG      3C0H
                           ;****************************************
                           ;********************************
     03C0 3E9B             OUTDAT:    TLA
     03C2 D6                          CALT     CSNDNB
     03C3 3EBB                        THA
     03C5 D6                          CALT     CSNDNB
     03C6 53                          RT
```

```
** UPD7502     ASSEMBLE LIST **          (16-AUGUST-1982-11AM )  PAGE    22

               (PD7502  -                            )

E STNO ADRS OBJECT   M   SOURCE STATEMENT

  1093 03AB 8C                     JCP     OT14     ,NOT F,D,C SO A NUMBER-SEND IT
  1094 03AC 4E48                   LHLI    048H
  1095 03AE 60                     SKMBF   0
  1096 03AF 87                     JCP     OT9      ;SEND DP FOR MM
  1097 03B0 8C                     JCP     OT14     ;NO DP SO SEND DATA
  1098                     ;**********************************
  1099                     ;
  1100                     ;***********************************
  1101           03C0              ORG     3C0H
  1102                     ;*****************************************
  1103                     ;**********************************
  1104 03C0 3E9B           OUTDAT: TLA
  1105 03C2 D6                     CALT    CSNDNB
  1106 03C3 3EBB                   THA
  1107 03C5 D6                     CALT    CSNDNB
  1108 03C6 53                     RT
  1109                     ;*********************************
  1110                     ;ROUTINE TO PASS TIME FOR 4 UPDATES PER SECOND IF NO TXDATA
  1111                     ;*************************************************************
  1112 03C7 3E06           IDLE:   LEI     06H      ;TIME FOR 7 CHARACTERS
  1113 03C9 D7                     CALT    CSYNC
  1114 03CA 33D7           IDLE1:  CALL    NOTX
  1115 03CC C2                     LHLT    LFLG3    ;IGNORE PUSH BUTTON IF FMAX EXCEEDED
  1116 03CD 64                     SKMBT   FMX
  1117 03CE 313B                   CALL    INPUTK
  1118 03D0 3F42                   SKI     INTOFL
  1119 03D2 94                     JCP     IDLE2
  1120 03D3 5B                     RTS
  1121 03D4 48             IDLE2:  DES
  1122 03D5 8A                     JCP     IDLE1
  1123 03D6 53                     RT
  1124                     ;*******************************
  1125 03D7 3E8E           NOTX:   PSHDE
  1126 03D9 3E0A                   LEI     0AH      ;11 BIT CHARACTER
  1127 03DB D7             NOTX1:  CALT    CSYNC
  1128 03DC 48                     DES
  1129 03DD 9B                     JCP     NOTX1
  1130 03DE 3E8F                   POPDE
  1131 03E0 53                     RT
  1132                     ;******************************
  1133                     ;
  1134                     ;
  1135                     ;**********************************************
```

*Again the listing of the segment is self explanatory. The data is shifted out of a single bit port at 300 baud which drives an open collector PNP transistor.*

*The serial port is interrupt driven so that data is available immediately upon request. In the case where more than one gauge is to be read, the data is transmitted almost simultaneously from each gauge, within a few microseconds.*

### 5.12.5 The Display System

*Originally a standard calculator display was chosen which proved satisfactory except for the viewing angle. The gauge is used mainly in applications which require it to be viewed above the normal, unlike a calculator which is viewed from below the normal. A triplexed L.C.D. has the property that it can only be viewed from one of these attitudes to give optimum clarity. It was therefore necessary to commission the manufacture of a custom L.C.D.*

### 5.13 Checks on Operation and Design Correctness

*One of the difficulties encountered here was the testing of the complete system before comitting designs to silicon, in the case of the ULA, and to mask in the case of the microprocessor and to PCB in the case of the whole.*

*The approach adopted was to define areas of the system which could be individually and rigourously tested and thus reduce the risk of integration error to a minimum. The task was achieved by extensive breadboarding in the case of analog design and ULA design, using standard devices having as similar characteristics as possible to the target devices.*

*In the case of the microprocessor a simulation/development system was arranged around N.E.C.'s evaluation kit for the 7502 device. In fact, this is an 8085A based system using LSTTL devices so a series of CMOS* *buffers had to be designed around it. Estimations had to be made of the differences in system timing which would inevitably occur due to the sheer physical size difference between the emulation system and the commercial product.*

*However, the first samples of chips, both ULA (now comitted) and the mask programmed microprocessor were found to function correctly in every way.*

### *5.14 The Multi-Gauging System Concept*

*Referring again to the gauge circuit diagram Fig. 5.9.1, one notices that the serial data output from the microprocessor is via a PNP open collector transistor T6. This serial port works in the following way:*

*A data request signal consisting of a rising edge is applied to an interrupt pin of the microprocessor, which responds after one instruction cycle by (1) saving registers on the stack and (2) sending out ASCII data corresponding to that in the L.C.D. of the instrument, followed by line feed and carriage return characters. T6 is normally turned off: thus a pull down resistor is required in the receiving instrument to cause a voltage swing, between +4.5V and whatever voltage the pull-down resistor is connected to. Thus, the gauge can drive a 'TTL level' input serial device, or, if pulled down to -5V or less, a standard RS232 V24 device (± 3V is sufficient to drive a fully specified RS232 receiver).*

*Furthermore, because T6 is normally off it is possible to tie common all the collectors of as many gauges in the system as desired, up to a theoretical maximum limited only by leakage current through the transistors, the pull down voltage, and the pull down resistor value. Taking pessimistic values of 1uA, -12V and 2K7 respectively the maximum number of gauges, N, is given by:*

*Vmargin = N.Ico R(pull down) where*

| | | |
|---|---|---|
| *Vmargin* | = | *Vmin - V pull down = 9V* |
| *Ico* | = | *leakage collector current @ 40°C* |
| *R(pulldown)* | = | *2K7* |

$$\text{ie. } N_{max} = 9/10^{-6} \times 2.7 \times 10^{3}$$

$$N_{max} = 3333$$

*It is difficult to imagine a practical system requiring or having room for 3000+ gauges. The practical system is designed to accomodate 64 (maximum) units. At the data rate of 300 Baud loading capacitance of leads etc. is insignificant for lead lengths of 1 where*

$$1 = 1/(20 \; R(pulldown) \times (C/unit\ length) \times 300)$$

*where C = capacitance per unit length*

*This relation gives a maximum total cable length of 600m assuming ideal noise free conditions and a cable capacitance of* $100_pFm^{-1}$*, before signal deterioration becomes significant.*

*Perhaps the simplest multi-gauging concept is that of a printer to which is connected several gauges as described above. Pressing the print buttons in turn then produces a sequential print of all the measurements.*

*It is a simple step from there to envisage an automatic sequencer which automatically requests data from each gauge, thus eliminating the possibility of operator error in sequencing the readings correctly.*

### *5.15 **The Master Interface Unit***

*See Sales Brochure*

*A multiplexing unit was required to take the common outputs of N gauges and selectively address them via the RS232C bidirectional port of a micro or other computer. The Master Interface unit will accept 8 gauge inputs and is expandable in sets of 8 via a 20 way ribbon cable. The circuit (see Fig. 5.15.1) is implemented in standard CMOS logic and also incorporates a power unit for the microcomputer.*

*Since the gauges have a commoned data line it is only necessary for the unit to route the data request line to the gauge to be selected. This is accomplished by using the computer's output RS232 line as a clock to increment a binary address counter; sending N null characters down the line (at the maximum data rate of 9600 Baud) causes the counter to select the Nth gauge connected to the system. The counter's output is decoded by a 1 of 8 decoder, which is then enabled by the Data Request (RTS, request to send) line of the computer's serial input port.*

*After data has been transmitted, and received by the computer, the logic causes the counter to be reset in readiness for the next data transfer.*

*The expansion is handled by further decoding of the higher order output lines of the address counter within each individual slave unit. See circuit diagram in Fig. 5.15.2.*

*In the 'printer only' mode of operation, the busy line of the printer is used as the clock to increment the address counter; it is thus necessary to use a printer which has a line buffer only, otherwise the address will not be incremented as the previous gauge's data is being printed.*

*For operator convenience, a footswitch is provided to initiate a data request, asynchronously with the computer's data request line.*

## 5.0 *THE RESEARCH AND DEVELOPMENT TASK*

*Fig. 5.15.1.*

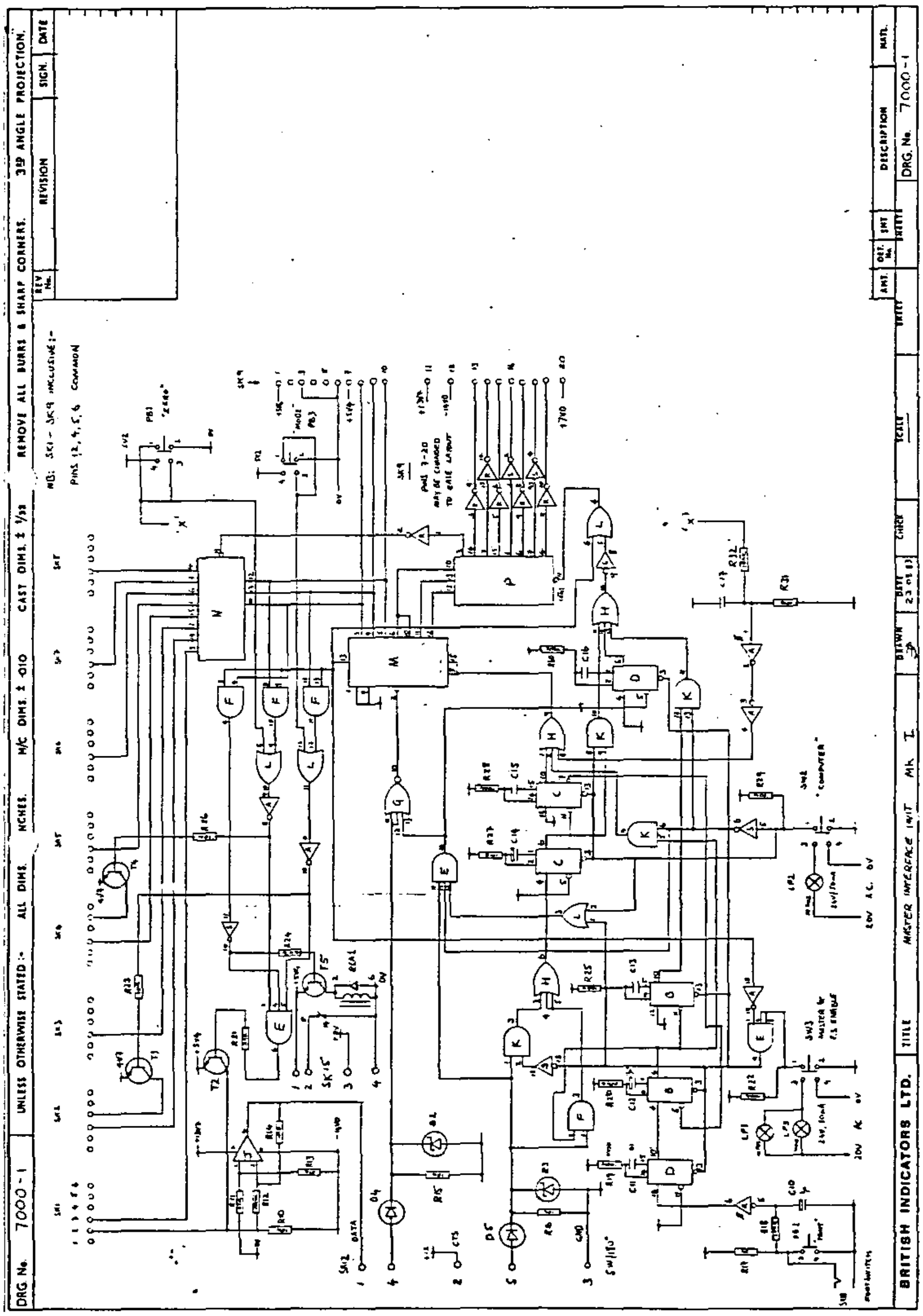
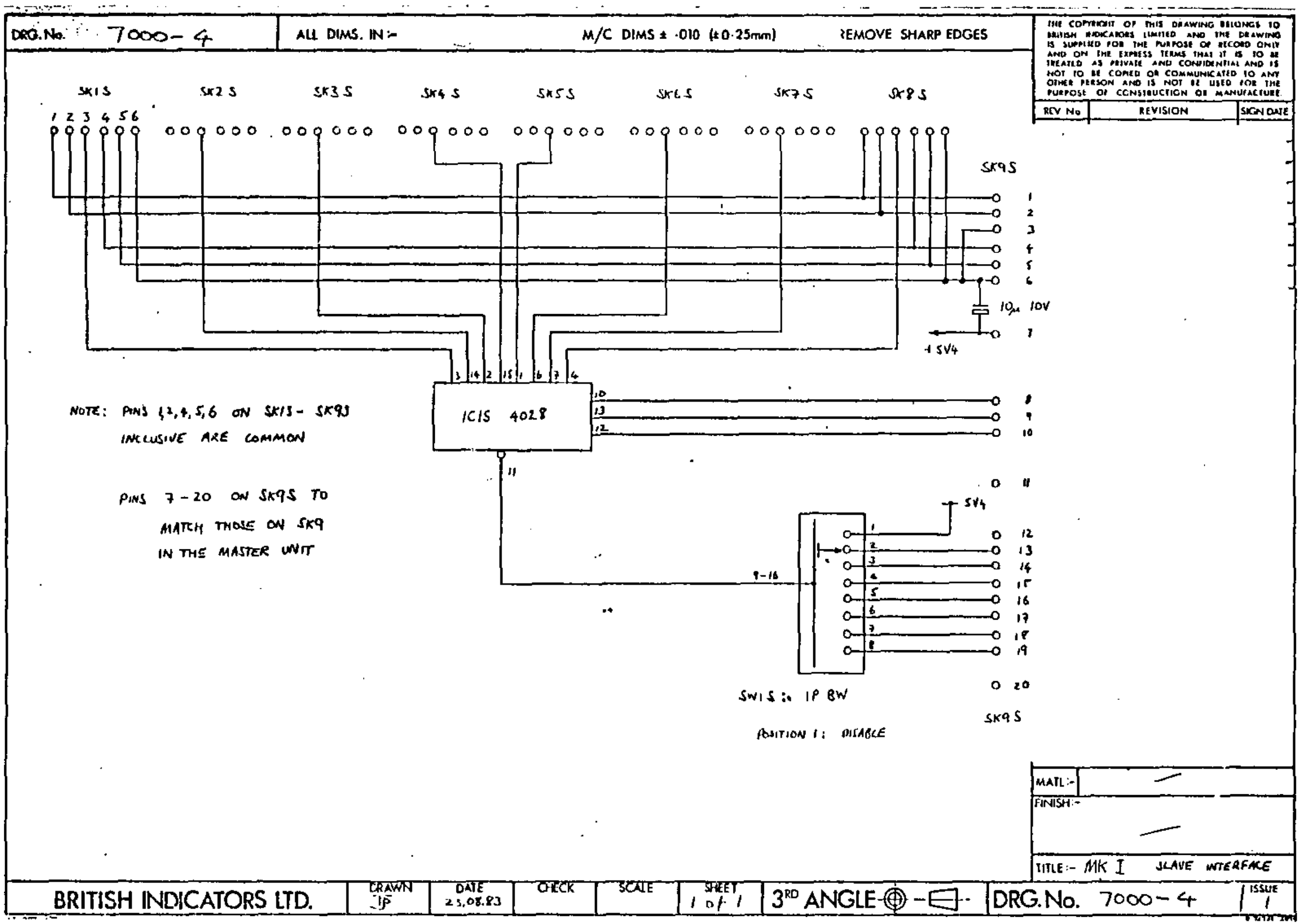


Fig. 5.15.2.


DRG. No. 7000-4
ALL DIMS. IN :-
M/C DIMS ± ·010 (±0·25mm)
REMOVE SHARP EDGES
THE COPYRIGHT OF THIS DRAWING BELONGS TO BRITISH INDICATORS LIMITED AND THE DRAWING IS SUPPLIED FOR THE PURPOSE OF RECORD ONLY AND ON THE EXPRESS TERMS THAT IT IS TO BE TREATED AS PRIVATE AND CONFIDENTIAL AND IS NOT TO BE COPIED OR COMMUNICATED TO ANY OTHER PERSON AND IS NOT BE USED FOR THE PURPOSE OF CONSTRUCTION OR MANUFACTURE.
REV No
REVISION
SIGN DATE
SK1 S
SK2 S
SK3 S
SK4 S
SK5 S
SK6 S
SK7 S
SK8 S
SK9 S
ICIS 4028
10µ 10V
+5V4
NOTE: PINS 1,2,4,5,6 ON SK1S - SK9S INCLUSIVE ARE COMMON
PINS 7-20 ON SK9S TO MATCH THOSE ON SK9 IN THE MASTER UNIT
SW1 S :- 1P 8W
POSITION 1 : DISABLE
MATL :-
FINISH :-
TITLE :- MK I SLAVE INTERFACE
BRITISH INDICATORS LTD.
DRAWN JF
DATE 23.08.83
CHECK
SCALE
SHEET 1 of 1
3RD ANGLE
DRG. No. 7000-4
ISSUE 1

## 5.0 THE RESEARCH AND DEVELOPMENT TASK

### 5.16 Choice of Microcomputer *See Sales Brochure*

*The original system concept was to provide a low cost statistical quality control system which was compact and simple to use, which necessitated the choice of a microcomputer providing all the required interfacing hardware (preferably at no extra cost) and with the facility to allow user program storage in UVEPROM (Ultra-Violet Erasable Programmable Read Only Memory). All available microcomputers were carefully analysed for these features and the one chosen was the (then) Grundy Business Systems NewBrain. This machine is a compact Z80 based unit with bi-directional ½ Duplex serial port, and a serial printer output port (which fill the interfacing requirements). There is a paged memory expansion port which allows a tokenised BASIC program to be connected to run automatically at power on (thus eliminating the need for disk drives or tapes). Also provided is a 16 character vacuum-fluorescent display which is useful for prompts and results. An adequate CP/M dual disk drive system is avaiable to promote ease of program development; a Z80 assembler program completes the requirement for writing machine code programs for applications requiring compact code and fast execution.*

### 5.17 System Software and Modus Operandi

*The program is listed in Supplement IV and the operation manual for the system is shown in Supplement V. An overview of the system is given by the sales brochure.*

### 5.18 Statistical Data Provided by the Software

#### 5.18.1 Refer also to Supplement V (Operation Manual)

*The first data to be supplied to the system at switch on relates to the configuration of the particular system - whether a monitor is being used or not, how many gauges are connected, sample (lot) size for each channel, tolerance the dimensional data, and so on. The software is completely error trapped and instructive error messages are displayed in* *inverse video (if a monitor is fitted) if nonsensical or illogical data is input.*

*The operator is then instructed to enter the gauge readings for the selected channels; each reading appears on the computer's line display as it is collected.*

*5.18.2*

*The first output data from the computer, to the screen (if connected), is a list of all the readings taken for a given channel (in a multichannel configuration the channels are taken in turn).*

*If more than a screen full of readings was taken (ie. more than 20) then they are displayed in blocks of 20 with continuation by pressing the space bar.*

*This serves as visual confirmation that the correct channel is being accessed. If a reading below or above tolerance was taken it is highlighted by '*L' or '*H' respectively. At this point the numerical average of the readings is calculated and each reading is compared with the mean and the tolerance band. If a reading is greater than one tolerance band away from the mean of the sample it is defined as a flyer; the case is highlighted by appending an 'F' to the reading. The flyer is usually an indication to the operator of faulty location in a measuring fixture, or end of stock in the machining plant etc.*

## 5.18.3 *Statistical Data*

*After displaying the readings taken, the following statistical data is displayed, which is self explanatory.*

| | |
|---|---|
| DATE | TIME |
| MACH | PART |
| OP.NO. | SIGNED |

CHANNEL 1

-----------

INDICATOR
INCH SYSTEM
ACTUAL MODE

| | | |
|---|---|---|
| MAX.SIZE | | .0050 |
| MIN.SIZE | - | .0050 |
| LOT SIZE | | 16 |
| LOT NO. | | 1 |

| | | | |
|---|---|---|---|
| R 1 | | .0040 | |
| R 2 | | .0040 | |
| R 3 | | .0040 | |
| R 4 | - | .0040 | |
| R 5 | - | .0040 | |
| R 6 | - | .0040 | |
| R 7 | | .0047 | |
| R 8 | - | .0047 | |
| R 9 | - | .0051 | *L |
| R 10 | | .0051 | *H |
| R 11 | | 0.0000 | |
| R 12 | | 0.0000 | |
| R 13 | - | .0020 | |
| R 14 | | .0020 | |
| R 15 | | .2010 | *HF |
| R 16 | - | .2046 | *LF |

| | | |
|---|---|---|
| FLIERS | | 2 |
| OUTOF TOL | | 4 |
| ABOVE TOL | | 12.5 % |
| BELOW TOL | | 12.5 % |
| TOL. USED | | ***** % |
| MAX READ. | | .2010 |
| MIN READ. | - | .2046 |
| RANGE | | .4056 |
| AVERAGE | - | .0002 |
| S.D. | | .0741 |
| +3 S.D. | | .2222 |
| -3 S.D. | - | .2227 |
| +4 S.D. | | .2964 |
| -4 S.D. | - | .2968 |

## 5.18.4 Histogram (Tally Chart) of Results

*After the statistical data have been displayed, the next information to be output is a histogram of all the readings in the sample. A visual representation of the distribution of the sample is given and a shift away from the normal is readily apparent. The shift is quantified in the next two charts however. It is not possible for the chart to overflow since the value of 'X' is adjusted to represent one, two or more readings as appropriate for large samples.*

```
-     .0085 X
-     .0075
-     .0065
-     .0055 X
MIN.TOL -------------------------
-     .0045 XXXX
-     .0035
-     .0025 X
-     .0015
-     .0005 XX
      .0005
      .0015 X
      .0025
      .0035 XXX
      .0045 X
MAX.TOL -------------------------
      .0055 X
      .0065
      .0075
      .0085 X

          'X'= 1 READING
```

### 5.18.5 X-BAR or Average Chart

```
X-BAR CHART
-----------
1 DIV=                    .0010
UTL(=)                    .0050
UCL(-)            -       .2241
LCL(-)                    .2241
LTL(=)            -       .0050

     -
UTL==
     -
     -
     -
     -
     -F
     -
     -
     -
     -
LTL==
     -
```

*This chart is a plot of the accumulating averages of the samples taken to date. The control limits UCL and LCL, Upper and Lower respectively, are computed as 3.09 x standard deviation inside the Upper Tolerance Limit (UTL) and Lower Tolerance Limit (LTL) in the direction towards the mean, in each case. Reference to standard texts on Quality Control theory [25] show that as long as the mean of the sample lies within these control limits then there exists a 99.9% probablilty that no out of tolerance part has been produced.*

*If a flyer was present in the sample then an 'F' is printed instead of the 'X'. If, as in the case of a large standard deviation for the sample, the LCL is higher than the UCL, (ie. the control limits have crossed over), then an 'E' is printed on the chart.*

*Since the width of the paper is limited to 40 characters it is necessary to allow the chart to overflow after about 30 plots. When this happens* *all the plotted points scroll left one space.*

*When the control limits are approached, it is an indication to the operator that the machine requires attention soon if scrap production is to be avoided.*

### 5.18.6 R-CHART (Range Chart)

*The range chart is a progressive plot of the Ranges measured per sample. Range is defined as the maximum reading minus the minimum reading for a given sample and must always be positive. Therefore, the plot lies between 0 and the Upper Tolerance Limit (UTL). The control limit in this case is fixed at 0.65 of the UTL. As in the X-BAR chart, as the range approaches the control limit, the operator is advised that the machine requires attention. Range gives an indication of the machine capability. Scrolling is handled as per the X-BAR chart.*

*Both the X-BAR and R chargs give an indication of the TREND of dimensions versus time.*

```
R CHART
-----------
1 DIV=                    .0010
UTL(=)                    .0100
UCL(-)                    .0065

   -X
UTL==
   -
   -
   -
UCL--
   -
   -
   -
   -
   -
0----
```

#### 5.18.7 Program Flow

*After the whole of the foregoing data has been displayed or printed, the operator is given options to re-screen the data (Screen Review) or Print Copy. After these options have been taken or passed, the next option is to select a channel or multiple channel for further measurements. At this point it is also possible to allocate channel 0 to key in previously collected data, perhaps from some manual process or remote plant, to obtain the statistical data for the sample.*

*As long as power is applied, the program is self supporting and will continue to run indefinitely. Customer applications have run the whole system for two weeks continuously.*

#### 5.18.8 Foreign Languages

*STAT-AN has been translated into French, Spanish and German, and agents have been appointed for these and other European countries.*

#### 5.18.9 Future Software Development

*The program described above was devised as an 'introductory' package to statistical Quality Control. Feedback from present and potential customers indicates the requirement for mass data storage and system configuration storage. Further disc-based systems will therefore be developed to allow this facility to be implemented.*

## 6.0 MANUFACTURING DETAILS AND TESTING

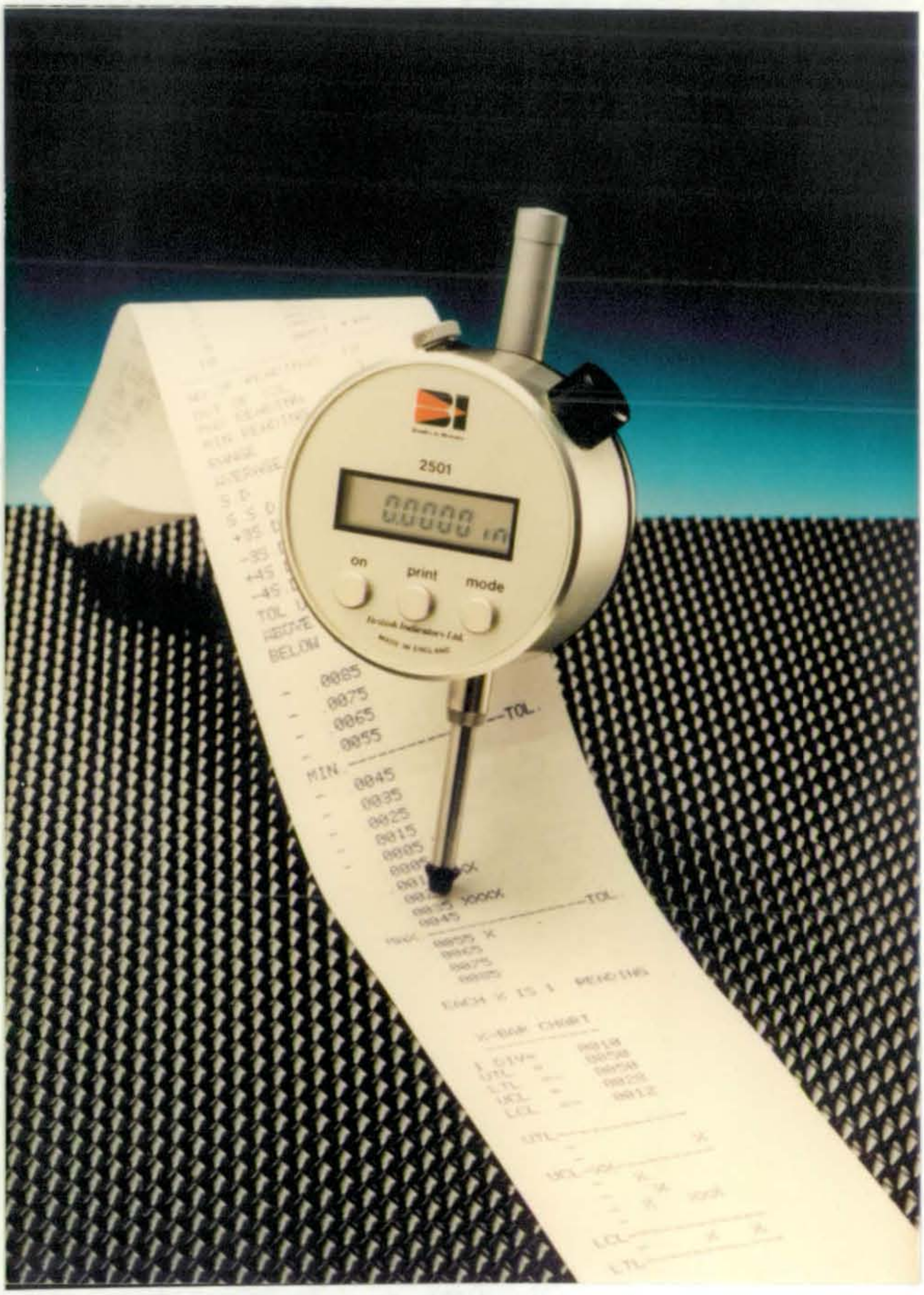



*Plate VI. The Production 2501 Electronic Indicator.*

## *6.0 MANUFACTURING DETAILS AND TESTING*

### *6.1 Manufacture of 2501 Gauge*

*The design and manufacture of the MCE ULA chip has been described in Appendix I. The manufacture of the microprocessor was a matter of supplying the fully de-bugged microprocessor program to NEC for mask making. It has already been mentioned that the mechanical section of the gauge is a modified version of the standard mechanical product and so no problem was experienced in its production except for calibration which has been described in Chapter 5.*

*Other mechanical parts, such as the cylindrical case, the push buttons and silk screened 'Makrolon' (polycarbonate) front panel were contracted to companies with NC machine capacity and printing equipment respectively.*

*A decision had to be made about the assembly of the discrete opto and analogue section of the circuitry. Hybridisation was explored - the laying down of the circuit of naked dice and film resistors onto a glass fibre or ceramic substrate. In the quanitites under consideration however (approximately 100 per month) the extra cost, versus manual PCB assembly was not justifiable economically. The development timescale of eight weeks was also not acceptable (bearing in mind that 10 prototypes had been developed using standard PCB assembly techniques). In view of the now acute cashflow problem at B.I.L., it was therefore decided to contract assembly and test of the PCBs to a nearby company experienced in this kind of work. It was soon found however that control of such manufacture at a distance was causing quality problems, so eventually a small electronics production unit was founded at B.I.L. It was possible to retrain some of the mechanical assembly workers to assemble and test parts of the unit. The present situation at B.I.L. is one of change, as electronic products comprise an increasing proportion of the product mix.*

## 6.0 MANUFACTURING DETAILS AND TESTING

*Full details of manufacture and testing techniques are to be found in Supplement V.*

*Here, the route from goods inwards to packing is given as a list of key operations:*

1. *Good inwards 100% functional test on all ICS and LCD;*
2. *Visual inspection of all other electronic components;*
3. *Assemble lower and upper PCBs;*
4. *Full functional test on each PCB;*
5. *Assemble PCBs together with cells;*
6. *Full functional test of completed PCB assembly;*
7. *Assemble into cases;*
8. *20 minute vibration soak;*
9. *Re-test assemblies;*
10. *Fit front panels;*
11. *Final assembly to mechanical section;*
12. *Quarantine for two weeks;*
13. *Final test and visual inspection*
14. *Charge unit;*
15. *Package.*

*The vibration soak isolates 'infant mortalities' at a reject level of about 1%. Most failures are due to severed or faulty connection, either to the cells or the display.*

## *7.0 APPLICATIONS*

*7.1*

*Included is the sales brochure showing how the traditional mechanical indicator has been replaced by the electronic indicator which has simplified and enabled more error free measurements in these applications.*


# A new, low cost digital gauge system from British Indicators

*Quality in Measure*

Well known throughout industry in this country and overseas for nearly half a century, British Indicators has built-up an enviable reputation for "quality in measure". Its products are in use in most major industries — ***automotive, aircraft, medical, food processing, oil exploration and, of course, general engineering.***

*Quality in Measure*

It is this background and breadth of experience which has enabled BI to pioneer the design and development of a new range of electronic indicators and associated computer systems. Competitively priced, these instruments both individually and in system form, provide today's industry with the means of ensuring more accurate, faster and therefore more profitable production. Simple to set-up and use, they will not only monitor production processes on a continuing basis, but also provide automatically, a print-out as a permanent record.

## CONTENTS



In line with its policy of continuous product development, British Indicators reserves the right to modify the specifications contained herein without notice.

# Digital Indicators


Designed to incorporate the precision and quality of the conventional "John Bull" Dial Indicator, these instruments include all the advantages of advanced electronic technology. They constitute a range of exceptional measuring instruments ideally suited to servicing the needs of today's industry in the fields of inspection and quality control.

| Model | Resolution | Travel |
|---|---|---|
| 2501 | .0004 in<br>.01 mm | 1 in<br>25 mm |
| 3002 | .0001 in<br>.002 mm | .125 in<br>3 mm |

## Features

- **Compatible size and fittings with conventional $2\frac{1}{4}''$ Dial Indicators.**
- **Switchable for Imperial or Metric reading.**
- **Liquid Crystal Display can be rotated through 360° to obtain the most advantageous viewing position.**
- **RS 232C Serial output facility to run printer or computer.**
- **Direct conversion when switched from Imperial to Metric.**
- **Powered by long life re-chargeable battery, or by mains via the charger/mains power unit.**
- **Accurate to BS 907, and other International Standards.**
- **Will convert existing Dial Indicator Measuring instruments and fixtures to provide digital readout and statistical analysis of measurements when linked to the B.I. Stats System.**

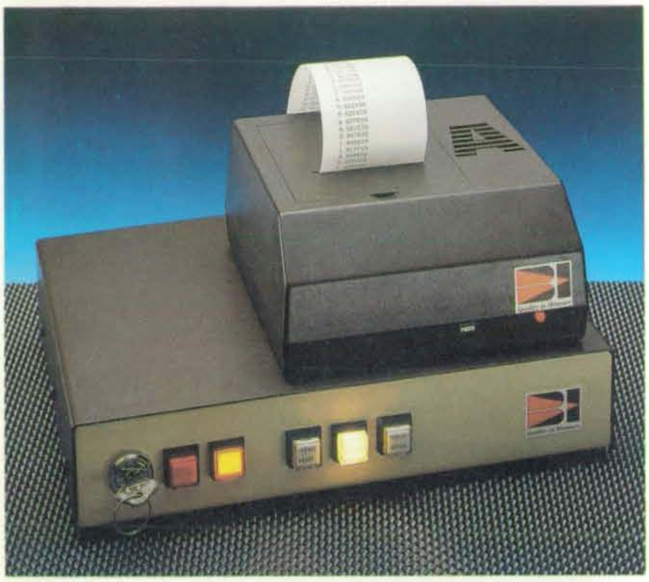
# Computer/Interface/Printer

## STATISTICAL ANALYSIS

The System is of modular design and, in its basic form consists of:—
A 32K Computer, a 24 column Dot matrix Printer and an 8 Channel Master Interface which contains the standard STAT-AN Program on ROM Chip.

The basic system can be expanded to control up to 64 Digital Indicators by the simple addition of extra individual 8 Channel Slave Interfaces.

Special programs can be supplied on ROM Chip or can be written by the user and loaded into the system by tape. A monitor or TV can also be linked to the system to provide enhanced visual display.



# Interface and Printer

The Master Interface can be used without the computer. In this form it provides an 8 Channel facility and will simply print out the reading of each indicator linked to the system in sequence.

A timer can be plugged into the footswitch socket to provide a printout of measurements taken at pre-determined intervals.

# Digital Indicator & Printer only

A two channel printer is also available and offers remote controls for the Indicators linked to it.
Master control buttons for the Zero-reset, Print and Mode change are provided.

This unit is ideal for linking two indicators to an optical projector to provide both digital read-out and a recording of the measurements taken. The Printer is also capable of accepting 2 footswitches. This enables the operator to use both hands to control the actual measuring instrument whilst signalling the printer to record the readings.

## THE STAT-AN PROGRAM

STAT-AN is a comprehensive program for the provision of machine capability data and of statistical information for production quality control.

STAT-AN is contained in a ROM chip in the Master Interface and is activated through the computer system. It can monitor from 1 to 64 Digital Indicators in a mix of single and multiple configurations.

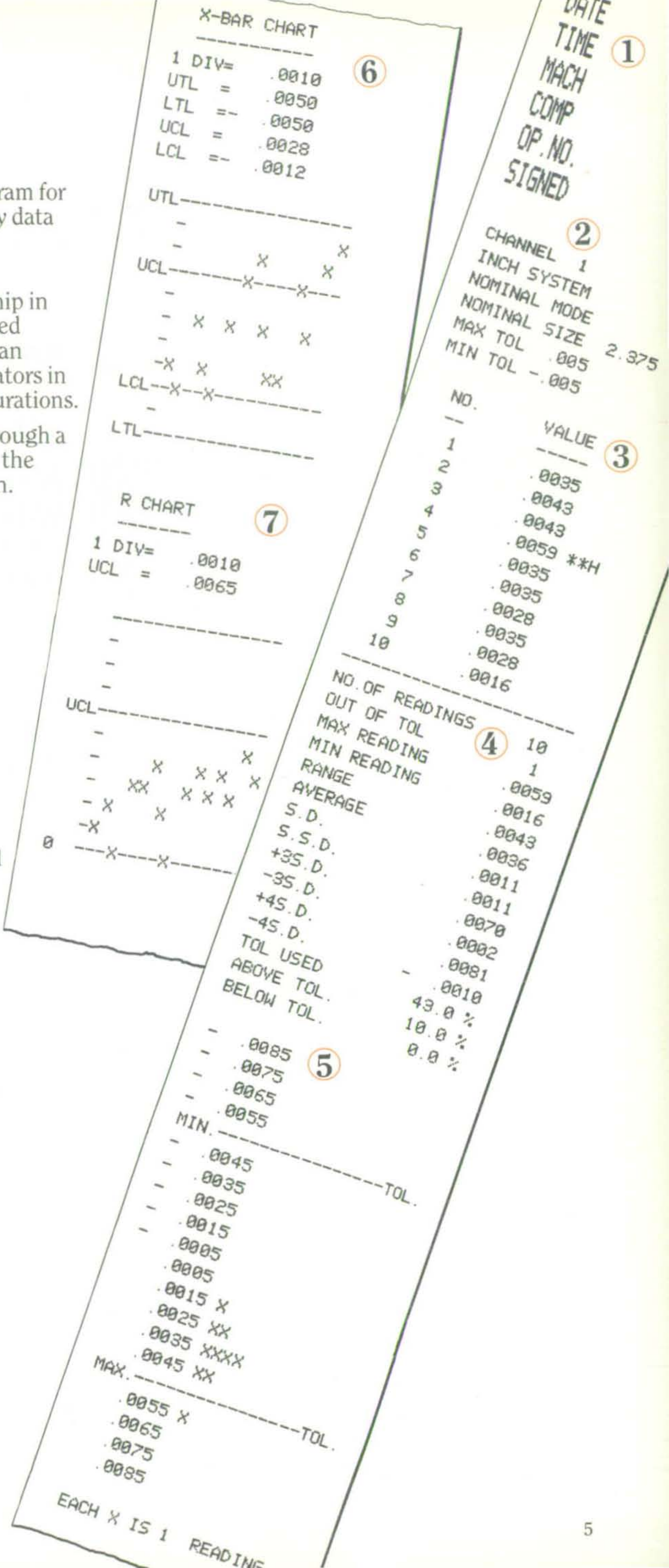
The Program is easily operated through a series of prompts which appear on the computer's Integral Display Screen.

## STAT-AN PRINT-OUT

1. Automatic Heading Printout
2. Prints pre-programmed data for the channel selected
3. Prints measurements signalled by the Digital Indicator Symbols **H = above Tol. **L = below Tol.
4. Automatic printout of the Statistical Data
5. Tally Chart (Histogram). This shows each measurement plotted in its respective position in relation to the maximum and minimum tolerance positions
6. X-Bar Chart (Average). This shows the average value of the sample plotted between the upper and lower tolerance and control limits
7. R-Chart (Range). This shows the range value of the sample plotted against the upper control limit

   The computer remembers previous X-Bar and R readings and plots them together with latest reading from the last sample

* Additional copies of each printout are available if requested
* Manual entry of sample data is possible by direct entry via the computer's keyboard


DATE
TIME
MACH
COMP
OP. NO.
SIGNED ①

CHANNEL 1 ②
INCH SYSTEM
NOMINAL MODE
NOMINAL SIZE 2.375
MAX TOL .005
MIN TOL -.005

| NO. | VALUE ③ |
|---|---|
| 1 | .0035 |
| 2 | .0043 |
| 3 | .0043 |
| 4 | .0059 **H |
| 5 | .0035 |
| 6 | .0035 |
| 7 | .0028 |
| 8 | .0035 |
| 9 | .0028 |
| 10 | .0016 |

| ④ | |
|---|---|
| NO. OF READINGS | 10 |
| OUT OF TOL | 1 |
| MAX READING | .0059 |
| MIN READING | .0016 |
| RANGE | .0043 |
| AVERAGE | .0036 |
| S.D. | .0011 |
| S.S.D. | .0011 |
| +3S.D. | .0070 |
| -3S.D. | .0002 |
| +4S.D. | .0081 |
| -4S.D. | -.0010 |
| TOL USED | 43.0 % |
| ABOVE TOL. | 10.0 % |
| BELOW TOL. | 0.0 % |

⑤
.0085
.0075
.0065
.0055
MIN. ------------------TOL.
.0045
.0035
.0025
.0015
.0005
.0005
.0015 X
.0025 XX
.0035 XXXX
.0045 XX
MAX. ------------------TOL.
.0055 X
.0065
.0075
.0085

EACH X IS 1 READING

X-BAR CHART ⑥
1 DIV= .0010
UTL = .0050
LTL =- .0050
UCL = .0028
LCL =- .0012
UTL, UCL, LCL, LTL

R CHART ⑦
1 DIV= .0010
UCL = .0065
UCL, 0

# Applications

## Intercheck Gauge

The Intercheck Gauge is an extremely efficient instrument for measuring internal recesses, bores or thread dimensions.

It can be used with Electronic or Mechanical Indicators in either the horizontal or vertical plane.

- Standard Recess Mandrels ¼″ - 5¾″ dia, *0.25mm - 146.05mm dia.*
- Standard Bore Mandrels ¼″ - 1″ dia, *6.35mm - 25.40mm dia.*
- Thread measurement of, Effective, Major or Minor diameters
- Special Mandrels to customers specifications.

**RECESS MANDRELS**

| Model | Range | | Reach | | Probe Width | |
|---|---|---|---|---|---|---|
| 60/R0 | 0·25–0·31 in | *6·35– 7·87 mm* | 1·69 | *42·93* | 0·027 | *0·69* |
| 60/R1 | 0·31–0·38 in | *7·87– 9·65 mm* | 2·44 | *61·98* | 0·037 | *0·94* |
| 60/R2 | 0·38–0·44 in | *9·65– 11·18 mm* | 2·44 | *61·98* | 0·037 | *0·94* |
| 60/R3 | 0·44–0·50 in | *11·18– 12·70 mm* | 2·44 | *61·98* | 0·037 | *0·94* |
| 60/R4 | 0·50–0·56 in | *12·70– 14·22 mm* | 2·44 | *61·98* | 0·037 | *0·94* |
| 60/R5 | 0·56–0·63 in | *14·22– 16·00 mm* | 2·44 | *61·98* | 0·037 | *0·94* |
| 60/R6 | 0·63–0·69 in | *16·00– 17·53 mm* | 2·44 | *61·98* | 0·037 | *0·94* |
| 60/R7 | 0·69–1·00 in | *17·53– 25·40 mm* | 3·75 | *95·25* | 0·12 | *3·05* |
| 60/R8 | 1·00–1·75 in | *25·40– 44·45 mm* | 3·75 | *95·25* | 0·16 | *4·06* |
| 60/R9 | 1·75–5·75 in | *44·45–146·05 mm* | 4·50 | *114·30* | 0·19 | *4·83* |

**BORE MANDRELS**

| Model | Range | | Reach | |
|---|---|---|---|---|
| 60/7 | 0·25–0·31 in | *6·35– 7·87 mm* | 2·38 | *60·45* |
| 60/8 | 0·31–0·41 in | *7·87– 10·41 mm* | 2·38 | *60·45* |
| 60/9 | 0·41–0·50 in | *10·41– 12·70 mm* | 2·38 | *60·45* |
| 60/10 | 0·50–0·63 in | *12·70– 16·00 mm* | 3·38 | *85·85* |
| 60/11 | 0·63–0·75 in | *16·00– 19·05 mm* | 3·38 | *85·85* |
| 60/12 | 0·75–0·88 in | *19·05– 22·35 mm* | 3·38 | *85·85* |
| 60/13 | 0·88–1·00 in | *22·35– 25·40 mm* | 3·38 | *85·85* |

## 220 Series Snap Gauges

These gauges are for measurement of outside diameters and each instrument has a wide adjustment range.

- Wide Range — Instruments from 0-12½″, *0-138 mm*
- Flat Tungsten Carbide Anvils as standard
- Lifting Lever for Sensitive Anvil
- 2½″, *64 mm* adjustment on each gauge
- Adjustable Backstop
- Electronic or Mechanical Indicators
- Special Anvils to customers specifications
- Ideal for P.C.D. measurement when fitted with Roller Anvils

*Special models are available with detachable anvils making them ideally suited to special applications.*

**STANDARD MODELS**

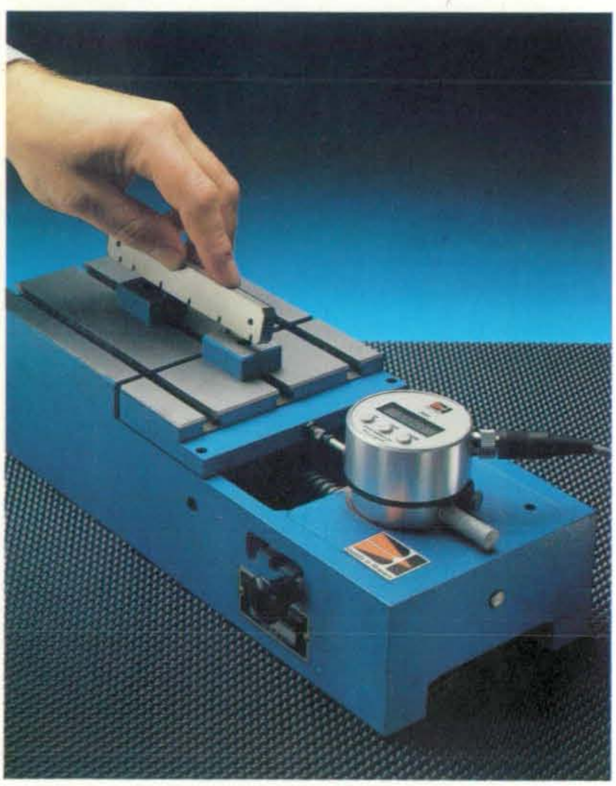
| Model No | Range | |
|---|---|---|
| 221 | 0-2½ in | *0-64 mm* |
| 223 | 2-4½ in | *51-115 mm* |
| 225 | 4-6½ in | *102-165 mm* |
| 227 | 6-8½ in | *153-217 mm* |
| 229 | 8-10½ in | *204-267 mm* |
| 231 | 10-12½ in | *255-318 mm* |

# Comparator Stands

These provide the most popular inspection vehicle for both Mechanical and Electronic Indicators and are capable of measuring a wide range of component dimensions.

- Sturdy Construction
- Chrome Plated Columns & Cross Arm
- Standard Lug Fittings
- Cast Iron and Granite Bases

| Model Number | 2 | 3 | 4 |
|---|---|---|---|
| Base Dimensions | $6\frac{1}{2} \times 5\frac{1}{4}$ in<br>*165 × 134 mm* | 9 × 6 in<br>*229 × 153 mm* | $4\frac{1}{4} \times 4\frac{1}{4}$ in<br>*108 × 108 mm* |
| Capacity | 9 in *229mm* | 9 in *229mm* | 7 in *178mm* |
| Base Material | Cast Iron | Cast Iron | Granite |
| No of Columns | 1 | 2 or 1 | 1 |
| Column Diameter | 1 in<br>*25 mm* | 1 in<br>*25 mm* | 1 in<br>*25 mm* |



# Checkmaster Horizontal Comparator

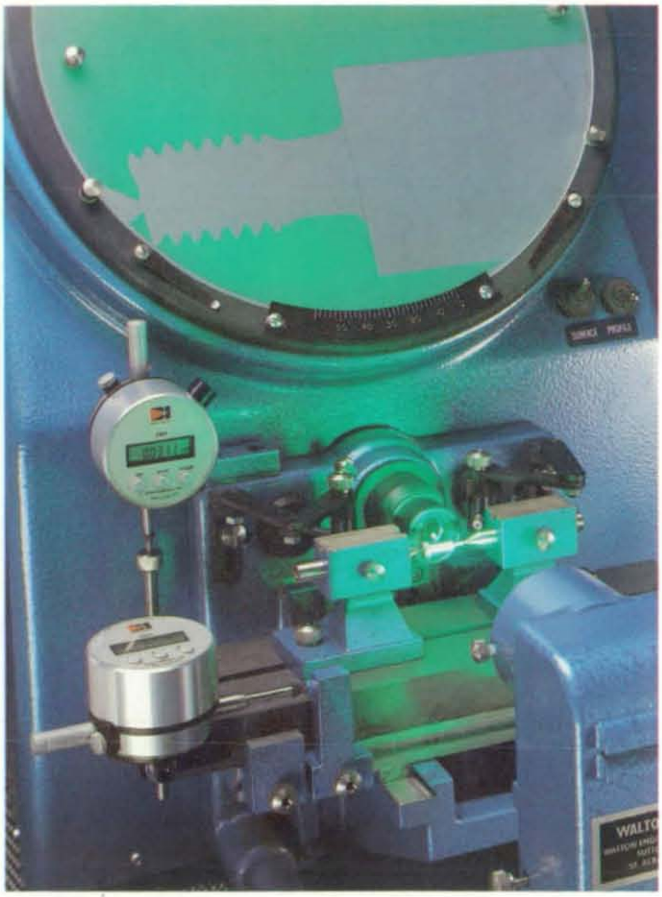
The Checkmaster is a robust but extremely sensitive measuring instrument ideally suited to the accurate gauging of components in both workshop and inspection conditions. It will accept standard and special tooling for gauging internal and external dimensions.

- Floating Sensitive Table unaffected by dirt or swarf
- Internal or external measuring bias
- Variable measuring pressure
- Ideal for gear concentricity and PCD checks
- Accurately ground tee slots for tooling location
- Fixed table 5″ × $5\frac{1}{4}$″ *125 × 134 mm.* Sensitive table 2″ × $5\frac{1}{4}$″ *50 × 134 mm.*

# Special Gauges and Fixtures

To complement their standard range of measuring products, British Indicators can also design and manufacture special gauging instruments and fixtures.

These instruments cover both single and multi-dimensional applications and are ideally suited for use with the computer system to provide statistical analysis of each individual dimension.



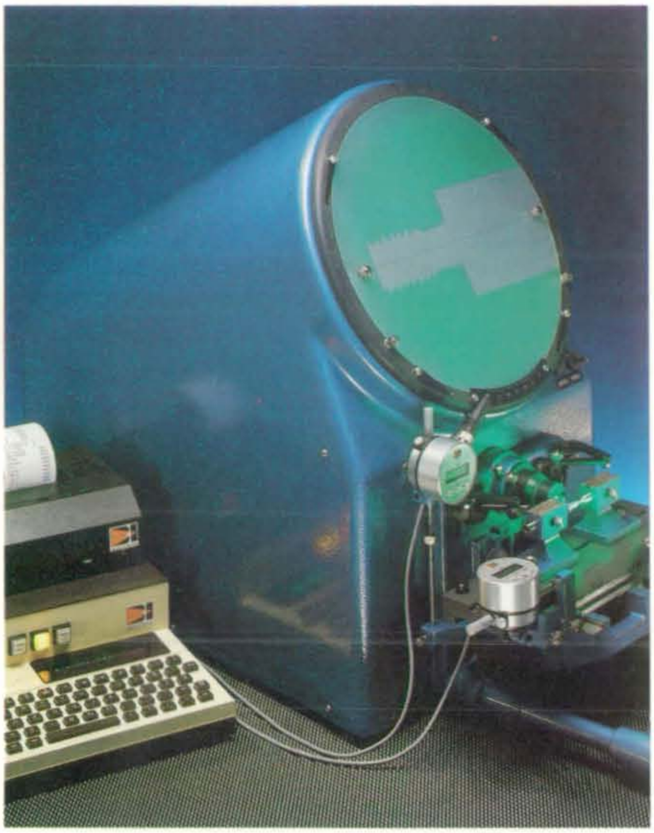
# Optical Projectors

There are many units in use where the measurement is taken from Dial Indicators.

Although this offers a practical method of achieving a measurement, it is laborious and open to miscalculation by the operator.

Due to the design of the Digital Indicator, old mechanical units can be easily replaced with new Digital Indicators and zero setting and actual readings become faster and of course more reliable!

They can also be linked to the Computer System to provide statistics.



# Computerised Optical Projectors

Optical Projectors provide a fast, convenient means of measuring many difficult engineering features which normally would require expensive or elaborate dedicated measuring devices.

When 2501 Digital Indicators are fitted to the Horizontal and Vertical axes of a projector workstage, they offer immediate connection to the BI Computer System.

This system can be used to provide statistical analysis of measurements taken from both axes by using the standard STAT-AN program. Special programs can be supplied by BI on tape or ROM chip, or can be written by the customer in the popular "BASIC" computer language.

*British Indicators offer two projectors which incorporate the above facilities*

| Model | 305 | 405 |
|---|---|---|
| **Workstage** | | |
| Dimensions | $11\frac{1}{2} \times 3$ in *292mm × 76mm* | $15 \times 4$ in *381mm × 102mm* |
| Lateral Travel | $5\frac{1}{2}$ in *140mm* | $9\frac{1}{2}$ in *241mm* |
| Vertical Travel | $2\frac{1}{2}$ in *63mm* | $3\frac{1}{2}$ in *88mm* |
| **Centres** | | |
| Max Dia of work | $3\frac{1}{2}$ in *88mm* | $3\frac{1}{2}$ in *88mm* |
| Max length of work | 7 in *177mm* | $10\frac{1}{2}$ in *267mm* |
| **Front working distance** | | |
| × 10 Mag. | $2\frac{9}{16}$ in *65mm* | $3\frac{3}{32}$ in *78.5mm* |
| × 20 Mag. | $1\frac{3}{16}$ in *30mm* | $2\frac{5}{32}$ in *55mm* |
| × 50 Mag. | $\frac{9}{16}$ in *14mm* | $\frac{7}{8}$ in *21mm* |
| **Overall Dimensions** | | |
| Height | 24 in *610mm* | 30 in *762mm* |
| Width | 15 in *381mm* | 24 in *610mm* |
| Length | 36 in *914mm* | 44 in *1117mm* |
| Screen Diameter | 12 in *305mm* | 16 in *405mm* |
| Lamp Projection | 12v 50w | 24v 150w |
| Lamp Surface Illumination | 12v 150w Diacrylic | 12v 150w Diacrylic |
| Weight | 70lbs *32 Kilos* | 115lbs *52 Kilos* |
| Voltage | 240/220<br>120/110 | 240/220<br>120/110 |

# Digital Indicator Specifications

These units consist of conventional Dial Indicator bodies with an add on electronic package which replaces the normal dial face and pointer with an easily read Liquid Crystal Display.

| Model | 2501 | 3002 |
|---|---|---|
| Range | 1 in - *25 mm* | .125 in - *3 mm* |
| Resolution | .0004 in - *.01mm* | .0001 in - *.002 mm* |
| Accuracy | BS 907 | BS 907 |
| **Size** All dimensions except front body depth to BS 907 Series 2 Dial Indicator Specification | | |

## BUTTON FUNCTIONS

| | |
|---|---|
| **On:-** | Switches indicator on and will also reset digits to zero at any point throughout the spindle travel. The display will exhibit a minus sign when the spindle moves down from a zeroed position. |
| **Print:-** | Signals printer or computer the size which is on display. |
| **Mode:-** | This button has two separate functions.<br>(a) A short press and release (less than 2 seconds) will hold the digits which are being displayed. If the spindle is moved whilst the hold is on, the digits will remain as held. If the button is pressed again it will release the hold and indicate the new dimension which the spindle has travelled to from the original zero position.<br>(b) Metric/Inch Change<br>The button should be held for over 2 seconds and, upon release, the display will change to the other measuring mode. When changing over it will show a direct conversion into the alternative mode of the size being displayed. |
| **Power Supply:-** | 3 integral re-chargeable cells with 80 hours working life between charges. When the cells are in a low charge state, this is indicated by a flashing 'B' in the lower left hand corner of display, which indicates that re-charging is necessary.<br>The Indicator will switch off automatically if it has not been used within 4 minutes to conserve battery life.<br>When the indicator is linked to a printer or computer system the power is supplied by these units and the cells are not in use. The indicator will not automatically switch off under these conditions.<br>The Indicator can also be used with the charger connected for continuous power supply using the mains and will not switch off in this situation. |
| **Output Socket:-** | Provides for connection to a printer or the computer system and also provides the necessary connection for the charging unit and outside power supply if required. |
| **Output Signal:-** | Open Collector RS232C serial type. |
| **Gauge Mounting:-** | 8 mm Stem and Offset Backlug as standard fitting. Backlugs can be fitted from the full range of Dial Indicator fittings offered by B.I. |
| **Operation Temperature:-** | 0 - 40°C. |


# Computer Specifications

## MODEL AD

- Z80A microprocessor running at 4MHz COP 420M micro controller with
- 1K system ROM
- 32K byte RAM
- 28K ROM
- Dual 1200 baud cassette ports with drive motor control
- 75 ohm UHF composite video output
- RS232/V24 Bi-directional port
- RS232/V24 Printer port
- (Both RS232/V24 ports are software driven and non-autonomous)

Character generator provides 512 characters, including the 96 upper and lower case ASCII/ISO printing characters, 64 viewdata mosaic graphics symbols, Western European accented characters, full Greek upper and lower case characters, line drawing graphics, games graphics and other symbols generated by $8 \times 10$ and $8 \times 8$ matrices.

Video and UHF outputs provide a display of up to 25 or 30 lines of 40 or 80 characters per line. A high resolution display of up to 250 dots vertically by 256, 320, 512 or 640 dots horizontally may be mixed with a separately scrollable character mode display.

An on-board blue-green vacuum flourescent 16 character, 14 segment display behind a brown tinted filter.


# Master Interface Specifications

- Security Key on Switch
- Size

| | WIDTH | DEPTH | HEIGHT |
|---|---|---|---|
| | 11in | 9in | $2\frac{1}{2}$in |
| | 280mm | 230mm | 65mm |

- Weight 3.6 lbs 1.65 Kgs
- Operating Temp. 0 - 40°C
- Illuminated Computer select switch
- Illuminated Signal Entry Switch
- Master ON/RESET Switch
- Master PRINT Switch
- Master Mode Switch
- 8 DIN Sockets for Indicator
- Footswitch/Timer Socket
- Integral Power supply for Computer/Printer

Quality in Measure


# British Indicators Ltd.

Acrewood Way, Hatfield Road,
St. Albans, Hertfordshire AL4 0JX, England.

Telephone: St. Albans (0727) 60491
Telex: 28538 GAUGING STALBAN


*Makers of the **John Bull** range*

## 8.0 *FUTURE DEVELOPMENTS*

### 8.1 *Electronic Gauges*

*While the 2501 gauge has a wide market appeal, increased still further by the added facilities provided by the statistical analysis package, it is categorically excluded from areas of application requiring resolution and accuracy an order of magnitude higher than can be provided at present. Approximately 30% of all mechanical contact gauging is embraced by this order of accuracy, namely 1-2 micron resolution. Four solutions to this demand have emerged.*

#### 8.1.1 *The 3002 Gauge*

*Following on from the concept of the 2501 indicator is the 3002. Using the identical electronics add-on unit but with two links altered to provide:*

*i) an extra decade of count (the 7502 microprocessor was programmed to provide this facility);*

*ii) increment of .002 microns which converts to the nearest 1/10,000 inch in imperial system. (A count-by-two facility was designed into the semi custom counter).*

*B.I.L.'s standard range of mechanical indicators includes a .002 mm reading geared DTI which has very similar physical dimensions to the series II incorporated in the 2501. It was therefore an obvious step to provide an electronic version of this instrument also. Because of the 5 times increase in gear ratio it was decided to limit the travel of the plunger to 3 mm (hence 3002 for the name) and the gauge is limited to static or slow moving applications.*

## *8.0 FUTURE DEVELOPMENTS*

### *8.1.2 Analog Transducers*

*There are many analog transducers in use in the industry today and customer feedback indicates the desirability of connecting these devices to the B.I.L. stats. system. Such transducers are of the LVDT (Linear Variable Differential Transformer), or capacitive type and provide resolutions of 1 micron or better. Thus, a future development will be a transducer interface to connect many of these transducers to the B.I.L. stats system. The interface will consist of a multiplexed A.D. converter of at least 12 bit resolution followed by a microprocessor to handle data acquisition, system timing and serial data port implementation. It could be housed in a slave interface unit case (see brochure in Chapter 7) and would be a means of greatly enhancing the system - both in accuracy and speed, since serial data could now be transmitted at 9600 Baud to the micro computer. Software enhancements could be incorporated also, for instance a multi-channel bar graph type display could be implemented on a monitor screen to replace bulky, costly LED hardware units which are so ubiquitous in precision gauging applications.*

*Software tolerancing and 'go - no go' indications would greatly increase operator efficacy.*

### *8.1.3 Non Mechanical Gauge*

*The possibility of developing a non-mechanical electronic plunger gauge, again aimed at B.I.L.'s existing market has been mentioned previously. When the chip set for the 2501 was developed, always in mind was upwards compatibility with any transducer giving two square waves output in quadrature - the system foremost in mind was an optical one based on the Moiré fringe concept using two glass slides as the transduction element. However, experience has since shown that relatively heavy current consumption (in the region of 0.3 mA) is the minimum possible for the relatively low frequency of the 2501 gauge (up to 12 kHz) which has built in inertia to limit output frequency, and 5 times lower resolution than the proposed 2 micron gauge. Since output frequency is proportional to* the quotient of the plunger speed and gauge resolution, it would be necessary to provide damping, increase dissipation of the analog/pseudo optical system or hope for improvements in device performance.

Battery life is becoming a major selling point with devices using silver zinc, lithium or other primary cells having an operational life of at least 1 year.

Coupled with the alignment difficulty of opto devices, due to gain spreads, the use of Moiré fringe gratings has been effectively ruled out.

The Sylvac capacitive system [29] for example is a low power system requiring no alignment procedure.

### 8.1.4 The Universal Interface

There is a very wide range of electronic gauging instruments produced by manufacturers in Switzerland, Japan, U.S.A., Britain and other European countries. These include the above mentioned transducers. All of them have different data output modes, as listed below:

i) RS232 serial (as 2501 gauge)
ii) BCD strobed parallel (as Baty JB80, Sylvac et al)
iii) I.E.E.E. 488 standard bus
iv) Various non-standard serial outputs (adopted probably for ease of hardware implementation and/or marketing reasons, to force the user to use special interfaces)
v) Analog voltage or current outputs

F.V. Fowler, the U.S.A. agent for B.I.L. and many other foreign manufacturers has indicated great interest in a 'universal interface' which will enable all of these outputs to interface to the B.I.L. statistical analysis system, and a very large market is predicted for such a device.

## 8.0 *FUTURE DEVELOPMENTS*

*The B.I.L. modular system lends itself very well to such a concept. All the above styles of output could be converted to RS232 serial and then fed into the 'NewBrain'. A separate slave interface could be used to perform the conversion for each different style. Thus, a truly universal, but modular, interface system can be envisaged.*

### 8.5.1 *Other Microcomputers*

*The 'NewBrain' is not the only microcomputer considered for this system. Interfacing of the 2501 has been accomplished for the HP85 (Hewlett Packard), the Commodore 64, the Apple II and III, and an Epson portable. The 'STAT-AN' program previously described has been translated to run on HP85 machines though this has not yet been commercially released.*

*Additionally, a visit was made to the Buick car manufacturing plant in Saginaw, Detroit, where 2501 gauges were successfully interfaced to digital microcontrollers placed around the factory. These programmable controllers have direct control over press tools and other N.C. (numerically controlled) machinery and are linked directly to the host minicomputers and a mainframe in the 'white collar' section of the plant. The situation is a developing one however, and B.I.L. awaits feedback on Buick's comments and future requirements.*

## 8.1.6 *Other Future Developments*

*In conclusion, let it be said that any or all of the instruments outlined in Chapter 4 (possible research directions) could form the basis of future B.I.L. developments. The market for electronic measuring tools is rapidly expanding and changing, and is almost subject to the whims of fashion. The development team at B.I.L. embraces sales and marketing personnel as well as engineers, is an international organisation and as a result of its recent new innovation is inviting and receiving input from all established and new customers, some small and some large, eg. Buick, Ford, Leyland and General Electric. These markets are at present being cultivated.*

# 9.0 <u>ECONOMIC ASPECTS</u>

## 9.1 **Government Funding for the Project**

### 9.1.1 <u>Product and Process Development Grant</u>

*This grant from the Government D.o.I. was initially applied for on 31st March 1982. The development projects specified were:*

*i) Geared/optical system - the 2501 indicator, .01mm resolution*

*ii) Moiré fringe type system, non programmable gauge, of .001 or .002 micron resolution*

*iii) Programmable version of (ii) possibly with detachable/remote display*

*Although the market and development direction changed during the three year progress of the project, the following monies were granted after visits from D.o.I representatives:*

*Total grant: £31,912 (25% of eligible costs).*

*The cash was received in instalments:*

| | | |
|---|---|---|
| 2 September 1983 | received | £8,741.50 |
| 25 October 1983 | " | £9,464.50 |
| 27 February 1984 | " | £7,113.25 |
| Final payment April 1985 | | £6,593.25 |

### 9.1.2 <u>Microprocessor Application Project (M.A.P.) Grant</u>

*This grant was applied for to fund in part the development of the statistical analysis system. The date of initial application was 9th June 1983. After consultations with the D.o.I. an offer for a grant not exceeding £36,368 was received which was worth ⅓ of net eligible costs. Instalments have been recieved as follows:*

## 9.0 ECONOMIC ASPECTS

| | | |
|---|---|---|
| January 1984 | received | £ 6,614.16 |
| June 1984 | " | £10,160.56 |
| Pending | | £ 7,005.19 |

Grand total = £55,692.

### 9.2 Marketing and Sales Aspects

#### 9.2.1 Launch of the New Product

*Unusually, the initial sales launch took place in North Americà. The principal reason for this was that via a single distributor, F.V. Fowler Inc., a large order could be secured which would take the risk of low sales out of the initial production run. The U.S.A. market is the single largest worldwide for mechanical dial indicators, and it therefore follows that it would be so too for the 2501 due to its simple operation and functionally equivalent size. Another consideration was that in the U.K., British Indicators had no reputation at all for innovative products; the market might therefore be expected to react cautiously to a radical departure from its established (low) technology. In the U.S.A., by contrast, Fowler has an excellent reputation for supplying the latest technology in electronic gauging. Therefore, with a re-styled front panel (in America the 2501 indicator is known as the Fowler 'ULTRA DIGIT') it was felt that the new product would have an excellent start in the market against the competition. At the time of writing, the U.K. and European market is being explored and the products have recently been exhibited at MACH '84, the machine tools exhibition at Birmingham's N.E.C. Forthcoming and past/international exhibitions where the system has been shown are:*

| Exhibition | Time | Venue |
|---|---|---|
| Quality Expo-Time | March | Chicago |
| WESTEC | October | Los Angeles |
| INSPEX | March-April | Birmingham |
| MICROTECNIK | November | Zurich |

## 9.0 *ECONOMIC ASPECTS*

### 9.2.2 *Launch Costs*

*British Indicators has been manufacturing instruments for nearly 50 years. The name and range of products are well-known in the U.K., and also certain export areas.*

*To extend the company's current range of mechanical instruments with electronic units, it was necessary to utilise special literature, advertising and exhibitions to ensure the market is made aware of our new products.*

*Advertising estimated (U.K. only)*

*12 insertions each year at £300 each.*

*Literature single leaflet on each unit*
*5,000 copies each, £400 each unit.*

*Technical data 3 x £100 each*

*Three exhibitions to:*

| | |
|---|---|
| *INSPEX (U.K.)* | *£5,000* |
| *WESTEC (U.S.A.)* | *£5,000* |
| *MICROTECNIK (Switzerland)* | *£2,000* |

*Other methods of launch will be used to take advantage of free publicity in trade and technical press.*

*Also selected target sales via mail shots were thought necessary.*

*Market Survey re: Digital Dial Gauge*

*The marketing information which our decisions had to be formulated from was obtained by a selective programme of discussions with major users of mechanical dial indicators. They were chosen to represent a range of* users, ie. O.E.M., Direct and Indirect measurement uses. The discussions and visits were carried out by:

1 Mr B James, who was independently employed to carry out an initial survey.

2 B.I.L. Sales and Technical personnel.

3 Mr T Preston, Research Associate.

Following are listed some of the major users contacted in our survey.

| | |
|---|---|
| Rolls Royce | (user) |
| Ford Motor Co | (user) |
| Ford Tractor Co | (user) |
| F.V. Fowler | (U.S.A. Distributor) |
| Wykeham Farrance | (O.E.M.) |
| H.W. Wallace | (O.E.M.) |
| L. Hartridge | (O.E.M.) |
| B. Leyland | (user) |
| F.J. Cox | (Canadian Distributor) |
| G. Nissel | (O.E.M.) |
| H. Roberts | (U.K. Distributor) |
| Hardy Spicer | (user) |

### 9.3 Sales Progress

#### 9.3.1

In March 1983 the prototype 2501 and computer system were shown at the Quality EXPO-Time show in Chicago. Following this show an order was placed by F.V. Fowler, the distributor, for 2000 indicators and 100 computer systems for delivery commencing later in the year.

### 9.3.2 Current Sales Figures

| | |
|---|---|
| B.I.L. established products value end 1983 | £ 60,000 |
| B.I.L. new products value end 1983 | £ 40,000 |
| | £100,000 |

(above calculated on 500 indicators and 10 systems/month to U.S.A. only).

By December 1984 these figures will be:

| | |
|---|---|
| B.I.L. established products value | £ 70,000 |
| B.I.L. new products value | £ 90,000 |
| | £160,000 |

Calculated at 1000 indicators/month + 20 systems (note better negotiated prices on electronics).

Note that, as intended, orders for established accessories like snap gauges, bore gauges etc. have started to increase due to compatibility with our new electronic indicator.

### 9.3.3 Further Sales

As the U.S.A. market proved so succesful it became easier to develop the sales elsewhere, which meant that increased production must occur. Early orders came from Canada, Scandinavia, France, Spain, Australia, and of course the U.K. The markets are being developed steadily due to the suitability of B.I.L.'s current distributor network.

So far, the product has proven both technically and financially sound, and will provide the Company with a regular and profitable business.

### 9.3.4 Future Market

The two main markets being developed now are Germany and Japan. Visits to both these countries later in the year 1984 will follow up initial *investigations in trying to find and establish a suitable distribution system for the new product line.*

*China is a potential growth market due to her oil exploration activities and present use of established oil pipe measurement tools.*

9.3.5 Analysis of Market Proportions by December 1984

| Market | Digital indicators/ month | Stats systems/ month | £ Value/mth |
|---|---|---|---|
| U.S.A | 500 | 20 | 160,000 |
| U.K. | 200 | 5 | 40,000 |
| Germany | 100 | 5 | 40,000 |
| Japan | 100 | 5 | 40,000 |
| Others | 100 | 5 | 40,000 |
| | 1,000 | 40 | 320,000 |

## 10.0 REFERENCES

### REFERENCES


Books and References

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# *11.00 ACKNOWLEDGEMENTS*


## *ACKNOWLEDGEMENTS*

1 *To Professor K.W. Brittan, Department of Design and Technology, Loughborough University, for initiating the project and for continual support and advice throughout its duration.*

2 *Mr S.J. Branson, Department of Design and Technology, Loughborough University, for advice and help in electronics design and checking of correctness of U.L.A. design.*

3 *Mr D.W. Hoare for writing the N.E.C. 7502G micro-processor program.*

4 *British Indicators Ltd for sponsoring the research program.*

5 *Individual staff members of B.I.L. for support and encouragement and aid with some of the drawings.*

*APPENDIX I*

*MT 72006 Semi Custom I.C.*

*APPENDIX I*

27.10.81 ***THE NEED FOR A SEMI-CUSTOM LSI CHIP***

## 1 **What is a custom LSI chip?**

*A custom designed and manufactured Large Scale Integrated circuit or chip is a complex array of transistors fabricated onto a single slice of silicon measuring a few millimetres square. It replaced whole circuit boards of logic which would previously have occupied several square inches or square feet of area.*

*The major difficulty from the small to medium volume manufacturer's point of view is interesting a custom LSI company in quantities of less than 100,000 units per year, since to amortise the very large tooling costs, and to utilise fully their capital equipment representing hundreds of thousands of pounds, it simply is not an economic proposition to produce LSI in smaller quantities.*

## 2 **What is a semi-custom LSI chip?**

*A semi custom LSI chip is similar to a custom LSI chip except that a single, basic range of silicon slices, with most of the active elements already formed, is used for every semi customised chip that the company produces. Thus, capital investment is lower, design turn around time is shorter and smaller numbers become feasible as a consequence.*

*MCE (Microcircuit Engineering) Ltd of Tewkesbury is such a company and it was established that they could produce the chip required.*

## 3 **Why is a semi-custom chip required at all?**

i) *Size - if a range of small gauges is to be produced it simply would not be possible to achieve the desired level of miniaturisation without going to a custom or semi-custom integrated circuit. For example, a circuit board the size of* *this page can be condensed into a chip package the size of a postage stamp.*

*ii)* *Reduced power consumption - a major marketing consideration is that the battery powered equipment should have a long working life - this is achieved by careful design of the chip.*

*iii)* *Increased reliability - fewer soldered connections = increased reliability.*

*iv)* *Reduced parts count - this means reduced ordering and stock control, reduced assembly time and inspection, and ultimately lower product cost. (See below).*

*v)* *Increased security of design - it is extremely difficult for a competitor to plagiarise a custom or semi-custom chip.*

*4* ***What are the costs involved?***

*i)* *Investment of £7,000 for initial design work to commence - most of work done by T.J.P.*

*ii)* *Sixteen weeks later the first prototypes should become available, and subject to approval, the first production batch shortly after this.*

*iii)* *Unit cost of the chip has been estimated at £4.00 in 10,000 quantities.*

*iv)* *Alternative to (i), M.C.E. Ltd will undertake the design work for an additional £7,000. This would be the quickest route to obtaining the first samples and would free T.J.P. to perform other tasks which ought to proceed in parallel if production is to commence a.s.a.p.*

*APPENDIX I*

5 ***What is the break-even number?***

*To see if it is worthwhile financially to substitute this custom chip for a handful of off-the-shelf chips and a circuit board, consider the formula*

*break-even no., N = (Y - X)/(x - y) where*
*X = total development cost of printed circuit board*
*Y = total development cost of semi custom chip*
*x = manufacturing cost of PCB (includes testing & Q.C.)*
*y = purchase price of semi custom chip*

*in our case N = £(14,000 - 2,000)/(10 - 4)*

*N = 2,000 units*

*Summary*

*Since this chip would be used for all the projects under consideration it is certainly a financially sound proposition. On technical grounds in terms of meeting the specifications for size and power consumption, it is the only solution.*

*In view of the timescales involved, it is vital that authorisation to release the capital required be given as soon as possible if our production deadlines are to be approached.*

*APPENDIX I*

15.07.82 **ULA GAUGE CHIP - SPECIFICATION**

| | |
|---|---|
| *Part No:* | *72006* |
| *Type:* | *560 gate ULA* |
| *Technology:* | *CMOS* |

*1.0 General Description*

*The gauge chip is a 5 decade bidirectional counter having dual clock inputs which consist of two square waves in quadrature. A clock generator circuit within the chip discriminates the phase relationship of these two clock inputs (CKA and CKB) to determine the count direction.*

*The direction of count is arranged to automatically reverse when the counter 'underflows' in the downward direction through zero; a "-" sign is generated at this time.*

*Data is output on a 4 Bit multiplexed unidirectional output bus, DOUT.*

*Each decade is selected by means of the 3 Bit decade select bus (DSEL) which is decoded on chip.*

*1.1 Inputs*

| | | | | | |
|---|---|---|---|---|---|
| *RST* | - | *active high master reset* | | | |
| *DIR* | - | *direction input - determines count direction* | | | |
| *CKA)* | - | *clock inputs, 90° phasing* | | | |
| *CKB)* | | " " " " | | | |
| *N/X2* | - | *active low multiply-by-two input. When high, count sequence is 0, 1, 2, 3, 4, 5 . . . When low, sequence is 0, 2, 4, 6, 8 . . .* | | | |
| *DSO,1,2:* | - | *Decade select inputs:* | *000* | - | *LSD* |
| | | | *100* | - | *MSD* |
| | | | *101* | - | *Sign Information* |

## *APPENDIX I*

### *1.2 Outputs*

*00,1, 2, 3:-   4 bit data output bus, multiplexed.*

*F:-  This output is the OR of the 'clock up' (CU) and 'clock down' (CD) signals generated in the clocking section of the ULA. It enables the clock frequency to be measured in the system.*

### *2.0 DC (Static) Specification*

*All voltages referred to* $V_{ss}$ = *0V*
*Max. supply voltage* $V_{dd}$ *max* = *6.0 V*
*Min. supply voltage* $V_{od}$ *min* = *3.0 V*
*Max. quiescent current IddMax* = *100uA @* $T_A$ = *40°C and* $T_A$ = *0°C.*
*(*$T_A$ = *Ambient Temperature)*

*Operating temperature range 0°C - 70°C.*

### *3.0 AC (dynamic specification)*

*Max. clock rate required over range of parameters specified in 2.0 above:*

*fmax = 1MHz*

*(This corresponds to CKA and CKB each running at 250KHz, 90° apart).*

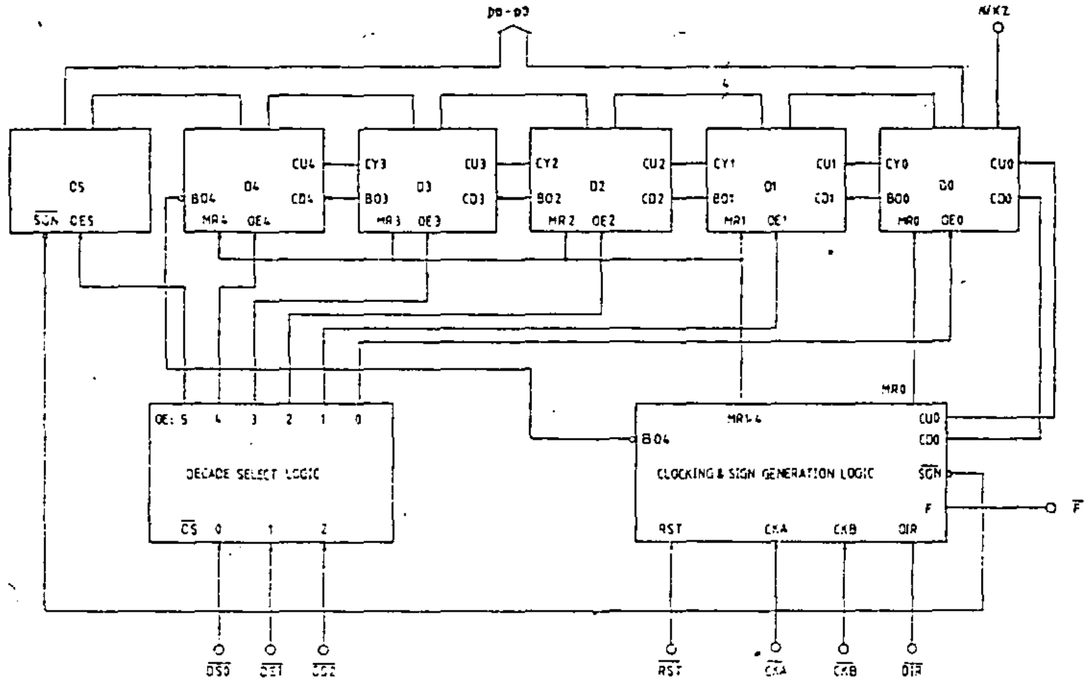
*Other propagation delays and response times are uncritical.*

### *4.0 All other testing as standard MCE procedure.*

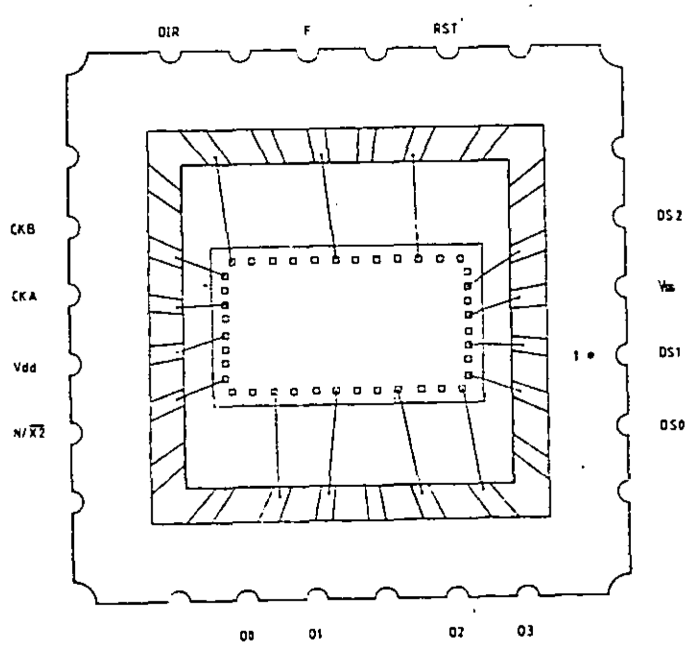
### *5.0 Test Patterns for automatic testing*

*These are enclosed and should be run at TG0 = 250KHz.*
*See TN 062 - AC test specification.*

***APPENDIX I***

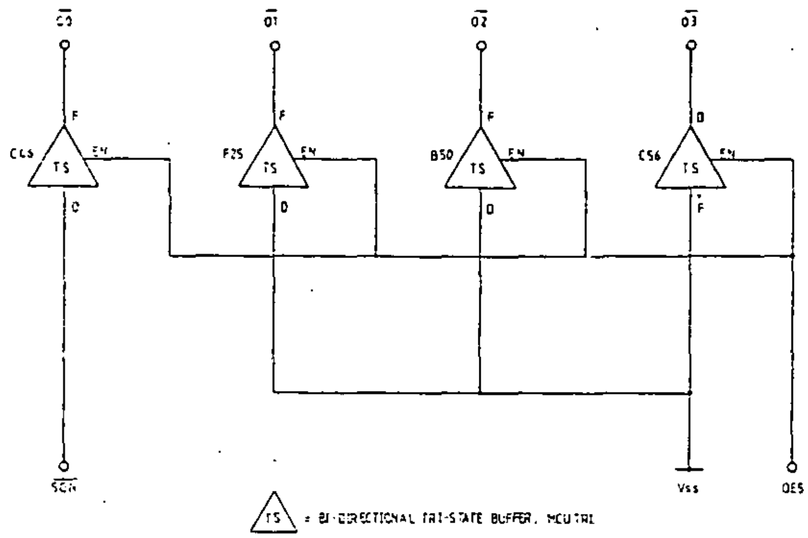



BLOCK SCHEMATIC OF 550 GATE ULA COUNTER SHOWING INTERCONNECTIONS PERIPHERAL CELLS OMMITTED © T J PRESTON 24/06/82

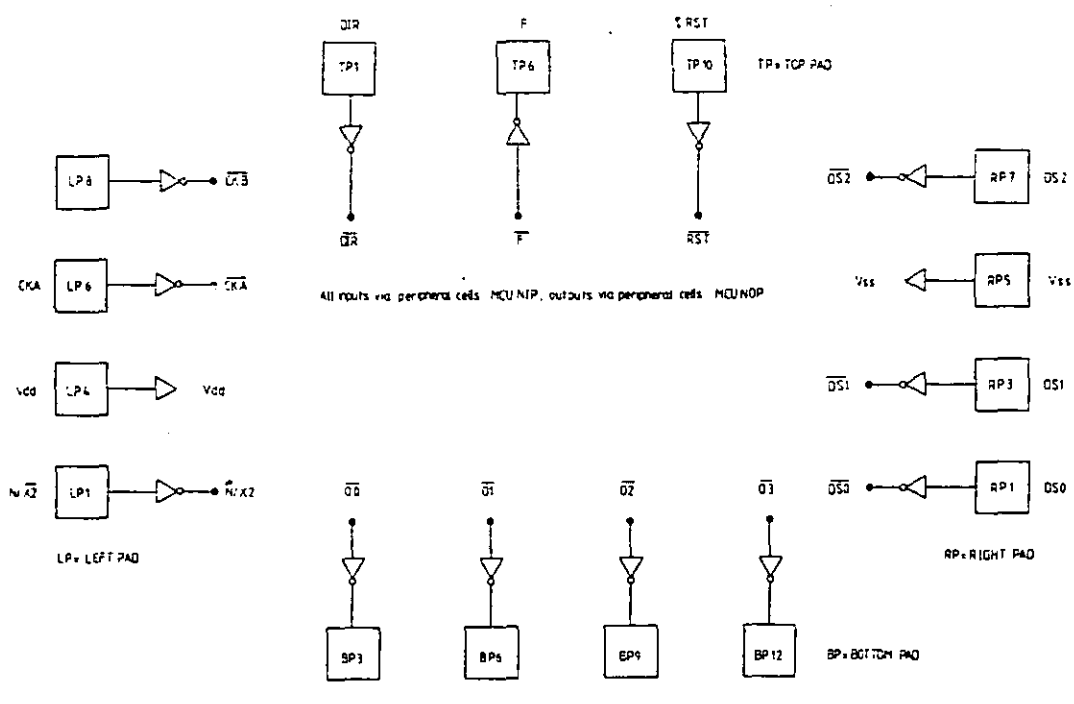



X20 BONDING DIAGRAM FOR ULA CHIP NO. 72006 IN 24 LEAD CHIP CARRIER. © T J PRESTON 16/07/82.

# *APPENDIX I*

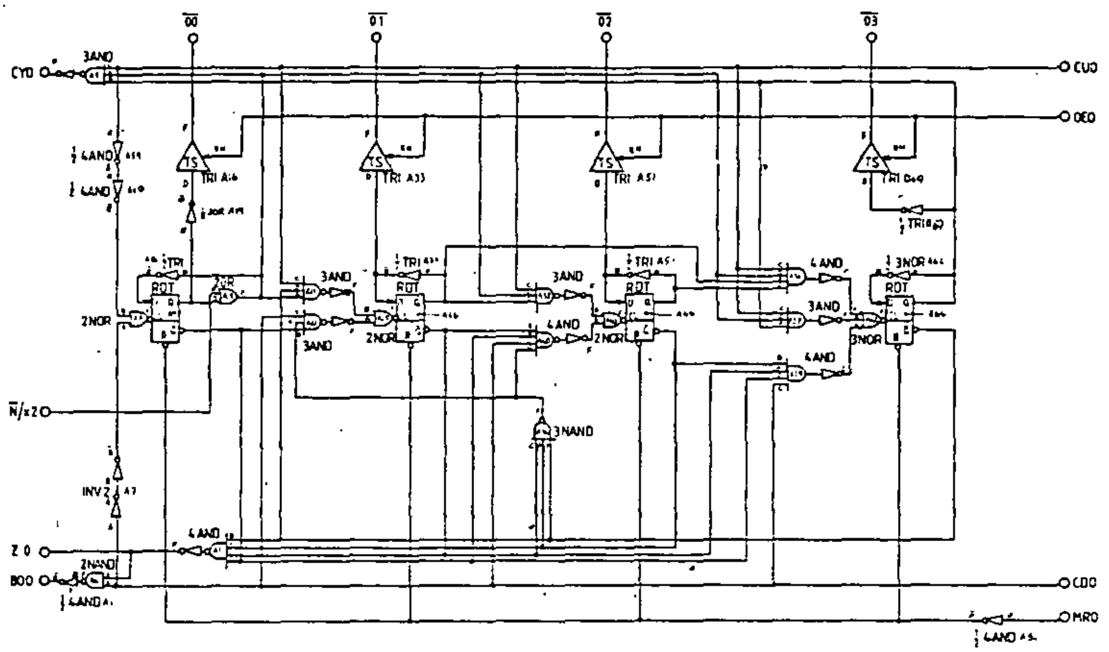



OS: MOST SIGNIFICANT 'DECADE' OF ULA COUNTER OUTPUTTING SIGN BIT ONLY IN LSB POSITION © TJ PRESTON 24/06/82

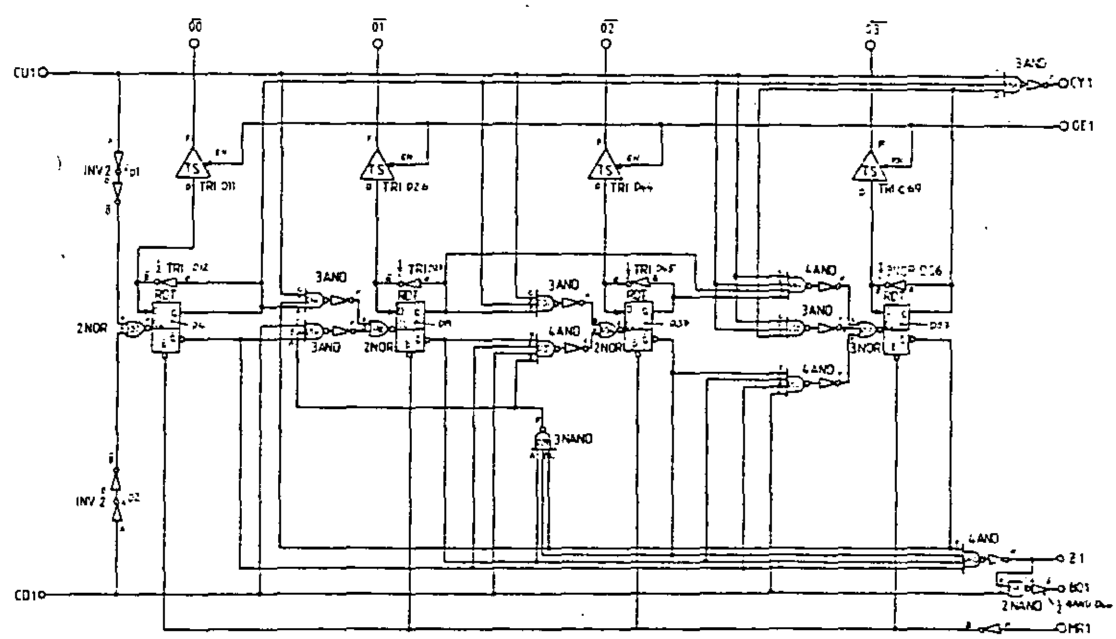



ARRANGEMENT OF BONDING PADS AND PERIPHERAL CELLS OF 550 GATE ULA © TJ PRESTON [illegible]

## *APPENDIX I*

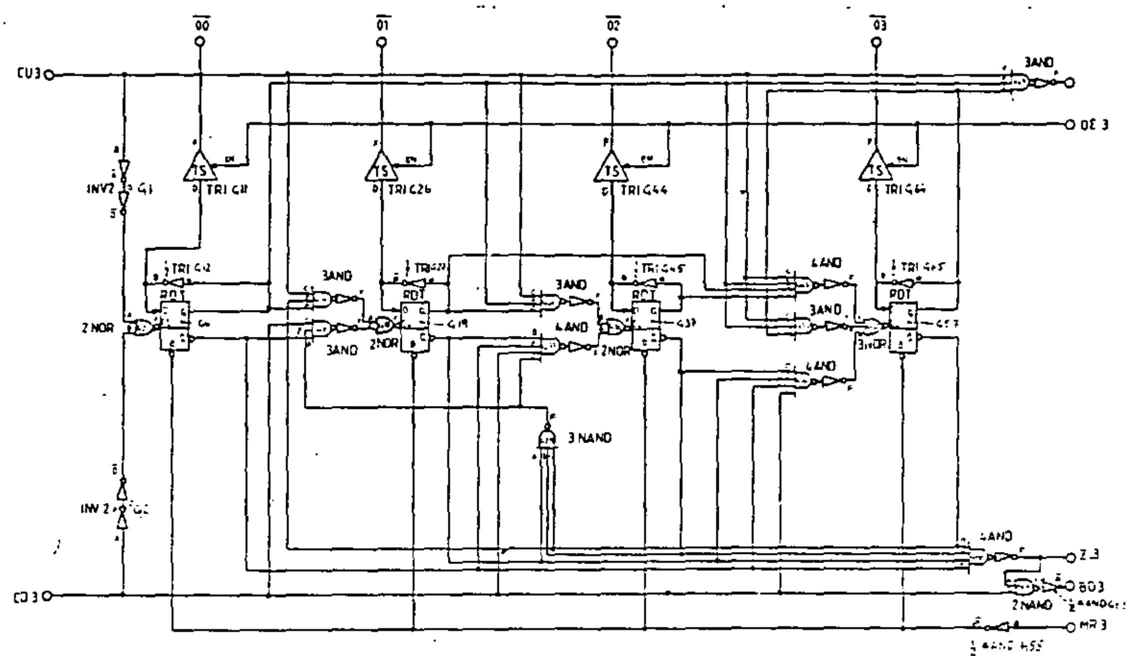



DO :- LEAST SIGNIFICANT DECADE OF ULA COUNTER INPUT AT RIGHT, CARRY OUTS AT LEFT, ROW A & PART OF B. © T.J Preston 8-6-82

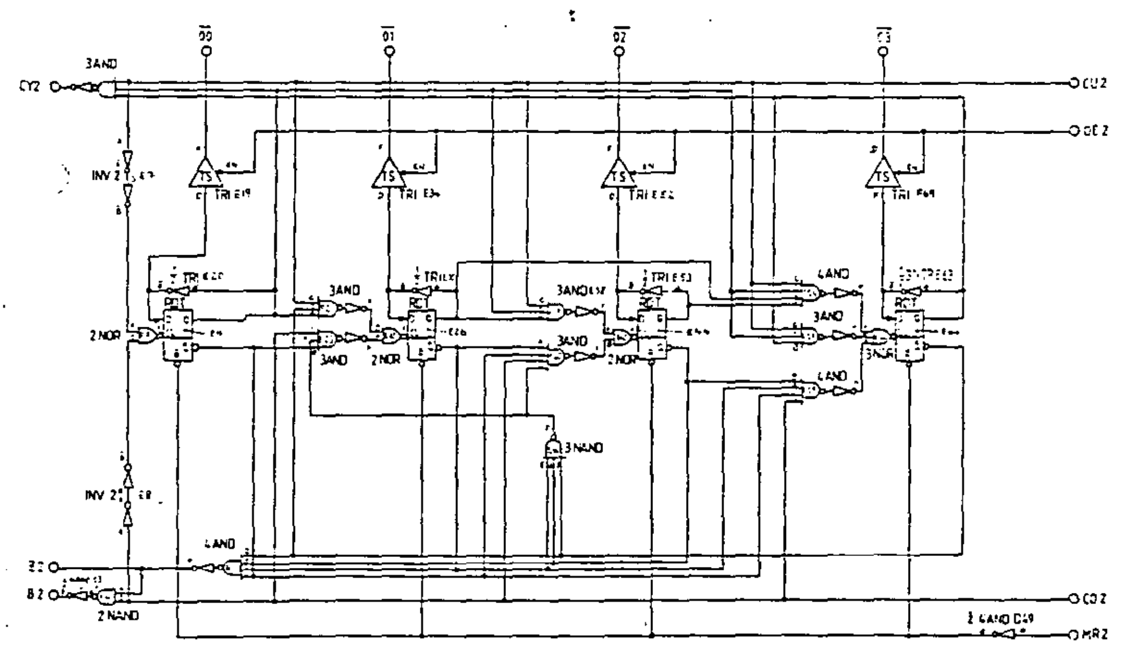



D1:- 2ND DECADE OF ULA COUNTER, INPUTS AT LEFT, CARRY-OUTS AT RIGHT. LOCATION:- ROW B & PART OF C. © T.J Preston 9-6-82

## *APPENDIX I*

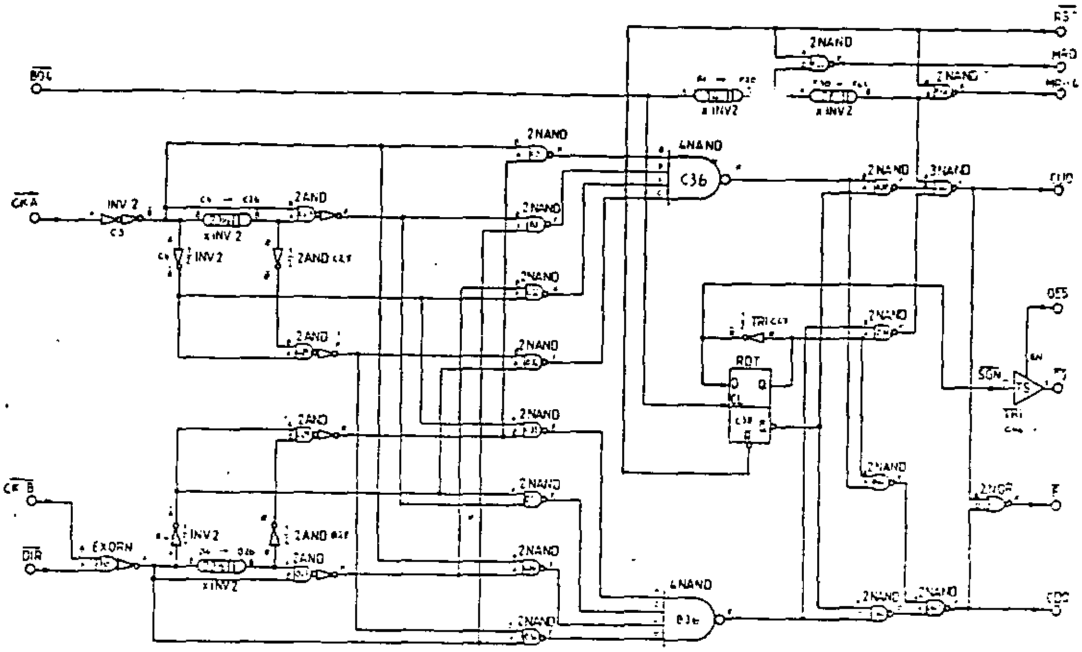



D3: 4th DECADE OF ULA COUNTER INPUTS AT LEFT, CARRY-OUTS AT RIGHT. LOCATION: ROW G & PART OF F © T.J. Preston 9-6-82

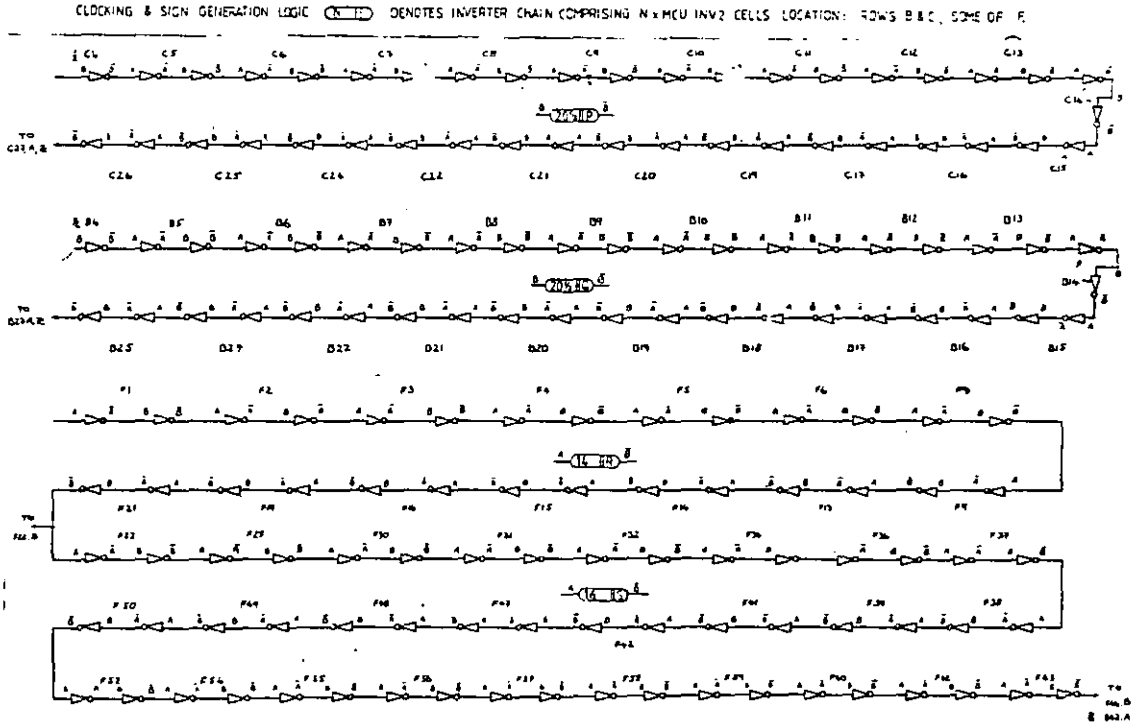



D2. DECADE 2 OF ULA COUNTER, INPUT AT RIGHT, CARRY-OUTS AT LEFT. LOCATION: ROW E & PART OF F.

## *APPENDIX I*

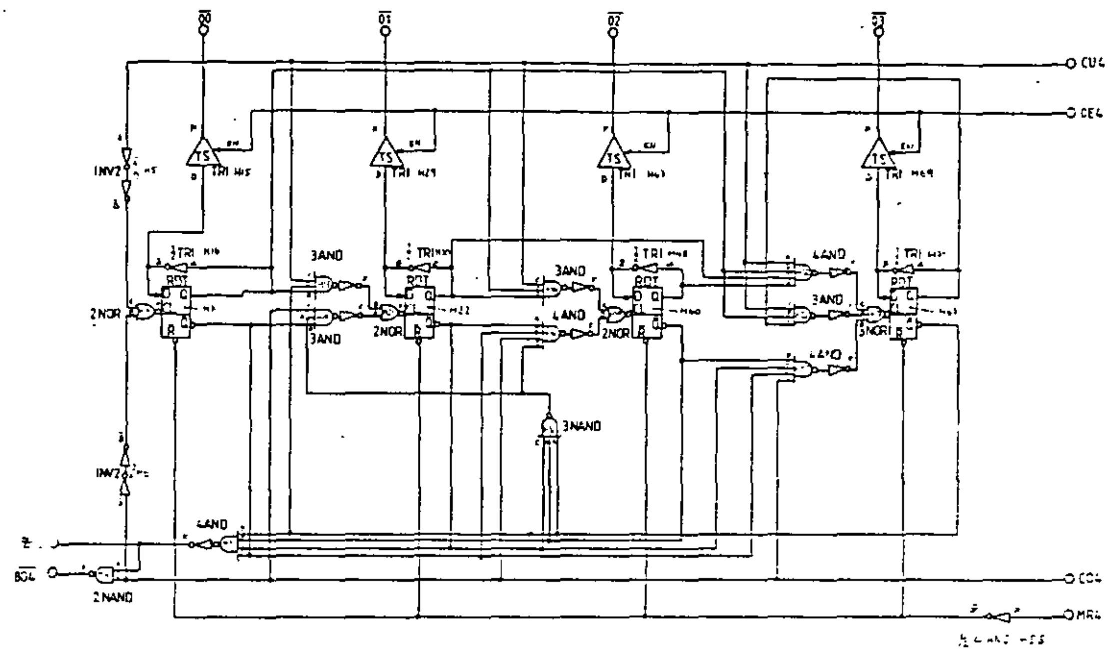



CLOCKING & SIGN GENERATION LOGIC (N I) DENOTES INVERTER CHAIN COMPRISING N x MCU INV2 CELLS LOCATION: ROWS B & C, SOME OF F

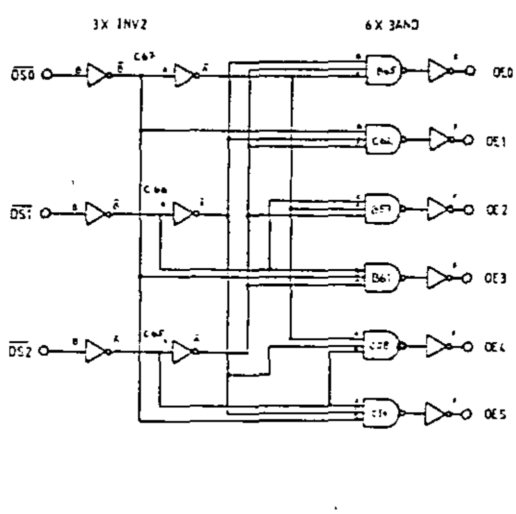


DETAIL OF INVERTOR CHAINS IN CLOCKING AND SIGN GENERATION LOGIC ALL CELLS MCU INV2. TJPRESTON 01/07/82.

## *APPENDIX I*

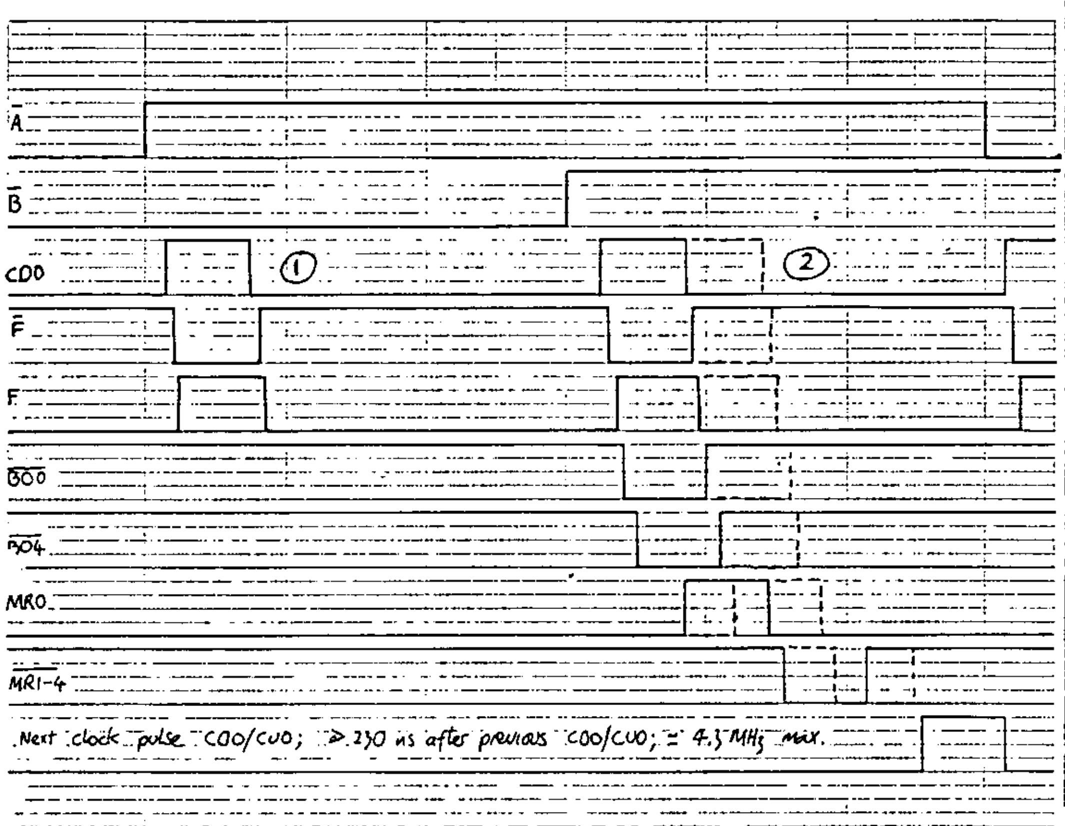



D4:- MOST SIGNIFICANT DECADE OF ULA COUNTER. INPUTS AT RIGHT, BORROW ($\overline{BO4}$) AT LEFT. LOCATION: ROW H © T.J Preston 9-6-82




DECADE SELECT LOGIC LOCATION ROWS B&C © TJ PRESTON 23/05/82

*APPENDIX I*



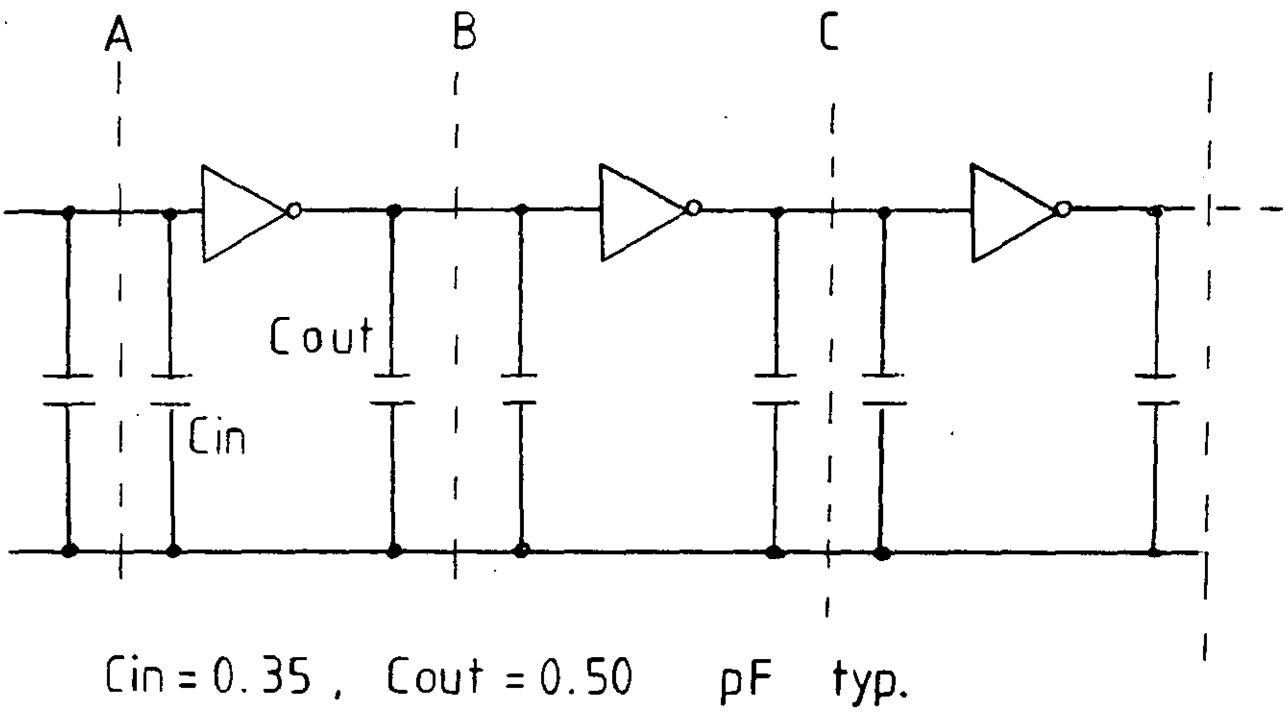

*Timing diagram for clock pulse generation, allowing for maximum 'propagation' delays through circuit.*

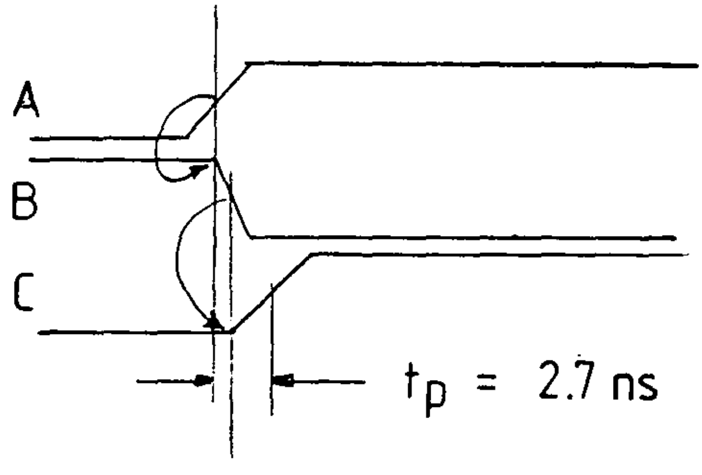
*NB: count value at position 1 = 00000*

*count value at position 2 = 00001*

*Monostable type output F is of 60-100 ns duration occuring approximately 30 ns after A or B or A or B ; the timing is not critical.*

*APPENDIX I*




*Estimation of typical propagation delay per invertor*

## *1.0 Test Strategy - Overview*

*The test routine must test the correct operation of all logic elements in the chip. In a 5 decade bi-directional counter with a multiplexed output bus, with other features, this involves:*

*1.1 Checking error free count in up direction.*
*1.2 Checking error free count in down direction.*
*1.3 Checking error free count in down direction through zero, which then causes a "-" sign to be output and a count reversal.*
*1.4 Checking that all the tristate bus buffers operate correctly.*
*1.5 OTHER FEATURES:*

*a) Reset - checking that all decades and signs are reset to '0' on application of reset pulse.*

*b) N/x2: on the application of logic '1' to this input pin, the counter counts normally: on application of logic '0', the counter should count in 2s, ie. in the sequence 0, 2, 4, 6, 8, 10, 12 . . .*

*c) Dir: This pin sets the count direction in conjunction with the relative phase of inputs CKA and CKB.*

*d) F output: The timing of the signals from this pin is not critical but typically consists of a monostable type pulse of 60-100ns duration occuring approximately 30ns after any edge of CKA or CKB. This will necessitate additional hardware on the test rig as detailed later.*

*1.6 Summary*

*With a little thought it is possible to condense the test patterns considerably, bearing in mind that it is the circuit elemental function, not the logic design itself, which is being tested. An upper limit of 200 lines or test patterns is aimed for.*

## *2.0 Test Details*

### *2.1 Up counting, bus buffer and decade select testing.*

*By careful choice of count length it is possible to test these functions thoroughly and simply, as follows:*

*The numbers 54320*
*and 19876*

*output each decimal digit, 0-9 inclusive, on the bus. This tests correct counting in the up direction and (redundantly) checks correct operation of the bus output peripherals and the decade select logic.*

*These numbers are multiples of 4 and are therefore easily generated by the timing generators TG0 and TG1 of the test equipment; TG0 and TG1 run in quadrature (90° phase) at 1/4 MHz each; therefore 4 count pulses (edges) are present, at a net clocking rate of 1MHz, per cycle.*

*General Test Routine*

1 Reset
2 Run TG0 and TG1 for 13580 cycles
3 Test for count of 4 x 13580 = 54320
4 Run for further 16389 cycles: count = 4 x (13580 + 16389) = 19876

*APPENDIX I*

## 2.2 *Tristate Bus Buffer Testing*

*To test TS bus buffer for correct operation it is necessary to output a '0' and a '1' successively to the output bus, to check that there is not a bit stuck high or low. This fault would not necessarily have shown up in the previous test.*

*To do this, the decimal values 9 and 6 which are BCD complements (1001 and 0110) can be output as follows:*

| | |
|---|---|
| *69696* | *(12455 additional cycles)* |
| *96969* | *(6818+1/4 additional cycles)* |

*Unfortunately, only a whole number of cycles can be generated so a compromise is necessary: 96968 instead of 96969.*

*This means that the LSD, LSB tristate buffer has so far only been tested in the low state. (ie. only even numbers have been output).*

*However, with the clocks CKA and CKB (TG0 and TG1) low (static) the DIR input can be taken high, which is equivalent to a falling edge at the CKB input; thus one down count is obtained, and an odd number, namely 7, is obtained in the least significant decade; thus the number*

*96967 is obtained and the LSD, LSB tristate buffer has been tested.*

## 2.3 *N/X2 Input Testing*

*All that is necessary here is to reset the counter, give 4 count pulses (1 cycle of TG0) and check that the output reads 00008.*

## 2.4 *Down Counting and Sign Reversal*

1 *Reset counter*
2 *Set up for down counting: DIR = '1'*
3 *Clock for 1 cycle*

4 *Check that outputs of LSD = 4*

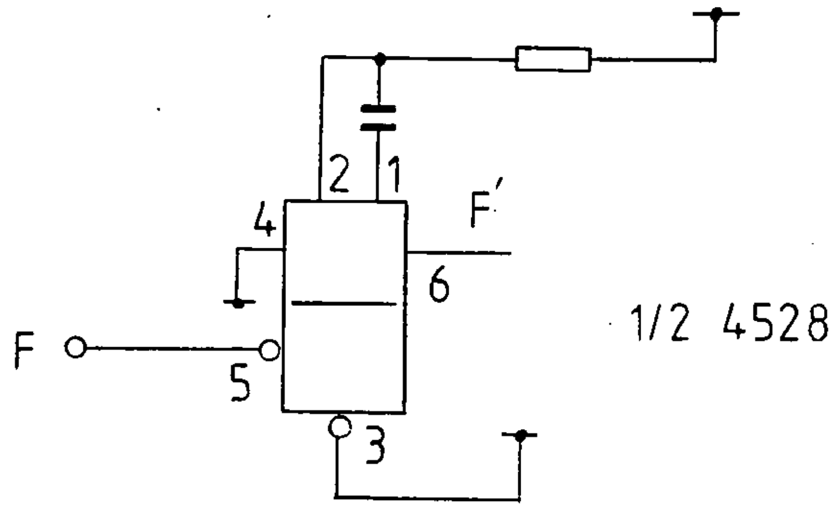
5 *Check that outputs of MSD = 1111 ($F_H$)*

2.5 F Output

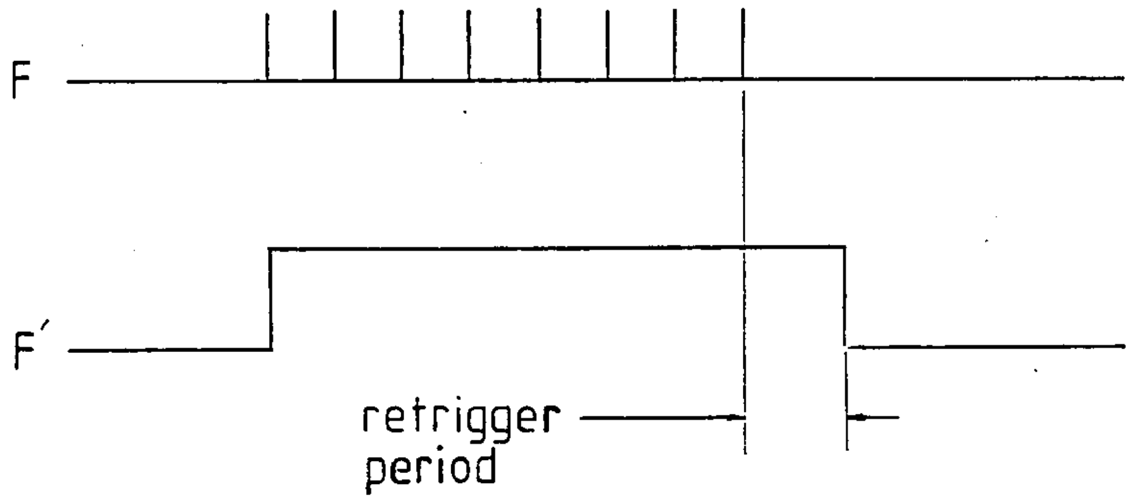
*It is necessary to attach a monostable flip flop to this output to test for the presence of the pulses, in view of their narrow width (60-100ns) and variable propagation delay through the circuit. See pages 6-14 for timing and hardware diagrams.*

*After the signal has passed through the monostable it is only necessary to test for 'ones' at 'Q' on the strobe signal (TG4).*

*APPENDIX I*




*The F' output is tested for low with no clock applied to CKA and CKB (ie. static) to check that the monostable is functioning correctly.*



Chip No: 72006 Date: 15.07.82 Sht: 1

Group No. 1

| Test No. | Dwell Count | Dir. Cont. | CKA | CKB | DIR | NX2 | RST | DSEL | DOUT | F |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | Ø | Ø | Ø | 1 | 1 | 0 | X | X |
| 2 | 1 | | | | | | Ø | | Ø | |
| 3 | 1 | | | | | | | 1 | Ø | |
| 4 | 1 | | | | | | | 2 | Ø | |
| 5 | 1 | | | | | | | 3 | Ø | |
| 6 | 1 | | | | | | | 4 | Ø | |
| 7 | 1 | | | | | | | 5 | E | |
| 8 | 13580 | | 1 | 1 | | | | Ø | X | |
| 9 | 1 | | Ø | Ø | | | | | Ø | |
| 10 | 1 | | | | | | | 1 | 2 | |
| 11 | 1 | | | | | | | 2 | 3 | |
| 12 | 1 | | | | | | | 3 | 4 | |
| 13 | 1 | | | | | | | 4 | 5 | |
| 14 | 1 | | | | | | | 5 | E | |
| 15 | 16389 | | 1 | 1 | | | | Ø | X | |
| 16 | 1 | | Ø | Ø | | | | | 6 | |
| 17 | 1 | | | | | | | 1 | 7 | |
| 18 | 1 | | | | | | | 2 | 8 | |
| 19 | 1 | | | | | | | 3 | 9 | |
| 20 | 1 | | | | | | | 4 | 1 | |
| 21 | 1 | | | | | | | 5 | E | |
| 22 | 12455 | | 1 | 1 | | | | Ø | X | |
| 23 | 1 | | Ø | Ø | | | | | 6 | |
| 24 | 1 | | | | | | | 1 | 9 | |
| 25 | 1 | | | | | | | 2 | 6 | |
| 26 | 1 | | | | | | | 3 | 9 | |
| 27 | 1 | | | | | | | 4 | 6 | |

Chip No: 72006 Date: 15.07.82 Sht: 2

Group No. 1

| Test No. | Dwell Count | Dir. Cont. | CKA | CKB | DIR | NX2 | RST | DSEL | DOUT | F |
|---|---|---|---|---|---|---|---|---|---|---|
| 28 | 1 | | Ø | Ø | Ø | 1 | 0 | 5 | E | X |
| 29 | 6818 | | 1 | 1 | | | | Ø | X | |
| 30 | 1 | | Ø | Ø | | | | | 8 | |
| 31 | 1 | | | | | | | 1 | 6 | |
| 32 | 1 | | | | | | | 2 | 9 | |
| 33 | 1 | | | | | | | 3 | 6 | |
| 34 | 1 | | | | | | | 4 | 9 | |
| 35 | 1 | | | | | | | 5 | E | |
| 36 | 1 | | | | 1 | | | Ø | 7 | |
| 37 | 1 | | | | | | 1 | | X | |
| 38 | 1 | | | | | | Ø | Ø | Ø | |
| 39 | 1 | | 1 | 1 | | | | | X | |
| 40 | 1 | | Ø | Ø | | | | | 4 | |
| 41 | 1 | | | | | | | 1 | Ø | |
| 42 | 1 | | | | | | | 2 | Ø | |
| 43 | 1 | | | | | | | 3 | Ø | |
| 44 | 1 | | | | | | | 4 | Ø | |
| 45 | 1 | | | | | | | 5 | F | |
| 46 | 1 | | | | Ø | | | Ø | 3 | |
| 47 | 2 | | 1 | 1 | | | | | 5 | |
| 48 | 1 | | | | | | | 1 | Ø | |
| 49 | 1 | | | | | | | 2 | Ø | |
| 50 | 1 | | | | | | | 3 | Ø | |
| 51 | 1 | | | | | | | 4 | Ø | |
| 52 | 1 | | | | | | | 5 | E | |

Chip No: 72006 Date: 15.07.82 Sht: 3

Group No. 1

| Test No. | Dwell Count | Dir. Cont. | CKA | CKB | DIR | NX2 | RST | DSEL | DOUT | F |
|---|---|---|---|---|---|---|---|---|---|---|
| 53 | 1 | | Ø | Ø | Ø | Ø | 1 | Ø | X | X |
| 54 | 1 | | | | | | Ø | | Ø | |
| 55 | 2 | | 1 | 1 | | | | | 6 | |
| 56 | 1 | | Ø | Ø | | | | 1 | 1 | |
| 57 | 1 | | | | | | | 2 | Ø | |
| 58 | 1 | | | | | | | 3 | Ø | |
| 59 | 1 | | | | | | | 4 | Ø | |
| 60 | 1 | | | | | | | 5 | E | |
| 61 | 1 | | | | 1 | | | Ø | 4 | |
| 62 | 2 | | 1 | 1 | | | | | 2 | |
| 63 | 1 | | Ø | Ø | | | | 1 | Ø | |
| 64 | 1 | | | | | | | 2 | Ø | |
| 65 | 1 | | | | | | | 3 | Ø | |
| 66 | 1 | | | | | | | 4 | Ø | |
| 67 | 1 | | | | | | | 5 | F | |

Chip No: 72006 Date: 15.07.82 Sht: 4

Group No.

| Test No. | Dwell Count | Dir. Cont. | CKA | CKB | DIR | NX2 | RST | DSEL | DOUT | F |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | Ø | Ø | Ø | 1 | 1 | Ø | X | X |
| 2 | 1 | | | | Ø | 1 | Ø | | Ø | Ø |
| 3 | 4 | | 1 | 1 | | | | | | 1 |
| 4 | 1 | | Ø | Ø | 1 | | | | X | Ø |
| 5 | 1 | | 1 | 1 | | | | | | 1 |

*APPENDIX I*

*TN043* ***Design Routes for ULA Semi-Custom Chip*** *17/11/81*

*MCE (Micro Circuit Engineering) Ltd is capable of producing the semi-custom chip required in the whole range of instruments described in previous technical notes. This note outlines the two possible design routes, the assocated timescales and the tooling costs involved.*

*Route 1 £7,000 Tooling Cost*

*This is the cheaper of the two routes and places the burden of circuit development and design, layout of interconnect pattern and generation of test patterns on the customer. These steps are detailed below:*

*1. Circuit Development and Design*

*The first step is to draw up a detailed logic design of the circuit required (1.5 man weeks). The circuit should then be prototyped using standard '4000' series CMOS (Complementary Metal Oxide Semiconductor) logic circuits on a large circuit board (1.5 man weeks). The board must then be fully tested and debugged (1-2 man weeks) after which time the circuit diagram can be corrected and frozen (0.2 man weeks). Total time for this phase: 4.2 - 5.2*

*2 Translation of Logic Design into MCE Standard Cells*

*In order to convert the circuit into a form suitable for going onto the chip the various technical differences between the prototyped design and the microcircuit must be taken into account. These differences are mainly concerned with signal propagation times between logic elements (which due to the difference in size of the two circuits can be significant), and progagation delays through the elements themselves.*

*This phase requires familiarisation on the part of the person concerned with the task with the various electrical characteristics and special properties of the microcircuit (1 man week) before the task can begin.*

*It should be noted here that MCE undertake no responsibility for the design and development phase of the circuit.*

*The MCE standard cells comprise a library of logic units (gates and flip-flops etc.) which is stored in their computer-aided design (CAD) system. These cells are called from the library at a later stage in the development.*

*A skilled operator can perform the layout in a form suitable for digitisation in about 2 weeks. MCE estimate that for a first attempt, 3-4 man weeks would be required to complete the layout. The layout is created on plastic film using adhesive decals and tape to form a much magnified image of the chip itself. Total time for this phase: 4-5 weeks*

*3 Generation of Test Patterns*

*In order that the completed chips can be fully tested, it is necessary to program MCE's test equipment to stimulate all of the inputs to the chip and examine all the outputs and internal states. For a 5 decade up down counter with other sundry logic there are an estimated 200,000 or so combinations of internal states. Test patterns must be devised to check all these states.*

*Estimated time to develop test patterns: 1-2 weeks*