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Celebrating the Birth of Television

JUST four years ago the British Broadcasting Corporation celebrated its 50th anniversary: this month the 40th anniversary of the world's first high-definition television service from the BBC's station at Alexandra Palace in North London on 2nd November 1936 was marked by a 90-minute documentary 'The Birth of Television'. The relatively short interval of fourteen years between the start of radio and the start of television represented a notable achievement, made possible by two very diverse forces, both, as it happens, British but outside the BBC.

The documentary, which blended the story of television programmes with the technical development, gave a reasonably fair if condensed history of the early struggles of John Logie Baird, showing him in the role of the traditional inventor, perhaps justifiably secretive, but combining with this the 'razzmatazz' of the typical entrepreneur of the 'twenties. It was this second aspect which undoubtedly lead to opposition to and almost fanatical denigration of Baird's work which pervaded the scientific and engineering establishment (with the notable exception in those early years of the British Post Office, as was brought out in Mr. Maurice Exwood's IERE Monograph*) and remains to this day, as correspondence in the IEE's journal *Electronics and Power* earlier this year starkly revealed.

The BBC, rather reluctantly, gave Baird facilities for experimental low-definition (30 lines) transmissions in 1929 and his subsequent achievements included the first televised play and the televising of the Derby, both of which were shown in 'The Birth of Television'. Baird certainly blazed the trail during these years and proved television could work, for in 1932 the BBC took up his electro-mechanical system and this low-definition service continued experimentally until September 1935.*

The other television force soon revealed itself for Electric and Musical Industries, collecting together under Isaac Shoenberg a team seldom matched in innovative ability, evolved an all-electronic system. The next stage was that the Committee set up under Lord Selsdon in 1935 recommended that a high-definition service should be started in 1936 with transmissions in alternate weeks on the 240-line Baird system and the 405-line EMI-Marconi system. Reminiscences in the documentary by pioneers, both performers and engineers, confirmed the almost foregone conclusion, and, indeed, relief, that the EMI-Marconi system should prevail since its superiority in all operational and technical aspects, save possibly that of telecine, was overwhelming.

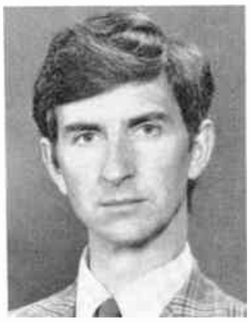
After forty years of television, perhaps agreement can now be reached on the significance of Baird's part in it, fairly to him and without in any way detracting from the EMI contribution. Certainly he was not the greatest inventor since Leonardo da Vinci as the panegyrics of some would indicate: nor was he the charlatan who merely took the ideas of others, who fudged demonstrations and misled both press and public. As is so often the case, truth lies somewhere between the extremes. So too does the ultimate benefit to mankind of television itself lie between the poles of continuous artistic and educational inspiration on one hand and the lowest common factor of mental pap on the other! But whatever balance we each may strike, there is no question that technically television represents one of the great engineering triumphs of our age in which the British contributions are undeniable and immensely important.

F.W.S.

* 'John Logie Baird: 50 years of television'. IERE History of Technology Monograph, 1976. £1.25 post free.

Contributors to this issue*

Colin Page received his initial technical training as a student apprentice with the British Steel Corporation between 1967 and 1971. He graduated with a first class honours degree in electrical and electronic engineering from Nottingham University at the end of his apprenticeship and following postgraduate research on the use of visual and tactile feedback for the automatic manipulation of engineering components, he was awarded a doctorate by the University in 1974. Dr. Page subsequently joined Instem Limited, computer-controlled automation systems manufacturers, and in October 1976 he took up a lectureship in electronics in the Department of Physics at the University of Keele.



Alan Pugh (Fellow 1970, Member 1965) obtained a first class honours degree in electrical engineering at University College, Cardiff, in 1957. This was followed by appointments with the BBC and with Rolls Royce and Associates Ltd. and in 1961 he joined the academic staff at the University of Nottingham where he now holds the position of Senior Lecturer in electronic engineering. In 1968 he was awarded a doctorate for work on non-binary codes applied to digital control. Dr. Pugh's current research interests are in the field of control for automation and industrial robots as well as visual and tactile feedback. He was recently appointed Chairman of the IERE Components and Circuits Group Committee and he also serves as a member of the Papers Committee. In 1968 Dr. Pugh was awarded the J. Langham Thompson Premium for a paper on 3-valued codes applied to digital control systems.

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* See also pages 542, 548, and 560.

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New techniques for tactile imaging

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SUMMARY

A simple, parallel-mode tactile transducer for extracting three-dimensional digital representations of complex engineering components is proposed. In addition, algorithms for computer processing of the tactile information to produce a compact structural description of the scrutinized object are evolved. The possibility exists that these techniques might be applied to future generations of automatic assembly machines with sensory feedback.

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1 Introduction

The work described in this paper falls into the general area of scene analysis, which in turn can be thought of as a subset of pattern recognition. Scene analysis also forms a major part of studies on artificial intelligence; commercial, but much simplified uses of these techniques have, in recent years, been incorporated in industrial robots. The techniques to be described are specifically intended for this application, or more particularly for imaging three-dimensional engineering components for subsequent handling and assembly.

Much of the research on scene analysis and picture processing up to the present has focused on visual imaging using monochromatic television cameras. These techniques convert the television picture into a two-dimensional array of discrete picture points or elements. The intensity of each point is in turn quantized into as many coded shades of grey as required. The simplest of these quantization schemes is the interpretation of an image as a silhouette, i.e. a binary-valued picture. Scene analysis techniques are then used to infer the three-dimensional structure of the imaged scene from the relative intensities of the component picture points.[1] However, this is a complicated procedure as an attempt is being made to extract three-dimensional structure from two-dimensional information. In addition, perspective distortion and the effects of shadows cause problems.

To overcome some of these difficulties, transducers with 'three-dimensional capability' have been used in some experiments; the simplest of these being an optical rangefinder.[2, 3] However, the rangefinder's main deficiency is that it must function in an essentially serial manner; that is, sampling one point after another. It is therefore relatively slow in operation. Tactile techniques have been given only limited attention for scene analysis work, despite the fact that they are capable of providing three-dimensional information. Most previous work has focused on intelligent search techniques with sets of probes; much in the manner of a blind man using a cane.[4–7]

The combination of the merits of both visual and tactile imaging techniques can provide easily obtainable, unambiguous three-dimensional data which is acquired by parallel rather than serial sampling. The following discussion will show that this proposal is physically realizable and that the resultant data can be processed by a set of simple heuristic algorithms. A more extensive treatment has already been published.[8]

2 A Simple Tactile Sensor

Tactile techniques are attractive in this context for two reasons. Firstly, they do not suffer from perspective distortion and most of the other difficulties associated with visual scene analysis. Secondly, they can be easily adapted to extract three-dimensional information. Figure 1 shows in schematic form the device used. It basically consists of a thick, rigid mount with a square matrix of circular holes drilled in it orthogonally to the plane of the mount. A thin ferrous rod is inserted into each hole with its top end flush with the upper surface of

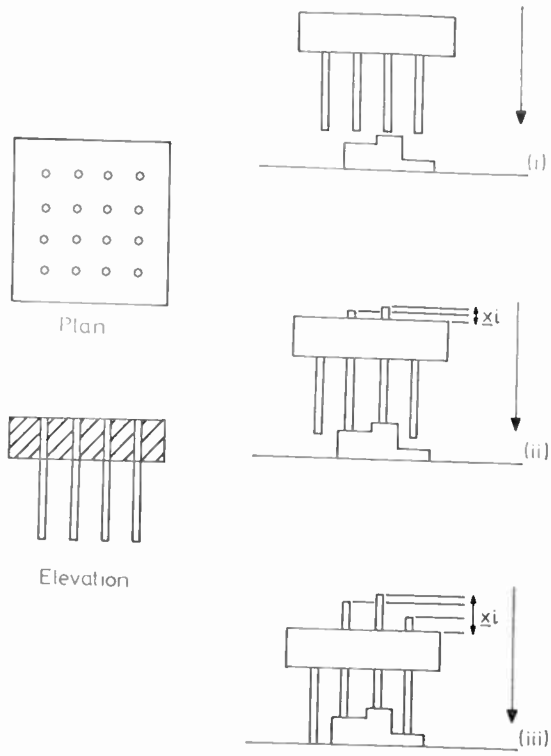


Fig. 1. Schematic representation of proposed tactile sensors. (i), (ii) and (iii) taken in sequence illustrate the operation of the sensor when used to image a three-dimensional component on a flat ground-plane. At the point when the base of the sensor touches the ground plane, projections x_i of the rods provide a simplified representation of the part's shape.

the mount, the tolerances being sufficiently small to ensure that each rod is a sliding fit. When this assembly is lowered over an object, with the plane of the mount parallel to that of the working area, the rods move axially in their respective guides according to the contours of the specimen. The protrusions of the rods above the upper surface of the mount provide a measure of the relative heights of the contours of the object.

If the height of the base of the tactile sensor probe matrix above the ground plane is continually monitored as it is being lowered onto an object, then the height registered when any probe first moves by more than some small threshold displacement from its rest position defines the height of the component at the co-ordinates specified by that particular probe. Position sensing is then simplified as the information required from the probes themselves becomes purely binary, namely 'displacement' or 'no displacement' from the rest position.

The operation of the tactile sensor can be broken down into three subprocesses: the lowering of the device onto a component and the continuous monitoring of height, the sampling of the probe states, and the correlation of these two sets of results to form a table of height values for the part. Practical realization of this system presupposes the availability of a memory (for storing the results of sensing) and some means of lowering the tactile sensor vertically onto a component in small, precise and repeatable increments. At the start of a sensing cycle, the sensor probes are pushed down flush with the body of the device and the data store allocated for the retention of the height of the probe tips above the work surface is initialized. The tactile sensor is then lowered until the tips of the probes are at a distance from the ground plane equal to the length of the probe protruding downwards from the sensor body. Interrogation of probe states is now initiated. When a probe has moved with the corresponding location in the data store still initialized, then that probe has moved for the first time; that is, it has touched the component under examination. The height of the base of the probe matrix at this instant is loaded into the memory location corresponding to the displaced probe. When the state is reached where the last remaining initialized location in the memory has been loaded, no more information can be gained, downward movement is halted and the sensing cycle terminated.

A tactile sensor utilizing these principles has been specifically designed to be mounted on an existing research rig.[9,10] This is a computer-controlled industrial robot which possesses manipulative and sensory capabilities. The tactile sensor is monitored by a relatively simple electronic control system which is itself under the supervision of the executive processor.

Sensing the displacement of each probe is achieved by associating with each probe a co-ordinate winding similar to that used for magnetic core interrogation. This is illustrated in Fig. 2. Each 'read' winding is energized sequentially with a suitable current. 'Sense' windings, in the orthogonal direction, monitor the magnitude of induced e.m.f. of the row of probes under interrogation. If a probe is displaced into the intersecting winding, the mutual coupling between the windings is increased and a higher e.m.f. will be induced in the corresponding sense winding. The displacement of each discrete probe is interrogated after each increment of downward motion. Consequently, it is possible to assemble data appropriate to the progressive motion of each and every probe in the matrix.

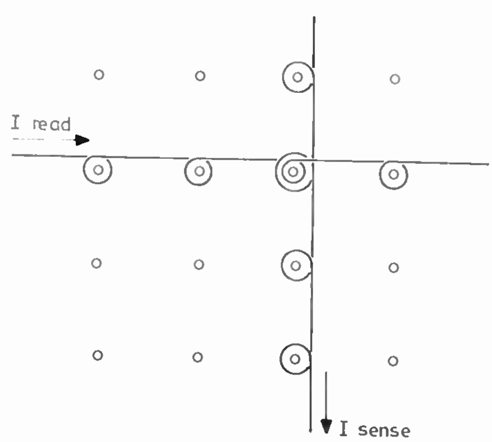


Fig. 2. Schematic illustration of method used to sense probe displacement. The matrix of small circles represents the probes when viewed from vertically above. Each 'read' winding (of which only one is shown) forms a series-connected set of transformer windings along a row of the probe matrix. 'Sense' windings form a similar set of transformer secondaries down each column of the matrix, thereby enabling simple $X—Y$ addressing to be used.

The read and sense windings form a matrix of wires with what is effectively a low-voltage differential transformer at each probe position. The matrix is positioned on the top surface of the tactile sensor body and is excited by a sinusoidal current of frequency 500 kHz. The electronic drive system is supplied by a master oscillator. This energizes the read windings via an amplifier and also clocks a counter which switches the amplifier output to the read windings of the sensor matrix in a sequential fashion via a group of analogue switches. Another set of analogue switches, again operated sequentially by the counter, directs the outputs of the sense windings to amplification and thresholding circuitry. The counter also controls the addressing circuitry of a random access memory (r.a.m.) used to hold the height values for the probe matrix. The supervisory computer controls this system (via suitable interfacing logic) by triggering either an initializing cycle to set up the contents of the r.a.m., a monitoring cycle to scan the probe states while the tactile sensor is being lowered onto a component, or a read cycle to read the results of this operation from the r.a.m. into computer memory.

3 Algorithms for Processing the Tactile Data

The tactile sensor described above extracts from the scrutinized component a set of height values sampled over a square matrix in the X–Y plane. Some method must now be found of processing these parameters and forming a compact, unambiguous description of the object. The tactile sensor, because of its relatively low resolution (e.g. 16×16), produces a representation of a component which, in effect, partitions it into a set of horizontal 'slices' or 'laminations'. This is illustrated in Fig. 3(a). Any representation of the part must effectively describe it in terms of the relationship between its component laminations as seen by the tactile sensor. In turn, each lamination must be uniquely described by one or more definitive properties.

3.1 Basic Techniques

The most commonly used method for expressing spatial relationships in scene analysis uses the so-called 'relational graph'. This is, in effect, a hierarchical tree structure which expresses one or more symbolic relationships, such as 'inside'; 'above'; 'to the left of'; between component parts of the scene.[11] Figure 3(b) shows a possible relational graph describing the object shown in Fig. 3(a). Each dot or 'node' represents a lamination, and each arrow or 'directional arc' expresses some relationship between the node at either end. In this case, each arc specifies that the lamination represented by the node at its 'tail end' is physically above that represented by the node at its 'point end'.

The main advantages of this type of structural description for the computer representation of spatial relationships is that it provides a simple and unambiguous method of linking sets of parameters in such a way as to define the underlying structure.

The structural description to be used here describes each lamination in terms of its peripheral contour and

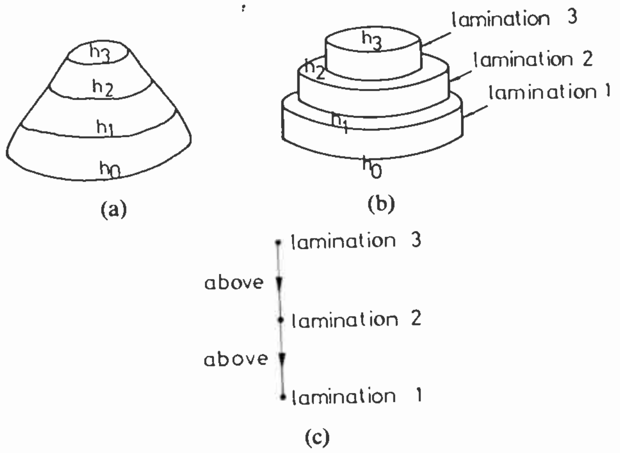


Fig. 3. Tactile sensor and relational graph representations of a simple object. (a) shows an object represented by the contour-line technique used in relief maps. (b) illustrates the tactile-sensor representation of the object. (c) is a possible relational-graph interpretation of the information contained in (b). The relationship expressed by the tree is that of one 'slice' or 'lamination' being physically above another.

its maximum and minimum height values. The relational graph, or 'connection tree', relates the laminations, or rather their peripheral contours, in terms of the enclosure of one lamination by another. A directional arc 'between' two nodes means that the peripheral contour at the tail of the arc encloses that at its head. Representing regions of the object by peripheral contours rather than by 'laminations' makes it easy to cater for internal depressions and holes in the surface of the examined component. This is because the 'hole', while not producing another lamination, nevertheless has a peripheral contour and can be considered as a separate region. The fact that some laminations are essentially 'virtual' or 'imaginary', that is, they represent holes or depressions in the surface of the components, can be added to the connection tree by expanding the definition of the tree nodes to include the maximum and minimum heights of the lamination as well as its peripheral contour. The maximum and minimum heights of the parent lamination are appended to the connection-tree node representing the peripheral contour of the lamination. A simple convention to distinguish between 'real' and 'imaginary' laminations can be adopted as follows.

Where the lamination is real, the maximum height value precedes the minimum height value when appended to the appropriate node. Where the lamination is imaginary, the order is reversed, i.e. the minimum value comes first. An additional feature of the tactile-sensor representation which can be put to good use is that for some components two or more of the laminations may share common segments of their peripheral contours. By inserting extra linkages between the appropriate contours in the connection tree to specify this relationship, the structural description can be further strengthened.

Figure 4 shows examples of some tactile representations of simple components and their corresponding structural descriptions. In all cases the tactile parameters have been reduced to a set of laminations for clarity. In addition, the plan view of each component is identical,

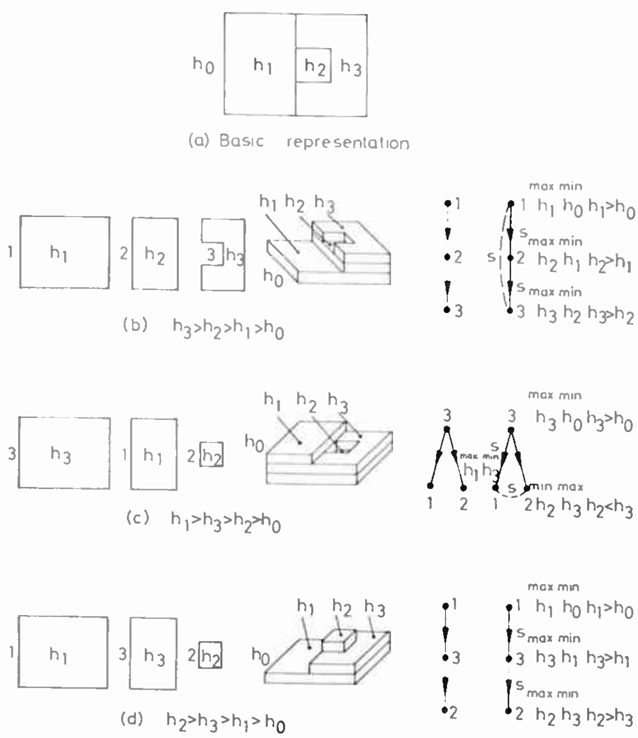


Fig. 4. Connection tree representations of some simple components. The plan views of all the parts are identical (shown in (a)). Each of (b), (c) and (d) shows the peripheral contours of the component laminations, a three-dimensional view of the object, the basic connection tree, and the tree with height and shared-contour data added. Note that contour 2 in (c) encloses a depression and the order of the appended height values is reversed. Note also from (c) that enclosure is not necessary for contour sharing.

and has been reproduced only once as a set of three regions of height, h_1, h_2 and h_3 on a ground plane of h_0. The connection trees of three different objects are obtained by varying the relative values of these heights to give three different interpretations of the basic structure. As explained above, the trees relate the component laminations of the part (as defined by their peripheral contours and maximum and minimum height values) by means of the enclosure of one contour by another when viewed from above. The sharing of a common segment by two contours is shown by appending an 's' to the arc linking the two when one is immediately enclosed by the other. When this is not the case, the appropriate nodes are linked by a dotted line with an 's' appended. The simplicity of the overall tree structure arises from two axioms. These can be stated as follows:

(a) A contour may enclose many other contours, but it can itself be enclosed by only one other contour.

(b) The enclosure of contours obeys an associative law (for example, if contour A encloses contour B, which in turn encloses contour C, then A also encloses C).

However, neither of them apply to the sharing of contours, as shown by the connection trees of Fig. 4. In addition, Fig. 4(c) shows that two contours which have common segments are not necessarily positioned one inside the other as might be suggested from the other examples.

Processing of the tactile data can conveniently be split into two separate operations: extracting the component contours of an object, together with all necessary quantitative information; and the linking of these contours into a coherent structural description.

A possible complicating factor is that there may be more than one component in the 'scene'; that is, the tactile sensor may be lowered onto a group of objects instead of just one. Therefore, the algorithms must partition the regions of the scene into discrete objects during one or the other of the operations.

3.2 Contour Extraction

It is evident that the contours must be obtained by tracing out the boundaries between the regions of the object with due reference to the heights of those regions. The first rule to be adopted for contour extraction is that boundaries are always traced with the region of greater height on the left of an imaginary observer travelling with the contour follower. If this rule is adhered to, the contours of internal holes or depressions can be easily distinguished as they are traced in a clockwise direction rather than in the normal anticlockwise sense. The basic philosophy of the contour-extraction algorithms lies in the fact that the contours of any lamination with a specified upper-height value can be correctly extracted by tracing the boundary between regions of height greater than or equal to the set value and those of lower height than the set value. Figure 5 illustrates this principle for a simple component composed of two laminations of heights h_2 and h_1 respectively, on a ground plane of height h_0. By applying the aforementioned rule twice in succession with the set value at h_2 and h_1 in turn, the contours of the two laminations are correctly traced out as shown in the diagram.

Figure 6 describes the overall operation of contour following in flow-chart form. One complete 'scan' of the matrix is performed for every discrete height value represented so as to extract all contours of that height which are present. To ensure correct operation, the tracing of each contour must start at a point where the set height is actually represented, and has not therefore

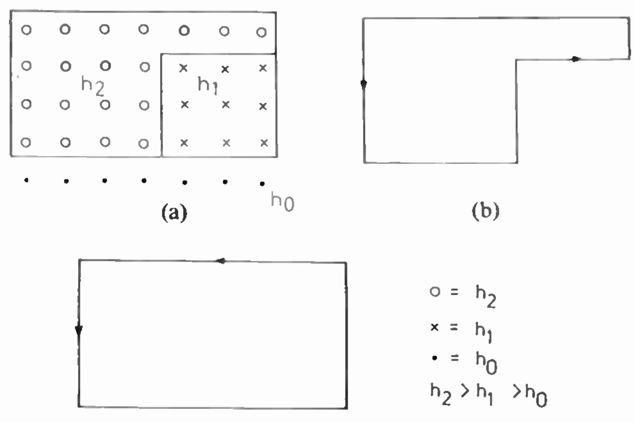


Fig. 5. Illustrating the operation of contour extraction. (a) is the tactile representation. The contour enclosing the h_2 region is traced first (b), followed by that enclosing the h_1 region (c).

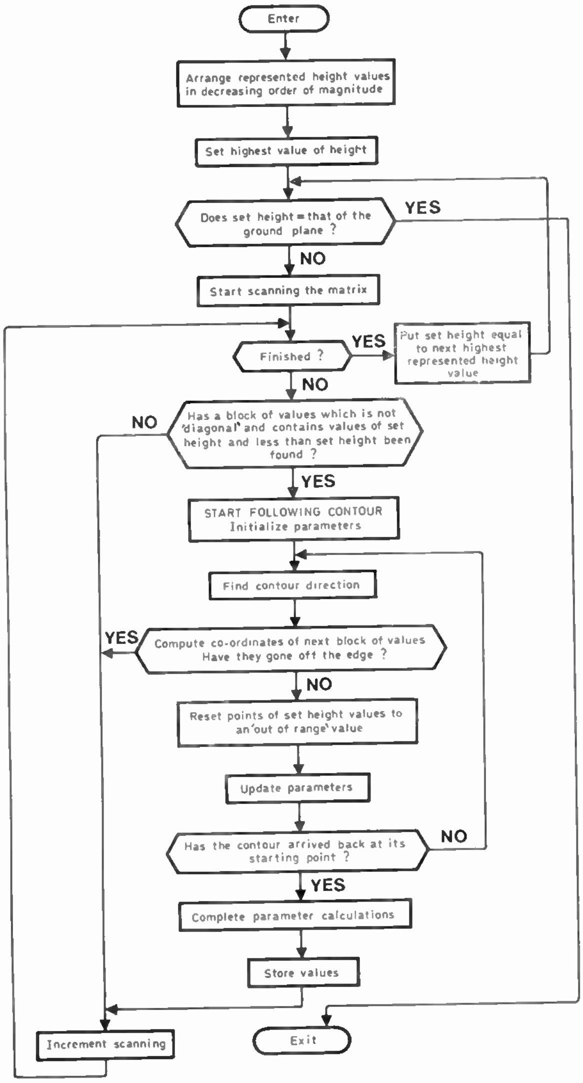


Fig. 6. Flow chart for contour extraction.

been previously encountered, rather than being set to the 'already used' value. When implementing a scheme such as this, it is necessary to ensure that no contour is traced more than once. In addition, contours with shared segments must be noted. Contour points are marked as they are found by setting their height values to a pre-determined out-of-range value. At the same time, the point is marked with the number of the contour and the numbers of all previously traced contours traversing this point are noted. It can be seen that by extracting the contours in descending order of height, a 'marked' point encountered during the following of a contour must have been marked on a previous scan. It must therefore have originally been of greater value than the present set height and is treated accordingly. The particular form of the contour follower used prevents any point being traversed twice on the same scan.

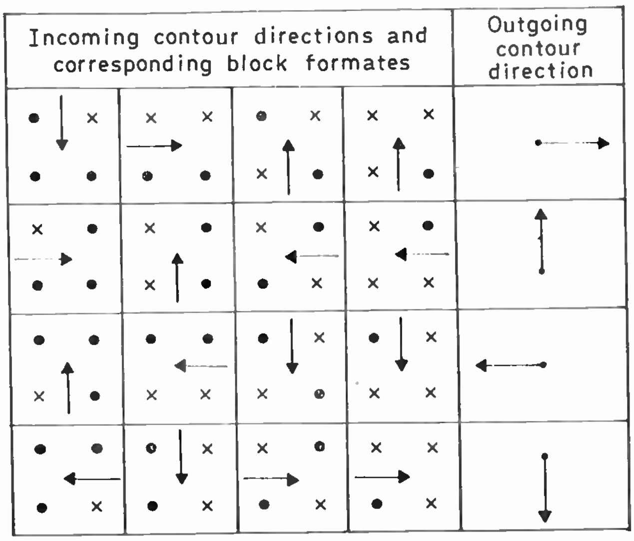
While the contours are being extracted checks are made to ensure, for example, that the contour has not been followed to the edge of the 'frame', in which case tracing of this particular contour is terminated. This can occur frequently in a practical situation because of the limited size of the sensor. The contour is stored point-by-point as it is being traced. The digitized curve is stored in so-called 'chain code' as a pair of starting co-ordinates and a difference sequence of direction vectors.[12] Concurrently with tracing, calculations of the enclosed area, perimeter length, centroid co-ordinates and maximum and minimum excursions of the contour in directions parallel to the co-ordinate axes are updated. These parameters will provide quantitative information about the parent object which can be used in conjunction with the final structural description.

Because of the nature of their operation, the contour following algorithms rearrange a scene consisting of several discrete objects into sets of contours, each set containing all contours with a particular maximum height. Re-allocation of contours to specific components must therefore be performed at some later stage. The next stage of processing must also identify those contours which form part of a component not completely covered by the tactile sensor. These can be assembled into 'incomplete' connection trees which are then either discarded in the hope that the complete object will be imaged during a subsequent application of the sensor at a different position, or are matched up with connection trees obtained from this later sensor application.

Table 1 defines in condensed form the contour follower used. The crosses and dots represent two height values, with that of the cross being greater than that of the dot. 'Tactile points' are examined in blocks of four by the contour follower. When contour following has been initiated, by finding one of the specified block formats during a row-by-row scan of the frame, the follower traces the contour until it either goes off the edge of the frame or arrives back at its starting point. In all but two block permutations the particular format defines both the incoming and outgoing contour directions. This simplicity is a direct result of constraining the

Table 1

A coherent set of contour-follower rules



Convention: × is higher than •
→ is the direction of contour tracing.

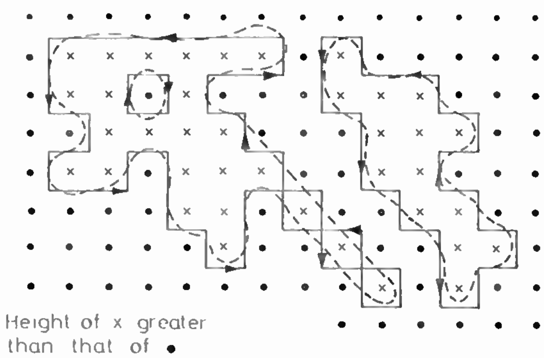


Fig. 7. The application of the contour-follower algorithms to two adjacent, disjoint regions. The dashed curves represent the original outlines of the regions. The solid curves show the path followed by the contour follower in tracing these curves. The arrows show the direction of tracing (anticlockwise around the peripheries, clockwise around the hole in the larger region).

follower to trace contours with the point of greater height on its left. The exceptions are the blocks of two crosses positioned diagonally opposite each other. In these cases, the outgoing contour direction also depends on its incoming direction. It is for this reason that contour following never commences on one of these so-called 'diagonal' blocks.

The contour follower is a very simple one: its main feature is that it produces a single, continuous closed curve which includes every point of the contour. Figure 7 shows the follower applied to two adjacent, digitized regions and also illustrates another feature in that the follower can distinguish between two regions which are almost touching.

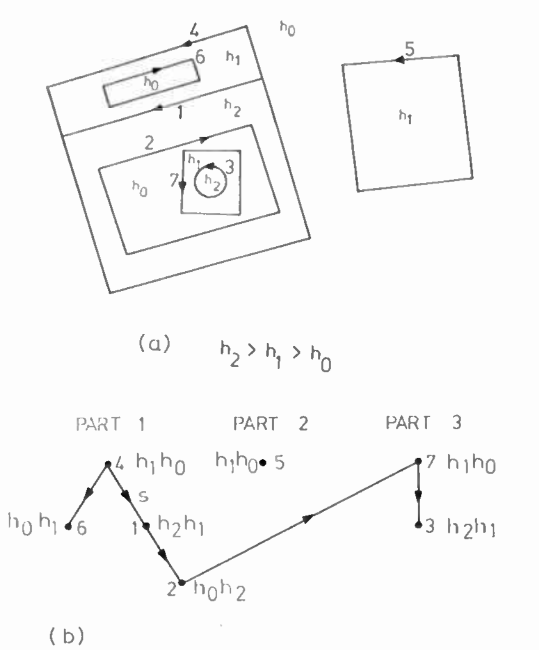


Fig. 8. A possible scene as imaged by the tactile sensor. (a) shows the scene with all the contours numbered and each region labelled with its height. (b) shows the complete connection trees. Note that two separate trees can be linked as shown by the arc joining contours 2 and 7. Table 2 illustrates one of the three lists used in building up the connection tree; that describing contour enclosure. Note that the enclosing contour number of a peripheral contour is set to zero.

3.3 Connection Tree Synthesis

Figure 8(a) shows a scene which, although hardly typical, is not outside the realms of possibility. The suffixed letters refer to the heights of the enclosed regions, the arrows to the directions in which the enclosing contours are traced, and the numbers to the order in which the contours are extracted. Three parts are present, one of which is positioned inside an internal perforation of another. The component contours of this 'scene' must be classified into three separate connection trees, as illustrated in Fig. 8(b). In addition, the situation where one of the parts overlaps the edge of the tactile sensor must be detected as it results in some of the contours being incomplete and subsequent rejection by the following algorithms. Table 2 shows the format of the list used to represent contour enclosure in the connection tree. The overall table representing the connection tree consists of a total of three parallel lists; that shown in Table 2, one which holds the height values associated with each contour, and one which lists the linkages between shared contours.

Table 2

List representation of contour enclosure for Fig. 8

PART 1		PART 2		PART 3	
Contour number	Enclosing contour number	Contour number	Enclosing contour number	Contour number	Enclosing contour number
4	0	5	0	7	2
1	4			3	7
2	1				
6	4				

Tree synthesis is broken down into three sequential stages as an aid to simplicity and ease of implementation. These are the formation of the basic tree structures (but without shared contour information), the elimination of those contours whose presence can be attributed to the effect of the poor resolution of the tactile sensor and finally, the addition of shared contour information.

Figure 9 shows a flow chart for the formation of the basic connection tree. The practical implementation of this consists of allocating an entry to each contour in a list on the basis of one list for each individual part. Each entry is composed of two parts, one denoting the number of the contour, and one denoting the number of the enclosing contour. Table 2 illustrates the lists describing the connection trees of Fig. 8(b). It can be seen that this representation is simple and easy to process with a computer. In addition to the axioms quoted previously, there is another simple observation which aids the formation of these part lists. This is that a contour which encloses another must enclose a greater area than that of the contour being enclosed. All of these simple axioms are put to good use as can be seen from the flow chart. The initial ordering of all contours in descending order of enclosed area means that the search for the enclosing contour for any particular

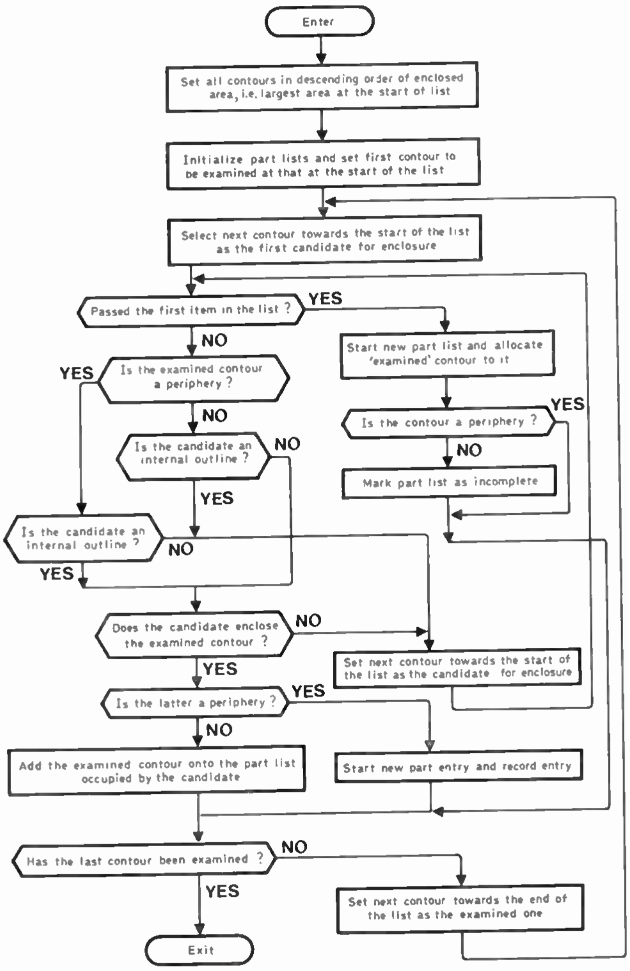
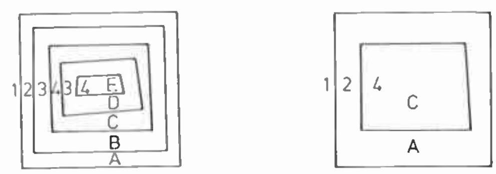


Fig. 9. Flow chart for basic tree synthesis.

candidate can be limited to those positioned above it in the list. The algorithm uses two other subsidiary observations: the peripheral contour of the component must be at the top of its respective contour list, and the contour of a depression or internal hole in a component can only enclose the peripheral contour of another part. A consequence of the former is that if a contour is encountered which is not enclosed by another but which is not a 'periphery', then it is part of an 'incomplete' component caused by partial overlapping of the tactile sensor boundary by the original part. In this case, the contour is allocated to the head of a new part list and the list is marked as incomplete.

At this point, there exists a basic structural description of the scene which, though simple, is adequate for the application of criteria to differentiate between contours which represent significant features of the scene and those caused by the effects of tolerances in the tactile sensor. The simplest method of eliminating extraneous regions is to merge them with adjacent 'significant' regions, or in other words to delete the entry for the corresponding contour from the part list. The criterion applied here is that if two adjacent regions differ in height by less than a fixed threshold, they are merged. The adjacency condition is satisfied by stipulating that two regions can only be candidates for merging if one of the contours immediately encloses the other. 'Immediately encloses' in this context means that there are no intervening contours. The height of the resultant region is taken to be that of the enclosing contour rather than the average of the two; this prevents erroneous propagation of the merging process through a set of concentric regions of gradually increasing or decreasing height.

In practice, each region is represented by its contours and a set of quantitative parameters. Each part list is examined contour by contour from the periphery downwards, or in physical terms, from the component's periphery inwards. Each entry in the list is regarded in turn as the contour into which suitable, immediately enclosed contours are absorbed. All lower contours in the list are examined in this respect, and when found the corresponding entries are deleted. The entries relating to all regions enclosed by the merged region are then modified. Figure 10 illustrates the effect of merging on a set of concentric regions of heights 2, 3, 4, 3 and 4 respectively (Fig. 10(a)). The threshold here is one, the minimum possible. The result of the merging process is shown in Fig. 10(b). It can be seen that some of the regions have been selectively absorbed, effecting a reduction of data without masking the significant features.



(a) Before merging. (b) After merging.

Fig. 10. The merging of contours.

The final operation to be performed is that of allocating to the connection tree the links between pairs of contours which share portions of their length. This is done by examining the list of numbers of the contours sharing part of their length with each contour traced by the 'follower' algorithms. For every pair of contours which are linked in this fashion, the number of the other contour is written into the part-list entry of the contour with the smaller enclosed area. Therefore, each entry eventually consists of the contour number, the number of the contour which immediately encloses it, the associated maximum and minimum height values, and the numbers of all larger contours which share part of their length with this particular contour.

4 Concluding Remarks

It has been mentioned previously that the algorithms described here are intended for use in artificial intelligence work. This is indeed so. They arose as an indirect result of the shortcomings of visual techniques when applied to practical three-dimensional components. For the past several years, research into automatic handling and assembly has been in progress in the Departments of Electrical Engineering and Production Engineering at the University of Nottingham. Visual feedback employing a vertically-mounted television camera producing a binary-valued two-dimensional image has been used to control an assembly machine with movable manipulators. This machine can in turn perform simple sorting, assembly, and manipulative tasks on selections of small engineering components, none of which have previously been specified to the machine.

In the first projected application of the techniques described in this paper, the tactile sensor will take the place of one of the manipulators presently mounted on the existing assembly machine. It is the intention that it will function as a low-resolution adjunct to the visual sense, enabling features of the scrutinized component to be imaged in a three-dimensional fashion.

The algorithms which have been outlined here are not necessarily restricted to operating on tactile data: they can obviously work equally well with data from any transducer capable of providing three-dimensional information. A suitable, though slow, device in this context would be the optical rangefinder mentioned previously. The algorithms owe their simplicity without loss of power to one particular constraint upon the application environment, namely that every 'scene' consists of a flat 'ground plane' upon which rest one or more objects. The tactile sensor is then applied with its axis normal to this ground plane. If an optical rangefinder, for example, is used to image some part of what could be called a conventional three-dimensional scene, say a table in a small room, then in the absence of a physical ground plane normal to the axis of the transducer, a hypothetical plane must be constructed at the furthest point of the scene, for the purposes of subsequent analysis.

In conclusion, the tactile sensor and associated software algorithms presented in this paper, although purpose-designed for imaging three-dimensional components resting on a flat ground plane can nevertheless provide great improvements over conventional imaging techniques.

5 Acknowledgments

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A probability diversity combiner for digital h.f. transmission

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SUMMARY

The switched *a posteriori* probability (s.a.p.) diversity combiner has equivalent performance to maximum *a posteriori* probability (m.a.p.) combiner for dual diversity when binary transmission is used. Moreover, it is much simpler to implement since it is similar in principle to the conventional switched diversity combiner. The difference is that instead of switching to the branch with the highest signal-to-noise ratio, the switching is done between the branches on a bit-by-bit basis and to the branch which is most likely to be correct about what was sent. Some examples of impulse noise are used to show the difference between the m.a.p. (or s.a.p.) methods and the conventional methods of maximal ratio combining, selector branch combining, and no diversity, in terms of average error probability.

The examples also illustrate the different processing that is done on the signals by the different methods. One possible method of implementing the s.a.p. technique is proposed for the case of 4-phase p.s.k. with differential encoding.

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1. Introduction

Conventionally, the best method of diversity combining, in the presence of Gaussian noise, is to add the signals in each diversity branch together after they have been phase-corrected so as to be coherent, and weighted by their respective signal-to-noise ratios (s.n.r.). This type of combiner is known as the maximal ratio combiner.[1]

A growing interest for diversity combining is for application on medium speed 2·4–4·8 kbit/s digital links which are obtained by using modems on a conventional 4 kHz h.f. voice channel. Without diversity, a very large s.n.r. would be required to reduce the high error rate due to the effects of fading at these data rates. The modems commonly employ 4-level phase-shift-keyed (p.s.k.) modulation with differential encoding and although this type of modulation has a good performance against Gaussian noise, it presents difficulties to the maximal ratio combiner, since it would almost be impossible in practice to rotate the phases of the diversity signals, before adding them coherently. One reason is that current carrier phase recovery circuits have a fourfold ambiguity in phase which is normally resolved by differential decoding after detection. Another complication is the differing timing jitter in each diversity branch due to the multi-path propagation. Consequently it is common to use in practice the selector diversity combiner which detects the signal in that branch which has the strongest s.n.r. This is justified by saying that for dual diversity, the degradation in s.n.r. is only 1·6 dB. However, this figure assumes that the noise is Gaussian. In practice, the noise is commonly not Gaussian but impulsive noise, in which case the degradation of selector diversity, compared to an optimum diversity method, becomes much more serious and can be as much as 10–20 dB, or even higher due to an irreducible error rate from hard limiting at the receiver.

The proposed diversity combiner is based upon processing the signals in each diversity branch independently down to baseband level, and then combining the baseband signals in a detector so as to form a reconstituted signal having the minimum possible error rate.

It is shown that the best detector of this kind is the well-known maximum *a posteriori* probability (m.a.p.) detector and that for dual diversity with binary transmission, this is equivalent to a simpler detector, termed a switched *a posteriori* probability (s.a.p.) detector. The processing and detection may be done straightforwardly by a digital processor since the symbol rate of two branches combined is less than 5 kHz. One possible method of implementation is given.

2. Comparison of Diversity Methods for Non-Gaussian Noise Characteristics

It has already been established[1] that for Gaussian noise, the maximal ratio and m.a.p. diversity combiner are both optimum with the minimum error probability, and the selector diversity combiner is within 1·6 dB of s.n.r. of this optimum for dual diversity. For non-Gaussian noise, this situation does not remain, as will become evident from the examples below. For each probability distribution for signal, plus noise, the average error probabilities are calculated for the different methods.

When a signal x is transmitted, the signal y received contains the signal x plus noise. The different noises are characterized by the different distributions of the probability of y given x, i.e. $p(y|x)$. The familiar signal plus Gaussian noise has the distribution.

$$p(y|x) = \frac{1}{\sqrt{2\pi n}} \exp -[(y-x)^2/2N]$$

where $x^2/2N$ is the s.n.r.

It is obvious that for a received symbol y, that is given y, the minimum error probability is obtained by selecting $\tilde{x}$ where $p(\tilde{x}|y)$ is the maximum of the set of probabilities $\{p(x|y)\}$, since the probability of error given y,

$$p(e|y) = 1 - p(\tilde{x}|y).$$

The average probability of error is found by weighting $p(e|y)$ by the probability of y and summing over y, i.e.

$$p(e) = \int_{-\infty}^{\infty} p(e|y) . p(y) . \mathrm{d}y.$$

Noting that

$$1 - p(\tilde{x}|y) = \sum_{x \neq \tilde{x}} p(x|y)$$

and

$$p(x|y) = \frac{p(y|x)p(x)}{p(y)},$$

then

$$p(e) = \frac{\int_{-\infty}^{\infty} \sum_{x \neq \tilde{x}} p(y|x)p(x)}{p(y)} \cdot p(y)\, \mathrm{d}y$$

$$= \int_{-\infty}^{\infty} \sum_{x \neq \tilde{x}} p(y|x) . p(x)\, \mathrm{d}y.$$

Frequently x is binary, with a uniform *a priori* probability and $p(x) = \frac{1}{2}$. Therefore

$$p(e) = \tfrac{1}{2} \int_{-\infty}^{\infty} p(y|x_0)\, \mathrm{d}y$$

where $p(y|x_0)$ is the smaller of the binary set $\{p(y|x)\}$.

It is illuminating to consider noise with discrete probability functions in which case

$$p(e) = \tfrac{1}{2} \sum_y p(y|x_0);$$

an example is listed in Table 1.

If a 1 were transmitted, the received values of -1, 1, 3 are possible, whereas if a -1 were transmitted only

Table 1

y	$p(y\|1)$	$p(y\|-1)$	$p(y\|x_0)$
-3	0	.1	0
-1	.1	.8	.1
1	.8	.1	.1
3	.1	0	0

-3, -1 and 1 values for y are possible. The average probability of error for an m.a.p. detector working on signals with this noise, is given by

$$\tfrac{1}{2} \sum_y p(y|x_0),$$

i.e. one half of the summation of the last column of Table 1. The average probability of error is found to be 0·1.

When there are two diversity branches receiving y and z say with independent noise on the signal in each branch and assuming for simplicity that they have the same power and probability distributions, then the probability of error is given, similarly to before, as

$$\tfrac{1}{2} \sum_{y,\, z} p(y, z|x_0)$$

and as the noises are independent

$$p(y, z|x_0) = p(y|x_0) . p(z|x_0)$$

and

$$p(e) = \tfrac{1}{2} \sum_{y,\, x} p(y|x_0) . p(z|x_0).$$

Table 2 is an exhaustive list of all the possibilities for y and z, and the error probability component

$$p(y|x_0) . p(z|x_0).$$

Table 2

y	z	$p(y\|1).p(z\|1)$	$p(y\|-1).p(z\|-1)$	$p(y\|x_0).p(z\|x_0)$
-3	-3	0	0·01	0
-3	-1	0	0.08	0
-3	1	0	0·01	0
-3	3	0	0	0
-1	-3	0	0·08	0
-1	-1	0·01	0·64	0·01
-1	1	0·08	0·08	0·08
-1	3	0·01	0	0
1	-3	0	0·01	0
1	-1	0·08	0·08	0·08
1	1	0·64	0·01	0·01
1	3	0·08	0	0
1	-3	0	0	0
3	-1	0·01	0	0
3	1	0·08	0	0
3	3	0·01	0	0
			Total	0·18

It is found again by summing the last column of the Table that the average error probability for dual diversity m.a.p. combining is 0·09. Although this is only a marginal improvement over that with no diversity, this is due to the simple nature of the noise and it does serve to illustrate the method.

The maximal ratio combiner adds the signals in the diversity branches together after weighting by the s.n.r. Since y and z have equal s.n.r. they are simply added together to form $y+z$.

The probability of error may be derived in similar fashion as before to give the expression

$$p(e) = \tfrac{1}{2} \sum_{y+z} p(y+z|x_0).$$

It is interesting that the conventional detector following the maximal ratio combiner would select x_0 by the rule, $x_0 = -1$ if $y+z \geqslant 0$ and $x_0 = 1$ if $y+z < 0$ and for most noise distributions, this gives identical results as choosing x_0 on the basis of the smaller $\{p(y+z|x)\}$.

Table 3 lists the distribution of $y+z$ and the error probability components. The error probability is found to be 0·09, and interestingly gives the same value as the m.a.p. dual diversity combiner. Selector diversity, since the s.n.r.s are equal, would give the same error probability as no diversity, 0·1.

Table 3

$y+z$	$p(y+z\|1)$	$p(y+z\|-1)$	$p(y+z\|x_0)$
6	0·01	0	0
4	0·16	0	0
2	0·66	0·01	0·01
0	0·16	0·16	0·16
−2	0·01	0·66	0·01
−4	0	0·16	0
−6	0	0·01	0
		Total	0·18

Table 4 is a distribution of noise with different characteristics. The characteristic is like simple impulse noise. When a 1 or −1 is transmitted, the signal is likely to arrive unperturbed, but occasionally it is received with a large perturbation. The average error probability with no diversity is found as before by summing up the smaller values of $p(y|x)$ over all y, and weighting by the *a priori* probability ($\tfrac{1}{2}$).

Table 4

y	$p(y\|-1)$	$(y\|1)$	$p(y\|x_0)$
−4	0·005	0	0
−3	0	0	0
−2	0·01	0·005	0·005
−1	0·97	0	0
0	0·01	0·01	0·01
1	0	0·97	0
2	0·005	0·01	0·005
3	0	0	0
4	0	0·005	0
		Total	0·02

The average error probability is found to be 0·01. The results obtained with m.a.p. dual diversity are found as before by listing all probabilities of the received signals y and z; mainly non-zero entries are listed.

Table 5

y	z	$p(y\|-1).p(z\|-1)$	$p(y\|1).p(z\|1)$	$p(y\|x_0).p(z\|x_0)$
−2	−2	10^{-4}	$2{\cdot}5 + 10^{-5}$	$2{\cdot}5 \times 10^{-5}$
−2	−1	$9{\cdot}7 \times 10^{-3}$	0	0
−1	−2	$9{\cdot}7 \times 10^{-3}$	0	0
−2	0	10^{-4}	5×10^{-5}	5×10^{-5}
0	−2	10^{-4}	5×10^{-5}	5×10^{-5}
−2	1	0	$4{\cdot}85 \times 10^{-3}$	0
1	−2	0	$4{\cdot}85 \times 10^{-3}$	0
−2	2	5×10^{-5}	5×10^{-5}	5×10^{-5}
2	−2	5×10^{-5}	5×10^{-5}	5×10^{-5}
−1	−1	0·9409	0	0
−1	0	$9{\cdot}7 \times 10^{-3}$	0	0
0	−1	$9{\cdot}7 \times 10^{-3}$	0	0
−1	1	0	0	0
1	−1	0	0	0
−1	2	$4{\cdot}85 \times 10^{-3}$	0	0
2	−1	$4{\cdot}85 \times 10^{-3}$	0	0
0	0	10^{-4}	10^{-4}	10^{-4}
0	1	0	$9{\cdot}7 \times 10^{-3}$	0
1	0	0	$9{\cdot}7 \times 10^{-3}$	0
0	2	5×10^{-5}	10^{-4}	5×10^{-5}
2	0	5×10^{-5}	10^{-4}	5×17^{-5}
1	1	0	0·9409	0
1	2	0	$9{\cdot}7 \times 10^{-3}$	0
2	1	0	$9{\cdot}7 \times 10^{-3}$	0
2	2	$2{\cdot}5 \times 10^{-5}$	10^{-4}	$2{\cdot}5 \times 10^{-5}$
			Total	$4{\cdot}5 \times 10^{-4}$

The average error probability is $2{\cdot}25 \times 10^{-4}$ for the m.a.p. method. For the maximal ratio method the average error probability is found by listing the probabilities $p(y+z|-1)$ and $p(y+z|1)$, which is done in Table 6.

Table 6

$y+z$	$p(y+z\|-1)$	$p(y+z\|1)$	$p(y+z\|x_0)$
−4	10^{-4}	$2{\cdot}5 \times 10^{-5}$	$2{\cdot}5 \times 10^{-5}$
−3	$1{\cdot}94 \times 10^{-2}$	0	0
−2	0·9411	10^{-4}	10^{-4}
−1	$1{\cdot}94 \times 10^{-2}$	$9{\cdot}7 \times 10^{-3}$	$9{\cdot}7 \times 10^{-3}$
0	2×10^{-4}	2×10^{-4}	2×10^{-4}
1	$9{\cdot}7 \times 10^{-3}$	$1{\cdot}94 \times 10^{-2}$	$9{\cdot}7 \times 10^{-3}$
2	10^{-4}	0·9411	10^{-4}
3	0	$1{\cdot}94 \times 10^{-2}$	0
4	$2{\cdot}5 \times 10^{-5}$	10^{-4}	$2{\cdot}5 \times 10^{-5}$
		Total	$1{\cdot}985 \times 10^{-2}$

The probability of error for maximal ratio is $9{\cdot}925 \times 10^{-3}$. As before selector diversity gives the same error probability as no diversity 1×10^{-2}. The results are summarized in Table 7. Unlike the previous noise, this type of noise reveals large differences in the performance of the m.a.p. method over the others.

Table 7

Diversity method	Error prob.
No diversity	10^{-2}
Selector diversity	10^{-2}
Maximal ratio	$9{\cdot}9 \times 10^{-3}$
m.a.p.	$2{\cdot}3 \times 10^{-4}$

3. Derivation of a Simple Method for Implementation that is Equivalent to M.A.P.

It has been shown that the minimum error probability, for dual diversity and binary transmission, is given by selecting the x_i which corresponds to the highest value for $p(y_i|1).p(z_i|1)$ or $p(y_i|-1).p(z_i|-1)$, assuming that the *a priori* distribution $p(x)$ is uniform ($p(x) = \frac{1}{2}$).

The rule for selecting x is therefore equivalent to the following.

If

$$\frac{p(y|1).p(z|1)}{p(y|-1).p(z|-1)} > 1, \quad x = 1,$$

otherwise $x = -1$.

$$L_1 \text{ is defined as } \frac{p(y|1)}{p(y|-1)}$$

and

$$L_2 \text{ as } \qquad \frac{p(z|1)}{p(z|-1)}.$$

These, incidentally, are the likelihood ratios. The selection rule then becomes, if $L_1.L_2 > 1$, $x = 1$. It may be noticed that this is equivalent to

$$x = \text{sign}\,[\log (L_1 . L_2)].$$

Therefore

$$x = \text{sign}\,[\log L_1 + \log L_2]. \tag{3}$$

The interesting aspect of this expression is that when $|\log L_1|$ is greater than $|\log L_2|$ the expression $[\log L_1 + \log L_2]$ is dominated by $\log L_1$ and

$$\text{sign}\,[\log L_1 + \log L_2] = \text{sign}\,[\log L_1].$$

Similarly, if $|\log L_1|$ is less than $|\log L_2|$, the expression is dominated by $\log L_2$. It follows that each diversity branch can be detected quite independently forming two streams of the reconstituted bits. Simply by switching to the detected output on a bit-by-bit basis according to which branch has the instantaneously highest *a posteriori* probability is exactly equivalent to the m.a.p. method. The system is depicted in Fig. 1. On a practical level, the signal is received in each branch, the timing and carrier phase are recovered separately and independently in each modem, and the information is detected independently. The *a posteriori* probabilities are continuously monitored and used to select for each bit which of the two detected outputs will be used to form the output data stream. This has been termed the switched *a posteriori* probability (s.a.p.) method.

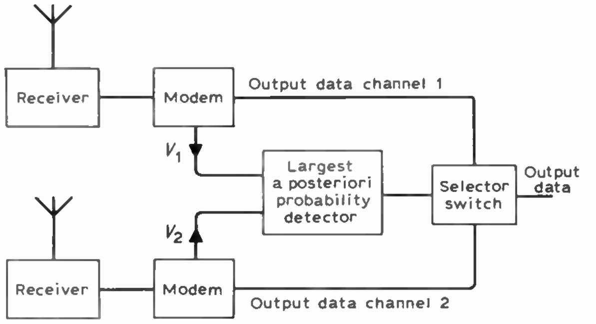

Fig. 1. Block diagram of the selector by highest *a posteriori* probability—the s.a.p. combiner.

The s.a.p. method is limited to dual diversity. This is evident since, if three branches were available, with likelihoods L_1, L_2 and L_3, then x would be chosen on the basis of

$$x = \text{sign}\,[\log L_1 + \log L_2 + \log L_3].$$

Although the largest magnitude of all the branches may be $|\log L_2|$, $|\log L_1 + \log L_3|$ could be larger and the s.a.p. method would not be equivalent to m.a.p.

A similar argument shows that s.a.p. is only equivalent to m.a.p. for binary transmission. Although s.a.p. is limited in application, it has the secondary advantage that, even if the noise in the diversity branches is not independent but correlated, it is still optimum. A common method of modulation is 4-phase p.s.k. with differential encoding and at first sight, since the modulation is not binary, the s.a.p. method would not seem useful. However, it is shown by the following that the 4-phase signal may be interpreted as two binary signals, despite the differential encoding, thereby permitting use of the s.a.p. technique.

4. A Block Diagram of S.A.P. for 4-phase P.S.K. with Differential Encoding

Four-phase p.s.k. with differential encoding is commonly used as a modulation method: normally reconstituting the signal as if it were absolute p.s.k., and then obtaining the data by differential decoding using logic circuits. The modulation method, though common, presents problems for diversity combining since the signals cannot be combined by a maximal ratio combiner prior to detection because of the fourfold phase ambiguity of the local receiver oscillator.

Diversity combining is, however, possible by the s.a.p. method. The differential encoding law commonly used is tabulated in Table 8, with the transmitted symbol phases represented by an in phase component A and a quadrature components B; the components for the first symbol are termed A_1, B_1 and for the second symbol A_2, B_2. The in-phase and quadrature components are received as I_1, Q_1 and I_2, Q_2, say.

The probability of the first data bit being a 0, given the received values I_1, Q_1 I_2, Q_2;

$$p(0_1|I_1Q_1I_2Q_2) = p(01|I_1Q_1I_2Q_2) + p(00|I_1Q_1I_2Q_2).$$

Table 8

Data	A_1	B_1	A_2	B_2
00	1	1	1	1
	−1	1	−1	1
	−1	−1	−1	−1
	1	−1	1	−1
01	1	1	−1	1
	−1	1	−1	−1
	−1	−1	1	−1
	1	−1	1	1
11	1	1	−1	−1
	−1	1	1	−1
	−1	−1	1	1
	1	−1	−1	1
10	1	1	1	−1
	−1	1	1	1
	−1	−1	−1	1
	1	−1	−1	−1

This equals

$$p(11|I_1Q_1).[p(11|I_2Q_2+p(-1\,1|I_2Q_2]+$$
$$+p(-11|I_1Q_1).[p(-11|I_2Q_2)+p(-1-1|I_2Q_2)]+$$
$$+p(1-1|I_1Q_1).[p(1-1|I_2Q_2+p(11|I_2Q_2)]+$$
$$+p(-1-1|I_1Q_1).[p(-1-1|I_2Q_2)+p(1-1|I_2Q_2)].$$

After simplification, this becomes:

$$p(1|I_1).p(1|Q_1).p(1|Q_2)+p(-1|I_1).p(1|Q_1).p(-1|I_2)+$$
$$+p(1|I_1).p(-1|Q_1).p(1|I_2)+$$
$$+p(-1|I_1).p(-1|Q_1).p(-1|Q_2). \quad (4)$$

Similarly, the probability of the second data bit being a 0,

$$p(0_2|I_1Q_1I_2Q_2) = p(1|I_1).p(1|Q_1).p(1|I_2)+$$
$$+p(-1|I_1).p(1|Q_1).p(1|Q_2)+$$
$$+p(1|I_1).p(-1|Q_1).p(-1|Q_2)+$$
$$+p(-1|I_1).p(-1|Q_1).p(-1|I_2). \quad (5)$$

Although these expressions look dissimilar it will be noticed that (4) becomes (5) if I_1 is replaced by Q_1 and vice versa, and if I_2 is replaced by Q_2 and vice versa. This is important since if expression (4) is calculated by means of circuitry, expression (5) may also be calculated using the same circuitry. If (4) is represented by the function $F(I_1Q_1I_2Q_2)$ then (5) is given by $F(Q_1I_1Q_2I_2)$. For equal *a priori* probabilities, the likelihood function

$$L_1 = \frac{1-F(I_1Q_1I_2Q_2)}{F(I_1Q_1I_2Q_2)}.$$

Similarly, if the received in-phase and quadrature components in a second diversity branch are R_1S_1 and R_2S_2 for two consecutive symbols, the new likelihood function

$$L_2 = \frac{1-F(R_1S_1R_2S_2)}{F(R_1S_1R_2S_2)}.$$

The first data bit is detected by the rule

$$x = \text{sign}\,[\log L_1+\log L_2]$$

according to the s.a.p. (or m.a.p.) results obtained previously. The second bit is given by

$$\text{sign}\,[\log L_3+\log L_4]$$

where

$$L_3 \text{ is defined as } \frac{1-F(Q_1I_1Q_2I_2)}{F(Q_1I_1Q_2I_2)}$$

and

$$L_4 = 1-F(S_1R_1S_2R_2).$$

Thus far, the combiner that has been described could be the s.a.p. or m.a.p. one. However, frequently, for different types of noise, when the average s.n.r. in one branch is greater than the other by, say, 15 dB, due to a fade in one branch, the *a posteriori* probability of the larger signal branch is almost certain to be greater and can be taken as such. This enables the s.a.p. combiner to be implemented with moderate complexity, and yet possess a large dynamic range. Figure 2 is a block diagram of such a combiner.

It is assumed that the level of the automatic gain control is proportional to the s.n.r. The automatic gain control depicted in the diagram has the unusual property that its gain moves in quantized steps; 15 dB steps are used since the quantized signal has a 12 dB range (2 bits magnitude). The 3-bit outputs G_1 and G_2 are measures of the s.n.r. in each branch. The modems each independently extract the timing, demodulate the waveform down to in-phase and quadrature baseband signals, where they are sampled, held, and converted into 3-bit words by an analogue to digital converter. Thus there are 3-bit representations for I_1, Q_1, I_2, Q_2, R_1, S_1, R_2, S_2.

The first data selector MX1 steers $I_1Q_1I_2Q_2$ or $R_1S_1R_2S_2$ to the second data selector which produces $I_1Q_1I_2Q_2$ or $Q_1I_1Q_2I_2$, etc. The rather complicated function $\log[(1-F)/F]$ with F defined by equation (4) is implemented by the programmable read-only memory (p.r.o.m.), producing 4 bits at the output representing $\log L_1$, $\log L_2$, $\log L_3$ or $\log L_4$ according to the clock signal. When the first bit is being detected, $\log L_2$ is at the output of the p.r.o.m., and $\log L_1$ is stored in Store 1. The inputs to MX3 are sign $[\log L_1]$ and sign $[\log L_2]$.

When the s.n.r.s are equal in each branch this is indicated by $G_1 = G_2$. Correspondingly, the signal C_3 is such that the output of MX3, C_4 is A_2 which is an indication of whether $|\log L_1|$ is greater than $|\log L_2|$ or not. C_4 controls whether the output data bit is sign $[\log L_1]$ or sign $[\log L_2]$. When G_1 is not equal to G_2, C_3 is inverted and MX3 selects A_1, an indication of which branch has the largest s.n.r., and $C_4 = A_1$. If the first branch has the larger s.n.r., C_4 selects sign $[\log L_1]$; if the second branch has the larger s.n.r., sign $[\log L_2]$ is selected. This is in keeping with the theory of the s.a.p. combiner. When the second bit is being detected, the same process occurs except that $\log L_3$ and $\log L_4$ instead of $\log L_1$ and $\log L_2$ are used.

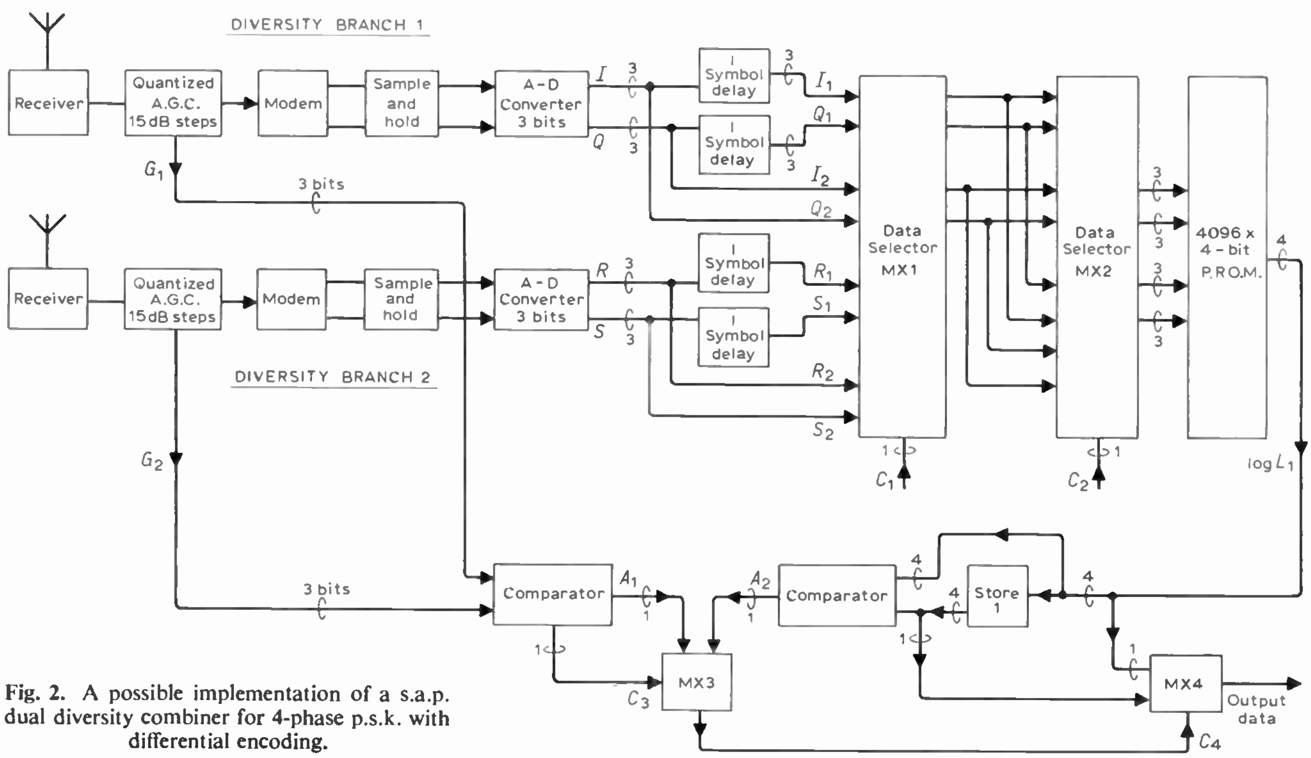

Fig. 2. A possible implementation of a s.a.p. dual diversity combiner for 4-phase p.s.k. with differential encoding.

Where a greater dynamic range is required to represent the logarithm of the likelihoods, an arrangement may be employed which uses the transitional probabilities between the in-phase and quadrature components to derive the logarithms of the likelihoods.

5. Conclusions and Future Work

It has been shown that the best diversity combiner in terms of performance and ease of construction would process the outputs of Woodward's[2] sufficient receivers. These are defined as those receivers which output the set of conditional probabilities $\{p(x|y_i)\}$. The diversity combiner, termed the s.a.p. combiner, has been shown for some types of noise to have equal performance to the best of the conventional combiners, and for other types such as impulsive noise to have superior performance.

The s.a.p. combiner utilizes a programmable r.o.m. to store the log likelihood values, for which the particular characteristics $\{p(y|x)\}$ are assumed to be known. Where these are unknown, one solution is for known data to be sent so that close approximation to the set $\{p(x|y)\}$ can be measured, that the log likelihoods would be calculated, and used to program the read-only memory. Alternatively, decision feedback could be used to continually-update the set and form an adaptive diversity combiner.

Future work remains to be done to characterize the different types of noise found on h.f. links and to compare the performance of the links for different types of diversity combiners and modulation methods so as to determine the trade-offs. Since the processes are similar, it is likely that s.a.p. diversity combining could be combined with Viterbi decoding when using convolutional error correcting codes.

Other work remains to be done on a practical level to determine the best encoding law to use in the analogue-to-digital converters, and to determine the trade-offs in performance against the word lengths, and hence the complexity, used in the combiner.

6. Acknowledgments

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Detection processes for distorted binary signals

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SUMMARY
The paper describes various iterative detection processes that are suitable for use in a synchronous serial data-transmission system, operating at a transmission rate of up to 10 000 bits per second over a slowly time varying channel. The methods of operation of the different detection processes are first described, and then the results of computer simulation tests are presented, comparing the tolerances of the detection processes to additive white Gaussian noise with the tolerances of conventional linear and non-linear equalizers. Several different time invariant channels are used in the tests. It is shown that a relatively simple detection process can achieve a considerable improvement in tolerance to noise over both linear and non-linear equalizers of optimum design.

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1 Introduction

A linear baseband channel that introduces time dispersion into a transmitted data signal may be equalized either linearly or non-linearly.[1–45] A linear equalizer is normally implemented as a feedforward transversal filter,[1–24] whereas a non-linear equalizer is usually a linear feedforward transversal filter followed by a non-linear feedback transversal filter.[25–45] The exact equalization of the channel is not normally achieved by a practical equalizer. A linear equalizer is sometimes designed to minimize the peak distortion in its output signal,[1–10] or more often to minimize the mean square distortion.[9–24] With the reasonably accurate equalization of the channel, either arrangement gives essentially the same tolerance to noise.[1–24, 45] In the presence of pure phase distortion, a linear equalizer gives the best available tolerance to additive white Gaussian noise.[45, 68] However, in the presence of any amplitude distortion, a better tolerance to Gaussian noise is achieved by a non-linear equalizer.[25–45] The latter is best designed to maximize the signal/noise ratio at its output, subject to the reasonably accurate equalization of the channel.[37, 68]

An even better tolerance to additive Gaussian noise than that given by the best non-linear equalizer can often be achieved by more sophisticated detection processes,[46–68] but some of these involve considerable equipment complexity. A technique has recently been proposed which is a development of a simple non-linear equalizer.[54, 68] It exploits the fact that with any non-linear equalizer only a portion of the available energy of the wanted signal is used in a detection process. The arrangement therefore uses a more complex detection process. It can, however, be held matched to a time-varying channel more simply and under considerably less favourable conditions than can either a linear or non-linear equalizer.[54, 68] Furthermore, its tolerance to Gaussian noise can be made to approach that of the optimum detection process.[68] The new technique can be implemented in many different ways, the various arrangements having different complexities and different tolerances to noise.

A detection process based on the new technique can be used in a data-transmission system, operating at up to about 10 000 bits per second over a time invariant or slowly-time-varying channel. The channel may be either baseband or bandpass, typical examples of the latter being telephone circuits and h.f. radio links.

The paper describes nine different arrangements of the basic detection process, and uses the results of computer simulation tests to compare their performances with those of conventional linear and non-linear equalizers.

2 Basic Assumptions

Consider the synchronous serial binary data-transmission system shown in Fig. 1. The signal at the input to the transmitter filter is a sequence of regularly spaced impulses, the ith of which occurs at time $t = iT$ seconds and has the value (area)

$$s_i = \pm 1. \qquad (1)$$

The $\{s_i\}$ are statistically independent and equally likely

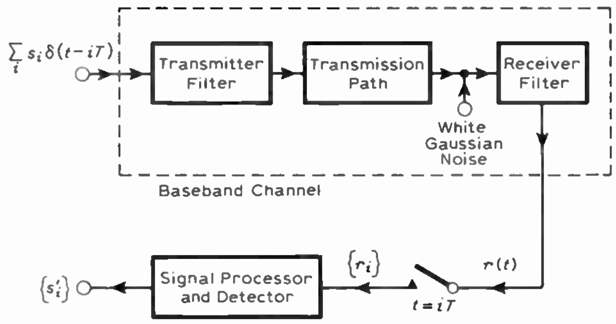

Fig. 1. Model of data-transmission system.

to have either binary value. In practice, of course, a rectangular or rounded waveform would be used, with the appropriate change in the transmitter filter.

The transmission path is a linear baseband channel that could comprise a bandpass channel, a linear modulator at the transmitter and a linear demodulator at the receiver. The transmitter filter, transmission path and receiver filter together form a linear baseband channel, whose impulse response $y(t)$ has, for practical purposes, a finite duration of less than $(k+1)T$ seconds, where k is a positive integer. It is assumed that $y(t)$ is either time invariant or varies only slowly with time, which implies that there is a negligible change in $y(t)$ during the reception of some $10k$ signal elements, k being of course the integer just defined.

White Gaussian noise with zero mean and a two-sided power spectral density of $\frac{1}{2}N_0$ is added to the data signal at the output of the transmission path, giving the Gaussian noise waveform $w(t)$ at the output of the receiver filter. Although many practical channels do not introduce significant levels of Gaussian noise, the relative tolerances of different data-transmission systems to Gaussian noise is a good measure of their relative tolerances to most practical types of additive noise.[69]

The signal waveform at the output of the receiver filter is

$$r(t) = \sum_i s_i y(t-iT)+w(t) \qquad (2)$$

and this is sampled once per signal element, at the time instants $\{iT\}$, where i takes on all positive integer values. Various techniques are available for holding the sampling instants correctly synchronized to the received signal.[70]

It is assumed that the transmitter filter is such that the average transmitted energy per signal element is unity, and the receiver filter is such that the noise components $\{w_i\}$ are sample values of statistically independent Gaussian random variables with zero mean and variance $\frac{1}{2}N_0$.[52,54]

The sampled impulse-response of the baseband channel in Fig. 1 is given by the $(k+1)$-component row vector

$$V = y_0 y_1 \ldots y_k \qquad (3)$$

where $y_i = y(iT)$. The delay in transmission, other than that involved in the time dispersion of the transmitted signal, is neglected here, so that $y_0 \neq 0$ and $y_i = 0$ for $i < 0$ and $i > k$. y_0 is not in general the largest component of V. Thus the sample value of the received signal at the output of the baseband channel, at time $t = iT$, is

$$r_i = \sum_{j=0}^{k} s_{i-j}y_j + w_i \qquad (4)$$

where $r_i = r(iT)$ and $w_i = w(iT)$.

In the signal processor and detector in Fig. 1, the values of the $\{s_i\}$ are detected from the $\{r_i\}$, using any one of a number of different operations. A high signal/noise ratio is assumed. It will also be assumed throughout that the signal processor and detector have prior knowledge both of V and of the two possible values of s_i. The detected value of s_i is designated s_i'.

3 Detection Processes

3.1 System 1

Instead of detecting a received signal-element from the corresponding sample value at the output of the appropriate filter, as is done when an equalizer is used, several sample values are now used in a detection process, these being the n output samples obtained from a non-linear operation on the corresponding n successive received samples $\{r_i\}$. All the received signal-elements involved in these samples are detected simultaneously in an iterative process. However, only the detected value of the first of these signal-elements is accepted as correct, and the components of this element in the received samples are now known and are cancelled (removed by subtraction) from the received samples. The second of these samples now becomes the first, the third becomes the second, and so on, the last sample of the new group being the first of the received samples not yet involved in a detection process. The whole process is now repeated to give the detected value of the next signal-element, which is then cancelled, and so on.

The arrangement is shown in Fig. 2, where the buffer store holds the n sample values used for a detection process, and the signal cancellation circuit has removed from these n sample values all components of the previously detected signal-elements, assuming for the moment that they have been correctly detected and that $n > k$.

Figure 2 shows the signals present just after the detection of s_i and just before the cancellation of the components of the corresponding signal-element from the n sample values $\{x_j\}$ used in the detection process. It is assumed here, for convenience, that the last received sample r_{i+n-1}, which is in fact also the nth of the $\{x_j\}$ used for the detection of s_i, is held at the input to the signal processor and detector until the receipt of the next sample r_{i+n}, at time $t = (i+n)T$.

With the correct detection of the element value s_i of the ith received signal-element, the cancellation circuit

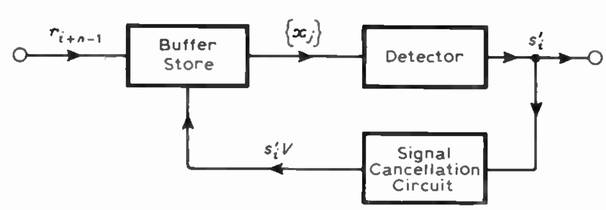

Fig. 2. Signal processor and detector.

uses this to generate the $k+1$ components of this element, which are given by the $(k+1)$-component row vector

$$s_i V = s_i y_0 \; s_i y_1 \ldots s_i y_k. \tag{5}$$

The $k+1$ components of $s_i V$ are removed by subtraction from the corresponding storage elements in the buffer store. This is an arrangement of decision-directed signal cancellation.[54] The sample values held in the buffer store are now shifted one place, as previously described, ready for the next detection process.

If $n < k+1$, the buffer store holds $k+1$ sample values instead of n, and the detection process operates on only the first n of these. Normally $n > k+1$, which will be assumed during the rest of this discussion.

If the n sample values held in the buffer store are given by the n components of the row vector

$$X = x_1 \; x_2 \; . \; . \; . \; x_n \tag{6}$$

and if the element values s_{i-1} to s_{i-k} have been correctly detected and the corresponding signal components removed by subtraction from the buffer store, then, immediately preceding the detection of s_i at time $t = (i+n-1)T$,

$$X = \sum_{j=1}^{n} s_{i+j-1}(\overbrace{0 \ldots 0}^{j-1} y_0 \; y_1 \ldots y_{n-j}) + $$
$$+(w_i \; w_{i+1} \ldots w_{i+n-1}) \tag{7}$$

where $y_i = 0$ for $i > k$, and the contents of a pair of brackets represent an n-component row vector.

To simplify the nomenclature, rename s_i as s_1, s_{i+1} as s_2, and so on, and let S be the n-component row vector

$$S = s_1 \; s_2 \ldots s_n. \tag{8}$$

Similarly, rename w_i as w_1, w_{i+1} as w_2, and so on, and let W be the n-component row vector

$$W = w_1 \; w_2 \ldots w_n. \tag{9}$$

Let Y be the $n \times n$ matrix whose ith row is given by the n-component row vector

$$Y_i = \overbrace{0 \ldots 0}^{i-1} \; y_0 \; y_1 \ldots y_{n-i} \tag{10}$$

where again $y_i = 0$ for $i > k$. Then

$$X = SY + W \tag{11}$$

where SY is an n-component signal vector and W is an n-component noise vector.

Since $y_0 \neq 0$, Y is a non-singular upper triangular matrix, and both vectors S and SY have 2^n possible values which are equally likely and are known at the receiver. Since the $\{w_i\}$ are sample values of statistically independent Gaussian random variables with zero mean and fixed variance, the detection process that minimizes the probability of error in the detection of S from X, at high signal/noise ratios, selects the value of S for which $|X-SY|$ has the minimum value.[71] $|X-SY|$ is the distance between the vectors X and SY in the n-dimensional Euclidean vector space containing these vectors. The receiver here generates, in turn, each of the 2^n vectors $\{SY\}$ and measures for each of these the corresponding distance $|X-SY|$.

Only the detected value of s_1, the first component of S, is accepted. With the correct detection of s_1, the detector knows the corresponding signal-element vector $s_1 Y_1$ and removes this vector by subtraction from X to give $X - s_1 Y_1$. The resultant sample values are now moved one place to the left to give the new vector X, whose extreme right-hand component is r_{i+n}, the first of the received samples not yet involved in a detection process.

The detection process for s_1 from X, as just described, is known here as System 1.

To start the process of detection and signal cancellation in System 1, a known sequence of more than k $\{s_i\}$ is transmitted and the components of the corresponding received signal-elements are cancelled automatically in the buffer store, without the detection of the corresponding $\{s_i\}$. The process of detection and signal cancellation now proceeds as previously described.

If a signal element is incorrectly detected, the cancellation of this element doubles instead of removes its intersymbol interference in the following elements, thus greatly increasing the probability of error in their detection. Thus the arrangement suffers from error-extension effects, and errors in the detected element values tend to occur in bursts. Tests have shown that with the detection process just described, the error rate may be increased typically up to about three times due to the wrong cancellation of signal elements. With inferior detection processes, the error rate may be increased typically up to about ten times. However, in the presence of additive white Gaussian noise, at high signal/noise ratios giving error rates of 1 in 10^5 or 1 in 10^6, an increase of up to ten times in the error rate corresponds to a reduction in tolerance to Gaussian noise of only up to about 1 dB, which is not very serious. Of course at low signal/noise ratios or with non-Gaussian noise, the error extension effects may introduce a significant reduction in tolerance to noise.

At high signal/noise ratios and as $n \to \infty$, the probability of error in the detection of a received signal-element, given the correct detection of the k preceding elements, approaches the minimum value obtainable with any detection process of whatever type, including the Viterbi algorithm and other optimum processes recently investigated.[46–68] Unfortunately, System 1 has the serious weakness that it requires 2^n sequential operations to determine the vector SY at the minimum distance from X, and this becomes excessive when $n > 10$. It is interesting therefore to consider some other detection processes that do not involve either complex equipment or an excessive number of sequential operations, but whose tolerance to noise may be made to approach close to that of System 1.

3.2 System 2

It has been shown[68] that a linear estimate of the vector S can readily be obtained from the vector X by means of the point Gauss-Seidel iterative process, whose method of operation can be explained with reference to Fig. 3. The n-component row vector

$$Z = z_1 \; z_2 \ldots z_n \tag{12}$$

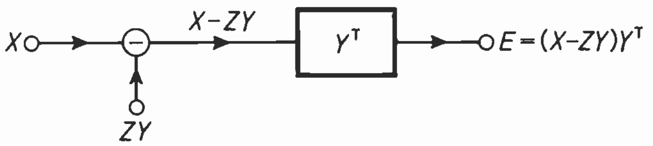

Fig. 3. Iterative detection process.

is initially set to zero, and the n-component vector ZY is subtracted from X to give the vector $X-ZY$. The square marked Y^T is an $n \times n$ network that performs the linear transformation Y^T on the input vector $X-ZY$, where Y^T is the transpose of the matrix Y. Thus the n input terminals of the network hold the n components of the vector $X-ZY$, and the n output terminals hold the n components of the vector

$$E = e_1 e_2 \ldots e_n \tag{13}$$

where

$$E = (X-ZY)Y^T. \tag{14}$$

When $Z = 0$ and $X \neq 0$, $E \neq 0$. The iterative process now operates as follows. z_1 is adjusted to set e_1 to zero. z_2 is then adjusted to set e_2 to zero, and the process continues in this way with the sequential adjustment of z_3 to z_n. The cycle of adjustments in the $\{z_i\}$ is now repeated in the same order many times until eventually $E \simeq 0$, when

$$(X-ZY)Y^T \simeq 0 \tag{15}$$

so that

$$Z \simeq XY^T(YY^T)^{-1} = XY^{-1}. \tag{16}$$

The iterative process is always convergent,[68,72] and can be implemented very simply.[51] Furthermore, the number of sequential operations in a detection process increases very much more slowly with n than in the case of System 1, although in the presence of severe amplitude distortion the number may still be excessive.[68]

In the final stage of the detection process, s_1 is detected from z_1 by setting s_1' to 1 or -1, depending upon whether z_1 is positive or negative, respectively. The detection process just described is known here as System 2.

Unfortunately, this detection process is equivalent to System 1 with $n = 1$, that is, the detection of s_1 from just the sample value x_1,[68] and it often has a tolerance to noise appreciably inferior even to that of a linear equalizer.[45] If used in practice, the arrangement would, of course, be implemented as System 1 with $n = 1$, rather than as the iterative process just described.

System 2 is nevertheless important for two reasons. Firstly, it is the least effective detection process for s_1 from X that is of any practical interest. Secondly, many of the more effective detection processes, other than System 1 itself, are developments of System 2. Any useful detection process has a tolerance to additive noise somewhere between that of System 1 and that of System 2.

3.3 System 3

This is a modification of System 2, having a greatly improved performance, with a negligible increase in equipment complexity.[51,58,68]

In the adjustment of z_i to set e_i to zero, the value of z_i is constrained so that its magnitude $|z_i|$ satisfies

$$|z_i| \leqslant 1. \tag{17}$$

The constraint overrides and so, if necessary, truncates the change in z_i dictated by the original process, so that e_i is no longer necessarily set to zero. Not only does the modification greatly increase the tolerance of the system to noise but it considerably reduces the number of sequential operations required in a detection process. These are further reduced by arranging that the change in each z_i, before the application of the constraint, lies somewhere near 1·25 times that needed to set the corresponding e_i to zero.[68]

At the end of the iterative process, s_1 is detected from z_1, as before. The arrangement just described is known here as System 3.

3.4 System 4

This is a modification of System 3 proposed by Mr. A. Clements of Loughborough University. Whenever, immediately following the appropriate change in z_i dictated by the iterative process, $|z_i| \geqslant 0{\cdot}87$, the magnitude of z_i is increased to unity and its sign is left unchanged.

The value of 0·87 has been selected as a compromise between two conflicting requirements. The smaller the value of this constant, the greater is the overall tolerance of the system to noise, but the greater also is the likelihood of an occasional error in the absence of noise. This possibility is, of course, not normally acceptable in a data-transmission system. The value of 0·87 is therefore the smallest value that ensures the correct operation of the system in the absence of noise, over all channels likely to be experienced.

3.5 System 5

This is a development of System 2. In the first part of a detection process, z_1 is set to 1 and held at this value during the whole of the iterative process of System 2. At the end of this, $|X-ZY|$ is measured. Of course, $z_1 = 1$ here. In the second part of the detection process, z_1 is set to -1 and once more held at this value during the whole of the iterative process of System 2. $|X-ZY|$ is then measured again. The detected value of s_1 is now taken to be the value of z_1 for which $|X-ZY|$ has the smaller value.

3.6 System 6

This is a modification of System 5. The iterative process of System 3 is used here in place of that of System 2, the arrangement being otherwise unchanged.

3.7 System 7

This is a modification of System 6. Immediately following the iterative process of System 3, for each of the two fixed values of z_1, the vector S is detected from Z (as described for System 2) to give the detected vector S', and $|X-S'Y|$ is then measured. The detected value of s_1 is now taken to be the value of the first component of the vector S' for which $|X-S'Y|$ has the smaller value.

3.8 System 8

This is a development of System 7, such that the iterative process of System 3 is repeated, first with z_1 held at 1 and then with z_1 held at -1, next with z_2 held at 1 and then with z_2 held at -1, and so on for all $\{z_i\}$. Of course, only one of the n $\{z_i\}$ is held at 1 or -1 during any one of these processes, the remaining $\{z_i\}$ being subject to the constraint $|z_i| \leqslant 1$, as in System 3. For each of the $2n$ processes, S is detected from the vector Z obtained at the end of the process (as described for System 2) to give the corresponding vector S', and $|X-S'Y|$ is then measured. The detected value of s_1 is now taken to be the value of the first component of the vector S' for which $|X-S'Y|$ has the smallest value.[58]

Although System 8 is more complex than System 1 and requires more sequential operations in a detection process than does System 1, when n is small, the number of sequential operations required in System 8 increases much less rapidly with n than in System 1, and for the larger values of n becomes much smaller than in System 1.

3.9 System 9

Perhaps the most attractive approach to the practical realization of the optimum detection process is to employ the basic technique of System 1, in which the n-component vector Z in the iterative process is only permitted to take on the possible values of S, but now limiting the number of different values of S tested to a small fraction of the total number 2^n. System 9 is such a system.

The detection process starts by adjusting the vector Z as follows. z_i is set to s'_{i+1}, for $i = 2, 3, \ldots, n-1$, where s'_{i+1} is the detected value of s_{i+1} at the end of the previous detection process, s_{i+1} being of course renamed s_i in the current detection process. z_1 is then set to 1, and z_n is determined as the value ± 1 for which $|X-ZY|$ has the smaller value. The resultant vector Z together with the corresponding value of $|X-ZY|$ are now stored. z_{n-1} is then changed to the other of its two possible values and $|X-ZY|$ is measured, z_{n-1} being then returned to its previous value. This is repeated for $z_{n-2}, z_{n-3}, \ldots, z_2$, in turn. If the smallest value of $|X-ZY|$ obtained as a result of these changes is less than the stored value of $|X-ZY|$, the corresponding z_i is changed to the other of its two possible values to give a new stored vector Z. The smallest value of $|X-ZY|$ now replaces the stored value of $|X-ZY|$, and the whole process is repeated, starting this time with z_n. If the stored value of $|X-ZY|$ is not changed as a result of the process just described, Z is left unchanged and the process is not repeated. The process is, in any case, not repeated a second time. The values of the $\{z_i\}$, for $i = 2, 3, \ldots, n$, are next changed in pairs over all possible combinations of the $\{z_i\}$ taken two at a time, and the corresponding values of $|X-ZY|$ measured, the values of the two $\{z_i\}$ being restored after each change. The smallest value of $|X-ZY|$ obtained as a result of these changes is then compared with the stored value of $|X-ZY|$. If it is smaller than this value, the corresponding two $\{z_i\}$ are changed to their other possible values, giving a new stored vector Z and a new stored value of $|X-ZY|$.

z_1 is now changed to -1 and the $\{z_i\}$, for $i = 2, 3, \ldots, n-1$, are set to their original values, used at the start of the previous operation. z_n is then determined as the value ± 1 for which $|X-ZY|$ has the smaller value, and $|X-ZY|$ together with the associated vector Z are stored. The whole of the previous operation is now repeated, with z_1 this time held at -1, to give a second stored value of $|X-ZY|$ and of the associated vector Z.

Finally, the detected vector S' is taken as the vector Z corresponding to the smaller of the two stored values of $|X-ZY|$. Only the detected value of s_1 is accepted, this being the value of the first component of S'.

Various simplifications of the above detection process have been tested but it has not been found possible to achieve a useful reduction in the number of sequential operations without at the same time a significant reduction in tolerance to noise.

In practice, the receiver operates with $|X-ZY|^2$ rather than with $|X-ZY|$, since the former is more readily evaluated.

4 Assessment of Detection Processes

4.1 Computer Simulation Tests

The tolerances to additive white Gaussian noise of the various detection processes have been compared by computer simulation, assuming the data-transmission system of Fig. 1, described in Section 2. The computer programs were written in *Fortran IV* and run on an ICL 1904A computer.

Eleven different baseband channels have been used in the computer simulation tests, and the sampled impulse-responses of these channels are given by the different values of the 5-component row vector V in Table 1. These values of V have been selected to give a wide range of signal distortions, including various combinations of amplitude and phase distortions. V has unit length in every case, so that there is no signal gain or attenuation in transmission. Also shown in Table 1 is the number of signal elements transmitted over a channel, this number

Table 1

Sampled impulse-response of each baseband channel and the corresponding number of signal elements transmitted in a computer simulation test

Channel	Sampled impulse-response V	Number of signal-elements transmitted
A	(1, 0, 0, 0, 0)	7 500
B	$2^{-\frac{1}{2}}$ (1, 1, 0, 0, 0)	15 000
C	$2^{-\frac{1}{2}}$ (1, 0, 1, 0, 0)	15 000
D	$1{\cdot}5^{-\frac{1}{2}}$ (1, 0·5, 0·5, 0, 0)	15 750
E	$1{\cdot}5^{-\frac{1}{2}}$ (1, 0·5, −0·5, 0, 0)	15 750
F	$1{\cdot}5^{-\frac{1}{2}}$ (0·5, 1, 0·5, 0, 0)	37 500
G	$1{\cdot}5^{-\frac{1}{2}}$ (0·5, 1, −0·5, 0, 0)	37 500
H	$1{\cdot}5^{-\frac{1}{2}}$ (1, 0·667, 0·235, 0, 0)	12 750
I	$1{\cdot}5^{-\frac{1}{2}}$ (1, 0·667, −0·235, 0, 0)	12 750
J	$2^{-\frac{1}{2}}$ (0·235, 0·667, 1, 0·667, 0·235)	97 500
K	$2^{-\frac{1}{2}}$ (−0·235, 0·667, 1, 0·667, −0·235)	97 500

Table 2

No. of dB reduction in tolerance to additive white Gaussian noise, at an element error rate of 4 in 10^3, when the given channel replaces Channel A and the given detection process replaces System 1

Channel	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	Linear equalizer	Non-linear equalizer
A	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
B	1·3	3·4	2·0	2·0	3·7	2·2	5·4	1·2	1·7	*	3·4
C	2·2	3·8	2·7	2·6	3·5	2·2	3·1	1·6	1·6	*	3·8
D	1·0	2·3	1·6	1·7	2·4	1·5	1·3	0·9	0·9	3·5	2·3
E	0·4	2·2	0·8	0·9	2·4	0·9	1·1	0·3	0·4	*	2·2
F	2·7	8·9	5·5	5·0	8·8	4·2	14·7	3·2	3·4	*	8·9
G	0·0	8·9	0·0	−0·1	0·1	0·0	0·0	0·0	0·0	0·3	0·2
H	0·9	2·2	1·5	1·5	2·2	1·7	1·5	0·9	0·9	3·5	2·2
I	0·3	2·3	1·2	1·1	2·3	1·0	1·1	0·4	0·5	8·2	2·2
J	6·5	17·8	9·6	8·7	17·5	7·2	41·8	7·0	7·0	20·6	11·9
K	1·6	17·9	2·4	2·4	17·8	2·5	4·7	1·4	2·3	*	4·3

being chosen to give no less than about 30 independent error bursts in a test involving any of the detection processes. The numbers of signal elements given in Table 1 apply to Systems 1–7 and 9, a smaller number of signal elements being used over some of the channels in the case of System 8.

In every test, the average transmitted energy per signal element is fixed at unity, and the two-sided power spectral density of the additive white Gaussian noise at the input to the receiver filter is adjusted for an average element error rate of 4 in 10^3. The noise level now gives a measure of the tolerance of the system to Gaussian noise.

The results of the computer simulation tests, comparing the different systems, are shown in Table 2. Each entry in the table gives the number of dB reduction in the level of the Gaussian noise needed to maintain the average element error rate at 4 in 10^3, when the given channel replaces Channel A and the given detection process replaces System 1. For all systems, 8 sample values are used in a detection process, and the receiver has exact prior knowledge both of the vector V and of the two possible values of s_i. The 95% confidence limits for the entries in Table 2 (other than those for System 8 and the linear equalizer) are up to about $\pm 0{\cdot}4$ dB. The confidence limits for System 8 are of the order of $\pm 0{\cdot}5$ dB. This is because System 8 requires a considerable amount of computing time, so that a reduction had to be made here both in the number of signal elements transmitted over some of the channels and in the number of sequential operations permitted in any iterative process.

The results in Table 2 include those for conventional linear and non-linear transversal equalizers. In every case, the channel is equalized fairly accurately, with negligible residual intersymbol interference. Furthermore, the non-linear equalizer is the optimum equalizer in the sense that it maximizes the output signal/noise ratio, given the correct equalization of the channel, and it therefore minimizes the error rate at high signal/noise ratios.[37] These equalizers are described elsewhere.[1–45, 68] The results for the non-linear equalizer have been obtained by computer simulation, using the basic transmission system described, the 95% confidence limits for these results being up to about $\pm 0{\cdot}4$ dB. The results for the linear equalizer have been obtained by theoretical analysis, since an exact evaluation of the error probability is possible here.[1–24] The symbol * in an entry for the linear equalizer indicates that the corresponding channel cannot be equalized linearly, because one or more roots (zeros) of its z transform lie on the unit circle in the z plane.[68]

The value 0·0 dB quoted against Channel A, in the case of each of the different systems tested, is the theoretically correct value.

Further tests have been carried out on Systems 1 and 6 to measure the variation in tolerance to noise of each system with the number of sample values, n, used in a detection process. The results of these tests are shown in Fig. 4, which plots the reduction in tolerance to additive white Gaussian noise of each system, against n for $n = 1, 2, \ldots, 9$, when Channel A is replaced by Channel J. Channel J is the channel that introduces the most severe signal distortion, whereas Channel A of course introduces no signal distortion.

4.2 Comparison of Systems

It can be seen from Table 2 that the advantage in tolerance to Gaussian noise of System 1 over System 2 varies from 0 to over 16 dB, so that, for some channels, System 1 has a very much better performance than System 2. System 3 has, in general, a much better performance than System 2, but its tolerance to noise is up to 3 dB below that of System 1. System 4 is marginally better than System 3, but it is still up to some 2½ dB inferior to System 1. It is because of the very limited improvement in performance of System 4 over System 3 that the particular technique employed in System 4 has not been tried with any of the other detection processes.

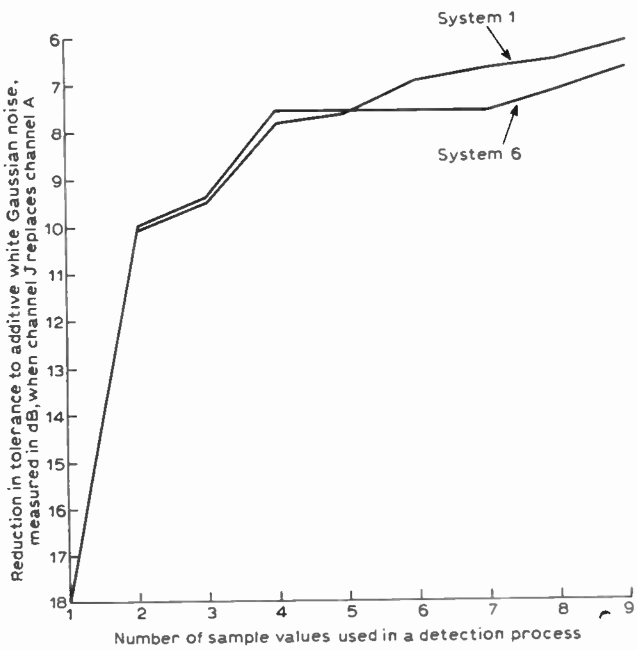

Fig. 4. Graphs of tolerance to noise against number of sample values used in a detection process, for Systems 1 and 6 operating over Channel J.

The tolerance to noise of System 5 is very similar to that of System 2, except in the case of Channel G where System 5 is very much better than System 2. Channel G introduces nearly pure phase distortion, as can be seen from the fact that it only slightly reduces the tolerance to noise of the linear equalizer.[68] System 6 is slightly better than System 4 and up to some 1½ dB inferior to System 1. System 7 has a very poor performance over Channels F and J and is not therefore a useful system. System 8 has a tolerance to Gaussian noise very similar to that of System 1, so that System 8 is for practical purposes an optimum detection process for the given number of sample values used. System 9 is consistently a little better than System 6 and typically up to about ½ dB inferior to System 1.

At the error rate tested, Systems 1, 3, 4, 6, 8 and 9 have tolerances to Gaussian noise that are always at least as good as and sometimes much better than that of a non-linear equalizer of optimum design, the latter having a tolerance to Gaussian noise that is always at least as good as and sometimes much better than that of a linear equalizer.

Figure 4 shows that the tolerances to additive white Gaussian noise of Systems 1 and 6 increase with n, the number of sample values used in a detection process. However the rate of increase becomes much smaller as n increases. It is clear from an extrapolation of the graphs in Fig. 4 that a noticeable improvement in tolerance to noise is obtained with either system if n is increased from 8 to 16, but it is doubtful whether a further useful increase in tolerance to noise is obtained by any additional increase in n. Obviously, to limit the equipment complexity, n must be no larger than necessary. Thus for System 1 or 6 operating over Channel J, the preferred value of n is likely to be in the range 8–16.

The two most interesting of the different detection processes are Systems 6 and 9. System 9 has a slightly better performance than System 6 and requires fewer sequential operations, but it is more complex.[68] Various techniques have been developed both for simplifying the practical implementation of System 6 and for reducing the number of sequential operations required in a detection process.[68] The number of sequential operations are normally the equivalent of less than 20 cycles of the iterative process of System 2 or 3 and often considerably below this value. The only detection processes having a better tolerance to Gaussian noise than Systems 6 and 9 are the Systems 1 and 8. However, for the maximum tolerance to noise of any of the detection processes other than System 2, the value of n must be fairly large. Systems 1 and 8 now require very many more sequential operations in a detection process than Systems 6 and 9.

An important property of the Systems 1–9 is that in an application of data transmission over a slowly time-varying channel, a linear estimate of the sampled impulse-response of the channel can be obtained from the received data signal itself, by means of a simple linear feedback transversal filter, and without the need for any additional training signal or even the scrambling of the data signal.[54,68] Since the estimate of the sampled impulse-response of the channel is not obtained by means of a cross-correlation technique, as it is in the case of a linear or non-linear equalizer, a significantly more rapid rate of change in the sampled impulse-response of the channel can be tolerated by the Systems 1–9 than by a conventional equalizer. Furthermore, since the sampled impulse-response of the channel, rather than its inverse, is used in a detection process, no great increase in equipment complexity is involved in converting any of the Systems 1–9 from operation over a fixed channel to adaptive operation over a time-varying channel.[68]

Again, in a non-linear equalizer, the channel is equalized partly by a linear filter and partly by a non-linear filter, and there is in general an infinite set of different possible combinations of the two filters that achieve the accurate equalization of the channel.[45] An adaptive non-linear equalizer is ideally adjusted to minimize the mean-square error in its output signal.[29,32,36] However, the noise over switched telephone circuits is largely impulsive noise that occurs in short bursts separated by relatively long noise-free intervals.[69] Thus, at the start of a burst of impulsive noise, the non-linear equalizer will normally be adjusted to give the most accurate equalization of the channel in the absence of noise, and this adjustment may often differ considerably from that which minimizes the mean-square error in the presence of noise. The result is an appreciable reduction in the tolerance of the system to noise relative to its ideal or correct value.[68] On the other hand, the adaptive arrangements of Systems 1–9 are correctly adjusted, so long as a sufficiently accurate estimate has been obtained of the sampled impulse-response of the channel, and this is readily achieved under normal conditions.[68]

In the practical implementation of the iterative process of Fig. 3, the $n \times n$ network Y^{T} is replaced by the $n \times 1$ network Y_i^{T}.[51,68] Immediately prior to the adjustment of z_i, the network Y_i^T forms the signal $e_i = (X - ZY)Y_i^T$ at its output terminal. Following the resultant change Δz_i in z_i, the network is changed to Y_{i+1}^T, by shifting, one place to the right, the stored values $\{y_j\}$ that formed the vector Y_i and hence the network Y_i^T. The network Y_{i+1}^T forms the next output signal e_{i+1}, and so on.[51] It follows that at any instant in time, when the network Y^T has become Y_i^T, it gives the same output signal as a linear feedforward transversal filter whose tap gains are given by the respective non-zero components of Y_i. The linear filter has m taps where $1 \leqslant m \leqslant k+1$, and the signals stored in the filter are the appropriate m components of the vector $X - ZY$. This suggests that the practical implementation of the network Y^T resembles that of an m-tap linear feedforward transversal filter. When the signals are handled as binary-coded numbers, a single multiplier is used to provide, in turn, each of the different multipliers, either for the network Y_i^T or for the corresponding transversal filter. The output signal e_i from the network Y_i^T is obtained by adding the m products formed by the multiplier. This summation process is the same operation as that carried out in the adder of the corresponding transversal filter, and can be implemented simply and rapidly.

A single multiplication is required to derive Δz_i from e_i. The new vector $X - ZY$ in Fig. 3 is now formed by multiplying the m non-zero components of Y_i by Δz_i, to give the n-component vector $\Delta z Y_i$, and then subtracting this vector directly from the stored vector $X - ZY$. Thus the vector ZY is not itself stored, as suggested by Fig. 3, the vector Z being stored instead and the vector X being held additionally in a separate store.[68] The subtraction circuit in Fig. 3 is the same as the subtraction circuit in the corresponding non-linear equalizer, except that it operates on n signals instead of one. The operation of subtraction can be implemented simply and rapidly.

It appears therefore that the equipment complexity involved in the iterative process of Fig. 3 and therefore of any of the Systems 3–8 is of the same order as the equipment complexity of the corresponding non-linear equalizer in which the signals are handled as binary-coded numbers. It may similarly be shown that the equipment complexity of System 1 is also of this same order, System 9 being a little more complex.[68] The main difference between the equalizer and an iterative detection process is that the latter involves many more sequential operations in processing the received signal than does the equalizer, so that it cannot be used at nearly such high transmission rates.

An alternative approach towards the optimum detection of the received $\{s_i\}$ in the data-transmission system of Fig. 1, that has recently received some attention in the published literature, uses the Viterbi algorithm.[53,56] The technique differs fundamentally from Systems 1–9 in that the detection process operates directly on the individual samples $\{r_i\}$ of the received signal, by comparing these with their different possible values in the absence of noise, for the different possible $\{s_i\}$ and the given sampled impulse-response V of the channel.[68] It uses the fact that the $\{r_i\}$ are formed by the addition of the statistically independent Gaussian noise samples $\{w_i\}$ to the sequence formed by the convolution of the $\{s_i\}$ and $\{y_i\}$. The process determines which of the different possible sequences has the maximum likelihood, given the received sequence of the $\{r_i\}$, and it accepts the corresponding $\{s_i\}$ as the detected element values. The Viterbi algorithm is a technique for computing the maximum-likelihood sequence, using only some h^{k+1} sequential operations for each received h-level signal-element instead of the very much larger number that would otherwise be required. Furthermore, the detection process ideally achieves the same tolerance to additive white Gaussian noise as does System 1 when $n \gg k$.[68] Unfortunately, the arrangement is probably more complex than Systems 6 and 9, and for large values of k it requires an excessive number of sequential operations per signal element, even with binary signals. It appears, therefore, that Systems 6 and 9 should often compare well with the alternative arrangements that use the Viterbi algorithm.

5 Conclusions

The most promising of the different detection processes studied here are Systems 6 and 9. These not only achieve a useful advantage in tolerance to additive white Gaussian noise over a non-linear equalizer of optimum design, but they are also basically better suited to adaptive operation over a time-varying channel. Furthermore, at transmission rates of up to 10 000 bits per second and when the signals are handled as binary-coded numbers, the systems are no more complex to implement. They also appear to compare well with the detection processes based on the Viterbi algorithm. Systems 6 and 9 are therefore well worth further investigation as possible replacements for linear and non-linear equalizers, particularly in the application of data transmission over voice-frequency channels.

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Error performance of p.s.k. and f.f.s.k. subcarrier data demodulators

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SUMMARY

The error performance of filter threshold and integrate and dump demodulators is calculated, for phase shift key (p.s.k.) and fast frequency shift key (f.f.s.k) modulated data signals. A review is given of existing theory and techniques and some material is presented on f.f.s.k. demodulators.

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List of symbols

T	bit duration
f_b	bit rate $(1/T)$
m	modulation index, peak to peak carrier swing divided by modulation frequency
$s(t)$	received signal waveform
$n(t)$	received noise waveform
N_0	noise power spectral density in watts/Hz
σ	r.m.s. noise voltage
erf	error function
erfc	complementary error function
P_s	signal power
S/N	signal-to-noise-voltage ratio
$[S/N]_p$	signal-to-noise-power ratio
E	energy in signal representing one bit
P_b	probability of bit error
$x(t)$	reference waveform or replica of received signal

1 Introduction

The error performance of optimum sub-carrier demodulators for signals contaminated with Gaussian noise is known;[1,2] however, sub-optimum demodulators are often used for economy, simplicity and ease of extracting a timing signal. Two types of sub-optimum demodulator are described and their performances with phase shift key (p.s.k.) and with fast frequency shift key (f.f.s.k.) modulation are calculated. F.f.s.k.[6,7] is frequency shift key with modulation index $m = \frac{1}{2}$.

The demodulators described here can only be used where the exact coherence of the data sub-carrier is preserved, as for example in f.m. mobile radio. Transmission over s.s.b. radio or f.d.m. telephone circuits loses this coherence due to the small frequency offset introduced.

We start with a brief review of the optimum demodulator, and proceed to find the performance of the filter-threshold and the integrate-dump demodulators for both modulation schemes.

2 Optimum Demodulators

An optimum demodulator is optimum at the task of extracting the signal energy from a background of Gaussian noise, which is taken as white with a power spectral density of N_0 watts/Hz. The maximum signal-to-noise power ratio that can be produced by a demodulator is[5]

$$[S/N_{\max}]_p = 2E/N_0. \quad (1)$$

Consider a data demodulator which treats each bit separately. The signal energy is then the energy per bit, $E = P_s/f_b$ and the voltage signal-to-noise ratio in a 1-ohm system is

$$S/N_{\max} = \sqrt{\frac{2P_s}{N_0 f_b}}. \quad (2)$$

Equation (2) gives the minimum r.m.s. noise level, σ that can be achieved in the demodulator output to the decision circuit. The decision will be in error if the instantaneous noise at the decision time exceeds the signal magnitude and has opposite polarity. The probability of noise of r.m.s. level σ exceeding a level V is

$$P = \tfrac{1}{2}\,\text{erfc}\,\frac{V}{\sigma\sqrt{2}} \tag{3}$$

where erfc is the complementary error function equal to one minus the error function erf which is defined as (ref. 3, p. 100)

$$\text{erf}\,Z = \frac{2}{\sqrt{\pi}}\int_0^Z e^{-z^2}\,dz. \tag{4}$$

Combining equations (2) and (3) and putting $V = \sqrt{P_s}$ and $\sigma = \sqrt{N_0 f_b/2}$ gives the much quoted[2] minimum error probability

$$P_b = \tfrac{1}{2}\,\text{erfc}\,\sqrt{\frac{P_s}{N_0 f_b}}. \tag{5}$$

This optimum performance can only be achieved with a matched filter or correlation receiver,[4] which can present problems in implementation. The filter threshold and integrate and dump circuits given below are approximations to these optimum techniques which are often used in practice.

3 Filter Threshold Demodulator for P.S.K.

P.s.k. with a filter threshold demodulator is frequently used in mobile radio data transmission. In coherent p.s.k. an audio sub-carrier of frequency equal to the bit rate f_b is phase modulated $\pm 90°$. A typical waveform is shown in Fig. 1 where it can be seen that a logical 1 is represented by a positive cycle of sinewave and a logical 0 by a negative cycle:

$$s(t) = \pm a \sin 2\pi f_b t. \qquad 0 \leqslant t < T. \tag{6}$$

The simple demodulator shown in Fig. 1 uses a low-pass filter, which removes as much noise as possible, and a limiter and bistable decision circuit clocked by the timing extractor at the bit rate. The limiter indicates the polarity of the signal and the bistable is clocked at $t = 3T/4$, i.e. three-quarters through the bit period, when the logical 1 symbol has its most positive and the logical 0 symbol its most negative value, as shown by the eye diagram in Fig. 1. This is the time when noise is least likely to reverse the decision and cause an error.

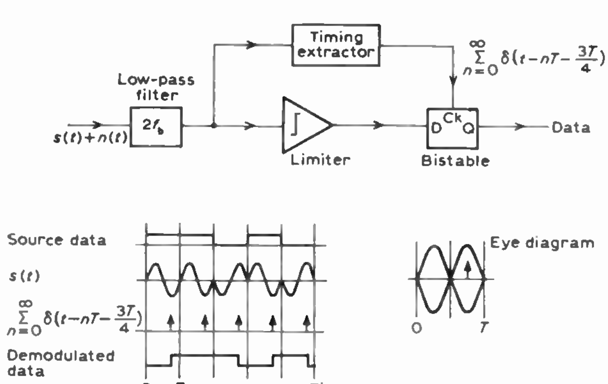

Fig. 1. Filter threshold demodulation of p.s.k.

The probability of error can be found by putting the signal level and the noise level into equation (3), which relates error probability to signal-to-noise ratio. The signal level at the decision time is a, corresponding to a sinewave signal power $P_s = a^2/2$. The low-pass filter cut-off is set to $2f_b$ (which just passes the p.s.k. spectrum which occupies the band 0–$2f_b$[9]) so the r.m.s. noise level is $\sigma = \sqrt{2N_0 f_b}$. Therefore from (3)

$$P_b = \tfrac{1}{2}\,\text{erfc}\,\frac{a}{\sqrt{2N_0 f_b}\sqrt{2}}$$

$$= \tfrac{1}{2}\,\text{erfc}\,\sqrt{\frac{P_s}{2N_0 f_b}}. \tag{7}$$

Comparison with the optimum, (5) shows there is twice the noise power and therefore a 3 dB loss in performance, as shown by curve 4 in Fig. 7.

Timing extraction is a problem with p.s.k. A common method uses a linear multiplier to square the data signal which gives a continuous sinewave at twice the bit frequency. A divide-by-two produces a timing signal at f_b but there is an ambiguity which can result in the signal being sampled at $t = T/4$ rather than $t = 3T/4$, which inverts the data signal. Whether this happens or not depends on the random content of the bistable on start up. The ambiguity is overcome with differential coding (d.c.p.s.k.) in which a logical 1 is represented by a change in phase and a logical 0 by the same phase as the last bit period. The decoder compares each decision with the last to find the value of each bit. An error occurs if either the present or the last decision is wrong, but not both. The probability of one wrong and one right decision is $2p(1-p)$, where p is the probability of a wrong decision, given in this case by equation (7). Consequently the bit error probability with d.c.p.s.k. is

$$P_b = \text{erfc}\,\sqrt{\frac{P_s}{2N_0 f_b}}\left[1 - \tfrac{1}{2}\,\text{erfc}\,\sqrt{\frac{P_s}{2N_0 f_b}}\right]. \tag{8}$$

The error performance is 3·6 dB below optimum and is plotted in Fig. 7, curve 5.

An alternative way of providing timing information is to precede each message by a preamble of say twenty logical 0 symbols, that is by twenty cycles of sinewave at f_b. The receiver uses the preamble to establish unambiguous timing which can be remembered in a phase lock loop or by resetting a divider chain driven by a crystal oscillator. This technique can only be used where short messages are required.

4 The Response of the Integrate and Dump Circuit to Noise

The integrate and dump circuit is useful in sub-optimum demodulators and is a simple circuit to implement. However we need to know how the circuit responds to noise to be able to calculate the error performance of demodulators which use it.

An interesting way of finding the r.m.s. level of the integrator noise output is to examine the performance of the correlation receiver shown in Fig. 2 for the special case where the signalling waveform is a unit amplitude pulse, of one-bit period duration. We are free to choose any signalling waveform we like because the optimum performance given in equation (2) is determined only by the energy per bit and the noise density and is independent of the particular signalling waveform used. In a correlation receiver the input waveform is multiplied by a replica, $r(t)$ of the expected signal waveform, which in this case is the unit pulse. Therefore

$$s(t) = r(t) = 1. \qquad 0 \leqslant t < T. \tag{9}$$

Multiplying by a pulse of unit amplitude has no effect on the received signal or the received noise during the bit period. The correlation receiver in this case has reduced to just the integrate and dump circuit alone and so we can find the r.m.s. level of the integrator noise output, σ, from the optimum signal-to-noise ratio of equation (2).

The integrator output due to the signal is

$$b(t) = \int_0^T s(t)r(t)\,dt = T. \tag{10}$$

The r.m.s. noise output is

$$\sigma = \text{r.m.s.} \int_0^T n(t)\,dt. \tag{11}$$

If we equate the signal-to-noise ratio, T/σ, to the optimum,

$$\frac{T}{\sigma} = \sqrt{\frac{2P_s}{N_0 f_b}}. \tag{12}$$

The signal power is $P_s = 1$, therefore

$$\sigma = \sqrt{\frac{N_0 T}{2}}. \tag{13}$$

5 Integrate and Dump Demodulation of P.S.K.

This is an approximation to a correlation receiver. Instead of multiplying the received signal by a replica of the expected signal, which in this case would be a cycle of sinewave, it is multiplied by a square wave of the same frequency, shown as $x(t)$ in Fig. 3. Multiplying by the square wave $x(t)$ is equivalent to selecting the signal during the first half of the bit period and selecting an inverted version of the signal during the second half. This can be done with a change-over switch and an inverter, which is much cheaper than a linear multiplier and sinewave reference. The result of this process, shown as $a(t)$ will be two positive half cycles during a logical 1 symbol and two negative half cycles for a logical 0. The integrate and dump circuit which follows the multiplier will therefore charge positively for logical ones and negatively for logical zeroes, $b(t)$ in the figure. A limiter and bistable are used to decide the polarity of the integrator output at the end of the bit period, when the signal is maximum and noise is least likely to cause an error. After the decision the integrator content is dumped and a new integration started.

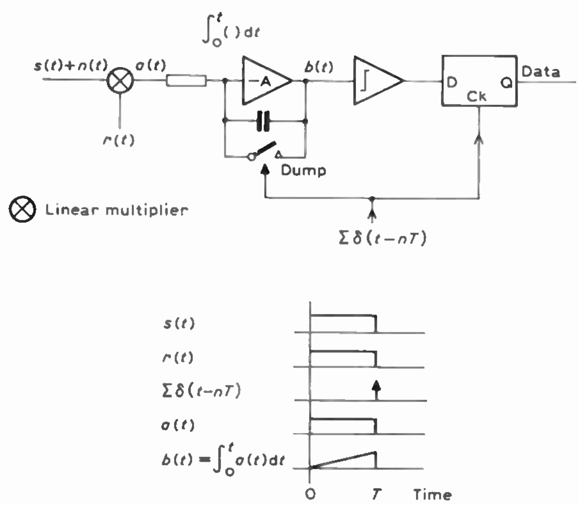

Fig. 2. Correlation receiver for unit pulse.

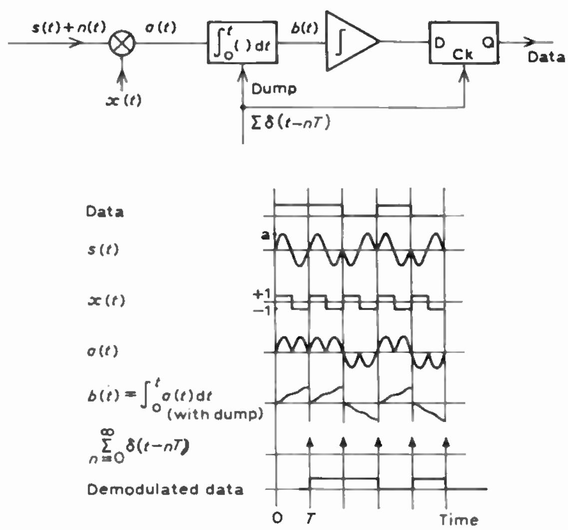

Fig. 3. Integrate and dump demodulation of p.s.k.

The integrator output due to the signal is

$$a(t) = \pm \int_0^T x(t).a \sin 2\pi f_b t\,dt$$

$$= \pm 2 \int_0^{T/2} a \sin 2\pi f_b t\,dt \tag{14}$$

$$= \pm \frac{aT}{\pi}\left[\cos 2\pi f_b t\right]_0^{T/2}$$

$$= \pm \frac{2aT}{\pi}. \tag{15}$$

In an optimum demodulator with a sinewave reference the integrator output would have been $\pm aT/\sqrt{2}$, which is 1·11 times larger.

Putting the signal level from (15) and the noise level $\sqrt{N_0 T/2}$ from (13) into equation (3) gives an error probability

$$P_b = \tfrac{1}{2}\,\text{erfc}\,\frac{2aT/\pi}{\sqrt{N_0 T/2}\sqrt{2}} \tag{16}$$

$$= \tfrac{1}{2}\,\text{erfc}\sqrt{\frac{a^2/2}{\frac{\pi^2}{8} N_0 f_b}}$$

$$= \tfrac{1}{2}\,\text{erfc}\sqrt{\frac{P_s}{1{\cdot}23N_0f_b}}. \qquad (17)$$

The error performance (Fig. 7, curve 2) is only 0·9 dB below optimum.

6 Fast Frequency Shift Key (F.F.S.K.)

Fast frequency shift key uses a coherent sub-carrier at $0{\cdot}75f_b$, frequency modulated by the data with a modulation index $m = 0{\cdot}5$. A typical f.f.s.k. data waveform is shown as $s(t)$ in Fig. 4 where it can be seen that a logical 0 is represented by a whole cycle of either positive or negative sinewave of frequency f_b and a logical 1 by a positive or negative half cycle at $f_b/2$. The choice between a positive or negative symbol is made so that the data waveform is kept smooth and sharp cusps are avoided. For example if the present symbol is a logical 1 represented by a positive half cycle then a following logical 1 must be represented by a negative half cycle.

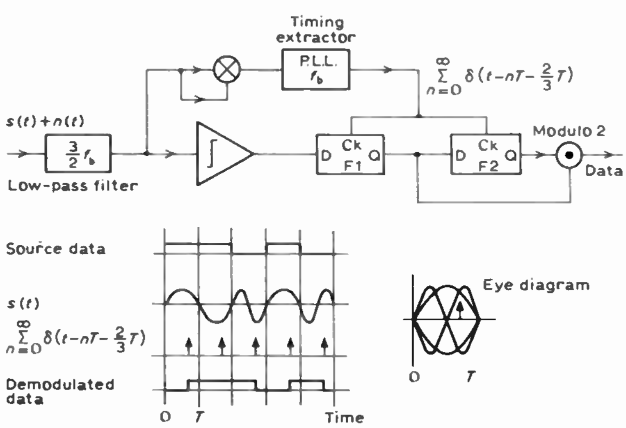

Fig. 4. Filter threshold demodulation of f.f.s.k.

De Buda[6,7] has shown that optimum demodulation of this signal is possible if the demodulator makes decisions based on the energy recovered in two-bit periods rather than the usual one-bit period. This requirement stems directly from the way each symbol determines the polarity of the next. With four symbols in use a two-bit interval could in general have sixteen forms but due to the constraint imposed only eight are used. Demodulation based on a single-bit period cannot make use of this prior knowledge and will therefore have a lower performance. Unfortunately the optimum demodulator described by de Buda is rather complicated and so it is worthwhile investigating the performance of less complicated sub-optimum demodulators.

7 Filter Threshold Demodulator for F.F.S.K.

A simple f.f.s.k. demodulator is shown in Fig. 4, which uses the filter threshold approach. The filter cut-off is set at $1{\cdot}5f_b$ to pass the spectrum of the data signal which occupies the band 0 to $1{\cdot}5f_b$.[10] The limiter passes the polarity of the data signal to the bistable which is clocked to make a decision at $t = 2T/3$, when the maximum signal level is available, as shown in the eye diagram in Fig. 4. The polarity decisions are stored in a second bistable and the value of each bit is found by comparing the polarities in the current and the last bit period in a modulo 2 gate. If the polarities are the same the current symbol must be a whole cycle of sinewave which represents a logical 0 if they are opposite the symbol must be a half cycle representing a logical 1.

The signal amplitude at the decision time is found from the eye diagram and is equal to $0{\cdot}868a$. The r.m.s. noise level from the low-pass filter of bandwidth $1{\cdot}5f_b$ is $\sigma = \sqrt{1{\cdot}5N_0f_b}$. Putting these values into equation (3) gives the probability of an incorrect decision p:

$$p = \tfrac{1}{2}\,\text{erfc}\frac{0{\cdot}868a}{\sqrt{1{\cdot}5N_0f_b}\sqrt{2}}$$

$$= \tfrac{1}{2}\,\text{erfc}\sqrt{\frac{P_s}{2N_0f_b}}. \qquad (18)$$

However, the demodulator compares each polarity decision with the previous one. The situation is the same as with differential decoding and the probability of a bit error is increased to $2p(1-p)$ which is

$$P_b = \text{erfc}\sqrt{\frac{P_s}{2N_0f_b}}\left[1-\tfrac{1}{2}\text{erfc}\sqrt{\frac{P_s}{2N_0f_b}}\right]. \qquad (19)$$

The performance (Fig. 7, curve 5) is 3·6 dB below optimum.

An alternative form of f.f.s.k. uses a whole cycle of cosine wave for a logical 0 and a half cosine cycle for a logical 1, rather than sinewaves. This has the advantage of a signal amplitude equal to a at the decision time at $t = T$, and gives an improvement of 1·3 dB, i.e. only 2·3 dB below optimum, as shown in Fig. 7, curve 3.

Timing information is extracted from the f.f.s.k. data signal by squaring the signal and using a phase-lock loop to extract the frequency component at the bit rate. When the signal is squared the logical 0 symbols consisting of a whole cycle at f_b are converted to two cycles at $2f_b$ and the half cycles at $f_b/2$ are converted to whole cycles at f_b. The component at $2f_b$ could be extracted and a divide-by-two used to produce a timing signal at f_b. However in the circuit of Fig. 4 the phase-lock loop extracts the timing signal directly from the component at f_b. The data signal must contain enough logical 1 symbols to keep the loop in lock. A phase-lock loop will not lock directly onto either the p.s.k. or the f.f.s.k. data signals because neither contain a discrete frequency component.

8 Integrate and Dump Demodulation of F.F.S.K.

The integrate and dump demodulator shown in Fig. 5 is rather more complicated than the corresponding circuit for p.s.k. However it is simpler than the optimum demodulator described by de Buda[6,7] and it was hoped that the integration would give an improvement over the filter threshold circuit.

The demodulator shown in Fig. 5 has two branches; the upper one integrates the signal and takes the modulus of the result, and the lower one multiplies the signal by a square wave $x(t)$, which inverts the signal during the second half of the bit period, and then integrates and takes the modulus. The two moduli are then subtracted and applied to a limiter and D-type flip-flop which

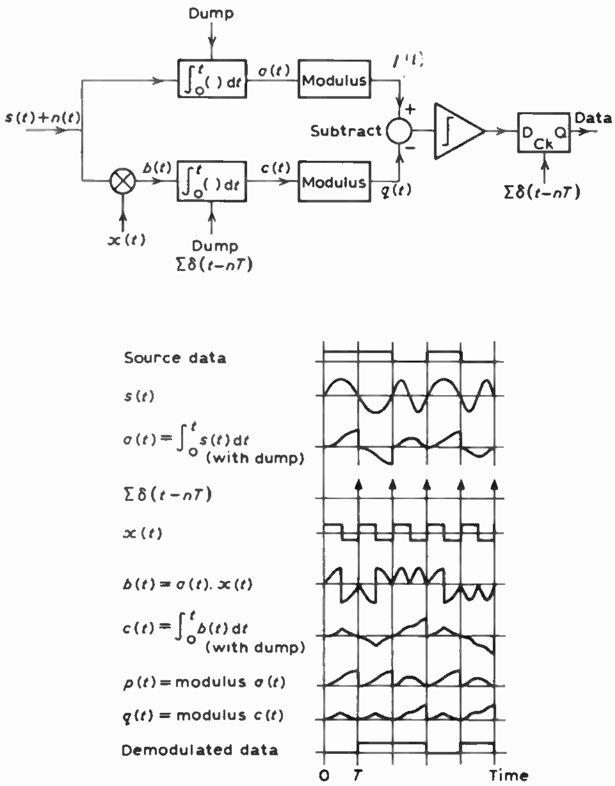

Fig. 5. Integrate and dump demodulation of f.f.s.k.

decides the polarity at time $t = T$. The waveforms in the figure illustrate how the circuit works. The integrator in the upper branch produces an output (either positive or negative) for a logical 1 input and zero for a logical 0 input, whilst the lower branch does the opposite and produces zero for logical 1 and a voltage for 0. The modulus circuits remove the polarity ambiguities so the decision is simply which branch gives the larger voltage; if it is the upper branch the input is taken as logical 1, if the lower then logical 0.

The calculation of the error probability is rather lengthy due to the effect of the modulus circuits, which are non-linear. Only the result will be given:

$$P_b^1 = \tfrac{1}{2}\left[1+\operatorname{erf} 0{\cdot}637\sqrt{\frac{P_s}{N_0 f_b}}\right]\operatorname{erfc} 0{\cdot}637\sqrt{\frac{P_s}{N_0 f_b}}. \quad (20)$$

Unfortunately the performance (Fig. 7, curve 6) is slightly worse than with the far simpler filter threshold arrangement. The performance of the circuit is low because the modulus circuit, which eliminates the sign from an input, gives a noise output which upsets the decision for either a positive or negative noise input. In the previous circuits only one noise polarity produced errors.

9 Measurements

Measurements were made to verify the theory for the filter-threshold demodulator and for the integrate-dump demodulator for d.c.p.s.k. Unfortunately no hardware was available to verify the theory for the integrate-dump detection of f.f.s.k. The theory assumes an ideal clock free of jitter at the demodulator. To make direct comparison with theory the demodulators were provided with an ideal clock taken from the data source. However measurements were also made for both the filter-threshold cases using a practical clock regenerated from the noisy input data signal.

The results are shown in Fig. 6. Curve 1, the theoretical prediction for integrate-dump detection of d.c.p.s.k. agrees closely with the measured points and confirms that the r.m.s. value of noise from an integrator is $\sqrt{(N_0T/2)}$. Curve 2, the predicted performance of filter-threshold demodulators agrees closely with the measured performance for both d.c.p.s.k. and f.f.s.k. (with sine-wave symbols). Also shown is the measured performance of practical demodulators using regenerated timing signals. In the case of d.c.p.s.k. the loss in performance is negligible but for f.f.s.k. there is a loss in performance of about 2·5 dB because the timing regenerator only uses 1 symbols to lock the loop, which free wheels during logical 0 symbols. This style of operation is used for simplicity and is not fundamental.

10 Conclusions

The results are shown in Fig. 7 as a plot of bit error rate against the ratio of signal power to the noise power in the bit rate bandwidth. The best demodulator is the integrate and dump demodulator for p.s.k. at 0·9 dB below optimum. Next is filter-threshold f.f.s.k. for the

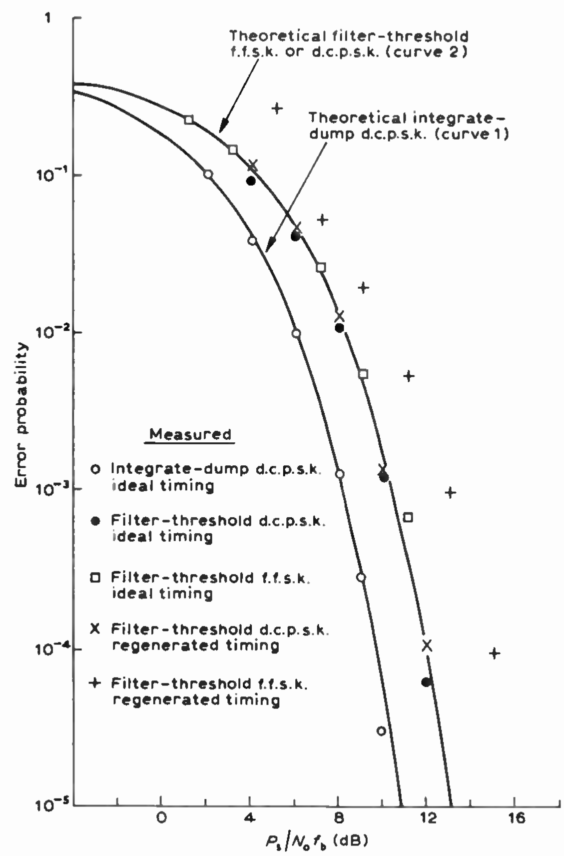

Fig. 6. Theoretical performances for filter threshold demodulator and integrate-and-dump demodulator compared with measured results.

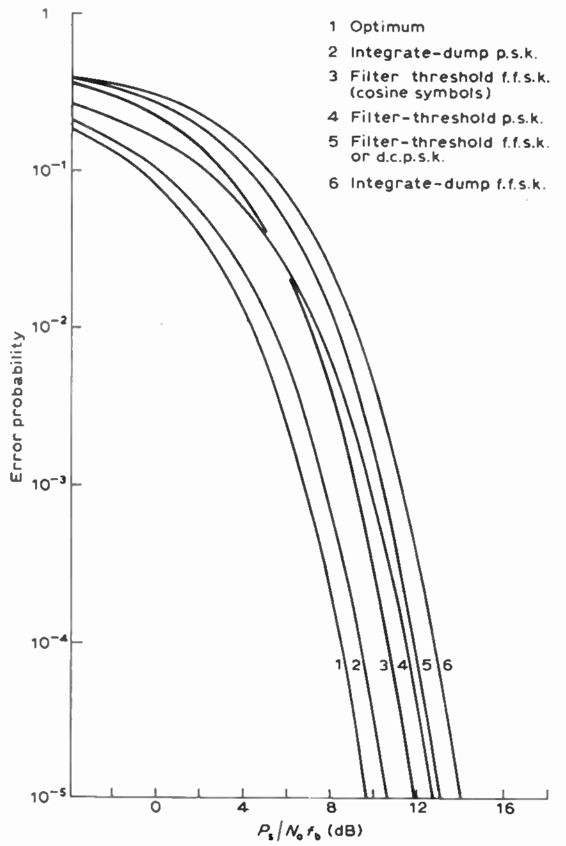

Fig. 7. Bit error rate versus s.n.r. for various arrangements.

cosine signal format at 2·3 dB below optimum, and then filter threshold p.s.k. at 3 dB below optimum. The filter threshold demodulators for differentially coded p.s.k. and f.f.s.k. with sinewave symbols have equal performance at 3·6 dB below optimum. Last is the integrate and dump demodulator for f.f.s.k. at 4·4 dB below optimum.

Error performance is not the only criterion in choosing a data transmission scheme and it may be important that f.f.s.k. offers a 33% higher bit rate than p.s.k., due to its narrower spectrum, and is simpler to implement.

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Theoretical and practical investigation of error rates for digital f.m.

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SUMMARY

The bounds for the probability of error for f.s.k. systems using optimum detection are stated. The upper bound is obtained for other cases of interest using non-optimum detection. The theoretical results are presented together with past practical results and some new practical results for a wide-band digital f.m. system.

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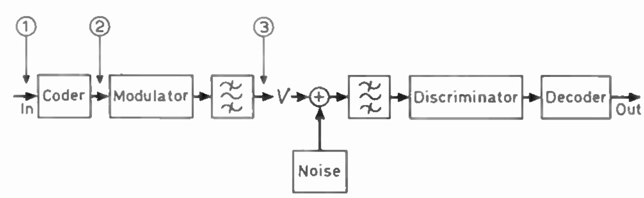
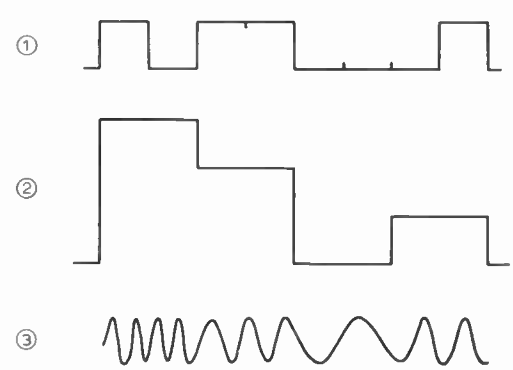
1 Introduction

The application of data transmission to non-noise-limited environments such as the switched telephone network make it necessary to consider multi-level frequency modulation techniques. These techniques may provide higher bit rates or lower baud rates depending upon the modulation parameters. Before any system may be used, it is important to know its error rate as a function of carrier-to-noise ratio. This ensures that the system remains non-noise-limited with a low error rate.

In this work systems are considered which consist of a coder, modulator, transmission channel, discriminator and decoder. Such a system is illustrated in Fig. 1. The input and output is always in the form of a binary digital signal, however, the coder may convert the binary signal into a multi-level signal, where each level represents several successive bits of the input. The coder output is used as the modulator input which will create time limited signals whose frequencies are defined by the input levels. Each frequency represents a unique bit pattern and each signal element, after filtering, gives a unique channel symbol.



(a) Outline of a digital f.m. system.



(b) Waveforms for a quaternary digital f.m. system.

Fig. 1.

Here, the range of digital f.m. has been divided into two. Systems with one or more channel symbols per Hz of bandwidth are referred to as f.s.k. systems and those with less than one channel symbol per hertz as d.f.m. systems. These are analogous to the divisions of wide-band and narrowband frequency modulation in analogue transmission. Channel symbols are transmitted serially with equal amplitude which ensures that all systems have the same transmitted power. Constant power ensures that the systems are comparable and is a necessary condition in some practical applications. The ratio of the received power to received noise power at the discriminator input is referred to as carrier-to-noise ratio (C). It can be seen from the definition above that in f.s.k. systems the number of channel symbols per second is equal to the transmission channel bandwidth. However, in d.f.m. systems the number of channel symbols per second is less than the transmission channel bandwidth.

2 Theoretical Probability of Error

2.1 Bounds for Optimum Systems

The probability of error due to the presence of Gaussian noise is a topic which has attracted some attention and still holds many problems. The problem of optimum detection has been considered by Arthurs and Dym[1] and bounds established for the probability of error (P_e) for a.s.k., p.s.k. and f.s.k. Given the energy per symbol (E), the number of symbols (m) and the two-sided noise power spectral density (N_0) then for f.s.k.:

$$\frac{1}{\sqrt{2\pi}}\int_{\sqrt{E/2N_0}}^{\infty} \exp(-x^2/2)\,dx < P_e < \frac{m-1}{\sqrt{2\pi}}\int_{\sqrt{E/2N_0}}^{\infty} \exp(-x^2/2)\,dx. \quad (1)$$

These bounds are entirely general for multi-level d.f.m. or multi-level f.s.k.: but the conditions under which they were generated must be noted in order to avoid over-estimating their generality. An outline of the process is given here.

Any set of signals S_i (i = 1 to m) may be represented by

$$S_i = \sum_{j=1}^{k} a_{ij}\phi_j(t)$$

where $k \leqslant m$ and the set of functions $\phi_j(t)$ are orthonormal. The set of coefficients a_{ij} are all real numbers. Computation of a_{ij} is straightforward as

$$a_{ij} = \int_0^T S_i(t)\phi_j(t)\,dt,$$

once the set of orthonormal functions $\phi_j(t)$ has been found. It is the determination of $\phi_j(t)$ that is difficult. For the realization of the bounds quoted in equation (1), the message signals are all sinusoids whose frequencies are harmonics of a common fundamental. This also implies that the message signals are orthogonal and the functions $\phi_j(t)$ easily specified. The detection is then carried out by finding a_{ij} as specified by the equation above. If there are m symbols then m multipliers and m integrate and dump circuits are required. When a particular symbol is sent, all outputs should be zero except one. This leads to a simple decision rule, for equi-probable symbols, that the detector with the maximum output indicates the symbol received. Naturally, the duration of a symbol must be *a priori* known by the receiver.

The lower limit of the integrals in equation (1) is the square root of:

$$\frac{E}{2N_0} = \frac{\text{energy per bit}}{2 \times \text{noise power spectral density}}$$

which should not be automatically equated to the carrier-to-noise ratio in a fixed bandwidth. Noting that these bounds only apply for orthogonal symbols, and optimum detection, probabilities of error can be calculated for various systems. In the binary case the upper and lower bounds coincide and for a system transmitting through a bandwidth equal to the bit rate, $E/2N_0$ = carrier-to-noise ratio. The results for this case are the solid curve on Fig. 2 which is labelled optimum binary f.s.k. Sunde[2] proposed a binary f.s.k. system with zero inter-symbol interference. The probability of error for a Sunde binary f.s.k. system was computed by Mazo and Salz.[3] This is an interesting example as the system uses two orthogonal symbols but does not use optimum detection. However, practical and theoretical curves were in close agreement and within 1 dB of the optimum curve. The error curve calculated by Mazo and Salz is given in Fig. 2 and labelled MS.

The probability of error with optimum detection is sometimes quoted as

$$P_e = \tfrac{1}{2}e^{-C}. \quad (2)$$

This is the probability of error for binary incoherent phase modulation with optimum detection[1] and requires approximately 3 dB less power for the same error rate as optimum f.s.k. detection. A Sunde system generates a continuous sinusoid at each of the switched frequencies and the sum of the power in these sinusoids is exactly half the transmitted power. F.s.k. binary systems have been built, with emphasis and de-emphasis networks,[4] which approach equation (2): but the conditions of white Gaussian noise and an f.m. signal no longer exist. This situation highlights the fact that optimum solutions are only optimum within the conditions specified in their derivation.

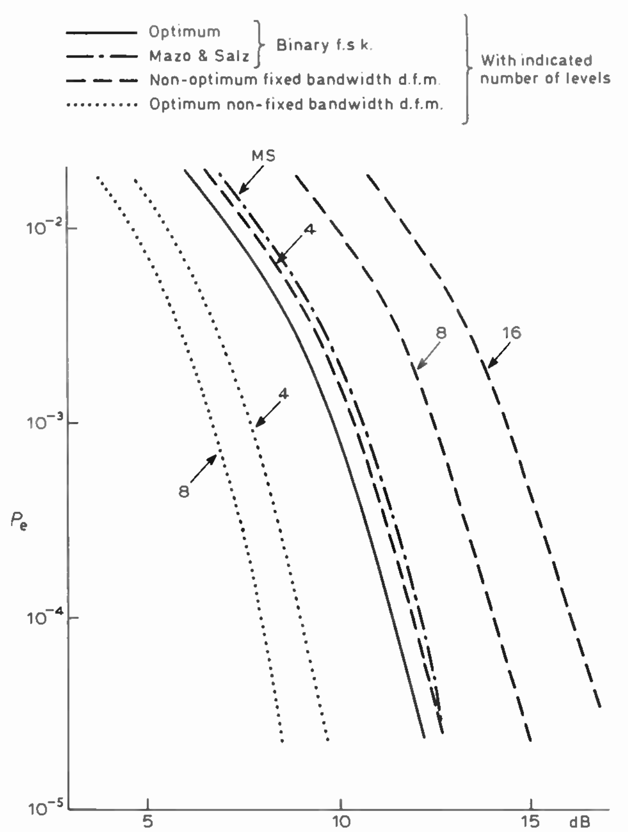


Fig. 2. Probability of error in f.s.k. systems due to Gaussian noise. Constant bit rate.

Moving to d.f.m. systems with 4 and 8 levels respectively the new probability of error can be calculated and the results plotted on Fig. 2 as dotted curves. This has been done with the abscissa $10 \log (E/2N_0)$ rather than carrier-to-noise ratio. The channel bandwidth required to transmit such signals is greater than 1 Hz per bit/s and they are more correctly described as multi-frequency systems. The term multi-frequency is used in this sense by Robin *et al.*[5] although, more recently, it has become accepted as the epithet for multi-tone systems using one or more tones simultaneously (e.g. Ref. 6).

The signal space model for f.s.k., developed by Arthurs and Dym, relies upon optimum detection, constant power, orthogonal symbols and unspecified bandwidth. Therefore, when non-orthogonal symbols, non-optimum detection and a fixed transmission bandwidth are used, the limits of equation (1) must be modified to suit the system.

2.2 Upper Bounds for Non-Optimum Systems

An argument has been developed by the author to give approximate solutions for multi-level systems. If a differentiating frequency detector is used then the total noise in the baseband is given as

$$N_1 = kW_1^3$$

where W_1 is the baseband width and k is a constant whose value depends upon the noise power spectral density and the discriminator transfer function. For n bits per channel symbol and constant bit rate, the binary baseband width can be divided by n. Therefore the ratio of the noise power for binary f.s.k. to multi-level d.f.m. is

$$n^3.$$

Similarly, assuming the maximum and minimum frequencies are held constant and normalized to the binary case, the ratio of the binary eye opening to the multi-level eye in power terms is

$$\frac{1}{(2^n-1)^2}.$$

These two factors can be combined to find the increase (I) in carrier-to-noise ratio required over binary f.s.k. to maintain a particular probability of error:

$$I = 10 \log \frac{(2^n-1)^2}{n^3} \text{ dB}.$$

It has already been noted that the optimum detection value for binary is reasonable for a practical system and therefore the probability of error for d.f.m. systems, with constant bit rate and constant transmission bandwidth, is written:

$$P_e \simeq \frac{1}{\sqrt{2\pi}} \int_{\sqrt{\frac{n^3}{C(2^n-1)^2}}}^{\infty} \exp(-x^2/2)\, dx.$$

The curves for 4, 8 and 16-level d.f.m. are the dashed curves on Fig. 2. It is interesting to note that for the same probability of error, quaternary d.f.m. only requires 0·5 dB more carrier-to-noise ratio than binary f.s.k. Even 16-level d.f.m. ($P_e > 10^{-5}$) requires much less than the 25–30 dB signal-to-noise ratio found in telephone connections even though the detection is non-optimum.

Considering multi-level f.s.k. rather than multi-level d.f.m., the probability of error will now be investigated. Assume the number of bits per symbol, n is increased but the bandwidth is held constant then the upper bound for optimum detection becomes

$$P_e \simeq \frac{2^n-1}{\sqrt{2\pi}} \int_{\sqrt{C}}^{\infty} \exp(-x^2/2)\, dx.$$

In this case the bit rate with n bits per symbol is n times the binary bit rate. However, the channel symbol rate remains constant. To maintain a particular probability of error ($P_e = 10^{-3}$), the carrier-to-noise ratio would have to increase as n increases. The value of this increase is approximately

$$\frac{n-1}{2} \text{ dB}.$$

The increase required becomes smaller as the probability of error becomes smaller. For a practical system, Salz[7] using Cahn's[8] results for phase modulation suggested that the increase required for quaternary f.s.k. over binary should be 5·5 to 6 dB. However, an alternative prediction can be made using the approximate theory generated above for d.f.m. If the system uses slicers after a differentiating discriminator and low-pass filter, the increase in carrier-to-noise ratio required for the same probability of error will rise as $(2^n-1)^2$ and the probability of error is given as:

$$P_e = \frac{1}{\sqrt{2\pi}} \int_{\sqrt{\frac{C}{(2^n-1)^2}}}^{\infty} \exp(-x^2/2)\, dx.$$

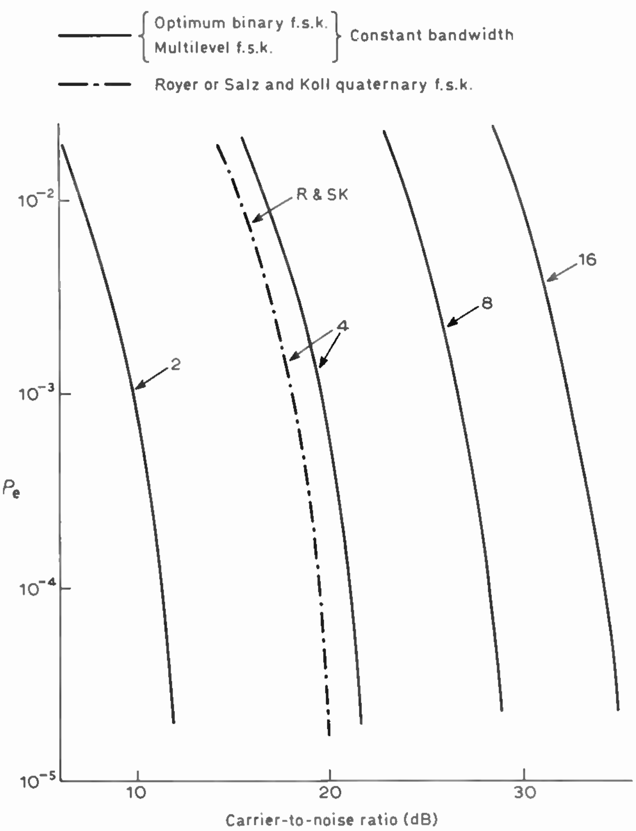


Fig. 3. Probability of error in f.s.k. systems due to Gaussian noise. Constant bandwidth.

Curves using this upper bound for 4, 8 and 16-level f.s.k. are plotted as solid lines on Fig. 3.

3 Practical Results

Practical measurements have been carried out by the author on a binary f.s.k. and quaternary d.f.m. system, both operating at 1200 b/s. The f.s.k. system was a British Post Office Modem 1 and the carrier-to-noise ratio was measured at the detector input. The quaternary d.f.m. system was built using four equally-spaced frequencies; the top and bottom frequencies being equal to the binary frequencies. The transmission bandwidth was the same in each case. The measured probabilities of error as a function of carrier-to-noise ratio, at the discriminator input, are given in Fig. 4 for the two systems. The results for the binary f.s.k. system intersect the optimum binary curve given in Fig. 2.

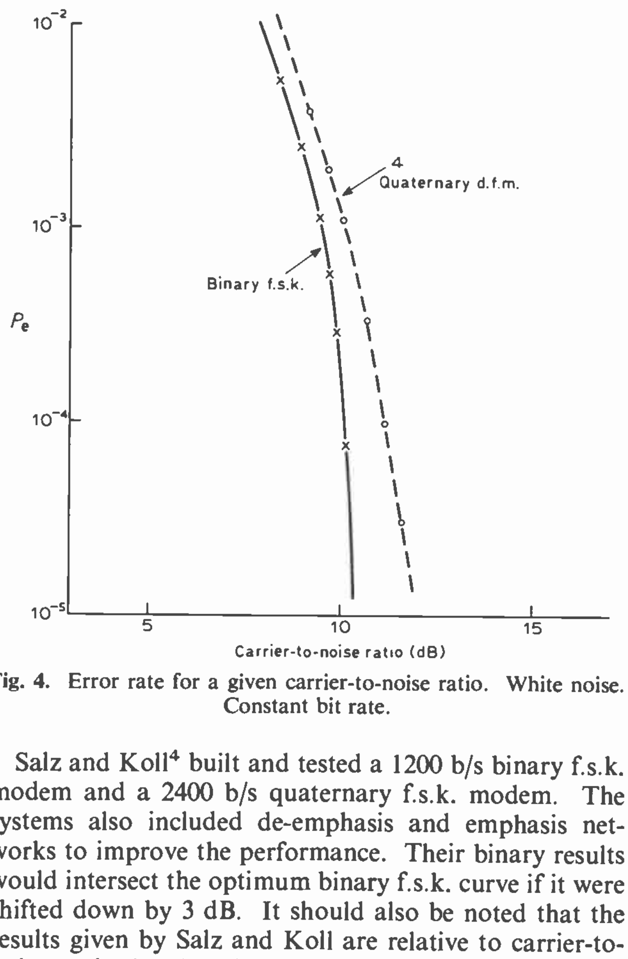


Fig. 4. Error rate for a given carrier-to-noise ratio. White noise. Constant bit rate.

Salz and Koll[4] built and tested a 1200 b/s binary f.s.k. modem and a 2400 b/s quaternary f.s.k. modem. The systems also included de-emphasis and emphasis networks to improve the performance. Their binary results would intersect the optimum binary f.s.k. curve if it were shifted down by 3 dB. It should also be noted that the results given by Salz and Koll are relative to carrier-to-noise ratio in the channel. However, the emphasis network increases the carrier-to-noise ratio at the detector input which might account for the 3 dB difference.

The results from two practical quaternary f.s.k. systems, one by Salz and Koll[4] and a similar one by Royer,[9] are plotted on Fig. 3 and labelled SK and R. The results of Salz and Koll given here are the difference between their binary and quaternary systems plotted relative to the optimum detection binary f.s.k. curve. This excludes the improvement obtained by Salz and Koll by the use of emphasis networks and makes the comparison realistic. Corazza[10] predicted an even higher increase in carrier to noise ratio for quaternary at 12·3 dB: but did consider the figure was excessive because the filters used in the calculation were unsuitable.

4 Observations and Conclusions

It is interesting to note that the approximate upper bound for non-optimum detection, obtained here, is close to the practical results given and is likely to be conservative for two reasons. The noise power spectral density will not be flat across the band, giving lower total noise power at the output, and the statistics of the noise will no longer be Gaussian. Furthermore, the theory presented above treats signal and noise separately and then superimposes the result. Hence only an estimate of the probability of error has been obtained. However, this particular method has gained acceptance in analogue f.m. theory and does give a good estimate of the probability of error.

The results displayed in Figs. 2, 3 and 4 indicate that binary data transmission using a differentiator and slicer for detection operates close to the optimum curve: but multi-level d.f.m. and f.s.k. system using similar techniques are far from optimum. For operation over systems such as the switched telephone network this is of little concern for the d.f.m. systems but is important in the multi-level f.s.k. systems.

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Simple method for analysis of cylindrical antennas at the interface between two media

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SUMMARY

An approximate, but simple and accurate method is presented for determining current distribution along and admittance of thin symmetrical cylindrical antennas situated at the interface between two homogeneous media and driven by a coaxial line.

1 Introduction

The problem of determining circuit and radiation properties of antennas located at or near the interface between two media arises in a number of practical situations. A wire antenna situated at or above a lossy ground, the so-called island antenna, and an antenna buried in the earth are examples of such structures. The problem is a very complex one, and no satisfactory method for solving it appears to be available. Rigorous solution of the problem implies determination of current distribution along the antenna, the electromagnetic field produced by which satisfies boundary conditions at the antenna surface and at the interface between the two media.

The problem of antennas located at the interface between two media can be solved approximately, but in a simple manner, by dividing it into two quasi-independent problems: first of determining (approximately) the current distribution along the antenna, and then determining the electromagnetic field in both media produced by this current distribution. The aim of the present paper is to show that such an approximate two-step solution is possible, and to present a method for obtaining the first part of the solution, i.e. for determining approximate current distribution along a cylindrical antenna located at the interface between two media.

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2 Theory

By a rigorous mathematical procedure Coleman[1] found that along thin, infinitely long straight wires parallel to the interface between two media, with time-harmonic current injected at a point along their length, there exists an exponential mode of propagation of current along the wire. If the wire is located at a distance of several diameters from the interface, the propagation coefficient (in general complex) equals approximately the propagation coefficient of the medium in which the wire is situated. If the wire is located at the interface, the propagation coefficient k of current is approximately given by

$$k^2 = \frac{k_1^2\mu_2 + k_2^2\mu_1}{\mu_1 + \mu_2}, \tag{1}$$

where k_1 and k_2 are the propagation coefficients of the two media, and μ_1 and μ_2 their permeabilities.

Consider a symmetrical dipole of radius a and length $2h$, centre-driven by a belt generator of convenient width to approximate a desired coaxial line excitation,[2,3] and situated (for the moment) in a homogeneous conducting medium of parameters ε, μ and σ. Let the e.m.f. of the generator be V, and its angular frequency be ω. The integral equation for current $I(z)$ along the dipole can be written in the form

$$\int_{-kh}^{kh} I(s)\,\frac{\exp(-jkr)}{kr}\,d(ks) = C\cos kz + \frac{4\pi\mu V}{j\omega}\int_0^{kz} f(s)\sin k(z-s)\,d(ks). \tag{2}$$

In this equation,

$$r = \{(z-s)^2 + a^2\}^{1/2}, \tag{3}$$

$$k^2 = \omega^2\varepsilon\mu(1 - j\sigma/\omega\varepsilon), \tag{4}$$

$f(z)$ is given in Reference 2, and C is a complex constant to be determined.

Now, k represents the complex propagation coefficient of electromagnetic disturbance along the dipole. Assume that the antenna is located at the interface between media of parameters ε_1, $\mu_1 = \mu_0$ and σ_1, and ε_2, $\mu_2 = \mu_0$ and σ_2. Then the propagation coefficient along the dipole is approximately given by equation (1), i.e.

$$k^2 \simeq \frac{k_1^2 + k_2^2}{2} = \omega^2\varepsilon_e\mu_0(1 - j\sigma_e/\omega\varepsilon_e), \tag{5}$$

where

$$\varepsilon_e = 0{\cdot}5(\varepsilon_1 + \varepsilon_2), \quad \sigma_e = 0{\cdot}5(\sigma_1 + \sigma_2). \tag{6}$$

By comparing equations (4) and (6) we see that ε_e and σ_e can be considered as permittivity and conductivity of an equivalent medium. Thus, by simply substituting in equation (4) ε by ε_e and σ by σ_e, equation (2) can be used for approximately determining current distribution along the dipole situated at the interface between the two media. It is also possible to show that with the concept of the equivalent medium the belt-generator approximation to coaxial-line excitation of the monopole remains valid as described in References 2 and 3.

3 Numerical Results

Extensive experimental results are presented by Iizuka[4] for admittance and current distribution of monopole antennas driven by a coaxial line and located at or close to the interface between air and a water solution of sodium chloride. Theoretical results obtained by the present theory were compared with the results of Iizuka. In all the cases agreement was found to be good. As one example, Figs. 1(a) and 1(b) display the theoretical and experimental curves for the monopole conductance (G) and susceptance (B) versus the ratio $\sigma/\omega\varepsilon$ for the solution, for a quarter-wave and half-wave monopole antenna (wavelength measured in the conducting medium). As the second example, Figs. 2(a) and 2(b) show real and imaginary parts of current along a quarter-wave and a half-wave monopole (wavelength measured in the conducting medium) for $\sigma/\omega\varepsilon = 1{\cdot}06$ and $\varepsilon_r = 77$. In all the cases agreement between theoretical and experimental results can be considered to be good.

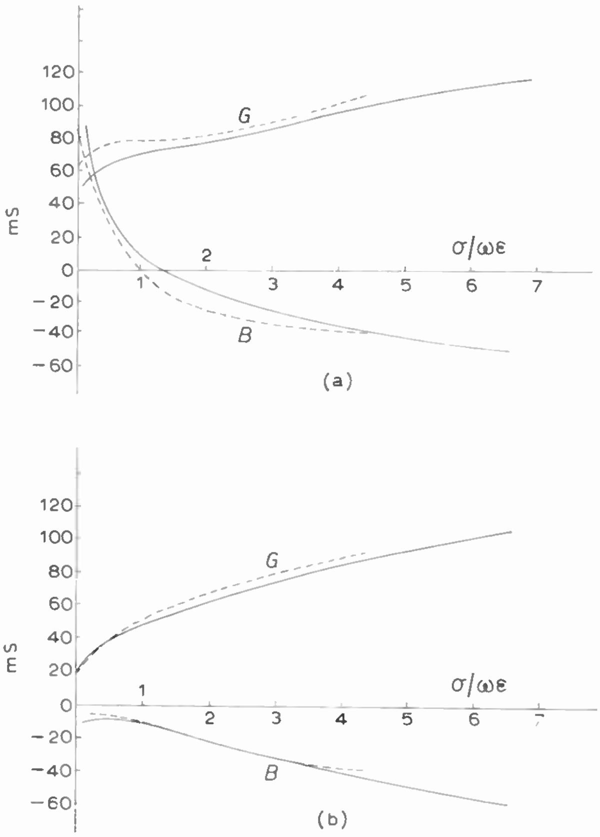

Fig. 1. Conductance (G) and susceptance (B) of monopole antenna located at the interface of air and lossy medium, versus $\sigma/\omega\varepsilon$ of the medium; $a = 0{\cdot}318$ cm, $b/a = 3{\cdot}5$ (see Ref. 2), $f = 114$ MHz. ----- experimental[4]; ——— present theory, 6th-order polynomial approximation for current (a) quarter-wave monopole; (b) half-wave monopole (wavelength measured in the conducting medium).

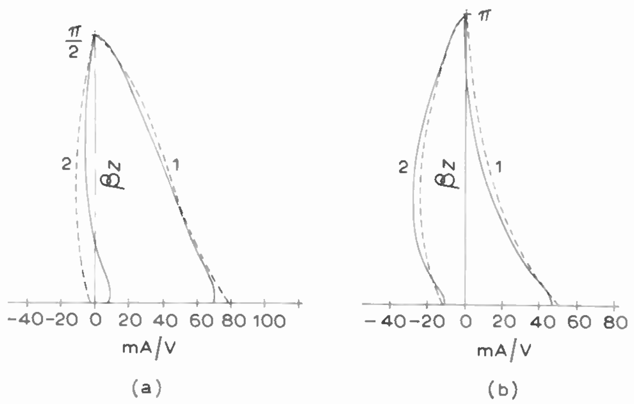

Fig. 2. Real (1) and imaginary (2) parts of current distribution along monopole antennas at the interface of air and lossy medium; $a = 0{\cdot}318$ cm, $b/a = 3{\cdot}5$ (see Ref. 2), $f = 114$ MHz, $\sigma/\omega\varepsilon = 1{\cdot}06$, $\varepsilon_r = 77$. ----- experimental[4]; ——— present theory, 9th-order polynomial approximation for current (a) quarter-wave monopole; (b) half-wave monopole (wavelength measured in the conducting medium).

4 Conclusions

A very simple approximate, but accurate, method is presented for determining current distribution and admittance in the case of cylindrical monopole antennas located at the interface between two media. The essence of the method is the equivalent medium concept, by which the present problem is reduced to a much simpler problem of the antenna in a homogeneous medium. Very good agreement is observed between available experimental results and those obtained by the present theory.

The paper deals only with the case when the antenna (i.e. the antenna axis) is situated exactly at the interface. It should be noted that the antenna parameters change very rapidly when the antenna is moved from the interface in either direction.[4]

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Microwave holographic remote sensing using a Fourier transform/spherical scanning technique

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SUMMARY

Spherical scanning is a very convenient means of mapping a microwave aperture for a localized remote imaging system. Provided that the scan angle does not exceed the derived limits for tolerable spherical aberration, a Fourier microwave hologram, recorded on a spherical surface, yields clearly identifiable, computer-reconstructed images.

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1 Introduction

Previously described methods of 'small scale' microwave imaging, that is to say, excluding radar systems, have utilized a planar aperture over which the microwave field is mapped, e.g. Refs. 1–5. The apparatus for detecting the field distribution, whether a mechanical scanning arrangement, an array of detectors or a liquid crystal panel, usually becomes unsuitable as larger apertures are required. A convenient method of mapping larger apertures is to scan a detector on an arc of fixed radius in two-dimensions so that the recording aperture is part of a spherical surface. In practice, spherical scanning can be readily achieved by attaching a detector to an arm whose centre of rotation is fixed on an elevation over azimuth turntable system. The time taken to form a hologram could be quite short, depending on the maximum driving speed of the azimuth turntable. This method of mapping also offers a means of forming holograms without ancillary scanning mechanics near the region of the hologram, and thus reduces unwanted scattering.

The use of spherical scanning raises the question: will holographic fields recorded on a convex spherical surface yield sufficiently undistorted images? Recording on a plane aperture in the Fresnel zone of the fields scattered from an object involves the usual approximations, and hence limitations, of the phase variation of object waves across the aperture. For the scanning technique envisaged here, the curvature of the recording surface exacerbates the phase errors arising from these approximations, and therefore places a more stringent limitation on the aperture size. Nevertheless, the study of this question has resulted in a working system producing computer-reconstructed microwave images with indiscernible distortion.

2 The Spherical Hologram Formation Geometry

The object distribution is denoted by $D(\underline{x}_1)$, where $(\underline{x}_1) = (x_1, y_1)$. The coordinate system of the formation geometry is shown in Fig. 1 (y_1 coordinate not shown). The field from the object scattered back into an isotropic receiver P, is probed over a spherical surface as P rotates about O. Although not practically desirable for a remote sensing application, the reference source is shown in the object region.

The distance from O_1 to a general point on the spherical recording aperture is given by

$$r_1 = (|\underline{x}_2|^2 + (-z - R_1)^2)^{\frac{1}{2}}$$

where

$$|\underline{x}_2|^2 = (x_2^2 + y_2^2).$$

Using the paraxial approximation $\underline{x}_1 \ll R$, then

$$r_1 = R_1 + \frac{|\underline{x}_2|^2 + z^2 + 2zR_1}{2R_1}. \qquad (1)$$

The reference wave arriving at the spherical surface from a source at O is given by

$$A = A_0 \exp\left\{-\frac{jk}{2R_1}(|\underline{x}_2|^2 + z^2 + 2zR_1)\right\} \qquad (2)$$

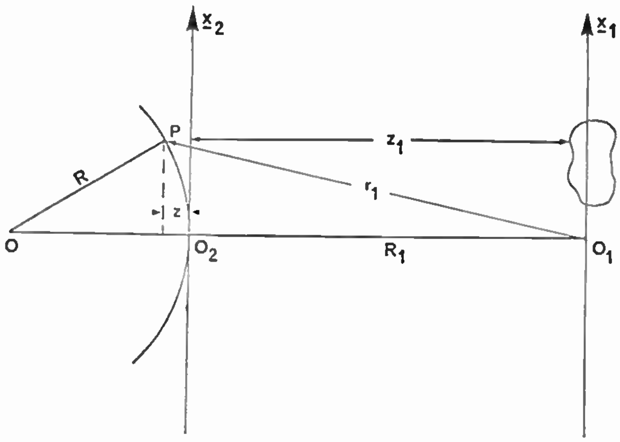


Fig. 1. Formation geometry for spherical hologram.

where constant terms have been neglected.

Similarly, the complex amplitude of radiation arriving at P, scattered from an object distant z, is given by

$$\psi(\underline{x}_2) = \int_x D(\underline{x}) \exp\left\{-\frac{jk}{2z_1}(|\underline{x}_2-\underline{x}_1|^2+z^2+2zR_1)\right\} dx_1 \quad (3)$$

where

$$|\underline{x}_2-\underline{x}_1|^2 = (x_2-x_1)^2+(y_2-y_1)^2.$$

The hologram intensity distribution is then

$$H(\underline{x}_2) = |A|^2+|\psi(\underline{x}_2)|^2+$$
$$+A^* \int_{x_1}\int_{z_1} D(\underline{x}_1) \exp jk\left[\left(\frac{|\underline{x}_2|^2+z^2}{2}\right)\left(\frac{1}{R_1}-\frac{1}{z_1}\right)\right] \times$$
$$\times \exp\left\{-\frac{jk}{2z_1}|\underline{x}_1|^2\right\} \exp\left\{\frac{jk}{z_1}(\underline{x}_2.\underline{x}_1)\right\} d\underline{x}_1\, dz_1 +$$
$$+\text{conjugate term.} \quad (4)$$

The quadratic phase factor

$$\exp\left(\frac{|\underline{x}_2|^2+z^2}{2}\right)\left(\frac{1}{R_1}-\frac{1}{z_1}\right)$$

is clearly due to the aperture surface geometry. However, if the object lies in the same plane as the reference source, then $R_1 = z_1$, and a situation equivalent to the Fourier transform hologram exists.[6,7] Under these circumstances, equation (4) reduces to

$$H(\underline{x}_1) = |A|^2+|\psi(\underline{x}_2)|^2+$$
$$+A^* \int_{x_1} D(\underline{x}_1) \exp\left\{-\frac{jk}{2R_1}|\underline{x}_1|^2\right\} \times$$
$$\times \exp\left\{\frac{jk}{R_1}(\underline{x}_2.\underline{x}_1)\right\} d\underline{x}_1 + \text{conjugate term.} \quad (5)$$

The image-producing terms are conjugate Fourier transform distributions of the object, multiplied by the spherical phase factor which varies rapidly when the recording aperture is in the near field of the object. This result for the two-dimensional object is identical to that obtained from a plane aperture.

There is also a difference between planar and spherical scanning arising from the process of field sampling. The minimum sampling criterion requires equal sample increments in $\underline{x}_2$ across the hologram aperture. As shown in Fig. 2, equal increments of $R \tan \theta'$ made along a plane aperture correspond to increments of $R \sin \theta$ performed on the spherical surface. The two cases are identical when $\tan \theta' = \sin \theta$, and therefore comparable over a small angular range.

3 Small Angle Approximation

If

$$x_2 = x_2' = R \sin \theta,$$

then

$$z = R(1-\cos \theta).$$

Writing

$$\frac{1}{f} = \left(\frac{1}{R_1}-\frac{1}{z_1}\right),$$

the hologram distribution of equation (4) is therefore given by:

$$H(\underline{x}_2') = |A|^2+|\psi(\underline{x}_2)|^2+$$
$$+A^* \int_{x_1}\int_{z_1} D(\underline{x}) \exp jk\left[\frac{R^2}{2f}\left\{\sin^2\theta+(1-\cos\theta)^2\right\}\right] \times$$
$$\times \exp\left\{-\frac{jk}{2z_1}|\underline{x}_1|^2\right\} \exp\left\{\frac{jkR}{z_1}(\underline{x}_1.\sin\theta)\right\} d\underline{x}_1\, dz_1 +$$
$$+\text{conjugate term.} \quad (6)$$

Since $(1-\cos\theta)^2 \ll \sin^2\theta$, the z^2 term may be ignored, resulting in the hologram distribution:

$$H(\underline{x}_2') = |A|^2+|\psi(\underline{x}_2)|^2+$$
$$+A^* \int_{x_1}\int_{z_1} D(\underline{x}_1) \exp\left\{\frac{jk}{2f}|\underline{x}_2'|^2\right\} \times$$
$$\times \exp\left\{-\frac{jk}{2z_1}|\underline{x}_1|^2\right\} \exp\left\{\frac{jk}{z_1}(\underline{x}_2'.\underline{x}_1)\right\} d\underline{x}_1\, dz_1 +$$
$$+\text{conjugate term.} \quad (7)$$

Thus, $H(\underline{x}')$ approximates to the hologram distribution of a three-dimensional object formed on a planar aperture.[8]

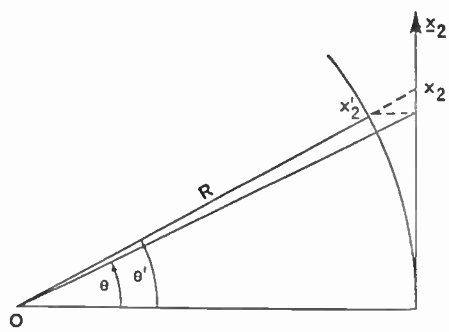


Fig. 2. Comparison of spherical and planar sampling.

4 Fresnel Zone Approximation in Spherical Scanning

In the foregoing analysis spherical wave functions have been replaced by the usual approximation $\exp(\pm jkx^2/2R_1)$, with third and higher order terms neglected. As x/R_1 increases, not only is the paraxial approximation violated, but also the quadratic approximation to a spherical wave is no longer valid. This

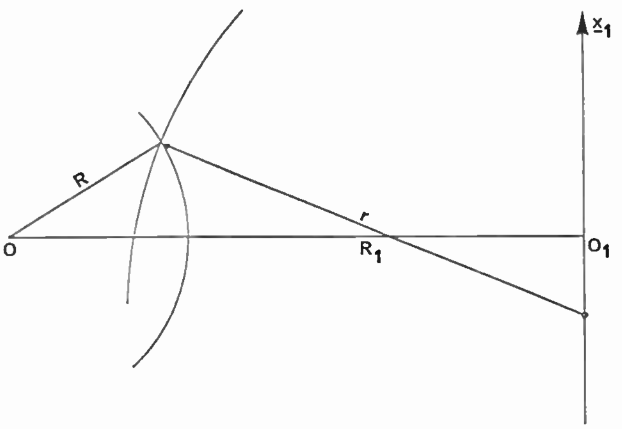


Fig. 3. Off-axis spherical wave arriving at spherical recording surface.

condition produces spherical aberration and hence image degradation.

Consider an off-axis spherical wave arriving at the spherical mapping surface shown diagrammatically in Fig. 3. The third term in the expansion of r is $[(x+x_1)^2+z^2+2R_1z]^2/8R^3$. Following the Rayleigh concept of a maximum permissible phase error across an aperture for tolerable degradation of its point image function, the leading error term in r should have the limit:

$$\frac{k[(x+x_1)^2+z^2+2R_1z]^2}{8R_1^3} \leqslant \frac{\pi}{8}.$$

Substituting $x = R\sin\theta$ and $z = R(1-\cos\theta)$, and following some trigonometrical manipulation, yields the following expression for the limit of θ:

$$\tan\frac{\theta}{2} \leqslant \frac{-2Rx_1 \pm \{4R^2x_1^2 - [4(R^2+RR_1)+x_1^2-(\tfrac{1}{2}\lambda R_1^3)^{\frac{1}{2}}][x_1^2-(\tfrac{1}{2}\lambda R_1^3)^{\frac{1}{2}}]\}^{\frac{1}{2}}}{4(R^2+RR_1)+x_1^2-(\tfrac{1}{2}\lambda R_1^3)^{\frac{1}{2}}}. \qquad (8)$$

In comparison to the corresponding limit for a planar aperture, $x^4 \leqslant \lambda R_1^3/2$, a spherical mapping surface reaches the Fresnel limit at a smaller aperture. The comparison is shown graphically in Fig. 4 for the conditions $R_1 = 15$ m, $R = 4{\cdot}5$ m and $\lambda = 0{\cdot}03$ m. Clearly, there is a sufficient angular excursion in this case to provide a recording aperture of approximately 100λ dimension.

5 Experimental System for Fourier Holograms using Spherical Scanning

An outdoor antenna test range has been used for mapping fields scattered from objects in a natural environment. A synchro-controlled elevation over azimuth positioner is mounted 5·0 m above the ground, and a flared waveguide antenna probe is fixed to the free end of a rigid arm attached to the elevation positioner. The probe can be scanned automatically over a spherical surface, with a radius of curvature of 4·5 m.

In order to maximize the remote sensing capability, either an off-axis reference wave of the required radius of curvature could be introduced physically into the

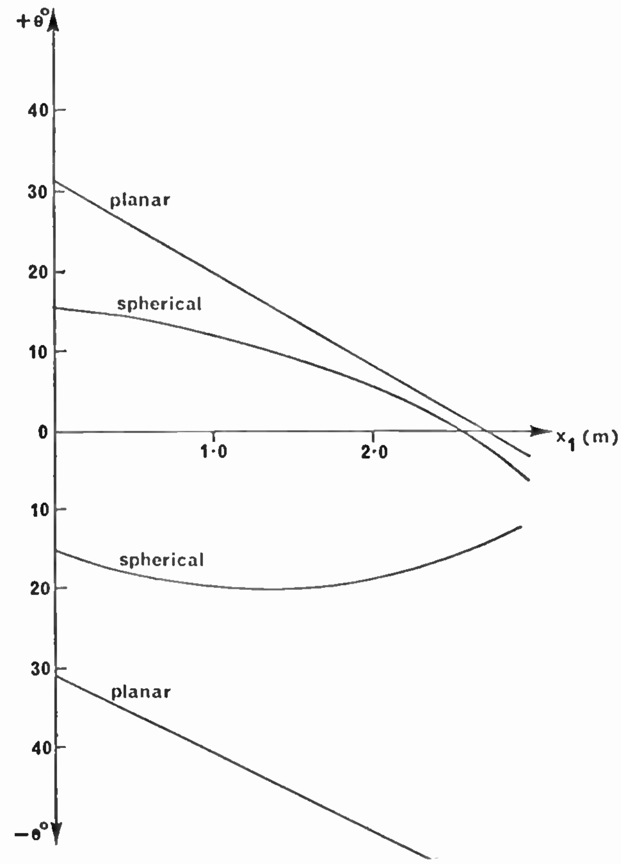


Fig. 4. Fresnel approximation limits for spherical and planar apertures.

microwave receiving system, or a phase and amplitude receiver could be used to record the field directly. In the present case, the reference wave distribution was introduced spatially in a manner analogous to optical holography, as shown in Fig. 5. The separation of reference source and object was set so that, on reconstruction, the image would not interfere with the autocorrelation distribution.

The object region was illuminated by a separate antenna fed from an X-band travelling-wave tube delivering approximately 1 W. The reference signal is coupled from the X-band source and made approximately equal to the maximum signal from the object regions.

The maximum permissible scan angle for this experimental configuration was obtained from equation (8) and found to be $\pm 15°$ in azimuth and elevation. The incremental sample angle was chosen to satisfy the minimum sampling criterion for adequate recording of object/reference fringes. The probe mapped the hologram field in raster format, incrementing in azimuth and scanning in elevation, giving a total of approximately 1270 samples. The receiver output was quantized into 1000 levels and recorded on punched paper tape.

6 Experimental Results

The viability of the imaging technique has been tested using metal targets with maximum dimensions of approximately 30 microwavelengths at X-band. A holo-

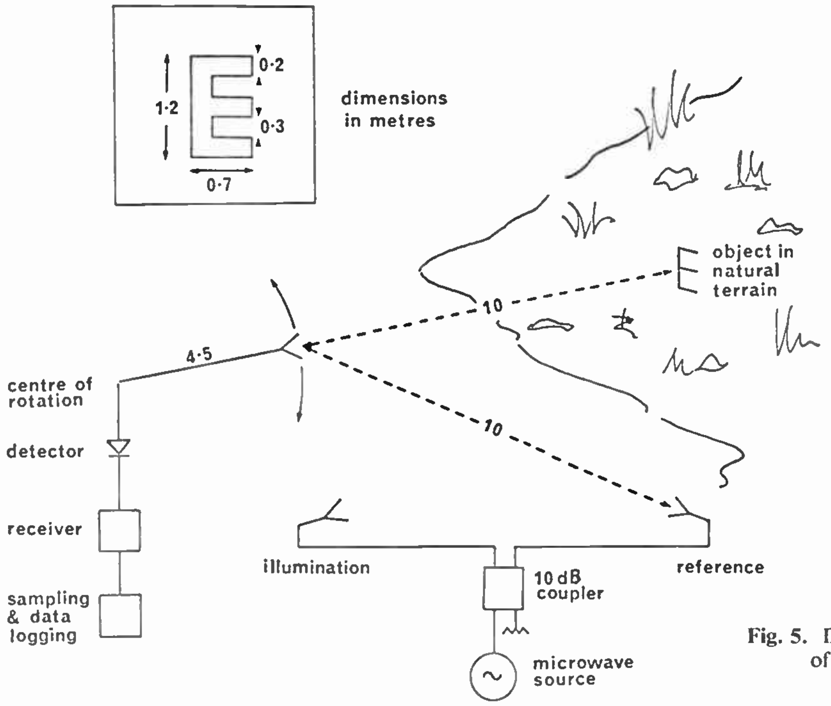
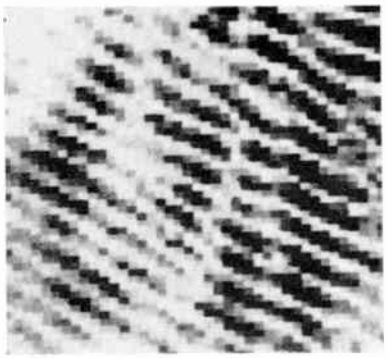


Fig. 5. Diagrammatic representation of experimental system.

gram was formed for the letter 'E', placed in the outdoor environment as shown in Fig. 6. The dimensions of the target are also given in Fig. 5 (inset) where the bars and spaces of the letter correspond to approximately twice the diffraction limited resolution of the aperture (considered planar). The measured hologram distribution, printed out in 8-levels on an intensity display system,[9] is shown in Fig. 7. Operation on this hologram data using the fast Fourier transform (F.F.T.) algorithm yields directly the image field distribution shown in Fig. 7. The target shape is seen to be clearly resolved although there is some expected deterioration of the edges. The display also shows the conjugate image and the autocorrelation response, duly separated by the function of the off-axis reference wave.

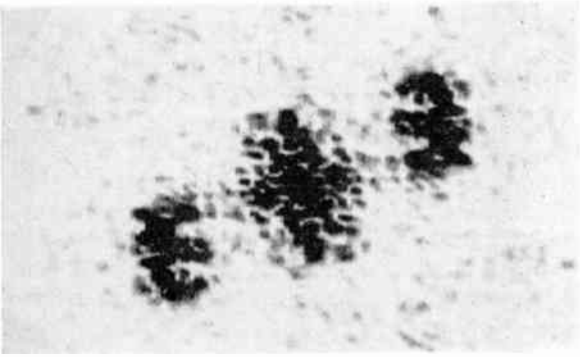
Another test-target is a metal triangular shape with dimensions shown in Fig. 8. The microwave image, shown alongside and excluding the autocorrelation and conjugate, indicates non-uniform illumination of the object. This effect can arise from ground reflections, which suggests that a transmit/receive scanning system (avoiding fixed illumination) might be considered as a superior alternative.

The quality of these images compares well with those obtained from a computer simulation of the experimental imaging system. As indicated in Fig. 9, the letter 'E',



(a) Recorded hologram (8 levels shown).

Fig. 6. Letter 'E' in natural environment.



(b) Computed reconstruction from experimental data.

Fig. 7.

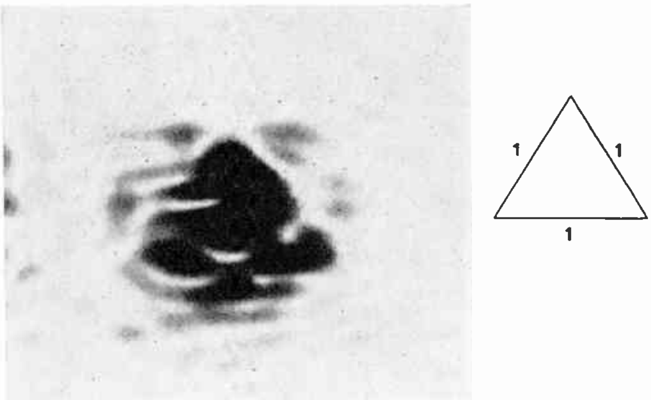
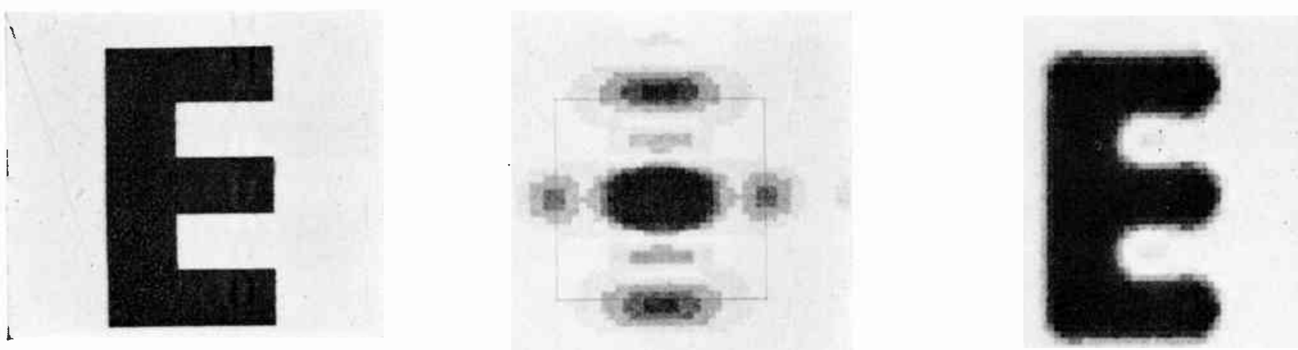


Fig. 8. Object dimensions (in metres) and microwave image.



(a) Object input data.

Fig. 9.

(b) Fourier transform distribution showing data window.

(c) Reconstructed object shape.

represented on a 40×40 element grid, is converted to its Fourier transform distribution using the F.F.T. The distribution is truncated by a window function corresponding to the experimental aperture, assumed to be planar. On performing the inverse transform the diffraction limited image is obtained and displayed in 8-levels. It is observed that the tendency for the spaces in the letter E to be filled in is predicted by simulation. However, recognition is clearly achieved since the criterion of capturing the significant lower spatial frequencies[10] has been met. The experimental result is therefore encouraging since it was obtained despite non-uniform illumination of the object and backscatter from the surrounding terrain.

7 Conclusions

Microwave holographic imaging may be performed using a Fourier transform spherical scanning technique. The permissible angular excursion is sufficient to conveniently provide adequate aperture dimensions without attempting any compensation. The technique is suitable for localized remote sensing of targets. Images of strong scatterers, typically a few tens of microwavelengths in dimension, are clearly resolved from a natural environment background. The images are substantially undistorted and correspond satisfactorily with those predicted computationally.

Spherical scanning is a microwave imaging technique worthy of further development to produce higher resolution and penetration of the surrounding environment. Because of the mechanical simplicity of spherical scanning, it could form the basis of a mobile remote sensing and imaging system.

8 Acknowledgment

The authors gratefully acknowledge the financial support from the U.K. Science Research Council for their microwave remote sensing studies.

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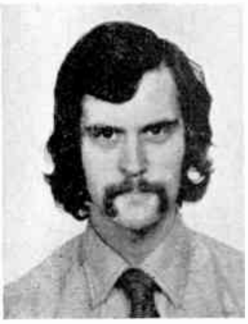
Contributors to this Issue

S. J. Mawani graduated from the University of Sheffield in 1972. He is currently reading for the degree of Ph.D., the subject of his research being microwave imaging using microwave lenses.

Alan Anderson obtained his Ph.D. at University College London for research into millimetre waves, and then went to Ferranti Ltd. where he was employed on the development of microwave parametric devices. He subsequently joined RCA and worked on the design of microwave transistors until taking up an appointment in the Department of Electronic and Electrical Engineering at the University of Sheffield in 1967, where is now a Senior Lecturer. His research interests are microwave holography, coherent optics and active antennas.



D. G. Jones graduated in electronic and electrical engineering at the University of Sheffield in 1971. Last year he was awarded a doctorate by the University for his thesis on microwave holography.

J. C. Bennett received the B.Eng. and Ph.D. degrees from the University of Sheffield in 1970 and 1974 respectively. Since 1972 he has been a Lecturer in the Department of Electronic and Electrical Engineering of the University of Sheffield. His research interests involve microwave image enhancement and the application of microwave techniques to remote sensing and antenna metrology.

Crisis in the Electronics Industry

Considerable disquiet has risen within the British electronics industry (among others) during recent months on the problems set by the influx of Japanese television sets and transistor radios. Quite recently a delegation from Japan visited Western European countries, including Great Britain, to discuss the general problems of Japanese competition, but earlier in the year three leading British electronics companies drew the attention of the Secretary of State for Trade to its anxiety at Japanese undercutting of British manufacturers within this country.

On 10th August Professor William Gosling, a Vice-President of the Institution and Professor of Electronics at the University of Bath, was interviewed on the BBC radio programme 'The World at One' and asked to explain the technical background.

Professor Gosling began by saying: 'Basically we have fallen behind because we have not put the money into microcircuits that is needed. It is a very expensive industry to get started in, and in the United States vast amounts of money have gone into the microelectronics industry through defence and space spending. In Japan the government pursues a more interventionist policy with industry and has put a great deal of money into it directly. We have not done either of these things. We have unfortunately just gone along on rather small government investment and the resources that industry can put into it and I am afraid that they just have not been enough.'

Asked to explain the importance to the country of this situation he said that he did not think the public generally realized how big the microelectronics revolution was. 'It is *the* major technological revolution of the twentieth century and makes nuclear power look trivial by comparison. The whole of the future of our industry is going to be dependent on electronics and electronics is going to be dependent on microelectronics.'

'Already Europe is importing about half its microcircuits from abroad, mainly from the United States. All the projections show that that trend will get much worse and we shall probably end up by the end of the decade importing something like 80% of our microcircuits. This is a disastrous situation, quite as bad as being dependent on foreign oil. We shall be dependent on foreign microelectronics which is as crucial to our economy, if not more so.'

The interviewer wondered whether this was a case for government aid or whether it was a lack of foresight on the part of electronics companies. Professor Gosling said that he believed that we should first of all look to Europe, where markets large enough to support a vigorous microelectronics industry could be found. He agreed that government investment was essential, as had been shown in other countries where a successful microcircuit industry had been launched. In concluding the interview, Professor Gosling said that he had reluctantly to agree that restrictions on imports of television and radio receivers would be necessary, though he hoped that it would only need to be a temporary expedient.

IERE News and Commentary

The 51st Annual General Meeting of the IERE

Held at the London School of Hygiene and Tropical Medicine on Wednesday 6th October, 1976.

The meeting was opened by the President, HRH The Duke of Kent at 6 p.m., when 45 Corporate Members had signed the Attendance Register.

The Secretary, Mr. G. D. Clifford, confirmed that due notice of the meeting, the Fourteenth Annual General Meeting of the Institution since Incorporation by Royal Charter, had been sent to all members in the June issue of *The Radio and Electronic Engineer*, with the nominations for election to the 1976/77 Council. The Notice and Agenda of the meeting had been published in the August/September issue of the Journal.

The Secretary further reported that the Minutes of the Fiftieth Annual General Meeting, held on 8th October 1975, had been published in the November 1975 issue of *The Radio and Electronic Engineer* (Vol. 45, No. 11, pp. 68–91). The President stated that there had not been any comment received on these minutes and his proposal that they be taken as read and signed as a correct record was agreed unanimously.

The President informed the meeting that it had become necessary to conduct a ballot for the election of three Members to fill vacancies on the Institution's Council for 1976/77. At his request the Secretary outlined the procedure for the counting of the votes and, through the President, asked for five Corporate members among those present to volunteer to act as scrutineers. Messrs. S. J. H. Stevens (Fellow), J. B. Bennett, J. D. Buffin, M. G. Hansen, and V. J. Phillips (Members) offered their services in this capacity. The Secretary said that the scrutineers would be required to report the result of the ballot to the President, if possible before the end of the meeting; otherwise the result of the election would be published in *The Radio and Electronic Engineer*.

The Annual Report of the Council

His Royal Highness then presented the 50th Annual Report of the Council for the year ended 31st March 1976 which had been published on pp. 431–448 of the August/September issue of *The Radio and Electronic Engineer*.

He began by saying that before going any further he had to make it quite clear that he accepted no responsibility for the opening paragraphs of the introduction to the Annual Report!

'I make this disclaimer not because my own year of office has been a difficult one—far from it—but because I believe that progress in a body such as this can only come about as the result of collective rather than individual efforts. Any contribution that I may have been able to make has only been possible as a result of the help and support I have enjoyed from my Vice-Presidents and fellow Council members. I cannot express too strongly my gratitude to them and I recognize also the excellent work of those members who serve on our various committees and those who have represented us in our relations with other organizations. I have found too that our Past Presidents and other officers continue to give their services unstintingly in many ways. On my own behalf and that of all members I thank them most warmly for their help in guiding our Institution through a year that, as the Report before you indicates, has not been without it problems. I do not intend to dwell on these, because they have been shared with most other organizations in this country and I am confident that we shall overcome them as we have many others in our 50 years and more of existence.

'Since this past year has seen the celebration of our Golden Jubilee I know you will expect me to touch on some of the activities that have distinguished this unusual year. Foremost among these must I believe be the Institution's continuing efforts towards strengthening and enhancing the position of its members as engineers.

'Too often the registered professional engineer is at a material disadvantage compared with his fellows in other professions and trades. The gaps in University courses and

(*Photograph above*) The Director, Mr. G. D. Clifford, reports to the President and members the procedure for the ballot for the election of Members to Council which will be necessary.

the difficulty firms have in recruiting suitably qualified engineers of all kinds are witness to this. There is certainly no easy solution to what is undoubtedly a serious national shortcoming, but one way of helping to overcome the problem is to make certain the high standards demanded as qualification for membership of the appropriate professional body are fully maintained and recognized. It was in order to secure this recognition that our Institution gave its sponsorship to the formation of the Council of Engineering Institutions.

'Many of you will be aware of the protracted and complex debate that has been going on during the past two years about the CEI's structure and composition. Part of this debate has focused on the issue of the relationship between the CEI and its member institutions and the CEI has recently announced a major revision of its Charter and Bye-laws which will include changes in the composition of its Board.* These changes reflect the views of this Institution and should, we believe, result in members of the various professional institutions having a more representative voice on the CEI Board.

'It is also I believe of interest to note that as a result of submissions by your own as well as sister institutions, the CEI intends allowing greater latitude in recognizing alternative sources of qualifications, such as the CNAA degree. These are I believe significant steps along the road to enhancing the engineer's standing and to attracting more recruits into the engineering professions. In accordance with this declared objective the Membership and Examination Committees were, I know, determined to provide new and higher records to mark our Golden Jubilee; our standards were in no way sacrificed and yet we ended the year with a slightly better return than many of our sister Institutions. Nevertheless the report shows the intensity with which these Committees study the need to encourage the development of our technology—as required by our Charter—by promoting recruitment based on the present and especially the future qualification needed of the truly professional engineer.

'This leads me to what I have found to be one of the most interesting aspects of my Presidency—I refer to that part of the Institution's work described as our learned society functions. These must have achieved unexcelled activity at all levels—whether it be the Local Sections providing a forum for discussing original papers (and the consistently high standard of these is most encouraging) or the various conferences and colloquia arranged through the Council's Central Committees. I must mention just two of these: first a conference on Electronics in Medicine was held at Southampton in April and the attendance and subject matter reflected the great importance attached to this growing area of our science. The second was of course our Golden Jubilee Convention at King's College, Cambridge and I believe all who attended it agreed that this outstandingly successful event was in every way an appropriate climax to our Jubilee Year. The theme of the Convention—Electronics in Society—was chosen to remind delegates of the central place which our technology of electronics now occupies in the life of the country, both economically as well as socially, while its setting at Cambridge could not have been bettered as a background to our learned discourses and discussions.

'We all know that it is impossible to please all the people all the time but without any doubt in this past year your Council has achieved success far above the average and must have managed to give at least 90% of the membership some intellectual satisfaction. No doubt if the money were available we could improve on that and even satisfy the magic 100%!

* See page 565 of this issue.

'That however leads me on to the next topic on our Agenda, where as you will see I shall happily follow precedent by handing over the presentation of our Accounts to the Honorary Treasurer. He will have the unfortunate task of explaining why we cannot have a quart of membership service out of a pint of subscription!

'However, before I turn to the money side there are two last subjects I must touch upon. Your Council, looking to the future as always, have for some time been seeking a permanent headquarters for the Institution which would more closely meet its needs at the most reasonable cost. If all goes according to plan we ought shortly to have a new headquarters not far from London which I am confident will enable the Institution to provide an even better service to all its members than before.

'This brings me to my final duty which is both a happy and a sad one. The happy part is to welcome Air Vice Marshal Sinclair Davidson who has been appointed Secretary Designate of the Institution and is due to take up his task in April next year. I congratulate him and, as a soldier, am delighted to offer my best wishes to a distinguished officer of a sister service. I know we all wish him well in his appointment.

'This is the last Annual General Meeting which Mr. Graham Clifford will be attending as our Secretary. I am not sure what his total score of A.G.M.s must be but I do know that when he hands over this office to Air Marshal Davidson next April he will have occupied it for exactly forty years! This in itself must constitute all kinds of records and it covers, I would remind you, a little less than four-fifths of the total lifespan of this organization. It would be quite impossible for me to thank Mr. Clifford adequately but I am sure it is no exaggeration to say that the IERE's debt to him is incalculable. He has served this Institution with unlimited dedication and devotion and whatever position and influence the IERE now enjoys in engineering circles is due very largely to his labours. Mr. Clifford, I can only say the warmest possible thank you from us all, together with our very best wishes to you and your wife for the future.'

The President then formally moved the adoption of the Institution's Annual Report, which was approved unanimously.

Auditors' Report, Accounts and Balance Sheet

The President called upon the Honorary Treasurer, Mr. S. R. Wilkins, to propose the adoption of the Institution's Accounts for the year ended 31st March 1976.

Mr. Wilkins began by saying that he had been tempted to preface his presentation of last year's accounts with the Latin tag 'Sic transit gloria'. This was because just two years ago he had said that it was a great relief that on his first appearance as Honorary Treasurer he could report that the Institution had spent less than it received. This year he was sad to report that we had a deficit on the income and expenditure account. Such is short lived glory!

'However, in the year in which Your Royal Highness presided over our affairs my colleagues on the Finance Committee resolved to make a really good show. We even persuaded the Executive and Membership Committees to add to their heavy programme by discussing with us ideas on improving our financial position.

'We then resisted all the efforts of our Director and Secretary to employ the staff he considered necessary for implementation of the decisions of our various Standing Committees. As the architect of our Annual Report, Mr. Clifford has diplomatically avoided the fact that my predecessors used regularly to refer to the number of staff employed. I feel, however, that members should know that we now have a smaller staff—36—than we have had for some twenty years.

'I pointed to this economy at last year's Annual General Meeting and refer to it again because the Finance Committee recognizes that the cost of staff is one of our highest commitments. And by cost I include all the ancillary charges that we now have to meet in pension, National Insurance, etc. which have increased so much both for employer and employee. For these reasons we owe a special debt of gratitude to a smaller staff who have identified themselves with the objects of the Institution just as much as have our members.

The President and other officers listen intently to Mr. Sydney Wilkins's presentation of the Accounts

'Your Royal Highness has shown considerable understanding of the external influences which have affected our finances. Would that I could report *not* a reduction but a holding position on such costs as rent, rates, postage and telephone, paper and printing. But I am not the Chancellor of the Exchequer. I am an engineer trying to balance the accounts of our voluntary society—and, Mr. President, I mention that our membership is voluntary because I think it is a pity that so many engineers benefit from the work of such Institutions as our own but do not support us.

'Even so our own Institution has a remarkable 40-year record created by the hard core of our members in providing a continuous record of a constantly increasing revenue from subscriptions and from the sale of our publications and the current year's income will maintain this record.

'We members in our private and business lives are only too well aware of external influences in taxation, increased cost of materials, rates, etc. in whittling down the value of increased income, but at least we have, in the Institution, shown an ability to contain inflation and will survive our present crisis if only the rate of inflation can be arrested. Meanwhile, I assure my fellow members of the Council's determined efforts to resist inflation by economy and enterprise in Institution administration. We still need the cooperation and help of all our members.

'My Committee has, Mr. President, continued its promise to make our accounts easily understandable and these hardly need explanation if coupled with the appropriate section of the Annual Report. Obviously I would like to indulge in forward thinking but today this is a dangerous occupation. I do report, however, that with six months gone in our current financial year we are in a very much better position, thanks to the acceptance of members to the rate of increased subscriptions. I believe that if costs beyond our control can be restrained I may yet one day have the pleasure of reporting, as I began, an excess of income over expenditure.

'With the help of our auditors, who are present, I shall be pleased to answer questions. Otherwise, I ask that Your Royal Highness will permit me to propose adoption of the Institution Accounts for the year ended 31st March last.'

There were not any questions from the Meeting and the Treasurer's proposal for the adoption of the Accounts, Balance Sheet and Auditors' Report was carried unanimously.

Election of Officers and Council for 1977

The President said that except for the class of Member there had not been any opposing nominations to those made by the Council and circulated to Corporate Members by a notice dated 26th June 1976 in the June 1976 issue of *The Radio and Electronic Engineer*. His Royal Highness continued:

'We are therefore honoured that we should have as our new President, Dr. P. A. Allaway.

'Professor D. E. N. Davies, Professor W. A. Gambling, Mr. D. W. Heightman, Professor J. R. James and Mr. John Powell are re-elected as Vice-Presidents, and we welcome the election of Professor W. Gosling and Mr. R. C. Hills, the former for a second term in this office.

'Mr. L. A. Bonvini, Sir Raymond Brown and Mr. L. F. Mathews are elected to fill vacancies for Fellows, and we await the report of the scrutineers on the ballot for the election of three Members.* Lieutenant Commander J. Domican, RN, is elected as an Associate Member, and Mr. T. D. Ibbotson as an Associate.

'Mr. S. R. Wilkins is re-elected as Honorary Treasurer and the remaining members of Council will continue to serve in accordance with the period of office laid down in Bye-law 48.'

His Royal Highness said that he could not let the occasion pass without expressing appreciation for the services of the retiring members of Council. On relinquishing the office of President he wished also to record his thanks and appreciation for the valued support of all members during the past year.

Appointment of Auditors and Solicitors

The President said that he proposed to combine Items 5 and 6 of the agenda, namely the appointment of auditors and solicitors, and he asked for members' approval to the re-appointment of Gladstone Jenkins and Company as the Institution's Auditors, their remuneration to be at the discretion of the Council, and the re-appointment also of Braund and Hill as solicitors to the Institution. This motion was carried unanimously.

Presentation of Premiums

The President then called upon Mr. F. W. Sharp, Editor of the Institution's publications, to describe the prizes and introduce the winners.

Nine of the annual Premiums were to be awarded for 1975 and details were published in an Appendix to the Annual Report. Mr. Sharp reported to the President that the recipients of two of the Premiums were resident abroad and were not able to be present in person to receive their awards. Dr. R. Smith, the Counsellor for Nuclear Energy at the Australian High Commissioner's Office in London,

*It was not possible for the scrutineers to complete their task until some time after the conclusion of the Annual General Meeting. The result was declared next day and published in the October issue of the Journal. Mr. N. G. V. Anslow, Mr. K. Copeland and Group Captain J. M. Walker were declared elected.

H.R.H. The Duke of Kent hands the Heinrich Hertz Premium to Dr. R. Smith

The first award of the Sir Henry Jackson Premium is made to Mr. R. J. Cox

Books and a certificate are handed to Mr. P. D. L. Williams for his Brabazon Premium

Congratulations from the President to Mr. W. A. Evans on being awarded the Wheatstone Premium

The President asks Dr. Nelson Blachman to accept the Charles Babbage Premium on behalf of two American authors

The President and Dr. Heppinstall are obviously wondering what Mr. Clayworth is receiving for his share of the Bulgin Premium came forward to accept the Heinrich Hertz Premium on behalf of Mr. F. E. Cook and Mr. C. G. McCue of the Ionospheric Prediction Service, Department of Science, Australia, while the Charles Babbage Premium, awarded to Dr. J. L. Tomlinson of the State Polytechnic University, Pomona, California, and Dr. H. H. Wieder of the Naval Electronics Laboratory Center, San Diego, California, was received on their behalf by Dr. Nelson Blachman of the Office of Naval Research, US Navy, London.

Any Other Business

The Secretary reported that he had not received notice of any further business. Sir Ieuan Maddock (Past President) rose and asked those present to join him in thanking His Royal Highness the Duke of Kent for the way in which he had fulfilled his year of office and the amount of time he had devoted to the Institution, both by attending meetings and making visits. Sir Ieuan said that the tutelage given in the art of chairmanship and his pungent comments on the Institution's affairs had been especially appreciated. These remarks were warmly applauded and His Royal Highness thanked Sir Ieuan and those present, and declared the Meeting closed at 6.40 p.m.

After a brief adjournment, members and guests reassembled to hear the Presidential Address of Dr. Percy Allaway. Welcoming Dr. Allaway, His Royal Highness said that it was the Institution's custom to inaugurate a new President by asking him to give his views on some of the broad issues facing the electronic and radio engineer and his profession.

'Dr. Allaway has had no lack of experience in facing up to difficulties. His whole working life has been in radio and electronics and he well knows the problems which beset the earlier years of radio and television coupled with the economic depression of the thirties.

'Our new President has shown his concern for improving opportunities for successive generations of engineers, and his service to our Institution and to Universities has been recognized by the honour given to him by Brunel University. I will not attempt to relate the list of Dr. Allaway's public services on Government and other Committees; we met as members of the Institution and as members of the National Electronics Council. In both capacities I have found him a forthright colleague, generous in the time and thought he gives to honorary labours in the interests of his country and profession.'

Dr. Allaway presents his Inaugural Address.

His Royal Highness then invited Dr. Allaway to give his Presidential Address (which will be published in the January 1977 issue of *The Radio and Electronic Engineer*).

The appreciation of all present was expressed by Mr. W. P. Nicol (Fellow) who said that Dr. Allaway's Address would give everyone much to think about. In particular he had brought out the importance of design and quality, which should be borne in mind as a conscious policy by all engineers.

CEI Board Agrees Reorganization

As foreshadowed in the August/September Journal, a decisive stage in the reorganization of CEI was reached on 22nd September when the Council's Board ratified constitutional changes made at its last meeting in July. The way is now clear for these to be submitted this month to the Privy Council for its consideration, a process likely to take about nine months. The Special Resolution, passed without dissent by the Board, was to the effect 'That this Council approves the draft Supplement Charter and By-Laws and draft Petition as submitted to this meeting and resolves that the Common Seal of the Council be affixed to the said Petition.'

Following the meeting, CEI's Chairman, Mr. Tony Dummett, said: 'After two years of protracted discussion on this controversial and complex issue we can now shape CEI into an organization that can more fully reflect the vital role played by the professional engineer in contributing to Great Britain's economy and to the wellbeing of its society as a whole. The decision reached today in effect produces a blueprint for the engineering profession which will enable the views and aspirations of individual chartered engineers, as well as those of their professional institutions to be given fuller consideration than has been possible hitherto.'

During the meeting the representative of the Institution of Electrical Engineers stated that it was the IEE's intention to withdraw its notice of resignation, an announcement welcomed by the Board Members.

The agreements reached by the Board in July and ratified on 22nd September will result in a membership of CEI comprising individual chartered engineers on the one hand and corporate bodies—including non-chartered ones as Affiliates—on the other. They will also allow for free national elections of individual chartered engineers to the new Board using the single transferable vote. At the same time the Board's composition will be representative of all the chartered engineering institutions by the nomination of one representative from each of the Constituent Members.

Announcements

Gifts to Mark a Fiftieth Birthday

Just over twelve months have now elapsed since the Institution began the celebration of its 50th anniversary, and reports have appeared in the Journal of the Banquet in the Guildhall, of the service at St. Clement Danes, and of the Golden Jubilee Convention at Cambridge in the summer. It is pleasant to record, too, the way in which our anniversary has been noted by sister Institutions, who sent appropriate gifts to convey their congratulations.

The list of donors and their gifts is as follows:

The Council of Engineering Institutions—an atmospheric clock

The Royal Aeronautical Society—a mounted presentation model of the *Sea Wolf* guided missile

The Institution of Electrical Engineers—an inlaid walnut bureau

The Institute of Marine Engineers—'The London Plate' (a decorated china plate with the coats of arms of the City and its Companies)

The Institution of Mechanical Engineers—a desk set in onyx comprising a clock and two pens

The Institution of Production Engineers—an inscribed silver salver

In addition, the Directors of Barclay's Bank Ltd., the Institution's bankers, gave a pair of silver goblets.

Conference on Crime Countermeasures—Science and Engineering

The second International Conference on 'Crime Countermeasures—Science and Engineering'—is planned for July 26th–29th, 1977, at Oxford University; it is being jointly sponsored by the University of Kentucky and the University of Oxford. The first conference was held at Edinburgh in 1973. This conference is specifically directed toward new and advanced concepts and developments in the science and engineering of crime countermeasures as well as the presentation of papers dealing with the operational aspects of crime prevention, law enforcement, and industrial and Government security. Radio and electronics topics feature prominently in the subjects on which papers are being invited. The 'Call for Papers' sets a deadline for 200 word abstracts of 14th January 1977; papers, which are to be refereed, are required by 4th April 1977.

Further information may be obtained from: Mr. George C. Byrne, Conference Chairman, Stanford Research Institute, Menlo Park, California 94025.

Dr. Dennis Shaw, C.B.E., Keeper of Scientific Books, Radcliffe Science Library, Parks Road, Oxford OX1 3QP.

Professor John S. Jackson, Department of Electrical Engineering, University of Kentucky, Lexington, Kentucky 40506.

The Clerk Maxwell Lodge

Mr. Donald A. Taylor has been elected as the 22nd Master of the Clerk Maxwell Lodge for the year 1976–77.

The Lodge is supported by a number of members of the Institution and information regarding Lodge Meetings can be obtained from the Secretary, Mr. R. W. Merrick, 6 Sudbrook Gardens, Ham Common, Richmond, Surrey.

Morse Code Proficiency Transmissions

Apart from the not inconsiderable number of members of all grades who are active radio amateurs, there may be some who would like to 'brush up' an erstwhile skill in receiving morse code. These members will be interested to know that the Royal Naval Amateur Radio Society sponsors and radiates a monthly morse code proficiency broadcast from G3BZU at HMS *Mercury*.

The transmission is made at 2000 (UK time) on 3520 kHz on the first Tuesday of each month. Speeds are 15, 20, 25, 30, 35 and 40 words/min. To gain basic proficiency certificates at 15 w.p.m. and 20 w.p.m. and for certificate endorsements at speeds above 20 w.p.m., 100% correct copy is required. Details of charges etc. are transmitted at slow speed (15 w.p.m.) before and after each transmission. Currently 30p is charged for the basic certificates. After each transmission the monthly RNARS news is transmitted at 15 w.p.m.

Further information may be obtained from Mr. D. W. Underdown (Member), 8 Upper Springfield, Elstead, Nr Godalming, Surrey GU8 6EQ. (Telephone Elstead 3419 or 01–632 3396).

FEANI's Twenty-fifth Anniversary

The Federation Européenne d'Associations Nationales d'Ingenieurs (FEANI) was formed in Luxembourg in 1951, and the 25th anniversary of this international organization of the professional engineering associations in 18 European countries was held in Luxembourg on 1st October. The occasion was marked by a ceremony in which delegates and previous office-holders of the organization were addressed by the Luxembourg Minister of Public Works, the present and Past Presidents of FEANI and the President of the Luxembourg Association of Engineers. In association with the ceremony there were meetings of several FEANI committees.

'Young Engineers for Britain' Competition

CEI is among organizations supporting a nationwide competition which has just started for the 'Young Engineer for Britain'. Launched jointly by the *Daily Express* and PETT*, the competition is aimed at encouraging youngsters to develop their interests in engineering. They are being invited to compete by producing a device, fabricating a piece of mechanical apparatus or electronic equipment (or model of it) which would benefit industrial production, have commercial potential, save waste, make better use of energy sources, or improve an existing mechanical or electronic process. Aids for the disabled, safety and comfort in the home or road, or an article of use to society generally will also be welcomed.

The competition, which will run until July next year, is designed for students aged 16–17 at school and those aged 18–19 in further education who can enter both group and individual engineering project work for regional and then national finals.

Attractive prizes for individuals and groups both for national and regional winners have been donated by industry and CEI, including flights to the USA by *Concorde*, or to an oil production platform by helicopter, and television and audio equipment.

Further details and entry forms are available from: 'Young Engineer for Britain' Competition, *Daily Express*, Fleet Street, London EC4.

*Project—Engineers and Technologists for Tomorrow, the Government/Industry/Profession Group for schools set up by the Interdepartmental Committee on Publicity for Engineering and Technology, on which CEI is represented.

Technical News

New Electronic Exchange in Service

The first of a new generation of electronic telephone exchanges forming the next phase in a major Post Office programme to modernize the British telephone service, has been successfully brought into operation. The new exchange, which is in Birmingham, is of the type known as TXE4, and it was brought into service when 3000 customers previously connected to the Sutton Coldfield exchange were transferred to the new exchange. The present Strowger electro-mechanical telephone exchanges are being progressively replaced by modern electronic systems capable of giving improved service and reliability. Between now and March 1980 the Post Office expects on present plans to spend about £330M on electronic exchanges at current price levels.

The TXE4 design originates from the joint electronic research activity of the Post Office and the telecommunications industry in the 1960s. Its development into a working system has been carried out by Standard Telephones and Cables, and GEC and Plessey are now well advanced in building up production capacity for the system also. A total of 84 TXE4 exchanges are now on the order books of industry.

GEC forms German Company

GEC (Radio & Television) Limited have formed a West German subsidiary company, GEC Fernsh und Phonotechnik GmbH, Dusseldorf. The new company has been established to distribute home electronic products, primarily colour television and audio units. These products will be tailored to the requirements of the German market in both technical and design features.

People in the News

Mr. Norman Goddard, M.A., F.Inst.P., C.Eng., M.I.E.E., succeeded Professor Kurt Hoselitz as Director of the Mullard Research Laboratories on the latter's retirement on 1st August. Mr. Goddard joined MRL in 1947 to do research on microwave systems and in 1965 became head of the Systems Division of the Laboratories. He was appointed Deputy Director in 1973.

Mr. Michael Mason, Secretary of the Electronic Components Board, retired on 1st August after nearly 45 years service with the Electronic Component Board and its predecessors the British Radio Valve Manufacturers' Association (BVA) and the Electronic Valve and Semiconductor Manufacturers' Association (VASCA). He is continuing to act on a part-time consultancy basis until the end of the year.

Mr. F. L. Tombs, B.Sc., C.Eng., F.I.Mech.E., F.I.E.E., has been appointed Chairman of the Electricity Council in succession to Sir Peter Menzies, who will retire on 31st March 1977. Mr. Tombs has been Chairman of the South of Scotland Electricity Board since 1974.

At the 66th Annual General Meeting of the Institution of Structural Engineers in London recently, Dr. W. Eastwood, B.Eng., Ph.D., C.Eng., F.I.C.E., F.I.Struct.E., was elected to succeed Mr. Peter Mason as President of the Institution for 1976–1977. Before forming his consultancy practice of W. Eastwood and Partners of Sheffield in 1970, Dr. Eastwood was Professor of Civil Engineering at the University of Sheffield. He will take office on 7th October.

Plessey Reorganization

A new product subsidiary has been set up by the Plessey Group. It will comprise the existing Radar, Avionics & Communications and Marine Divisions, and will be known as Plessey Electronic Systems Limited (PESL).

The Board of the new subsidiary company will be under the chairmanship of Mr. Michael Clark (Companion), who is also a Deputy Chief Executive of the Plessey Group; and its Managing Director and Chief Executive will be Mr. Frank Chorley (Member), at present Managing Director of Plessey Avionics & Communications.

The Merchant Shipping (Radar) Rules 1976

From 1st April United Kingdom registered merchant vessels over 1600 gross registered tons have been required to carry an approved radar installation. This requirement is contained in Rules published by the Department of Trade.* There are certain transitional arrangements to give those concerned time to take account of the new requirements. The Rules are published following consultations with representative organizations of shipowners, unions and equipment manufacturers. They give effect to a future IMCO requirement which is pending international ratification.

The Department considers it desirable that all sea-going ships *below* 1600 gross registered tons registered in the UK should, where practicable, have regard to the provisions in the Rules, and to the recommendations in a Merchant Shipping Notice to be published shortly. This 'M' Notice will include supplementary recommendations for vessels fitting and carrying radar in accordance with the new Rules. 'M' Notices are available free of charge from Trade Mercantile Marine Offices and Marine Survey Offices or direct from the Department of Trade Marine Library, Sunley House, High Holborn, London WC1V 6LP.

A new publication 'Instructions to Surveyors (Merchant Ship Radar Installation)' giving further and more technical information about the radar installation required by the Rules, their siting and performance is under preparation.

The BBC and Quadraphony

In a statement made by the British Broadcasting Corporation in October 1974 it was pointed out that although several commercial quadraphonic matrix systems were available, none of these had so far gained international acceptance as being suitable for broadcasting. Furthermore, BBC tests, both in the laboratory and transmitted, had indicated that their performance, taking all aspects into consideration, were not in all respects consistent with the high quality achieved by BBC v.h.f. radio. It was, however, said that the study of quadraphonic systems, suitable for broadcasting over the existing networks, would continue.

Investigations by the BBC Research Department have now led to the development of a new matrix system which has undergone very rigorous testing and comparison with other systems already known to broadcasters and the public. The tests have been judged by panels of engineers, acoustic experts, musicians, and producers of all forms of radio programmes, and little doubt remains that the BBC's experimental matrix system, which is known as 'Matrix H', is superior for broadcasting to other systems tested.

It will be appreciated that compatibility, that is to say the excellence with which a quadraphonic matrix signal gives stereo and mono reproduction on equipment operating in these modes, is a most important consideration. Some of the

* Merchant Shipping (Radar) Rules 1976. SI 1976/302 HMSO 12p.

commercial systems examined gave very good quadraphonic reproduction at the expense of compatibility; others have good compatibility with insufficient quadraphonic definition to justify their adoption, but BBC 'Matrix H' has been found to combine excellent compatibility with very good quadraphonic reproduction.

The BBC intends to base further investigations upon the use of 'Matrix H' with particular reference to compatibility on all types of programme material. It is noteworthy that an unannounced use of 'Matrix H' was made during a recent Promenade Concert broadcast and a panel of expert listeners (mostly BBC staff, aware only that some modification had been made) compared the standard of the transmission very favourably with normal stereo and mono reproduction of similar concerts. It should be understood that none of the quadraphonic decoders as present available to the public is suitable for use with the 'Matrix H' system.

The present BBC stereo distribution network is capable, without modification, of carrying 'Matrix H' quadraphony. But because the extension of BBC v.h.f. radio services and stereo throughout the UK remains the first technical priority, no regular quadraphonic service is envisaged at present.

The BBC is making the technical specification of the 'Matrix H' system known to members of the European Broadcasting Union and other interested professional bodies. A detailed article about it has been published in the *EBU Review* (*Technical*), No. 159, October 1976.

'Standards for Safety': Report of SAMB Seminar

A seminar to consider the implications of the Health and Safety at Work Act 1974 as it refers to hospitals, was held in London in May by the UK Liaison Committee for Sciences Allied to Medicine and Biology (SAMB). About 70 people representing 20 of the constituent societies of SAMB attended; the IERE has been a member of SAMB since its formation.

The seminar Chairman, Dr. K. P. Duncan, Director of Medical Services, Health and Safety Executive, opened the meeting by referring to the Health and Safety at Work Act 1974, regarding the future achievements of which there had been, as he said, an explosion of expectation. The scope of the Act was far greater than that of the old Factories Acts, etc., and a much greater population was covered—in fact all employers, employees (excepting domestic servants) and self-employed, besides the general public in so far as they might be affected by works activities. It was essential, he continued, that a scientific objective view of the necessary safety standards was maintained. In other words, facts should be ascertained first and then realistic standards set.

Dr. H. L. Green, Consultant in Clinical Monitoring, Charing Cross Hospital, London, discussed 'Electrical Safety Standards in Hospitals', beginning with some observations on the hazards of faulty earth wiring in mains plugs. The danger was not necessarily confined to the patient-apparatus complex itself: in certain faulty situations an attendant simultaneously touching the patient and an earth—e.g. another piece of equipment—could carry current which, though harmless to himself, might kill the patient. Some types of 'earth-free' equipment were not entirely safe but safety could be achieved by proper design, reinforced by the use of coloured and labelled power plugs to signal whether the patient was earth-free or not. Training the users of the apparatus was the most important safety measure: they must know what *not* to do. Regular testing by an engineer of the power sockets was very important.

Mr. R. Brennand (Member), Head of the Electromedical Section, DHSS Scientific and Technical Branch, began his presentation of 'Safety Standards for Electromedical Equipment' by stressing that the emphasis today should be on International standards, and he then described the work of the International Electrotechnical Commission and its various sub-committees. These latter received information regarding proposed standards from the various national organizations, in this country the British Standards Institution and its panels. He listed the categories of protection against leakage currents in electromedical apparatus and also categories relating to the degree of protection offered. Realistic limits were needed in setting standards for leakage currents and no single fault condition should lead to patient hazard. He discussed present IEC allowances for leakage current in various circumstances and conditions, and also some of the test apparatus and circuits. Mr Brennand also dealt with the need for adequate documentation accompanying commercial equipment, and various apects of surgical diathermy equipment including recently developed circuits. He ended by stating that the objective of the IEC was a harmonized philosophy of safety.

In the long discussion on these contributions Dr. Green said that although re-chargeable sealed battery operated equipment was used to some extent in the hospital service, widespread use was at present impractical. Both he and Mr. Brennand emphasized the potential dangers from wall plugs and sockets and also the metal shell connectors used on mobile apparatus. Replying to the question as to whom the DHSS regarded as being responsible for maintenance of hospital electrical equipment, whether the manufacturers, the Region, the Group or the Hospital itself, Mr. Brennand said that in-house maintenance at its best was very good. However, the onus of responsibility at this level was frequently underestimated, particularly in relation to the comprehensive stock of spares needed and the necessary high quality of the maintenance staff. He stressed that over-zealous maintenance, e.g. taking apparatus to pieces when a functional test was adequate, was also a hazard.

The last speaker, Professor G. R. C. Atherley of the Safety and Hygiene Department, University of Aston in Birmingham, discussed 'A Conceptual Framework for Health and Safety'. The point of intervention in the potential hazard situation, he said, was very important. One could concentrate on stopping or eradicating the hazards (as by ceasing to use a dangerous substance in a process) or one could protect against it (as by wearing a mask). The second procedure was often less effective than the first, but tended to be the one emphasized in the literature distributed by the various interested organizations. All proposed remedies had to be looked at from the point of view of economic and technical feasibility, and in certain situations political considerations might also be of importance. One of the most difficult points in considering health and safety was the question of who was responsible for maintaining standards. Was it the owners or the managers or the remainder of the work force? It would certainly be unfair if the managers were to be regarded as totally responsible since they were not in charge of the resources of the organization.

During the seminar two films, 'Fire Prevention in Hospitals' and 'It shall be the Duty' (relating to the Health and Safety at Work Act) were shown.

Dr. M. V. Driver,
Chairman, SAMB

Conference on 'Computer Systems and Technology'

Organized by THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS with the association of The Institution of Electrical Engineers and The British Computer Society.

University of Sussex—29th to 31st March 1977

Provisional Programme

(Note: Changes may be made within sessions)

MICROPROCESSORS

SYSTEMS DESIGN

'The design of digital systems'
By R. Dowsing (*University College of Swansea*)

'The influence of microprocessors on control and monitor unit design'
By A. V. Aellen and R. Thomas (*Sperry Gyroscope*)

'A software development workshop for programmable micro-electronics'
By J. L. Payne (*Computer Analysts & Programmers*)

'Emulation and verification of micro-computer software'
By C. J. Hall (*University of Sussex*)

'A general purpose prototyping unit for microprogrammable microprocessors'
By Dr. K. R. Dimond and G. King (*University of Kent*)

'An unorthodox approach to microprocessor language'
By R. Young and J. E. Brignell (*City University*)

'Reliability in a resident compiler'
By Dr. S. R. Lang, (*GEC Semiconductors*)

APPLICATIONS

'Industrial control using microprocessors: the Kent distributed control project'
By Dr. K. R. Dimond, Dr. K. F. Hanna and Dr. O. R. Hinton (*University of Kent at Canterbury*)

'Microprocessors in a university teaching laboratory'
By J. Standeven and Prof. K. F. Bowden (*University of Essex*)

'Microprocessors in a library automation environment'
By J. Standeven, D. M. Jones, Professor K. F. Bowden and B. G. T. Lowden (*University of Essex*)

'Automatic call recording equipment for operator switchboards—a distributed microprocessor system'
By B. L. Brinkman (*Post Office Telecommunications Development*)

'GEMINI—a twin-processor emulator'
By J. Kershaw (*RSRE*)

DISTRIBUTED AND DEDICATED SYSTEMS

'Microprocessor architecture, ease of programming and memory costs'
By Dr. B. K. Penney (*Imperial College*)

'A distributed bus-orientated multi-minicomputer system'
By Dr. F. Halsall and C. J. Hall (*University of Sussex*)

'The architecture of a reconfigurable multi-microcomputer system —POLYPROC'
By Professor R. L. Grimsdale (*University of Sussex*)

'Cellular multi-microprocessor systems'
By Dr. K. D. Baker (*University of Sussex*)

'A microprocessor-based parallel computer system'
By A. S. Cowan and D. G. Whitehead (*University of Hull*)

'The use of multiple microprocessor architecture to improve system performance'
By A. Reichert (*Logica*)

'Generalized semaphores and inter-process communication on a multi-processor machine'
By N. A. Goodall (*Plessey*)

RELIABLE SYSTEMS

'Integrity, reliability and fault tolerance in micro-programmable controllers'
By I. Williamson (*Cambridge Consultants*)

'The application of reliability techniques to a data communication system'
By Dr. B. H. Pardoe (*University of Salford*)

'Design principles to enhance the overall reliability of micro-processor systems'
By M. J. Kent (*Software Sciences Nederland*)

'Fault-tolerant microcomputer systems for aircraft'
By P. G. Depledge (*Hawker Siddeley Aviation*) and Dr. M. G. Hartley (*UMIST*)

'The l.s.i. central processor for the Hawker Siddeley space computer'
By B. J. Parsons, D. P. Dobson and D. J. Sharman (*HSD*)

'Fault management mechanisms in the Hawker Siddeley space computer'
By B. J. Parsons, D. G. Weaver and D. P. Dobson (*HSD*)

'Fault handling in a multi-processor terminal system'
By M. C. A. Johnson (*Plessey*)

INTERACTIVE SYSTEMS

'An interactive tutorial system for teaching programming'
By Dr. E. Edmonds and S. Guest (*Leicester Polytechnic*)

'Hardware design for high level databases'
By S. J. P. Todd (*IBM UK*)

'Software tools for developing interactive systems'
By G. Ringland (*Computer Analysts & Programmers*)

'A database system for handling real numbers'
By D. Richards (*Lawrence Berkeley Laboratory*) and G. Ringland (*Computer Analysts & Programmers*)

'Interactive systems in the service of engineering'
By R. K. Chisham (*IBM UK*)

'BASYS: a language for programming interaction'
By Professor B. R. Gaines and P. V. Facey (*University of Essex*)

'Interactive, easy-to-use simulation techniques'
By J. J. Holmes (*IBM UK*)

'An interactive graphics system for the analysis of complex scientific data'
By J. W. R. Hunter (*University of Sussex*)

Members' Appointments

CORPORATE MEMBERS

Wing-Cdr. J. M. Brown, RAF (Fellow 1973, Member 1959) has been posted to Signals 59 (Air) Ministry of Defence, London. He was previously Senior Project Officer (ADRS) in the Radio Introduction Unit at the Royal Radar Establishment, Malvern, where he has been serving since 1974.

Mr. A. V. Davies, B.Sc., M.Sc., F.Inst.P. (Fellow 1976) has taken up the appointment of Patents Engineer with EMI. Mr. Davies was with the Data Recording Instrument Company from 1961 until 1975, latterly as Chief Scientist, Data Recording Heads Ltd. In December 1975 he became Visiting Lecturer to the Department of Pure and Applied Physics of the University of Salford, and early this year he was appointed an Associate Consultant with Mackintosh Consultants Company of Luton. Mr. Davies served on the Organizing Committees of the IERE Conference on Video and Data Recording held in 1973 and 1976.

Mr. E. J. Proctor (Fellow 1974, Member 1967), for the past seven years with the Civil Aviation Department of the Government of Hong Kong, latterly as Chief Electronics Engineer, has taken up a post in Canada as Project Engineer with Litton-Stevens (Canada) Ltd., Rexdale, Ontario.

Mr. J. G. Alder (Member 1964, Graduate 1961) has been appointed General Manager of the Components Division of Plessey South Africa Ltd., Plumstead, Cape Province. Mr. Alder went to South Africa in 1970 as Engineering Manager, S.T.C. (S.A.) Ltd., Boksburg, Transvaal. He was previously with Smith's Aviation Division, Cheltenham.

Mr. M. C. Anderson (Member 1973, Graduate 1969) has been appointed Systems Manager with EMI Medical Ltd., Hayes, Middlesex. He previously had a similar position with Plessey Avionics and Communications since 1973.

Wing-Cdr. F. G. Buckle, RAF (Member 1969, Graduate 1967) has relinquished his command of Projects Wing at the General Servicing Development Establishment at RAF Swanton Morley and has taken up the appointment of Nav 3b at the Procurement Executive, Ministry of Defence.

Mr. B. M. Godwin (Member 1971, Graduate 1960) is now Senior Quality Engineer, Standard Telephones and Cables Transmission Division at Basildon, Essex. After some years with A. B. Electronic Components Ltd., as Chief Electronic Engineer, Mr. Godwin joined S.T.C. in 1970 as Chief Electronic Equipment Engineer ultimately becoming Manager, Industrial Engineering, at the Newport factory.

Wing-Cdr. C. Henderson, B.Sc., Dip.El., Dip.Ed., RAF (Ret.) (Member 1964) has been appointed Manager (Customer Training) with Racal Electronics Ltd., Bracknell. Before leaving the RAF earlier this year, Wing-Cdr. Henderson was Senior Education Officer, No. 1 Radio School, RAF Locking.

Mr. H. E. Hill (Member 1972) has been promoted from P&TO II to P&TO I and is now at the Department of the Environment, Manchester. He was formerly a Senior Engineer with Vacuum Generators Ltd.

Mr. D. W. Hilton (Member 1973, Graduate 1970) is now with Pilkington (South Africa) Ltd. in the Transvaal working as a Control Engineer; he has been with Pilkingtons since 1969 and was with the Swedish subsidiary from mid-1975.

Mr. N. O. Ilube (Member 1973, Graduate 1967) who was previously a Senior Engineer with the Nigerian Medwest Broadcasting Corporation, has moved to Nigerian Television, Benin City, and is now a Principal Engineer. Following experience in the UK with BBC Television he was for four years with Uganda Television in Kampala.

Mr. M. E. Jones, B.A. (Member 1972, Graduate 1969) has been appointed an Assistant Project Manager with BAC (GW) Ltd., Bristol. He was formerly Senior Project Engineer with Hawker Siddeley Dynamics Ltd., Hatfield, which he joined in 1975 after experience in a similar post with Hunting Engineering Ltd.

Mr. A. W. Jury (Member 1973, Graduate 1969) who is with the National Coal Board Establishment at Stoke Orchard near Cheltenham, has been promoted from the Management and Technical Grade 6 to Management Grade 5 in the Physics Section. Mr. Jury joined the N.C.B. in 1967 as a Scientific and Technical Officer.

Capt. I. R. Lidstone, B.A., R.Sigs (Member 1973, Graduate 1970) has moved to RAF Rudloe Manor as Technical Officer Communications in the offices of the Controller, Defence Communications Network. From 1972 to April of this year Captain Lidstone served as a Technical Officer Communications with RAF 229 Signal Squadron in Berlin.

Lt.Cdr. P. Nightingale, RN (Member 1972, Graduate 1967) is now serving as Avionics Section One Officer in HMS *Daedalus*, Lee-on-the-Solent, Hants, after a year's postgraduate study for an M.Sc. in information and systems engineering at the University of Birmingham. From 1974 to 1975 he was a Programmed Learning Instructor at the Army School of Instructional Technology, Beaconsfield.

Lt. H. C. Parker, RN (Member 1974, Graduate 1969) has been appointed Naval Engineer Officer with 360 RN/RAF Squadron, RAF Wyton, his previous posting was as Air Electrical Officer, 706 Naval Air Squadron, RNAS Culdrose.

NON-CORPORATE MEMBERS

Mr. T. Khanna (Graduate 1968) has returned to the UK from West Germany, where he has been with Siemens AG in Munich, and is now an Electronic Engineer with GEC Semiconductors, Wembley

Mr. N. Kelly (Graduate 1971) who is with the Science Research Council, Daresbury, Warrington, has been promoted to P&TO II (Crew Leader).

Mr. R. A. Moore, M.Sc. (Graduate 1964) has taken up an appointment as product planner with IBM France, La Gaude. He first went to IBM France at La Gaude in 1970, and since 1974 he has been in the United States as Publications Planner for the IBM 3790 System.

Mr. G. Rahmani, B.Sc. (Graduate 1965) has been appointed Senior Research Officer at the Medical Research Council's Clinical Research Centre in Harrow.

Mr. W. L. Sin, B.Sc. (Graduate 1966) has been appointed Lecturer in the Department of Electrical Engineering, Hong Kong Polytechnic.

Lt. R. G. Thorn, M.Sc., RN (Graduate 1970) has taken up an Instructor Appointment at the Royal Naval Engineering College, after being awarded the degree of M.Sc. in electronics from Southampton University. He was previously an Instructor Lieutenant in HMS *Collingwood*, Fareham.

Mr. H. M. Beaven (Associate Member 1973) has been appointed Head of the Technical Buildings Group (Planning Division) of the South Western Region of Post Office Telecommunications.

Mr. A. J. Fawcett (Associate Member 1973) has left the RAF where he was latterly Electrical Engineering Test Equipment Coordinator at the RAF College, Cranwell, and is now with AEI Semiconductors Ltd., Lincoln, as an engineer working on ratings and applications.

Mr. A. Hickling (Associate Member 1974, Graduate 1952) has joined the Industry Department of the Welsh Office, Cardiff, as Technical/Commercial Officer. He was previously a Technical Publications officer at the Royal Radar Establishment, Malvern.

Mr. R. A. Hynard (Associate Member 1973, Associate 1963) is now a technical author with H and M Technical Publications Ltd., Bath. He was formerly General Manager of Caserite Ltd., Borehamwood.

Obituary

The Council has learned with regret of the deaths of the following members:

Valentine Okechukwu Agbo (Associate Member 1975) died in July 1976 aged 26 years. An assistant technical officer with the Posts and Telecommunications Department of the Federal Ministry of Communications, Lagos, Nigeria, he was taken ill while in Finland on a course and died a few months after returning home.

Leonard Stanislaw Danilewicz (Member 1947) died in July 1976 aged 70 years. Born and educated in Poland he worked in the radio laboratory of AVA Warsaw for eleven years; he was in France for part of the war and came to England at the end of 1944 joining the Polish Military Wireless Research Unit. After the war and until his retirement in 1971, he was with British Communications Corporation.

Walter Frederick Dunn (Member 1938) died in August 1975 aged 70 years. A registered blind person since 1948, Mr. Dunn worked before the war in the design and development of electronically assisted and reproducing pianofortes. From 1939 until his retirement he was with the Air Ministry and subsequently the Ministry of Aircraft Production as a Senior Examiner attached to RAF workshops.

Raymond Victor Marshall (Member 1948, Associate 1948, Student 1942) died in November 1975 aged 61 years. Mr. Marshall worked as a test and installation engineer in the heavy electrical engineering industry both before the war, in which he spent 4 years as prisoner of war and was subsequently medically discharged, and after the war. He retired from full-time employment in 1966.

Eric Halstead McKoy (Graduate 1964, Student 1961) died in September 1975, aged 44 years. He leaves a widow and four daughters. A Jamaican citizen, Mr. McKoy had held appointments at the University of the West Indies and at the University of Ibadan, Nigeria. At the time of his death he was a senior electronics engineer in the Physics Department at Ibadan; he was associated for some years with the University's ionospheric research work and had contributed papers to technical journals on experimental techniques.

Donald Ridgeway Palmer (Member 1958, Graduate 1952, Student 1944) died in June 1976 aged 57 years. A progressively disabling illness had led to premature retirement two years previously from the Royal Greenwich Observatory, Herstmonceux. Since 1953 he had been responsible for designing electronic equipment for a wide variety of astronomical experiments.

Lloyd William Poole (Member 1962, Graduate 1959) died on 19th August 1976, aged 53 years, leaving a widow. Following service in the RAF, Mr. Poole worked for various electronic instrument manufacturers. In 1958 he joined Marconi Instruments Ltd. and was latterly in charge of post development services.

Flt.Lt. Robert Pritchard, RAF (Member 1973, Graduate 1969) died in August 1976, aged 35 years. Since 1974 he had been stationed at RAF Boscombe Down.

Frederick James Frank Properjohns, M.B.E. (Member 1948) died on 23rd July 1976 aged 75 years. He leaves a widow. For the whole of his professional life he was in Government Service, from 1937 until his retirement in the Aeronautical Inspection Directorate.

Prem Chand Saggar (Member 1952, Associate 1951) died on 16th September 1976, aged 59 years. He leaves a widow and a son and daughter.

Professor Saggar had been on the staff of St. Xavier's College Technical Institute, Bombay, since 1938 when he became a lecturer in radio subjects; he was promoted to senior lecturer in 1946 with responsibility for the teaching of advanced radio communication, acoustics and radio physics and he was appointed to a chair in 1967. It was largely due to his efforts that the College has achieved its considerable reputation as one of the foremost centres in India for radio engineering education. He had received part of his own technical education at the College where he went after passing the Diploma Course of Licentiate in Electrical Engineering from Dayal Bagh Technical College.

The Institution owes a considerable debt to Professor Saggar for his untiring efforts not only in helping aspiring radio engineers to qualify for membership but also as one of the founders and subsequently honorary secretary and chairman of the Bombay Zone Committee. This was the first Section to be set up in India in 1951, and until the opening of the Bangalore Office, he handled all the Institution's local correspondence and inquiries within India.

During 1960 Professor Saggar visited the UK on a four months' tour to familiarize himself with current manufacturing techniques in order the better to assist the numerous companies who consulted him about ways of modernizing their production facilities.

He impressed all who met him with his tremendous enthusiasm for developing radio in India and with his courtesy and concern for others. In paying tribute to Prem Saggar I recall the many ways in which he helped the IERE in India and his unfailing help during my visits to his country.

G.D.C.

Colin Charles Henry Washtell (Fellow 1952, Member 1942) died suddenly on 9th September 1976 at his home in Reach, near Cambridge, aged 69 years. He leaves a widow and daughter.

Born in Newnham, Cambridge, Colin Washtell was unusual in these days for having spent nearly the whole of his professional life in the same district, apart from war service, when he was initially a civilian instructor at No. 3 Electrical and Wireless School, RAF Compton Bassett, and later a Radar Officer in the RNVR. Before the war he had been a cinematograph sound engineer and later in charge of a radio servicing workshop but on returning to Cambridge he lectured on electronics at Cambridge Technical College. In 1948 he joined Labgear Ltd. as a Development Engineer, shortly becoming Technical Manager; he remained with the company as Chief Engineer until his retirement in 1971 during which period he had been particularly concerned with the design of the company's nucleonic and similar counting instruments.

After retirement from Labgear he formed a small consultancy and instrumentation agency, Electrotek of Cambridge Ltd., continuing his earlier activity in trade association affairs. Colin Washtell had contributed several papers on instrumentation matters to the Journal and to Conference Proceedings, and he had been for several years a member of the East Anglian Section Committee.

Like many electronic engineers Colin Washtell had a love of music and competence as an amateur performer but he was particularly fortunate in being able to bring his engineering knowledge to bear successfully on the original design of a new musical instrument, namely an electrophonic organ. Throughout his professional life he took an interest in organs of the traditional kind, building or rebuilding several, notably one for the church of St. Ethelreda and The Holy Trinity in his home village. This instrument was conventional in principle but its controls were based on solid state electronic switching devices.

Very different in principle and execution, although, in the opinions of many professional organists highly acceptable, was the electrophonic organ he designed and built in his spare time for another, nearby, Fenland church, at Swaffham Prior. This employed ingenious circuitry 'to overcome the musically important shortcomings in organs exploiting electronic means of sound generation which should help to reverse the present dislike of these by conservative musicians and perhaps herald the organ of the future'. These words which concluded the lectures he gave to a meeting of the East Anglian Section of the IERE and IEE in 1974 and, as recently as June of this year, in the IERE Golden Jubilee Convention, could perhaps be his musical epitaph.

F.W.S.

New Books Received

All the books which are described below are available in the Library and may be borrowed by members in the United Kingdom. A postal loan service is available for those who are unable to call personally at the Library.

Sir William Preece, F.R.S.: Victorian Engineer Extraordinary.

E. C. BAKER. Hutchinson, London 1976. 23·4 × 15·6 cm. 377 pp. £6·50.

W. H. Preece (1834–1913) was best known as Electrician and later Engineer-in-Chief to the British Post Office, and was well-known as a consulting engineer for electric lighting and electricity generating projects. In his time he was extremely influential, being generally highly regarded and well liked. He was an able administrator and very industrious, managing to give the Post Office good service while at the same time having numerous and varied outside professional concerns. The range of this outside work was astounding: telephones, telegraphs, electric lighting and power, sanitation, science generally, ranging from a local society in Wimbledon to advisory, consulting, and design work on a national and imperial level. Preece seems to have been a man of warm, kindly personality and of high standards of social conduct. Mr. Baker's book concentrates on this laudable side of him.

The relatively small size of engineering organizations in his day enabled Preece to deal personally with matters which nowadays a man of his eminence would have to delegate. This meant that Preece was able to attend to scientific ideas, experimental work, design problems, details of technique and practice, etc. Because of this exposure to problems at the working level, and also because of his habit of recording, and usually publishing, his technical thoughts and results, we can now see that he was no more infallible than the rest of us; the records, published and unpublished, are bespattered with his errors. He completely failed to understand the principle of parallel operation of incandescent lamps which he declared in 1879 to be an *ignis fatuus*, although he was converted by the subsequent practical success of the system; he could or would not understand the teaching of Oliver Heaviside in the mid-1880s on the transmission of telephone signals over lines, and obstinately refused to accept that increase in inductance could improve transmission until the work of Pupin and Campbell in 1899–1900 left no room for doubt; his calculations for the first Cross-Channel telephone cable, laid in 1891, were seriously wrong by large factors in several respects, although fortunately some of the errors largely cancelled out and others were detected in time, so that the cable was, in the end, a great success. There were, too, some serious discrepancies between what was said in internal memoranda and what was published.

Contemporary criticism of Preece was confined mainly to the sarcastic remarks of Heaviside and some caustic American commentaries; his strengths were evidently considered greatly to outweigh his weaknesses. But it is this interplay of the different aspects of his character that make him really interesting to me. Mr. Baker hardly discusses it at all.

Perhaps it is only the scholar or the engineer who is likely to be interested in this side of Preece. Mr. Baker has clearly not written his book primarily for them, but rather for the general reader. He states in his Preface: 'Readers of this book will generally not wish to inquire into sources.' Consequently he has largely avoided the controversial matters of Preece's career; and in dealing with the matter of telephone transmission, which he has discussed in Chapter 21, he has dealt generously with Preece and rather harshly with Heaviside, thus taking issue with most engineering historians.

The book is undoubtedly interesting and original. It is presented quite charmingly as a sort of scrap-book of Victoriana, with little formal structure apart from a generally chronological base. There is not much technical discussion, and some of the material is perhaps of questionable importance. Yet I enjoyed reading it. Mr. Baker has a nice turn of phrase, and quotes extensively from the wide range of relevant private and public papers of which he has an unrivalled knowledge. It is an excellent book for the non-specialist reader at whom it is aimed, and will introduce much new material even to the specialist.

References to sources are not given in the published book, but have been added to readily-accessible reference copies in Britain and the USA.

D. G. TUCKER

Automatic Testing: Systems and Applications

ROY KNOWLES. McGraw-Hill, Maidenhead, Berkshire 1976. 23 × 16·5 cm. 246 pp. £6·30*.

CONTENTS: Philosophy. Systems. Hardware. Interfaces. Software. Liveware. Management.

The author has set out to provide one of the first books on the modern concepts in automatic testing. It is not an easy task to do this on a difficult subject within the confines required for publication. He is however well qualified to treat the subject in depth.

The book aims to provide engineers and managers, who are not familiar with the potential of automatic testing, with an introductory understanding of the subject. Automatic testing has been approached from a systems point of view in a logical manner which makes easy reading. Of necessity, the author has had to leave out much detail of automatic testers. However, good coverage has been given to the fundamental concepts of automatic testing which must be understood for the successful introduction of automatic testing into any application.

It is interesting to note that many of the basic principles which are discussed apply to the whole discipline of testing regardless of whether implementation is by automatic or manual methods. For this reason alone, this treatment of the subject is valuable since it is always useful to have a clear and concise presentation of the basic principles which are not always apparent when first contacting a subject as complex as automatic testing.

The book closes with interesting case histories of successful applications of automatic testing.

In summary, Roy Knowles has certainly achieved his intention of introducing the subject of automatic testing to engineers and managers who are not concerned with the detail design of hardware and software but who are concerned with making decisions on new applications for automatic testing.

A. HANN

(Brigadier R. Knowles, C.B.E. (Fellow 1962) was appointed Secretary of the Institute of Quality Assurance on retiring from the Army; he has chaired organizing committees for IERE conferences on automatic test equipment).

Introducing Root Locus

P. DRANSFIELD and D. F. HABER. Cambridge University Press, London 1973. 25·5 × 19·5 cm. 132 pp. £2·00.

CONTENTS: Defining root locus. Interpreting root locus. Sketching root loci for negative feedback systems. Using root locus to improve system performance.

This is a programmed instruction text intended for university students of engineering mathematics.

Professor Dransfield is at Monash University, and Professor Haber is at the University of Idaho.

Book Supply Service

As a service to members, the Institution can supply copies of most of the books reviewed in the *Journal* at list price, plus a uniform charge of 35p to cover postage and packing.

Orders for these books, which are denoted by an asterisk (*) after the price, should be sent to the Publications Department at Bedford Square and must be accompanied by the appropriate remittance.

Installing and Servicing Home Audio Systems

J. Hobbs. W. Foulsham & Co., Slough 1974 21·5 × 13·5 cm. 256 pp. £1·60.

Contents: The audio business—opportunity unlimited. Test instruments for audio. AM receiver maintenance. Working with FM tuners. Servicing FM stereo equipment. Preamps and amplifiers. 'Combinations' and related problems. Solid-state power supplies. Tape recorders and players. Mobile radios and tape players. Servicing automatic record players. Selling and installing audio systems. Commercial audio systems. Home and business intercoms.

Intended for installation and servicing technicians.

(Mr. Hobbs was formerly Managing Editor of the Electronic Technician/Dealer Magazine.)

The International System of Units

C. H. Page and P. Vigoureux (Editors). HMSO London 1973. 21 × 15 cm. 47 pp. 63p.

Contents: The three classes of SI units. SI Units. Base units. Definitions. Symbols. Derived units. Expressions. Recommendations. Supplementary units. Decimal multiples and sub-multiples of SI units. SI prefixes. Recommendations. The kilogram. Units outside the International system. Units used with the International System. Units accepted temporarily. CGS units. Other units.

(Mr. Page works for the National Bureau of Standards, and Dr. Vigoureux for the National Physical Laboratory.)

Design and Control of Chemical Process Systems

J. R. Borer. McGraw-Hill, Maidenhead, Berkshire 1975. 23·5 × 15·5 cm. 153 pp. £5·00.*

Contents: What is a system. System description and definition. From theory to practice. Basic principles of design of systems. Compensation by control. Introduction to multivariable systems. State space theory. Multivariable compensation. Control of a real interactive process. System identification. Online computer control today.

A theoretical treatment of the systems engineering aspects of controlling processes.

(Dr. Borer is Process Control Specialist Engineer in Monsanto's Corporate Engineering Department for Europe.)

Essential Formulae for Electronic and Electrical Engineers

N. M. Morris. Macmillan, London 1974. 29·5 × 21 cm. 26 pp. 95p.*

Contents: Dimensions and dimensional analysis. Mechanics. Electrostatics. Electromagnetism. Electric circuits. Circuit theorems. Complex numbers. Single phase a.c. circuits. Three phase a.c. circuits. Transients. Rectification. Bridge measuring circuits. Instruments. Logic. Logic gates. Values of 2^{+N}. Equivalent circuits and four-terminal network equations. Electronic amplifiers. Feedback amplifiers. Oscillators. Control systems. D.c. machines. Transformers. Synchronous machines. Industion machines. The per-unit system. Power system short circuits. Modulation. Transmission lines.

(Mr. N. M. Morris is Principal Lecturer in the Department of Electrical and Electronic Engineering at North Staffordshire Polytechnic.)

Radio Valve and Semiconductor Data. (10th ed.)

A. M. Ball. Newnes-Butterworths, London 1975. 27 × 21 cm. 179 pp. £2·00.*

Contents: Valve data. Semiconductor device data. Base diagrams, trade names and indexes.

Semiconductor Electronics by Worked Example

F. Brogan. Macmillan, London 1974. 25 × 22·5 cm. 136 pp. £2·50.*

Contents: Semiconductor diodes, rectifiers, and stabilisers. Voltage and current common-emitter amplifiers. Equivalent circuits of small-signal, low-frequency amplifiers. Transistor power amplifiers. Tuned circuits and high-frequency transistor amplifiers. Field-effect transistors. Negative feedback. Transistor oscillators. Wave-shaping and computing circuits. Boolean algebra and logic circuits. Principles and applications of thyristors. Photoelectric devices and solid-atate manufacturing techniques.

Examples are mainly from C & G Electronic and Telecommunication Technical papers (Courses 281 and 271).

(Mr. Brogan is Senior Lecturer in Electronics and Computer Engineering, Wigan and District Mining and Technical College.)

Principles of Transistor Circuits (5th ed.)

S. W. Amos. Newnes-Butterworths. London 1975. 21 × 13·5 cm. 320 pp. £3·20.

Contents: Semiconductors and junction diodes. Basic principles of transistors. Common-base and common-gate amplifiers. Common-emitter and common-source amplifiers. Common-collector and common-drain amplifiers (emitter and source followers). Bias and d.c. stabilisation. Small-signal a.f. amplifiers. Large-signal a.f. amplifiers. D.c. and pulse amplifiers. I.f. amplifiers. Sinusoidal oscillators. Detectors, frequency changers and receivers. Pulse generators. Sawtooth generators. Digital circuits. Further applications of transistors and other semiconductor devices.

More information is given on circuits using f.e.t.s than in previous editions and the treatment of switching circuits has been expanded to cover the principles of digital equipment.

(The author was formerly Head of Technical Publications Section, Engineering Training Department, BBC.)

Foundations of Wireless and Electronics (9th ed.)

M. G. Scroggie. Newnes-Butterworths, London 1975. 21·5 × 13·5 cm. 521 pp. £3·75.*

Contents: Initiation into the shorthand of electronics. General view of a system. Electricity and circuits. Capacitance. Inductance. Alternating currents. Capacitance in a.c. circuits. Inductance in a.c. circuits. The tuned circuit. Diodes. Triodes. The triode at work. Transistor equivalent circuits. The working point. Oscillation. Radio senders. Transmission lines. Radiation and aerials. Detection. Low-frequency amplification. Selectivity and tuning. The superheterodyne receiver. High-frequency amplification. Cathode-ray tubes: television and radar. Electronic waveform generators and switches. Computers. Power supplies.

The ninth edition of this very well-known introduction to radio and electronics coincides with the quarter-millionth copy.

(The author is a consultant.)

Digital Logic and Switching Circuits: Operation and Analysis

J. C. Boyce. Prentice-Hall, New Jersey, 1975. 23 × 16 cm. 526 pp. £8·25.*

Contents: An introduction to digital logic. Numbers and counting. Basic combinational logic. Advanced combinational logic. Algebraic simplification methods. Graphic simplification methods. Analysis and trouble-shooting of combinational logic. Sequential logic analysis. Troubleshooting combinational/sequential logic. Counters and their applications. Registers and their applications. Miscellaneous logic functions. Binary codes. Code converters and display devices. Analysis of a simple digital subsystem. Digital applications.

A comprehensive work of reference for the practising engineer.

(Dr. Boyce is at Allan Hancock College.)

Intermediate Network Theory, Book 1

R. J. Maddock. Butterworths, London 1973. 22 × 14 cm. 184 pp. £3·95 hardback. £1·95 limp.*

Contents: Alternating voltages and currents. Network analysis. Network theorems. Three-phase circuits. Electrical resonance. Two-port networks.

For HNC and HND courses in electrical, electronic and control engineering.

(Mr. Maddock (Member 1962) is Senior Lecturer in Electrical and Electronic Engineering at the Southampton College of Technology.)

Introduction to Quantum Electronics

P. A. Lindsay. Pitman Publishing, London 1975. 24 × 16 cm. 202 pp. £6·00.*

Contents: Interaction between radiation and matter—semi-classical approach. Electric and magnetic polarization and dispersion. Atomic energy levels and spectroscopic notation. Introduction to matrix mechanics. Electric and magnetic dipole transitions. Field quantization and noise. Non-linear phenomena. Acoustic vibrations—phonons.

Aims to provide engineering and science students with a basic knowledge of lasers and of the quantum-physical principles of opto-electronics.

(The author is Professor of Physical Electronics at King's College, University of London.)

VHF-UHF Manual (3rd ed.) Edited by R. A. Staton.

D. S. Evans and G. R. Jessop. Radio Society of Great Britain. London 1976. 25 × 19·5 cm. 400 pp. £4·95.

Contents: Propagation. Tuned circuits. Receivers. Transmitters. Filters. Aerials. Microwaves. Space communication. Test equipment and accessories. Data.

The book is intended primarily for the amateur radio worker but it very reasonably suggests that it contains information likely to be of value to the professional engineer. *(The authors are active radio amateurs; Mr. G. R. Jessop (Member 1953) is general manager of the RSGB).*

Applicants for Election and Transfer

THE MEMBERSHIP COMMITTEE at its meeting on 14th October 1976 recommended to the Council the election and transfer of the following candidates. In accordance with Bye-law 23, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communication from Corporate Members concerning the proposed elections must be addressed by letter to the Secretary within twenty-eight days after publication of these details.

Meeting: 14th October 1976 (Membership Approval List No. 226)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Member to Fellow

POVALL, Alan Geoffrey. *St. Annes-on-Sea, Lancashire.*

Transfer from Graduate to Member

ARIES, Ian Francis. *Harpenden, Hertfordshire.*
BROWN Michael Harold. *Abingdon, Oxfordshire.*
FOXWELL, Derek Edward. *Stanmore, Middlesex.*
JORDAN, Peter James. *Reading, Berkshire.*
KEANE, Andrew James. *New Malden, Surrey.*
LEA, Terence Edward. *Keyworth, Nottinghamshire.*
SPENCER, Simon Howard. *Chelmsford, Essex.*

Direct Election to Member

SMITH, David Gordon. *Bath, Avon.*
YOUNG, Alan Gerald. *Colchester, Essex.*

NON-CORPORATE MEMBERS

Direct Election to Graduate

ARMSTRONG, Alan. *Morpeth, Northumberland.*
HOHAN, Damien James. *Cardiff.*
THICKETT, Eric Edward. *Radcliffe, Lancashire.*

Transfer from Student to Associate Member

WONG, Andrew Kui Hin. *London.*
YOUNG, Derek Ronald. *Reading, Berkshire.*

Direct Election to Associate Member

MUNIR, Shahid. *Heston, Middlesex.*
ROBERTS, Patrick Joseph. *Ennis, County Clare.*
TURNBULL, Cecil Ronald. *Wallington, Surrey.*

STUDENTS REGISTERED

BAUGHAN, Kevin John. *Tadworth, Surrey.*
FERNANDES, Edgar Paul. *London.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Member to Fellow

MULCAY, Michael. *Sunnyvale, California, USA.*

Transfer from Graduate to Member

HO, Kit-Fun. *Hong Kong.*
LIM, Sin Leong. *Penang, West Malaysia.*
SIDDIQI, Mohammad Sulaiman. *Rexdale, Ontario, Canada.*

Transfer from Student to Member

BUESNEL, Henry John. *Brussels.*

Direct Election to Member

HO, Kin-Yu. *Hong Kong.*
LEONG, James Tiu Kong. *Kuala Lumpur, Malaysia.*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

TANG, Kam Tong. *Hong Kong.*
WONG, Tat Wai. *Hong Kong.*

Direct Election to Graduate

TUKUR, Ahmadu A. Njidda. *Maiduguri, Nigeria.*

Transfer from Student to Associate Member

SARATHCHANDRA, Karunakalage Parakrama. *Panadura, Sri Lanka.*

Direct Election to Associate Member

WONG, Hon-Kwong. *Hong Kong.*

Transfer from Student to Associate

LEUNG, Kam-Por. *Hong Kong.*

STUDENTS REGISTERED

CHEAM, Chong Song. *Singapore.*
ERHAHON, Patience Nosakhare Ajayi. *Lagos, Nigeria.*
LAU, Shing Man. *Hong Kong.*
LIM, Lin Giap. *Singapore.*
LO, Chun Yi. *Hong Kong.*
LOW, Lian Kau. *Kuala Lumpur, Malaysia.*
PANG, Sui Kie. *Singapore.*
TAN, Sim Bee. *Singapore.*
TEO, Bok Seng. *Singapore.*
WAN, Kwing Yuen. *Hong Kong.*
WONG, Kwong Ming. *Hong Kong.*
YEO, Eng Lim. *Singapore.*
YONG, Siew Choo. *Singapore.*

Letter to the Editor

From: **R. E. George**, C.Eng., M.I.E.R.E.

Status and Qualifications of Engineers

The question of the status and qualifications of engineers, raised by Hewitt and Willis in their letters in the April 1975 Journal, is taken up by I. M. Joyce and four Members in the March 1976 Journal. The Editor's reply was that if engineers are to achieve professional parity, for example, with lawyers and doctors, 'engineers must concern themselves with the standards of competence and the means of maintaining professional ability'. In this comment, it is implicit that standards are still inadequate. Proposals for suitable standards could come from the Institution.

The Editor's second comment is, 'The Institution has provided . . . a recognized professional qualification . . .'. These two points, the failure to achieve parity with two of the older professions, and the provision of a recognized professional qualification, seem to contradict one another.

In both the legal and medical professions, the numbers entering for training are under close control. Each is practised as part of the Institution of State. Solicitors have the status of Officers of the High Court. Medical practice is regulated by the Medical Acts, and membership of a legal defence organization is a requirement. In contradistinction to law and medicine, engineering is an 'open' activity, i.e. any person regardless of training, knowledge or competence, can not only claim to be an engineer, but will obtain employment as an engineer, and practise as an engineer. The possession or lack of the title 'Chartered' makes no difference.

The assertion that the IERE has provided a recognized professional qualification is one which calls for supporting evidence. The Institution in conferring membership has undertaken, at least, a moral obligation to ensure that there are recognized professional opportunities for members.

32 Coventry Road, R. E. GEORGE
Ilford, Essex IG1 4QU.
13th September 1976

[There is not, unfortunately, any automatic link between 'professional parity' and 'recognized professional qualifications', as Mr. George rightly suggests, but failure fully to realize the first does not automatically negate the second. Corporate membership of this Institution has for many years been accepted on a par with that of other chartered engineering institutions as a relevant professional qualification for a wide range of appointments in both public and private sectors, as many members are personally aware. Certainly the situation is not overall as satisfactory as one would wish it to be, particularly in the private sector, where anomalies such as are referred to sometimes occur while implementation of the Fulton Committee's proposals in the Civil Service is widely regarded as a retrograde step. We would like to point out that the desirability of statutory registration of engineers, which is presumably what Mr. George has in mind, is a policy that has been advocated by this Institution for some 35 years! It cannot be attained single-handed but the amendments to CEI's Charter must improve the prospects of achieving this goal if engineers themselves will it so. EDITOR]

Forthcoming Institution Meetings

London Meetings

Tuesday, 7th December

ELECTRONICS PRODUCTION TECHNOLOGY AND AEROSPACE, MARITIME AND MILITARY SYSTEMS GROUPS

Colloquium on TESTABILITY AND TESTING TECHNOLOGY

Royal Institution, Albemarle Street, London W1, 10 a.m. Advance registration necessary. For further details and registration forms, apply to Meetings Officer, IERE.

Tuesday, 7th December

JOINT IERE/IEE MEDICAL AND BIOLOGICAL ELECTRONICS GROUP IN ASSOCIATION WITH THE BIOLOGICAL ENGINEERING SOCIETY

Physiology for engineers:
2—

Botany Theatre, University College London, 6 p.m. (Tea 5.30 p.m.).

Wednesday, 8th December

JOINT IERE/IEE COMPUTER GROUP

Colloquium on FAULT TOLERANT COMPUTER SYSTEMS

IERE Lecture Room, 2 p.m.

Advance registration necessary. For further details and registration forms, apply to Meetings Officer, IERE.

Tuesday, 11th January

AEROSPACE, MARITIME AND MILITARY SYSTEMS AND COMMUNICATIONS GROUPS

Colloquium on LAND VEHICLE AERIALS

Royal Institution, Albemarle Street, London W1, 2.30 p.m.

Advance registration necessary. For further details and registration forms, apply to Meeting Officer, IERE.

Tuesday, 11th January

JOINT IEE/IERE/BES MEDICAL AND BIOLOGICAL ELECTRONICS GROUP

Physiology for engineers:
3—The human thermo-regulatory system

Botany Theatre, University College, London, 6 p.m.

Wednesday, 19th January

JOINT IERE/IEE COMPUTER GROUP

Colloquium on THE ENGINEER'S APPROACH TO MICROPROCESSOR SYSTEMS

Royal Institution, Albemarle Street, London W1, 2.30 p.m.

Advance registration necessary. For further details and registration forms, apply to Meetings Officer, IERE.

Wednesday, 26th January

MEASUREMENTS AND INSTRUMENTS GROUP

Colloquium on R.F. MEASUREMENTS AND CALIBRATION IN BRITAIN

Royal Institution, Albemarle Street, London W1, 10 a.m.

Advance registration necessary. For further details and registration forms, apply to Meetings Officer, IERE.

Thursday, 27th January

COMMUNICATIONS GROUP

Colloquium on A REVIEW OF DATA MODEMS

Royal Institution, Albemarle Street, London W1, 2.30 p.m.

Advance registration necessary. For further details and registration forms, apply to Meetings Officer, IERE.

Thames Valley Section

Wednesday, 8th December

The automated warehouse

By A. St. Johnston (*Vaughan Systems and Programming*)

Caversham Bridge Hotel, Reading, 7.30 p.m

Thursday, 20th January

Electronic dashboard instrumentation

By P. N. Thomas (*Smiths Industries, Witney*)

Caversham Bridge Hotel, Reading, 7.30 p.m

East Anglian Section

Wednesday, 19th January

JOINT MEETING WITH IEE

Recent technological advances in microprocessors

By N. Carruthers (*Digital Equipment*)

King Edward VIth Grammar School, Broomfield Road, Chelmsford, 6.30 p.m. (Tea 6 p.m.)

Southern Section

Wednesday, 8th December

Electronic ignition

By Dr. M. J. Werson (*University of Southampton*)

Lecture Theatre L. University of Surrey, 7 p.m.

Thursday, 6th January

CEI SOUTHERN BRANCH MEETING

Symposium on POTENTIAL FOR POWER

Prospects for power from currently unconventional sources (seven papers)

Southampton University, 10 a.m.–5 p.m.

Registration fee of £25 includes preprints and lunch. Details and application forms from Dr. J. S. Hardman, Dept. of Chemistry, Portsmouth Polytechnic, White Swan Road, Portsmouth (Tel Portsmouth 27861, ext 238)

Wednesday, 19th January

JOINT MEETING WITH CEI

Radar assisted berthing of large tankers

By S. Thompson (*formerly Marconi International Marine Co.*)

Lecture Room 4A, Mathematics Building, Southampton University, 7 p.m.

Synopsis: With the increasing use of very large tankers for the transportation of crude oil, the accurate measurement of the tankers speed of approach to a land-based terminal is vital. The equipment found on such vessels is not usually sufficiently accurate and several alternative techniques have been considered. Of these, a Doppler radar system is the most suitable and a description of these techniques will be presented. Aspects of the problem from the point of view of the Master and Pilot on board and of the Berthing Master ashore will also be discussed.

Kent Section

Thursday, 9th December

Electronics on Saturday

By Dr. K. J. Dean (*Principal, S. E. London Technical College*)

Medway and Maidstone College of Technology, Chatham, Kent, 7 p.m. (Tea at 6.30 p.m.)

Beds & Herts Section

Tuesday, 18th January

Control and supervision of television transmitters

By V. Arnold (*Granada TV Rentals*)

Mander College, Bedford, 7.45 p.m.

South Wales Section

Wednesday, 8th December

University television services

By Dr. P. Whitaker (*University of Birmingham*)

West Midlands Section

Monday, 6th December

JOINT MEETING WITH IEE

Electronic techniques in archaeology

By Professor E. T. Hall (*University of Oxford*)

North Staffordshire Polytechnic, Beaconside, 7 p.m. (Tea 6.30 p.m.)

Tuesday, 18th January

Some aspects of running a local radio station

By D. Wood (*Chief Engineer, BRMB*)

Department of Electronic and Electrical Engineering, University of Birmingham, Edgbaston, 7 p.m. (Tea 6.30 p.m.)

East Midlands Section

Tuesday, 18th January

8080 microprocessor family application

By Dr. D. J. Quarmby (*Loughborough University*)

Leicester University, 7 p.m. (Tea 6.30 p.m.)

South Midlands Section

Wednesday, 8th December

Global communications from land line to satellite

By D. W. Weedon (*Cable and Wireless*)

Majestic Hotel, Park Place, Cheltenham, 7.30 p.m.

Monday, 10th January

JOINT MEETING WITH IEE

The impact of digital electronics in television illustrations

By A. A. Trainer (*ITN*)

BBC Club, Evesham, 7.30 p.m.

North Eastern Section

Monday, 6th December

JOINT MEETING WITH IEE

Dynamic ship positioning

By R. Bond (*G.E.C.*)

Merz Court, University of Newcastle, 6.15 p.m. (Tea 5.30 p.m.)

Tuesday, 11th January

High speed digital transmission

By G. W. Goddard (*Post Office Research Centre*)

Y.M.C.A., Ellison Place, Newcastle, 6 p.m. (Tea 5.30 p.m.)

North Western Section

Thursday, 16th December

Engineering in medicine

By Dr. J. A. Hewer (*Middlesex Hospital*)

Renold Building, UMIST, 6.15 p.m. (Light refreshments available before the meeting)

Synopsis: After a short historical resume the comparison is made between the attitude of clinicians towards measuring and monitoring compared with that of their scientific and industrial counterparts who reckon it as an essential part in the control of many processes. The reasons for medical measurement and monitoring are outlined and the essential part which it plays in medical investigation is discussed. Examples are given of the present scope of measuring and monitoring in wards, intensive therapy units and during certain surgical operations. The modern trend to use non-invasive measurements wherever possible in order to abolish any risk to the patient is discussed.

Thursday, 20th January

Optical fibre communications

By a speaker from the *Post Office Research Department*

Renold Building, U.M.I.S.T., Sackville Street, Manchester, 6.15 p.m. (Light refreshments available before meeting)

Safer Safety Signs

The publication of BS 5378: 'Safety Colours and Safety Signs', marks a major step forward in the European harmonization of industrial safety signs. The urgency of standardization in this field emerges from the interim results of research being carried out for BSI by the University of Aston, which show alarming diversifications and inconsistencies in the safety signs currently available in the UK.

The new British Standard, which is in fundamental agreement with draft proposals from the International Organization for Standardization (ISO) and from the EEC, provides a system of on-site safety signs which are clear, unambiguous and consistent. They are designed to convey, quickly and vividly, information of danger and do not, in general, require the use of words. Although they will be used initially for signs in industry the concepts are applicable to other activities and it is hoped that the Standard will be used as the basis for development of all future types of safety signing, since the advantages of using a single system in all fields would lead to less confusion and reduce the need for duplication of costly programmes of education.

BS5378 and the EEC and ISO proposals agree on the shapes for safety signs: circular for mandatory and prohibition; triangular for warning; square and rectangular for emergency information, or supplementary signs. There is also agreement on the combinations of shape and colour and their meanings. Red is for prohibition signs and for fire-fighting equipment. Yellow is used always with triangular signs to imply caution for possible danger. Green is used always with square or rectangular signs to show the position of rescue equipment, or to indicate a safe zone. Blue used with a circular sign is a directive—a mandatory instruction.

The EEC, ISO and UK proposals are closely in accord over a range of symbols for use on safety signs, the main point of contention at the moment being that the UK and EEC insist on the use of the crossbar for prohibition in all cases and ISO does not.

Copies of BS 5378 are available from BSI Sales Department, 101 Pentonville Road, London N1 9ND, price £4.

Standard Frequency Transmissions—September 1976

(Communication from the National Physical Laboratory)

September 1976	Deviation from nominal frequency in parts in 10^{10} (24-hour mean centred on 0300 UT)	Relative phase readings in microseconds NPL—Station (Readings at 1500 UT)	
	Droitwich 200 kHz	*GBR 16 kHz	†MSF 60 kHz
1	−0·2	695·6	611·7
2	−0·2	695·6	611·8
3	−0·2	695·4	611·9
4	−0·2	695·4	611·8
5		695·4	611·7
6		695·3	611·5
7	−0·2	695·2	611·6
8	−0·2	695·1	611·6
9	−0·2	695·1	611·3
10	−0·2	695·0	611·2
11	−0·2	695·4	611·4
12	−0·2	695·4	611·4
13	−0·2	695·2	611·4
14	−0·2	695·2	611·3
15	−0·1	694·9	611·3
16	−0·1	695·0	611·2
17	−0·1	694·8	611·0
18	−0·1	695·0	611·0
19	−0·1	694·7	611·0
20	−0·1	694·8	611·0
21	−0·1	694·7	611·0
22	−0·1	694·8	610·8
23	−0·2	694·8	610·6
24	−0·1	694·6	610·9
25	−0·2	694·9	610·9
26	−0·2	695·0	610·5
27	−0·2	TX OFF AIR	TX OFF AIR
28	−0·2	TX OFF AIR	TX OFF AIR
29	−0·2	TX OFF AIR	TX OFF AIR
30	−0·2	TX OFF AIR	TX OFF AIR

All measurements in terms of H-P Caesium Standard No. 344, agrees with the NPL Caesium Standard to 1 part in 10^{11}.

* Relative to UTC Scale; (UTC_{NPL}–Station) = +500 at 1500 UT 31 December 1968.

† Relative to AT Scale; (AT_{NPL}–Station) = +468·6 at 1500 UT 31 December 1968.