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Hybrid Microelectronics

NEW techniques of construction in the broadest sense are of enormous interest and importance to the electronic engineer and it is one of the functions of the Institution to report on progress in these fields. Thus during the 1950s numerous meetings were held on the potentialities of the various types of printed wiring which were then being introduced. In the following decade the integrated circuit based on semiconductor techniques emerged and the exciting nature of this new development, bringing with it a complete revolution in methods and thinking to every branch of electronic engineering, tended to push into the background the developments which were taking place in the technology of thin and thick films. Indeed the protagonists of semiconductor i.c.s often in their enthusiasm tended to regard film methods as a technological non-starter, soon to vanish under the flood of increasingly diverse new developments backed in every advanced technology country with vast financial support.

But film techniques have not been submerged and many of the new developments put forward at two IERE conferences in the 'sixties have gone forward to practical realization. The conference in 1966 on 'Applications of Thin Films in Electronic Engineering' introduced engineers to many new concepts and among them foreshadowed the 1968 conference, 'Thick Film Technology'. The latter subject, which has important differences from the earlier thin film approach, not so much in physical thickness as in basic preparation techniques, has in fact lead to a greater number and volume of applications. Both thick and thin films however have their advantages and disadvantages and they are really complementary.

Essentially the great contribution of the film technologies is in hybrid microelectronics where they provide a flexibility of approach that is not generally obtainable with purely semiconductor methods. Hybrid microelectronic circuits, combining active devices with thick and thin film circuits representing passive components and the interconnexions, can satisfy applications in which high voltage working, high frequency operation and good linear performance is required to an extent not easily achieved with s.i.c.s; where quantities required do not justify the large setting-up charges usually associated with s.i.c.s, the hybrid circuit has obvious advantages. In other applications there are savings in cost over conventional packaging by using film techniques as a means of assembling and interconnecting semiconductor i.c.s.

Hybrid microelectronics is a rapidly growing technology, estimates from the USA suggesting increases in sales of three, four or even more times over a five-year period to 1976 in consumer (including automotive) applications and in industrial applications: telecommunications is considered a particularly promising area. The same source suggests a threefold increase in Europe. It is somewhat ironical that Great Britain, where the relatively short production runs often point to the advantages of adopting a hybrid approach, has not persisted with its considerable activity in R and D of the 'sixties.

There seems to be a lack of awareness of the realities of hybrid microelectronics and the Institution has considered it timely to arrange a conference on the subject which will be held at Canterbury from 25th to 27th September next. The Conference Organizing Committee is under the chairmanship of Professor J. C. Anderson who also initiated the two previous IERE 'film' conferences, and the Programme Committee chairman is Mr. P. E. K. Donaldson. Associated with the conference are the UK Branch of the International Society for Hybrid Microelectronics, the IEE, the IEEE and the Institute of Physics, and the provisional programme comprising 36 papers was published in the July issue of the Journal. The comprehensive coverage of the sessions, dealing with materials and fabrication methods, reliability and applications, should go a good way to making engineers aware of this important constructional technique.

Contributors to this issue*

Mr. J. Hockley (Member 1972) studied for his professional qualifications whilst at the Post Office Research Station. In 1961 he joined the Canadian Marconi Company working on the Mid-Canada Early Warning System; on returning from Canada he entered the BBC as an Engineer on High-Power Transmitters. In 1964 Mr. Hockley joined the HF Aerials Research Branch at the Government Communications Headquarters and since then has worked on the design and development of h.f.d.f. systems. A Senior Scientific Officer, he is currently involved with the design of a multi-channel computer-controlled h.f. receiving system for a communications research project.

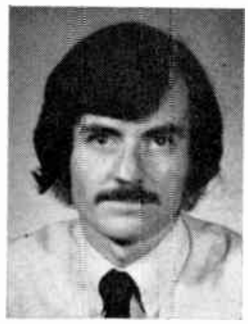
Dr. John Stevenson graduated in 1962 with an honours B.Sc. in physics. He then joined the Quartz Crystal Group at GEC Hirst Research Centre and investigated frequency ageing and interaction between modes of vibration for quartz crystals, later taking major responsibility in a small section designing, constructing and testing crystal filters. He went to Queen Mary College in 1966 for three years, working on crystal lattice filters for a Ph.D. in electrical engineering, and in the meantime gave part-time lectures in physics at Willesden College of Technology. He returned to GEC in early 1970, joined the Circuit Theory Group and worked primarily on digital filters. Last year he transferred to Marconi Space and Defence Systems, joining the Satellite Transponder Group as a Senior Microwave Engineer, and he is at present developing waveguide filter synthesis procedures.

Mr. R. T. Lovelock had early experience with design of telephone equipment, radio frequency measuring equipment, and television receivers. In 1935 he was appointed to take charge of a small laboratory at GEC Radio and Television Works where he was responsible for specialized measurements, environmental testing, and special materials processes.

From 1941 onwards Mr. Lovelock became increasingly engaged on component standardization in industry associations and BSI committees, and he has continued this activity and also IEC committee work.

From 1952 until 1957 he was in charge of the Technical Services laboratories of Murphy Radio's Electronics Division. He then moved to Belling and Lee and from 1957 until 1965 was Laboratory Controller. For the next seven years, until his retirement he was the Company's Technical Director and since 1972 he has been working as a consultant.

Miss Hilary J. Kahn graduated in 1965 from Bedford College, University of London with a B.A. degree in Latin and Greek. In 1966 she obtained a Diploma in Data Processing and Business Administration from the University of Newcastle upon Tyne. After one year working for English Electric - Leo - Marconi (Kidsgrove) she joined the Department of Computer Science, University of Manchester, where she is currently a Lecturer.



Dr. J. W. R. May obtained his B.Sc. in electrical engineering at Manchester University in 1965. This was followed by an M.Sc. and Ph.D. in computer science, also at Manchester, in 1966 and 1970 respectively. The research for his higher degrees concerned the development of logic network simulation systems. From 1968 to 1970 he held the position of Assistant Lecturer in Computer Science at Manchester University and between 1970 and 1972 he was a Visiting Assistant Professor of Computer Science at West Virginia University. Since September 1972 Dr. May has been a Software Designer with the North-Eastern Regional Hospital Board, Scotland. He holds an Honorary Lectureship in Computing at the University of Aberdeen.

Dr. V. J. Phillips graduated with first class honours in electrical engineering in 1955 from Imperial College, London. Following a period of research work at the College, he was awarded the degree of Ph.D. in 1959. From 1958 to 1960 he worked at the GEC Research Laboratories (now Hirst Research Centre) at Wembley, Middlesex, and he took up his present lecturing post at the University College of Swansea in 1960; he is now a Senior Lecturer. He received, jointly with two of his research students, the Dr. Norman Partridge Memorial Premium in 1971 for a paper on speech scrambling.

Mr. J. K. Watkins graduated from the Department of Electrical and Electronic Engineering, University College of Swansea, in 1972 with first class honours, for which he received the Institution of Electrical Engineers Western Centre Prize. He is at present working for the Guided Weapons Division of the British Aircraft Corporation.

* See also page 474.

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Speech scrambling by the matrixing of amplitude samples

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and

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SUMMARY

If a speech signal is scrambled by varying the order of transmission of its amplitude samples, a signal of very low intelligibility can be produced. The basic defect in the system is that there is always some of the original speech spectrum left in the scrambled signal, and this is the source of the residual intelligibility. This paper shows how this original signal component may be removed completely by matrixing of the samples. A scrambled signal of virtually zero intelligibility is then produced.

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List of Principal Symbols

$s(t)$	band-limited input signal
f_c	sampling frequency
N	number of samples in scrambling block
n	the general integer
$f(t)$	unmodulated samples
$u(t)$	modulated samples
$v(t)$	matrix-scrambled samples
$f_i(t)$, $u_i(t)$, $v_i(t)$	constituent sample trains of above
a_{ij}	coefficient of scrambling matrix
α	original signal component in scrambled signal
U_n, L_n	upper and lower sidebands
λ	figure of merit

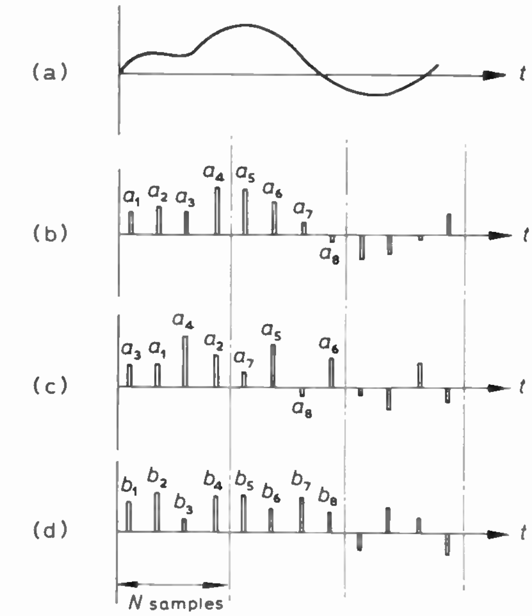
1 Introduction

The sampling theorem states that if a bandwidth-limited signal $s(t)$ such as that shown in Fig. 1(a) is amplitude-sampled as in Fig. 1(b), the resulting samples will contain all the information necessary to reconstruct the continuous signal provided that the samples are taken at a rate f_c which is at least twice the bandwidth of the signal. The sampled waveform has a frequency spectrum which consists of sets of lower and upper sidebands (as in simple amplitude modulation) centred on harmonics of f_c, together with a component which is the spectrum of the original signal $s(t)$. The sidebands may be removed by low-pass filtering, leaving the original spectrum only and thus producing a signal which, apart from a simple amplitude factor, is identical to the input signal $s(t)$. This sampling process forms the basis of all the digital communication systems in use to-day.

A previous paper[1] has investigated the degree of privacy which may be introduced into a transmission system by scrambling the order in which the samples are transmitted. The samples are divided into blocks of N, and are re-ordered within each block as illustrated in Fig. 1(c). It was shown that the spectrum of scrambled samples of this sort consists of a component which is the original signal spectrum weighted by an 'amplitude response' function, together with sets of sidebands centred on the frequencies nf_c/N. Many of these sideband terms fall within the original signal band. Thus if the scrambled samples are low-pass filtered, the signal is masked or obscured by all these extra components. It was shown that this masking can result in a monosyllabic word intelligibility as low as about 3% if the parameters of the scramble are correctly chosen.

The obvious weakness of this form of scrambling, and the source of the residual intelligibility in the scrambled signal, is the presence of the original component. The purpose of the system described in the present paper is to show how this original component may be eliminated, thereby reducing the intelligibility of the scrambled signal virtually to zero.

As stated in the paper previously cited, difficulties in descrambling due to distortion, etc., will doubtless occur if the scrambled samples are transmitted directly through



(a) Band-limited signal $s(t)$ (c) Sample re-ordering
(b) Amplitude samples (d) Matrix scrambling

Fig. 1. Scrambling of amplitude samples.

a dispersive noisy channel. The effects of such distortions are outside the scope of the present investigation which examines the effectiveness of the actual scrambling process itself.

The principle of operation of the system is as follows. The signal $s(t)$ is sampled and divided into blocks of length N as before. The first N samples $a_1, \ldots, a_N$ are stored in analogue stores, and an arithmetic unit operates upon these stored values to produce a new set of samples $b_1, \ldots, b_N$ as defined by the equations

$$\begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{vmatrix} = \begin{vmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{vmatrix} \cdot \begin{vmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{vmatrix} \tag{1}$$

where N is taken as 4 for purposes of illustration.

These new sample values are put into a set of output analogue stores, and they are then read out in turn to form a scrambled pulse train as in Fig. 1(d). A schematic diagram of such a system is shown in Fig. 2. The arithmetic unit operates continuously, and its outputs at any time will depend on the values stored in the input analogue stores at that time. It is therefore necessary to read out from the arithmetic unit after every fourth input sample; thus the circuit operates continuously with an overall delay equal to N sample periods.

2 Theoretical Analysis of System

A train of unmodulated sampling pulses of unit amplitude and repetition frequency f_c may be expressed by the Fourier series

$$f(t) = k + 2k \sum_{n=1}^{\infty} \frac{\sin n\pi k}{n\pi k} \cdot \cos\left[2\pi n f_c t\right] \tag{2}$$

where k is the duty cycle (= pulse duration/pulse repetition period) and n is an integer defining the particular harmonic of the fundamental frequency.

The scrambling is based upon division of the samples into blocks of length N samples, and so the sampling pulses of equation (2) may conveniently be considered as being made up of N constituent pulse trains, each having a repetition rate f_c/N and duty cycle k/N. If the first constituent pulse train is considered to define the zero point on the time axis, the time delay associated with the ith pulse train will be

$$t_i = (i-1) \cdot \frac{1}{f_c}. \tag{3}$$

The ith pulse train may therefore be written as

$$f_i(t) = \frac{k}{N} + \frac{2k}{N} \sum_{n=1}^{\infty} \frac{\sin\left(\frac{n\pi k}{N}\right)}{\frac{n\pi k}{N}} \cdot \cos\left[\frac{2\pi n f_c}{N}\left[t - \frac{(i-1)}{f_c}\right]\right]. \tag{4}$$

Since the original unmodulated pulse train is the sum of the constituent trains,

$$f(t) = \sum_{i=1}^{N} f_i(t). \tag{5}$$

An analysis of the proposed system may best be performed by considering a single frequency input signal,

$$s(t) = \cos(2\pi f_s t) \tag{6}$$

and then extending the computation by superposition to include signals containing many frequency components.

The sampled version of this single tone will be given by

$$u(t) = s(t) \cdot f(t) \tag{7}$$

and this may be decomposed into N constituent sample trains

$$u_i(t) = s(t) \cdot f_i(t) \tag{8}$$

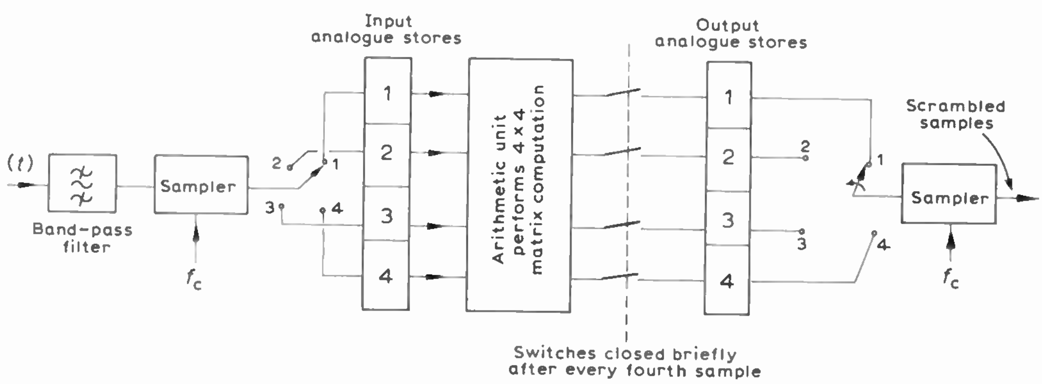


Fig. 2. Matrix scrambler.

so that

$$u(t) = \sum_{i=1}^{N} u_i(t). \tag{9}$$

The scrambling process operates continuously, matrixing one block of samples after another so that one may consider it to be the matrixing of sample trains rather than individual blocks of samples. Taking $N=4$ as an example, the scramble can be represented by

$$\begin{vmatrix} v_1(t) \\ v_2(t) \\ v_3(t) \\ v_4(t) \end{vmatrix} = \begin{vmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{vmatrix} \cdot \begin{vmatrix} u_1(t) \\ u_2(t) \\ u_3(t) \\ u_4(t) \end{vmatrix} \tag{10}$$

where $v_i(t)$ are the constituent scrambled sample trains, and the complete scrambled train

$$v(t) = \sum_{i=1}^{N} v_i(t). \tag{11}$$

The matrix equation (10) represents the constituent samples in magnitude, but a complete expression for the constituent sample trains must account for the time delays between them as follows

$$v_i(t) = \sum_{j=1}^{N} a_{ij} \,.\, s[t+t_{ij}].f_i(t) \tag{12}$$

t_{ij} is the time shift associated with coefficient a_{ij} and is given by

$$t_{ij} = (j-i) \,.\, \frac{1}{f_c}. \tag{13}$$

The complete scrambled waveform is then

$$v(t) = \sum_{i=1}^{N} \sum_{j=1}^{N} a_{ij} \,.\, s[t+t_{ij}] \,.f_i(t). \tag{14}$$

Substitution of equations (4), (6) and (13) into (14) gives

$$v(t) = \sum_{i=1}^{N} \sum_{j=1}^{N} a_{ij} \,.\cos 2\pi f_s \left[t + \frac{(j-i)}{f_c}\right] \,. \left[\frac{k}{N} + \frac{2k}{N} \sum_{n=1}^{\infty} \frac{\sin \frac{n\pi k}{N}}{\frac{n\pi k}{N}} \,.\cos \frac{2\pi n f_c}{N} \left[t - \frac{(i-1)}{f_c}\right]\right]. \tag{15}$$

Examination of this expression reveals that the product of the d.c. component k/N and the various delayed versions of the tone results in a frequency component in the scrambled waveform of the same frequency as the original tone.

$$s_0(t) = \frac{k}{N} \sum_{i=1}^{N} \sum_{j=1}^{N} a_{ij} \,.\cos 2\pi f_s \left[t + \frac{(j-1)}{f_c}\right]. \tag{16}$$

The amplitude α of this component can be found by resolving it into its two orthogonal components.

$$\alpha = \frac{k}{N} \sqrt{\left[\sum_i \sum_j a_{ij} \,.\cos \frac{2\pi f_s}{f_c} (j-i)\right]^2 + \left[\sum_i \sum_j a_{ij} \,.\sin \frac{2\pi f_s}{f_c} (j-i)\right]^2}. \tag{17}$$

The products of the other harmonics of $f_i(t)$ with the delayed versions of the tone produce an infinite number of pairs of sidebands, each pair centred on one of the frequencies nf_c/N. By resolution into orthogonal components as before, the amplitudes of the upper and lower sidebands (U_n and L_n) are given by the following expressions:

$$U_n = \frac{\sin \frac{n\pi k}{N}}{n\pi} \sqrt{\left[\sum_i \sum_j a_{ij} \,.\cos X\right]^2 + \left[\sum_i \sum_j a_{ij} \,.\sin X\right]^2}$$

where

$$X = 2\pi \left[\frac{n}{N}(i-1) - \frac{f_s}{f_c}(j-i)\right] \tag{18}$$

$$L_n = \frac{\sin \frac{n\pi k}{N}}{n\pi} \sqrt{\left[\sum_i \sum_j a_{ij} \,.\cos W\right]^2 + \left[\sum_i \sum_j a_{ij} \,.\sin W\right]^2}$$

where

$$W = 2\pi \left[\frac{n}{N}(i-1) + \frac{f_s}{f_c}(j-i)\right]. \tag{19}$$

In the case of a more complicated multi-tone input signal, the components produced by each tone may also be calculated from equations (18) and (19). Some of these components will lie within the input signal bandwidth, and thus any attempt to regenerate the signal from the matrix scrambled pulses by low-pass filtering will produce a signal obscured by these components.

Several interesting facts emerge from this analysis. Equation (17) for the amplitude of the original component in the scrambled signal contains the double summation

$$\sum_i \sum_j .$$

The purpose of this double summation is to include every coefficient a_{ij} in the scrambling matrix. However, these may all be included just as effectively by a slight rearrangement of the summation. If $(j-i)$ is defined as being equal to M, then in an $N \times N$ matrix M can have values between $(N-1)$ and $-(N-1)$. The cosine terms within equation (17) may be written as:

$$\sum_{M=-(N-1)}^{+(N-1)} \sum_{\substack{\text{all coeff.} \\ j-i=M}} a_{ij} \,.\cos \frac{2\pi f_s}{f_c}(M) \tag{20}$$

and the sine terms as

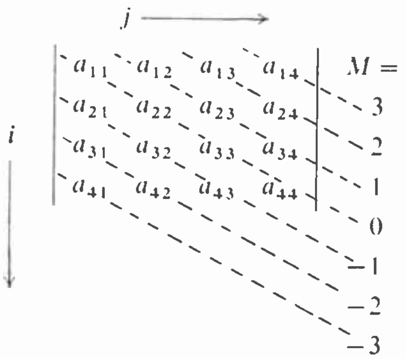
$$\sum_{M=-(N-1)}^{+(N-1)} \sum_{\substack{\text{all coeff.} \\ j-i=M}} a_{ij} \,.\sin \frac{2\pi f_s}{f_c}(M). \tag{21}$$

The inner summation runs through all the a_{ij} terms in a given diagonal of the matrix, and the outer summation takes each diagonal in turn. All the a_{ij} terms are still included in the expression, but they are now in a different order. M is the same for all the coefficients in a given diagonal, and thus if

$$\sum_{\substack{\text{all coeff.} \\ j-i=M}} a_{ij} = 0$$

for every diagonal, equations (20) and (21) both reduce to zero. There will then be no original component present in the scrambled signal.

The significance of this condition is perhaps best understood by means of the following diagram. Each dotted line represents the coefficients for which M is a constant, and the sum of the coefficients in each diagonal must be zero.



The use of matrices of this sort should result in a very good scramble, since the inherent weakness of the sample reordering scramble previously referred to in Section 1 has now been removed. A matrix obeying this rule will be referred to in future as an ideal matrix.

It can also be shown (see Appendix 1) that there exists a type of symmetry or pattern in the amplitudes of the sidebands described by equations (18) and (19). In the case of $N=4$ it is shown that $L_1 = U_3$, $L_3 = U_1$ and $\alpha = L_4 = U_4$. Similarly in the case of $N=6$ it can be shown that $\alpha = U_6 = L_6$, $L_3 = U_3$, $L_1 = U_5$, $L_5 = U_1$, $L_2 = U_4$ and $L_4 = U_2$.

Notice that the simple reordering of samples may be considered to be a special case of matrix scrambling. For example, the 4 × 4 scramble 3 1 4 2 may be represented by the matrix

$$\begin{vmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{vmatrix}$$

The frequency components resulting from such a scramble may then be obtained from equations (17), (18) and (19). The opportunity is taken here of pointing out a small error in the previous paper.[1] The expression given in Section 3 for the amplitudes of the upper and lower sidebands is in fact the correct expression for the lower sidebands. The upper sidebands are given by an expression which is identical save that the negative signs immediately preceding the terms $\gamma q\omega/f_c$ should be changed to positive. The implications of this change are not significant in the analysis which follows except that in the graphs of Fig. 3 the curves labelled $n=1$ are in fact L_1 and U_3; $n=3$ are L_3 and U_1. The other curves are correct.

3 Selection of the Scrambling Matrix

Any matrix used for scrambling samples by this method should have the following properties:

(i) As a general recommendation, its size N should be as small as possible consistent with achieving an adequate scramble. The smaller the matrix, the fewer will be the stores etc., required and the cheaper will the system be to construct.

(ii) In order to obtain a good scramble it should obey the diagonal rule outlined in Section 2, namely, $\Sigma a_{ij} = 0$ for every diagonal.

(iii) When the scrambled samples $v(t)$ are transmitted to a receiver, they must be de-scrambled in order to produce an intelligible signal. This may be done by multiplying the scrambled samples by the inverse of the scrambling matrix.

If

$$|v| = |a| \cdot |u| \quad \text{for scrambling, then}$$
$$|u| = |a|^{-1} \cdot |v| \quad \text{for descrambling.}$$

Thus the scrambling matrix must possess an inverse, which implies that it must not be a singular matrix and it should have a non-zero determinant.

(iv) It is well known[2] that for satisfactory conditioning of a set of equations all the coefficients in the equations should be of the same order of magnitude. If this is not the case inaccuracies will result in both the scrambling and descrambling processes. It would, in fact, be highly convenient if matrices having coefficients which are all +1, −1 or 0 could be used as this would be very easy to engineer using the inverting and non-inverting inputs of operational amplifiers. Matrices of this sort will be referred to as 'simple' matrices.

(v) It would be very convenient, although not essential, if the coefficients in the inverse descrambling matrix were also +1, −1 or 0.

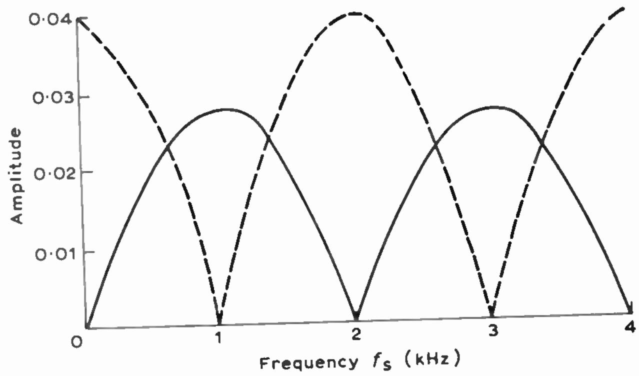
Taking the case of $N=4$ as an example, there will be 3^{16} matrices which can be constructed using the three possible coefficients +1, −1 and 0. Many of these will not obey one or more of the criteria set out above and will not be usable. It would be interesting to known how many useful matrices exist. A computer program has been run in order to determine this, and the results are as follows:

A total of 8379 matrices obey the diagonal rule; of these 4878 possess inverses, 1446 of them being simple inverses. Very many of those whose inverses are not simple are perfectly usable as the inverse coefficients are all of the same order of magnitude and would not demand extreme accuracy in practice.

To use these would merely mean providing appropriate weighting resistors at the inputs to the analogue adding amplifiers used at the receiver. There is thus ample choice of matrix available so that scrambles may be changed as required to provide extra security.

Whilst on the question of changing scrambles, it might be opportune to mention that certain matrices are equivalent from the point of view of the scramble they produce. For example, the matrix

$$\left|\begin{array}{ccc:c} 1 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ \hdashline 0 & 0 & 0 & -1 \end{array}\right|$$



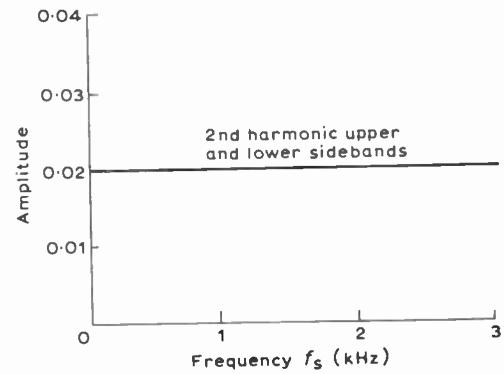
– – – – – 2nd harmonic upper and lower sidebands.

——— { 1st ,, ,, ,, ,, ,, / 3rd ,, ,, ,, ,, ,, }

N.B. $a=0$ i.e. no original component.

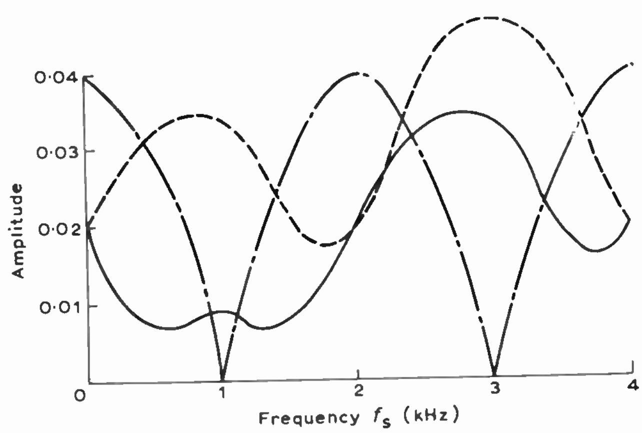
$L_4 = U_4 = 0$. No 4th harmonic sidebands.

GRAPH A
$$\begin{vmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{vmatrix}$$



N.B. $a = L_1 = L_3 = L_4 = U_1 = U_3 = U_4 = 0$.

GRAPH C
$$\begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{vmatrix}$$



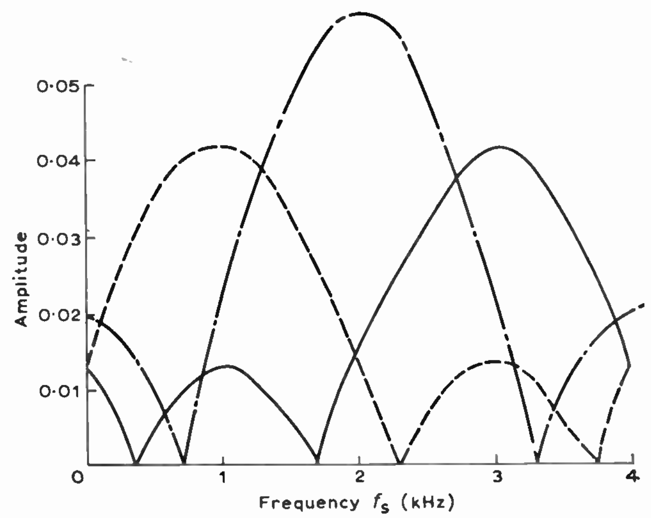
——— { 1st harmonic lower sideband. / 3rd ,, upper ,, }

– – – – – { 1st harmonic upper sideband. / 3rd ,, lower ,, }

— — — 2nd harmonic upper and lower sidebands.

N.B. $a = L_4 = U_4 = 0$.

GRAPH B
$$\begin{vmatrix} 0 & -1 & +1 & 0 \\ 0 & 0 & 0 & -1 \\ +1 & 0 & 0 & +1 \\ 0 & -1 & 0 & 0 \end{vmatrix}$$



— — — { 2nd harmonic upper sideband. / ,, ,, lower ,, }

——— { 1st ,, upper ,, / 3rd ,, lower ,, }

– – – – – { 1st ,, lower ,, / 3rd ,, upper ,, }

N.B. $a = L_4 = U_4$.

GRAPH D
$$\begin{vmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & -1 \\ 1 & 0 & -1 & 0 \\ 0 & -1 & 0 & 0 \end{vmatrix}$$

Fig. 3. Spectral component amplitudes after matrix scrambling; single tone input signal $s(t) = \cos 2\pi f_s.t$: $N = 4$.

can be decomposed into

$$|A| = \begin{vmatrix} 1 & 0 & 0 \\ 1 & -1 & 0 \\ 0 & -1 & 1 \end{vmatrix}$$

and

$$|B| = |-1|$$

The scramble produced could have been accomplished by operating on the incoming samples by the two sub-matrices in turn so that the identical overall effect would have been achieved by a matrix which performs |B| first and then |A|. This is the matrix

$$\begin{vmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & -1 & 1 \end{vmatrix}$$

Another example is

$$\begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{vmatrix}$$

which can be decomposed into

$$\begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix}$$

and

$$\begin{vmatrix} 0 & 1 \\ 1 & 0 \end{vmatrix},$$

or

$$\begin{vmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{vmatrix}$$

and $|1|$. There are thus two equivalent matrices, namely

$$\begin{vmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

and

$$\begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}.$$

It is sometimes possible for a matrix to decompose into two identical sub-matrices, in which case it is a degenerate case and the same scramble could have been achieved with a matrix half the size. An example of this is the 8×8 matrix

$$\begin{vmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & -1 & -1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & -1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 & -1 & -1 & -1 \end{vmatrix}.$$

4 Spectra of Scrambled Signals

The spectra of the signals produced by matrix scrambling have been investigated in two ways. A computer program was developed to calculate the spectra from the expressions derived in Section 2. A practical working scrambling circuit for $N=4$ was constructed and the output signals were investigated with the aid of a Sonagraph machine.[3] The sonograms produced by this machine show the frequencies present as a function of time, the amplitude of any particular component being indicated by the blackness of the trace.

It is not proposed to describe the circuit details of the scrambler since it is adequately represented for the purposes of this paper by the block diagram of Fig. 2. However, it may be of interest to note that the incoming signals were bandwidth-limited before sampling to a nominal bandwidth of 4 kHz. The frequency response of the filter used fell to -12 dB at a frequency $\frac{1}{3}$ octave above the nominal cut-off frequency, and to -36 dB at twice the cut-off frequency. The sampling frequency used throughout was $f_c = 8$ kHz.

The results of the computations are shown in Figs. 3(a) to (d). These graphs show the amplitudes of the sidebands of the harmonics of $n.f_c/N$ as functions of the frequency of the input signal, whose amplitude is assumed unity throughout. A duty cycle of $k = 0{\cdot}04$ was used for these calculations, although its exact value is not critical and does not affect the shapes of the curves. Curves are presented for four different scrambling matrices as indicated on the graphs.

These graphs should be studied in conjunction with the sonograms of Figs. 4(a) to (d). In making these sonograms one of two gliding tones was used as the input signal to the scrambler, these being shown in Figs. 4(f) and 4(g). The first of these rises from 300 Hz to 2 kHz, the second from 3 kHz to 4 kHz, the rise in both cases occurring over an interval of time equal to about 2 seconds. Sonograms in Figs. 4(a), (b) and (c) use the first tone, while those in (d) and (e) use the second. Since the amplitudes of the gliding tones are held constant throughout, the sonograms of (f) and (g) are lines of constant blackness. It should be remembered when interpreting these sonograms that trace blackness is a somewhat crude and approximate method of indicating amplitude, and that they are able to portray only a limited dynamic range. However, the sonograms in general confirm the predicted curves of Fig. 3.

This agreement may be illustrated by considering some of the main features of the curves. For example, Fig. 3(a) predicts that for this particular scramble the upper and lower sidebands centred on the second harmonic term $2.f_c/N = 4$ kHz are equal in amplitude. Their amplitude will fall to zero when the input tone passes through 1 kHz, i.e. when these sidebands are at 5 kHz and 3 kHz. The other sidebands are, however, at their strongest at this point.

The main features of Fig. 3(b) are that the second harmonic sidebands again fall to zero when the input tone is at 1 kHz, and that over the range of input signal used, the first harmonic upper and the third harmonic lower sidebands are larger than the first lower and third upper.

Figure 3(c) is an interesting case in that all the harmonic sidebands are zero except the upper and lower sidebands of the second harmonic, and these remain constant in amplitude throughout. Since a 4 kHz low-pass filter would remove the upper sideband, the net result of this matrix used with a multi-component input signal would be simply to invert the signal spectrum.

Figure 3(d), which uses the 3 kHz to 4 kHz input signal, again shows agreement between the computed and measured results in that over this range of input signal the first harmonic upper and third harmonic lower sidebands predominate.

The most noteworthy feature of all these sonograms is that there is no evidence in any of them of the presence of a component at the same frequency as the original signal. It has already been stated that these sonograms have to be treated with a little caution due to the limited dynamic range of the blackness indication of amplitude. It is possible that a small original component is present which is too weak to cause a mark to appear on the sonogram. However, bearing in mind the agreement obtained

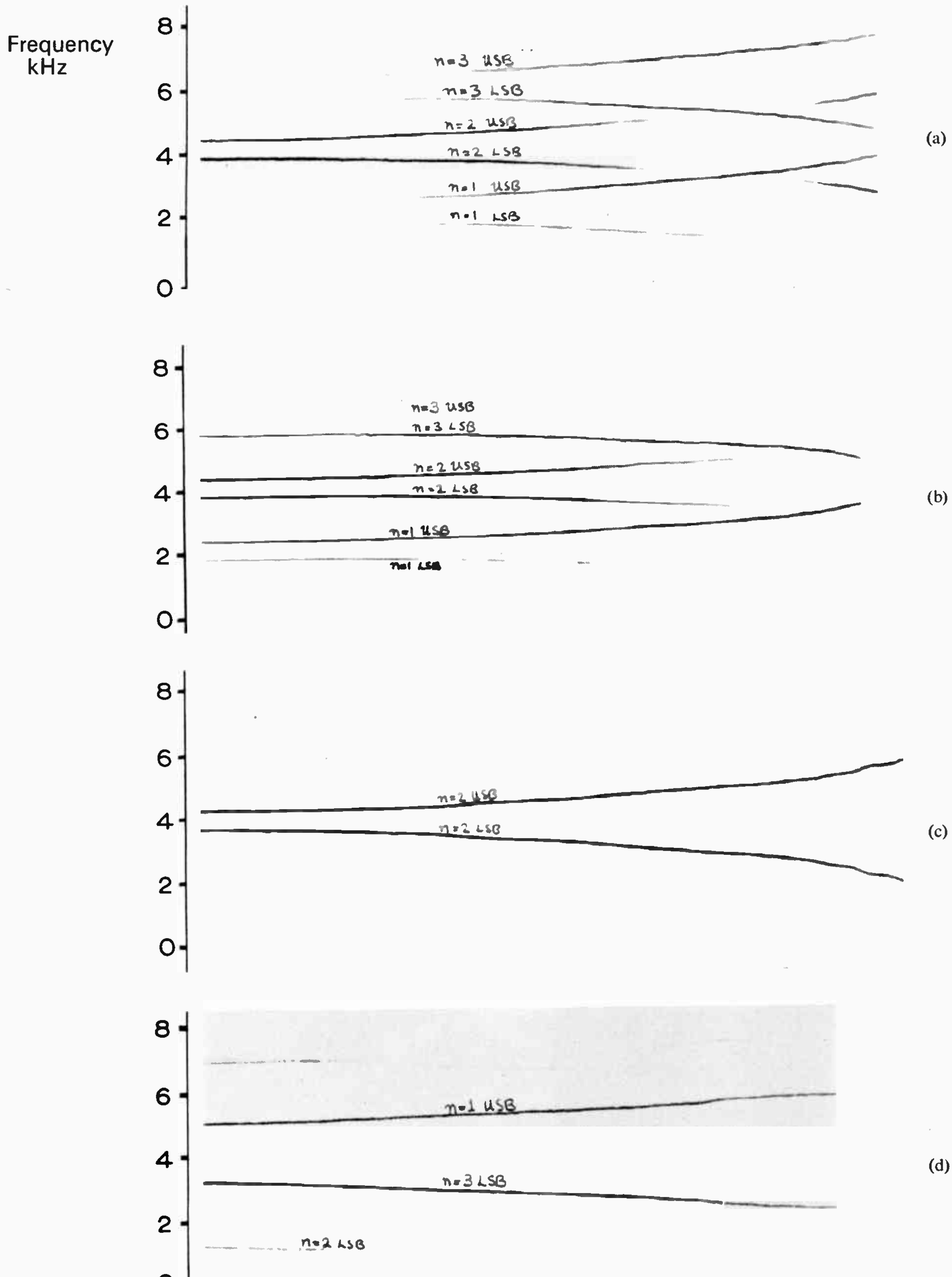


Fig. 4. Frequency spectra of scrambled samples; $N = 4$.
(a) (b) (c) and (d) correspond to the graphs of Fig. 3.
(e) using non-ideal matrix. (f), (g) rising tones used as input signals (300 Hz to 2 kHz for (a), (b) and (c), 3 kHz to 4 kHz for (d) and (e)).

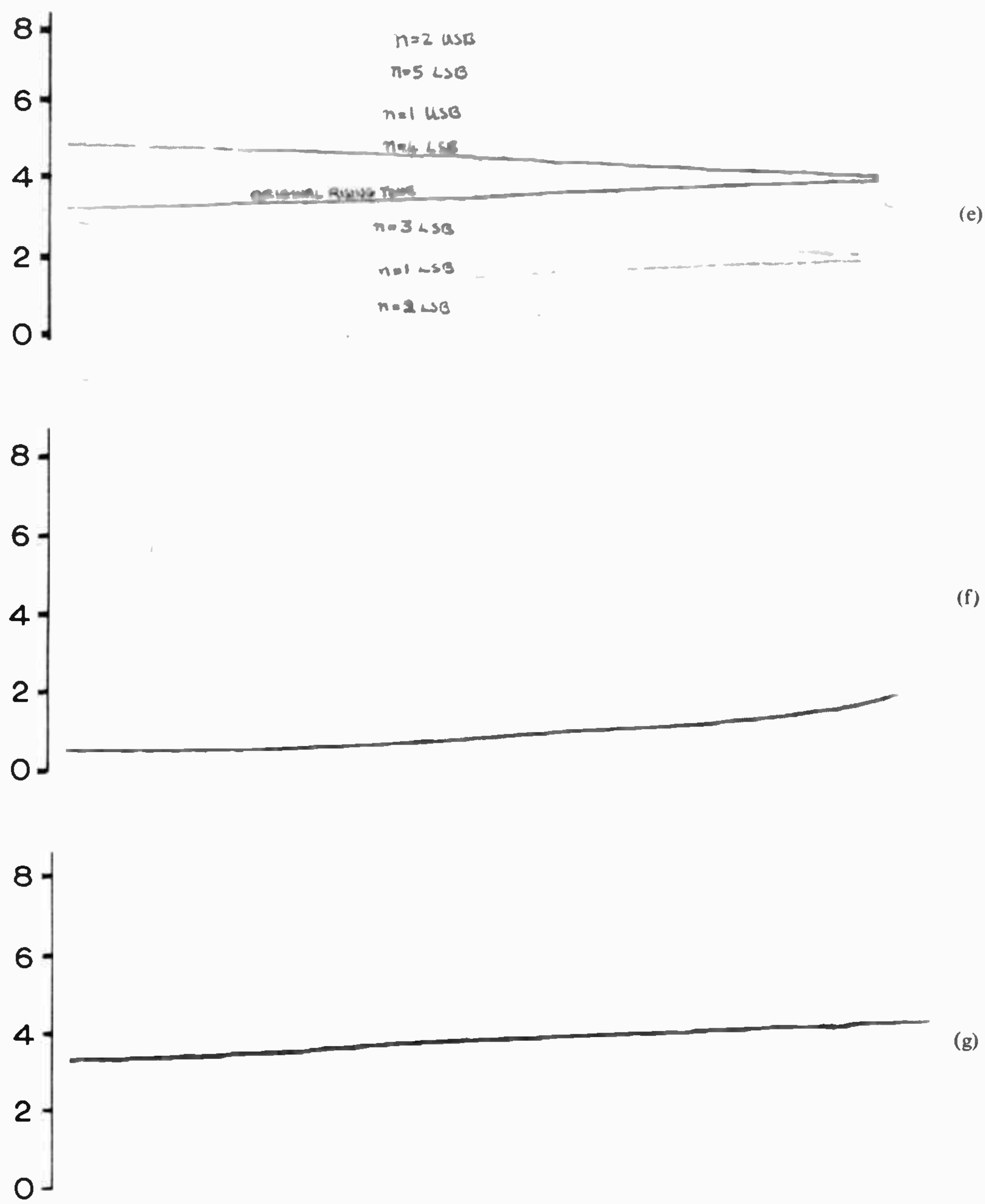
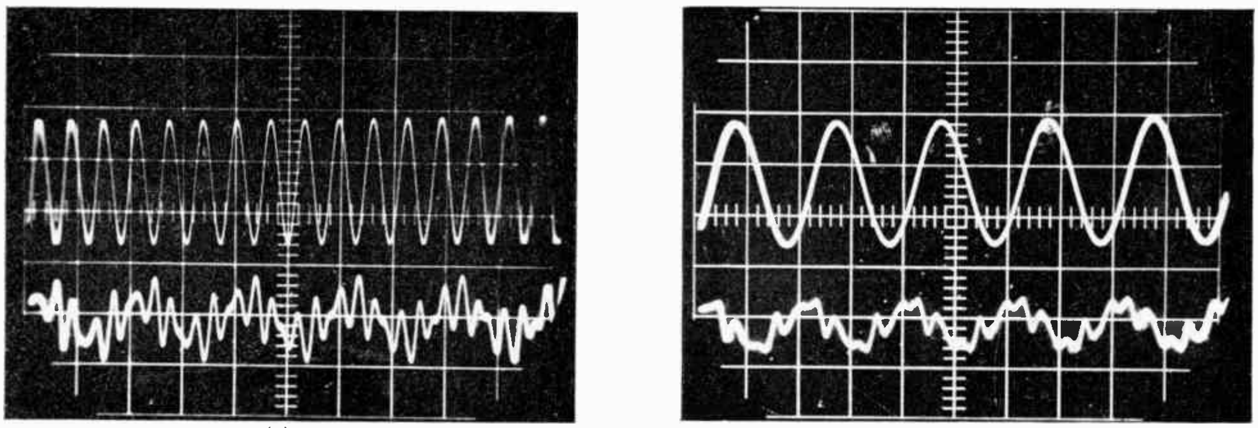


Fig. 4. (cont.)



(a) (b)

Fig. 5. Waveforms of matrix-scrambled signals. (1ms/division) upper traces - input signals: lower traces - scrambled signals. (a) 1·5 kHz input; ideal matrix (b) 0·5 kHz input; non-ideal matrix.

between the curves and sonograms for the other components this seems rather unlikely. The sonogram of Fig. 4(e) shows the spectrum which results from a scramble using the matrix

$$\begin{vmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & -1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{vmatrix}$$

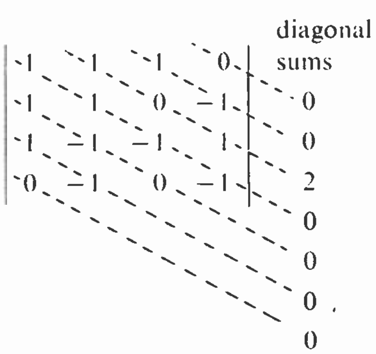
and the 3 kHz to 4 kHz tone as input signal. This is a non-ideal matrix which does not obey the diagonal rule and it will be seen that in this case there is very clearly a component at the input frequency present. There are also sidebands present around the fourth harmonic, which were absent in the previous spectra using ideal matrices.

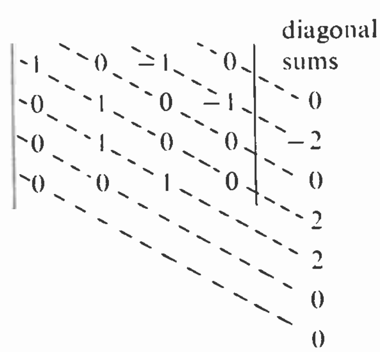
It may therefore be concluded that the results presented in this section seem to be consistent with those predicted by the Fourier analysis of Section 2. The difference between an ideal matrix and a non-ideal matrix has been demonstrated, and this may also be seen from the photographs of Fig. 5. The first of these photographs shows an input signal of frequency 1·5 kHz, together with the waveform produced by scrambling with an ideal matrix, the scrambled samples having been restored to the form of a continuous signal by passing through a 4 kHz low-pass filter. No component at 1·5 kHz can be seen here. The components present will be L_1 at 0·5 kHz, U_1 at 3·5 kHz and L_2 at 2·5 kHz. The 0·5 kHz component in this waveform is easy to spot, but the others, being somewhat more complicated multiples of the original, are harder to distinguish.

Figure 5(b) shows a 500 Hz input signal and the signal produced by scrambling with a non-ideal matrix. There is clearly a strong component at the original frequency left in the scrambled signal.

5 Figure of Merit

In order that the subjective effectiveness of the scrambling system may be predicted for any given simple matrix, ideal or non-ideal, a 'figure of merit' (λ) is tentatively proposed and is defined as the sum of the magnitudes of the sums of the coefficients in each diagonal (for which $(j-i)$ is a constant), divided by the sum of the magnitudes of the coefficients in the matrix. Since this is rather cumbersome to define in words, the figure of merit is best described by the examples of the following matrices:





In the first case, $\lambda = \frac{2}{12}$, there being twelve 1's in the matrix; in the second case $\lambda = \frac{8}{8} = 1$. An ideal matrix with all the diagonal sums being equal to zero has $\lambda = 0$. The first of these matrices is almost ideal and λ is small, whereas the second matrix is far from ideal and would be expected to produce a relatively poor scramble of high intelligibility. It is therefore suggested that the value of λ (lying between zero and unity), for any particular matrix might be expected to give some indication of the effectiveness of that matrix.

This is demonstrably an over-simplification since different matrices with the same value of λ would be expected to give different degrees of intelligibility, e.g.

$$\begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

and

$$\begin{vmatrix} 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

which both have $\lambda = 1$. The first of these is simply the unit matrix which produces no scramble at all and would thus give near-perfect intelligibility. The second matrix would be expected to produce some confusing components in the spectrum providing a degree of lowering of the intelligibility.

On the other hand, even the simple diagonal matrix

$$\begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{vmatrix}$$

having $\lambda = 0$ has been shown to provide an effective scramble since it inverts the spectrum of the speech. Therefore it is suggested that λ might be a reasonable guide to the effectiveness of the matrix when it approaches zero, and to test this hypothesis some intelligibility experiments were carried out.

6 Intelligibility Tests

Lists of phonetically balanced mono-syllabic words were scrambled using various matrices, and were played over to various listeners. The percentage of words correctly recognized was taken as a measure of the intelligibility of the speech. Since intelligibility tests are subjective in nature, and the results are apt to be rather variable, various precautions were taken as follows in order to remove as many of the uncertainties in the test as possible:

(i) No listener heard any particular word list more than once. This eliminates memory, conscious or unconscious.

(ii) The order in which the word lists were presented was varied from listener to listener. This helps to obviate the effects of the listener learning to cope with the particular type of distortion produced by scrambling as the tests proceed.

(iii) A passage of continuous speech scrambled by means of the same matrix as the list which followed was played over to the listener before commencement of the actual test. This helps to overcome initial learning phenomena and to bring the listener to some sort of familiarization with the scrambled speech before the test material itself is presented.

(iv) Two different word lists and two different listeners were used to assess each scramble, in order to lessen the effects of unequal difficulties in the various word lists and the varying skills of individual listeners.

The following four matrix structures were tested.

×	0	0	0
0	×	0	0
0	0	×	0
0	0	0	×

Structure 1

×	×	0	0
0	0	×	0
×	0	0	0
0	×	0	×

Structure 2

0	0	×	0
×	0	0	×
×	×	0	0
0	×	0	0

Structure 3

×	×	×	0
×	×	0	×
×	×	×	×
0	×	0	×

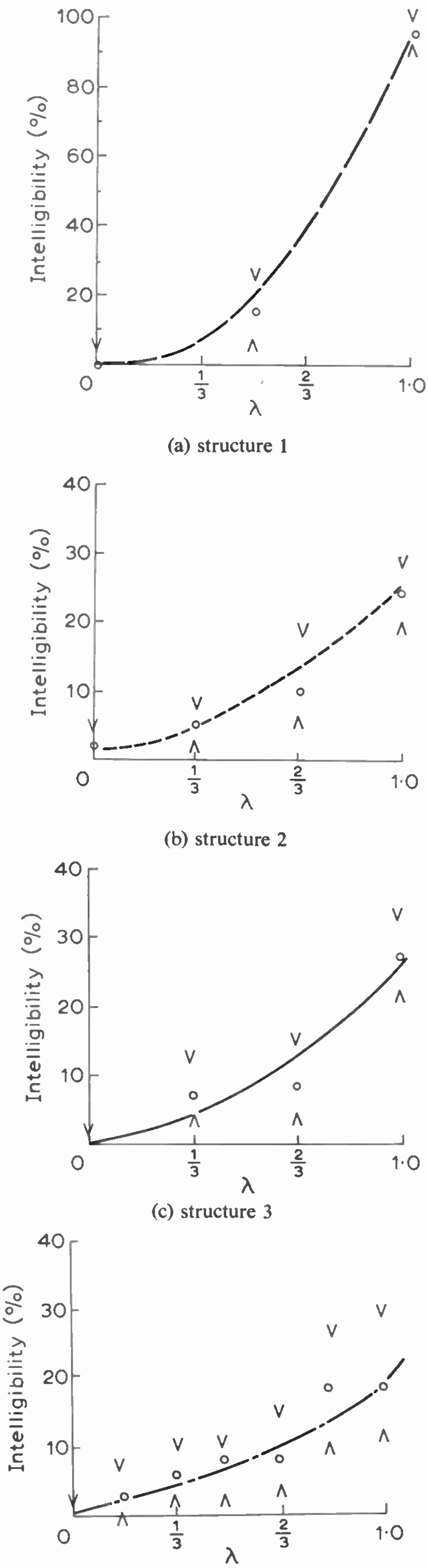
Structure 4

× represents $+1$ *or* -1.

For each matrix structure various values of λ are used, the actual matrices tested being listed in Appendix 2. The results for the individual structures are shown in Fig. 6(a) to (d); arrowheads denote spread of results.

These curves illustrate that there is a degree of dependence of intelligibility on the figure of merit λ, and that the intelligibility does indeed fall to a minimum when $\lambda = 0$, i.e. when the matrix is ideal and obeys the diagonal rule. The minimum intelligibility attained is very small, being zero in all cases save one, where it was 2%. This is an extremely good result, especially considering that only the relatively small matrix of size $N = 4$ was used. Even though the accuracy of curves obtained in subjective tests is not great, it can be seen from Fig. 6 that the curves differ quite markedly when λ is large, but that on the whole they tend to merge together when λ is small.

It can be concluded therefore that it is best to use matrices with small values of λ. However, since it has



(a) structure 1

(b) structure 2

(c) structure 3

(d) structure 4

Fig. 6. Word intelligibility as a function of λ

already been pointed out in an earlier Section that many simple ideal matrices are available, it seems unlikely that one would have to resort to using any other than those having $\lambda = 0$ in practice.

7 Conclusions

The results obtained have shown that the matrix method is able to produce a scrambled signal having virtually zero word intelligibility provided that the diagonal rule is obeyed by the scrambling matrix. The reason for this low intelligibility has been predicted theoretically and demonstrated practically, namely, that if the diagonal rule is obeyed there will be no original signal components remaining after scrambling.

It has also been shown that even with the relatively modest 4×4 scramble, there exists a large number of usable matrices which are simple, i.e. which have unity or zero elements, and which have inverses which are also simple. There is an even larger number of simple matrices which have inverses with non-unity coefficients, and since these coefficients are of the same order of magnitude these too may be used with very little extra circuit complication and without demanding very great accuracy from the descrambling equipment.

No scrambling matrices with non-unity elements have been tested but, provided that any such matrix obeys the diagonal law and has an inverse which is well conditioned, it will be usable. The use of matrices of this sort clearly extends the possibilities for different scrambles enormously. If the matrix size were to be increased beyond 4×4, the number of possible scrambles would also increase very rapidly. A rough estimate has shown that in a 6×6 matrix for example, there are many millions of usable simple ideal matrices. No attempt has been made to determine the exact number for obvious reasons.

Use of larger matrices means that greater numbers of stores, adding circuits etc., have to be provided. An alternative method would be to use a given scrambling matrix for the first block of four samples, then another for the next block, and so on for succeeding blocks according to some known rota, and even perhaps determined by some pseudo-random binary sequence. Matrices produced in this way would have many zero coefficients; for example three separate scrambling blocks repeated one after the other would produce a 'pseudo-large' matrix such as

$$\begin{vmatrix}
\times & \times & \times & \times & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\times & \times & \times & \times & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\times & \times & \times & \times & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\times & \times & \times & \times & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \times & \times & \times & \times & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \times & \times & \times & \times & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \times & \times & \times & \times & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \times & \times & \times & \times & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \times & \times & \times & \times \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \times & \times & \times & \times \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \times & \times & \times & \times \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \times & \times & \times & \times
\end{vmatrix}$$

$\times$ represents $+1$ or -1.

There will be fewer scrambles available than would be the case with a real 12×12 matrix, but this is hardly likely to be a disadvantage in view of what has been said previously about the number of 4×4 matrices available, and might provide a worthwhile economy in circuitry.

8 Acknowledgment

The authors wish to acknowledge the assistance given by Mr. R. T. Edwards and Mrs. Diana Phillips in the computerized evaluation of suitable matrices, referred to in Section 3.

9 References

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10 Appendix 1: Symmetries in Sideband Structure

The amplitudes of the original component and the upper and lower sidebands are given by equations (17), (18) and (19). If the duty cycle k is small, as is often the case in practice, the term

$$\frac{\sin \dfrac{nk}{N}}{\dfrac{nk}{N}}$$

which appears in these expressions may be assumed to equal unity.

When $N = 4$, they may be written as

$$\alpha = \frac{k}{4}\sqrt{\left[\sum_i \sum_j a_{ij} \cos \frac{2\pi f_s}{f_c}(j-i)\right]^2 + \left[\sum_i \sum_j a_{ij} \sin \frac{2\pi f_s}{f_c}(j-i)\right]^2} \qquad (22)$$

$$U_n = \frac{k}{4}\sqrt{\left[\sum_i \sum_j a_{ij} \cos X_n\right]^2 + \left[\sum_i \sum_j a_{ij} \sin X_n\right]^2}$$

where

$$X_n = 2\pi\left[\frac{n}{4}(i-1) - \frac{f_s}{f_c}(j-i)\right] \qquad (23)$$

$$L_n = \frac{k}{4}\sqrt{\left[\sum_i \sum_j a_{ij} \cos W_n\right]^2 + \left[\sum_i \sum_j a_{ij} \sin W_n\right]^2}$$

where

$$W_n = 2\pi\left[\frac{n}{4}(i-1) + \frac{f_s}{f_c}(j-i)\right]. \qquad (24)$$

Consider first

$$X_3 = 2\pi\left[\frac{3}{4}(i-1) - \frac{f_s}{f_c}(j-i)\right]$$

which may be rewritten

$$X_3 = 2\pi\left[-\frac{1}{4}(i-1) - \frac{f_s}{f_c}(j-i)\right]$$

but

$$W_1 = 2\pi\left[\frac{1}{4}(i-1)+\frac{f_s}{f_c}(j-i)\right]$$

therefore

$$X_3 = -W_1$$

and hence

$$L_1 = U_3.$$

It may be proved in a similar way that

$$L_3 = U_1.$$

Consider next X_2 and W_2.

$$X_2 = 2\pi\left[\frac{1}{2}(i-1)-\frac{f_s}{f_c}(j-i)\right]$$

$$W_2 = 2\pi\left[\frac{1}{2}(i-1)+\frac{f_s}{f_c}(j-i)\right]$$

X_2 can be rewritten

$$X_2 = -2\pi\left[\frac{1}{2}(i-1)+\frac{f_s}{f_c}(j-i)\right].$$

Thus

$$L_2 = U_2.$$

For the 4th harmonic terms

$$X_4 = 2\pi\left[(i-1)-\frac{f_s}{f_c}(j-i)\right]$$

$$W_4 = 2\pi\left[(i-1)+\frac{f_s}{f_c}(j-i)\right].$$

Therefore

$$L_4 = U_4 = \frac{k}{4}\sqrt{\left[\sum_i\sum_j a_{ij}\cos 2\pi\frac{f_s}{f_c}(j-i)\right]^2 + \left[\sum_i\sum_j a_{ij}\sin 2\pi\frac{f_s}{f_c}(j-i)\right]^2}$$

which, it will be observed, is equal to equation (22).

Thus

$$L_4 = U_4 = \alpha.$$

11 Appendix 2: List of Matrices Used in Intelligibility Tests

Structure 1

$$\begin{vmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{vmatrix}\quad\begin{vmatrix}1&0&0&0\\0&-1&0&0\\0&0&1&0\\0&0&0&1\end{vmatrix}\quad\begin{vmatrix}1&0&0&0\\0&-1&0&0\\0&0&1&0\\0&0&0&-1\end{vmatrix}$$

$\lambda = 1$ $\quad\lambda = \frac{1}{2}$ $\quad\lambda = 0$

Structure 2

$$\begin{vmatrix}1&1&0&0\\0&0&1&0\\1&0&0&0\\0&1&0&1\end{vmatrix}\quad\begin{vmatrix}1&1&0&0\\0&0&1&0\\1&0&0&0\\0&1&0&-1\end{vmatrix}$$

$\lambda = 1$ $\quad\lambda = \frac{2}{3}$

$$\begin{vmatrix}1&1&0&0\\0&0&1&0\\1&0&0&0\\0&-1&0&-1\end{vmatrix}\quad\begin{vmatrix}1&1&0&0\\0&0&-1&0\\1&0&0&0\\0&-1&0&-1\end{vmatrix}$$

$\lambda = \frac{1}{3}$ $\quad\lambda = 0$

Structure 3

$$\begin{vmatrix}0&0&1&0\\1&0&0&1\\1&1&0&0\\0&1&0&0\end{vmatrix}\quad\begin{vmatrix}0&0&1&0\\1&0&0&-1\\1&1&0&0\\0&1&0&0\end{vmatrix}$$

$\lambda = 1$ $\quad\lambda = \frac{2}{3}$

$$\begin{vmatrix}0&0&1&0\\-1&0&0&-1\\1&1&0&0\\0&1&0&0\end{vmatrix}\quad\begin{vmatrix}0&0&1&0\\-1&0&0&-1\\-1&1&0&0\\0&1&0&0\end{vmatrix}$$

$\lambda = \frac{1}{3}$ $\quad\lambda = 0$

Structure 4

$$\begin{vmatrix}1&1&1&0\\1&1&0&1\\1&1&1&1\\0&1&0&1\end{vmatrix}\quad\begin{vmatrix}1&1&1&0\\1&1&0&1\\1&1&1&1\\0&-1&0&1\end{vmatrix}\quad\begin{vmatrix}1&1&1&0\\1&1&0&1\\1&1&-1&1\\0&-1&0&1\end{vmatrix}$$

$\lambda = 1$ $\quad\lambda = \frac{5}{6}$ $\quad\lambda = \frac{2}{3}$

$$\begin{vmatrix}1&1&1&0\\1&1&0&1\\1&1&-1&1\\0&-1&0&-1\end{vmatrix}$$

$\lambda = \frac{1}{2}$

$$\begin{vmatrix}1&1&1&0\\1&1&0&-1\\1&1&-1&1\\0&-1&0&-1\end{vmatrix}\quad\begin{vmatrix}1&1&1&0\\1&1&0&-1\\1&-1&-1&1\\0&-1&0&-1\end{vmatrix}$$

$\lambda = \frac{1}{3}$ $\quad\lambda = \frac{1}{6}$

$$\begin{vmatrix}1&-1&1&0\\1&1&0&-1\\1&-1&-1&1\\0&-1&0&-1\end{vmatrix}$$

$\lambda = 0$

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An active filter for use in an a.c. carrier control system

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SUMMARY

The design of an active filter, suitable for use as the stabilizing element in an a.c. control system, is discussed. The modulating frequency characteristics presented show the relative insensitivity of the filter to tolerance, temperature and carrier drift effects.

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1 Introduction

A.c. carrier control systems often incorporate a notch filter as the phase-advance network to obtain a good system response. A passive bridged-T filter, with complex zeros located close to the $j\omega$ axis with imaginary components approximately equal to $\pm 1/C_1 C_2 R_1 R_2$ provides a good 'notch' response tuned to the carrier frequency $\omega_0 = 1/C_1 C_2 R_1 R_2$.

When an error signal is applied to a bridged-T notch filter with typical characteristics shown in Fig. 1, the output of the network can be expressed as eqn. (1):

$$V_0(t) = \tfrac{1}{2}(A_L + A_U)\cos(\omega_m t + \phi_3)\cos(\omega_0 t + \phi_2) + \\ + \tfrac{1}{2}(A_L - A_U)\sin(\omega_m t + \phi_3)\sin(\omega_0 t + \phi_2) \qquad (1)$$

where ω_m is the modulating frequency,

$$\phi_3 = \frac{\phi_U - \phi_L}{2},$$

$$\phi_2 = \frac{\phi_U + \phi_L}{2}.$$

and A_L, A_U, ϕ_L, ϕ_U are as shown in Fig. 1.

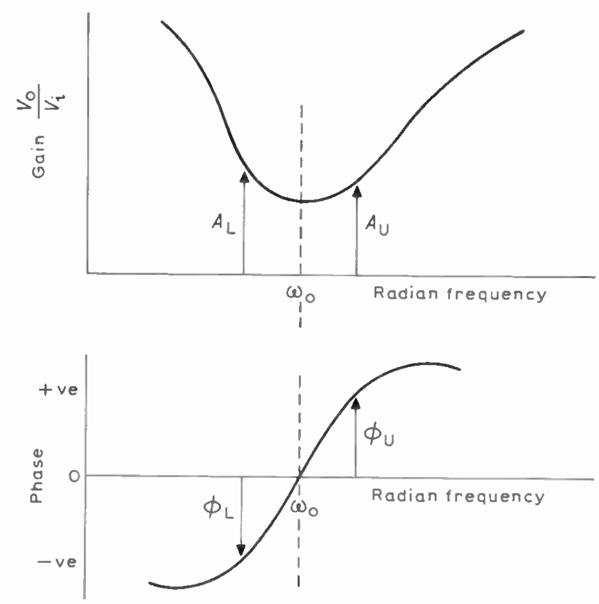

Fig. 1. Notch filter response.

However eqn. (1) must be rewritten in the form of eqn. (2) in order to investigate the phase-advance properties of the asymmetrical notch response:

$$V_0(t) = A\cos(\omega_m t + \theta_1)\cos\omega_0 t \pm \\ \pm B\sin(\omega_m t + \theta_2)\sin\omega_0 t \qquad (2)$$

where

$$A = +\sqrt{A_m^2\cos^2\phi_2 + A_q^2\sin^2\phi_2}$$

$$B = \pm\sqrt{A_m^2\sin^2\phi_2 + A_q^2\sin^2\phi_2}$$

$$A_m = \tfrac{1}{2}(|A_L| + |A_U|) \qquad A_q = \tfrac{1}{2}(|A_L| - |A_U|)$$

$$\theta_1 = \phi_3 - \alpha, \qquad \theta_2 = \phi_3 - \beta$$

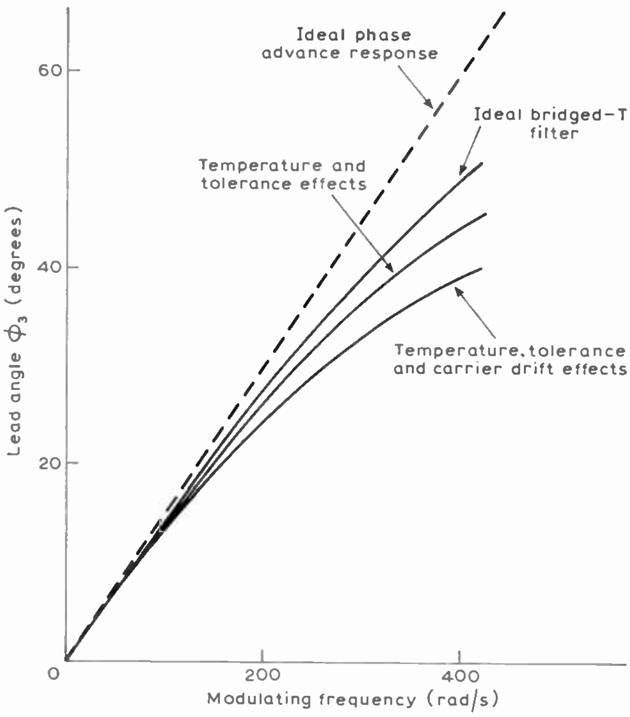

Fig. 2. Modulating frequency characteristics.

and

$$\alpha = \tan^{-1}\left(A_q \frac{\sin \phi_2}{A_m \cos \phi_2}\right)$$

$$\beta = \tan^{-1}(A_m \sin \phi_2 / A_q \cos \phi_2)$$

Assuming perfect action by the servomotor, only the first term will provide torque and therefore θ_1 is the phase lead supplied by the network.

Figure 2 shows the characteristics of an ideal bridged-T network and illustrates the effect of component tolerance and temperature variations. Nashman *et al.*[1] have shown that when carrier drift is present the response deviates even further from the ideal, and Douce and Edwards[2] have proposed a tracking filter to minimize carrier frequency drift effects.

This paper proposes an active filter which is simple to design and which provides a characteristic that is relatively insensitive to carrier frequency drift and temperature and tolerance effects.

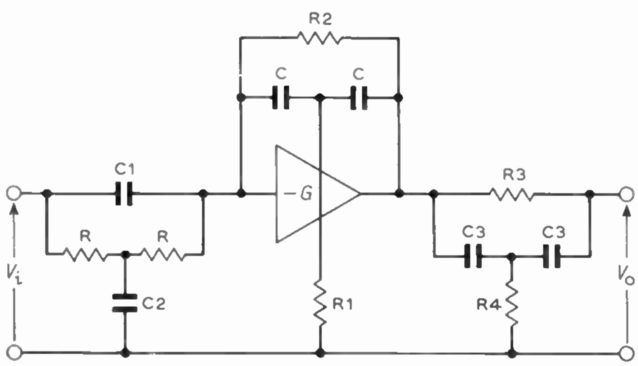

Fig. 3. The active filter.

2 The Active Filter

It is interesting to note that temperature variations, component tolerances and carrier drift, all affect the modulating frequency characteristics of a passive bridged-T filter in the same way. These effects are all produced because of gain characteristic deviations, and phase characteristic non-linearities or slope variations with temperature. Thus a filter with a flat gain response over the working region will provide $A_L = A_U$, and in order to provide linear phase lead a linear phase response over the working region is essential. The effect on such a filter of carrier frequency changes, temperature variations and component tolerances will be minimal although, as shown by the first term of eqn. (1) a phase lag is introduced into the carrier which effectively reduces the output torque generated in the two-phase servomotor.

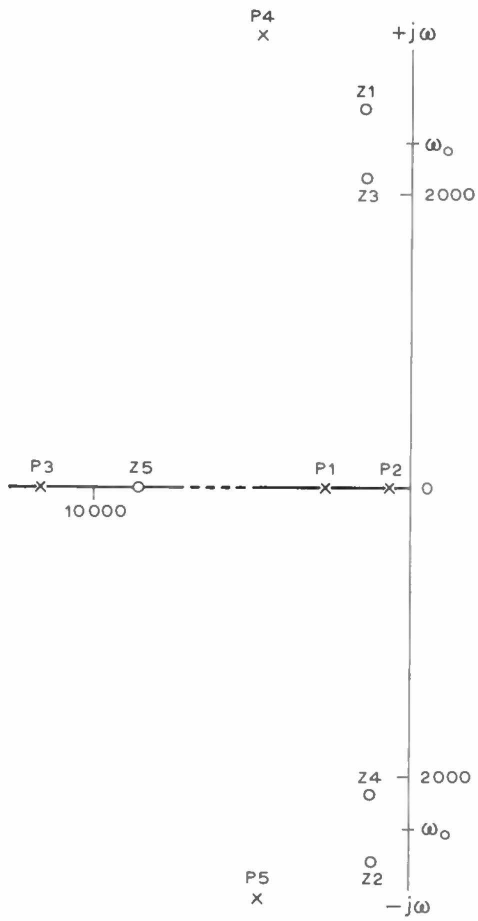

Fig. 4. Pole-zero location for the active filter.

In order to produce a closer approximation to the required constant gain characteristic and linear phase characteristic, the active filter of Fig. 3 was designed using the pole-zero locations for the filter as given in Fig. 4. The two zeros Z1 and Z3 both have equal negative real components and Z1 has an imaginary component greater than and Z3 has an imaginary component less than $j\omega_0$. Providing these zeros are close together about $j\omega_0$, a fairly flat amplitude response and a linear phase response will result.

The impedance function of the bridged-T network used as the input impedance to the amplifier can be expressed as

$$Z(s) = \frac{R(2+CRs)}{1+2C_1 Rs+C_2 C_1 R^2 s^2}$$

and this provides one negative pole at P1 and two complex zeros Z1 and Z2. Similarly the feedback bridged-T filter provides complex poles at P4 and P5 and a zero at Z5. The zero Z5 compensates for the errors introduced by the poles P1, P2 and P3. The bridged-T filter connected to the output of the amplifier produces the two complex zeros Z3, Z4 and real poles P2 and P3.

The overall transfer function of this active filter is given by

$$\frac{V_0}{V_i}(s) = -\frac{R_2(1+T_1 s)(1+2T_4 s+T_3 T_4 s^2)\times(1+2T_5 s+T_5 T_6 s^2)}{R(1+2T_1 s+T_1 T_2 s^2)(2+T_3 s)\times(1+(T_6+2T_5)s+T_5 T_6 s^2)}$$

where $T_1 = CR_1$, $T_2 = CR_2$, $T_3 = C_2 R$, $T_4 = C_1 R$, $T_5 = C_3 R_4$, and $T_6 = C_3 R_3$.

Considering the pole-zero plot of Fig. 4, it is evident that, for frequencies near ω_0, the zeros Z1 and Z3 are dominant since all other poles and zeros are remote from ω_0 and their effects on the filter response will be minimal. It seems reasonable therefore to locate the zeros Z1 and Z3 in their optimum positions, ignoring the effects of all other elements, because once these locations have been determined this automatically fixes the positions of poles P1, P2, P3 and zeros Z2 and Z4. Any necessary slight adjustments to the overall pole-zero plot, to obtain zero phase at the carrier frequency, can now be made by altering the components of the feedback element, thus moving the positions of poles P4 and P5 and zero Z5.†

Practical design results[3] show that by solely considering the dominant zero locations, an error of 25% occurs in the resulting phase response. It has also been observed that by overrating the phase design specification by 25% and using this phase to determine the zero locations good results are obtained.

As an example the design of a filter to produce a linear phase-frequency plot over the range 2513·28 rad/s (400 Hz)±400 rad/s with a phase of +60° and −60° at 2913·28 rad/s and 2113·28 rad/s respectively is considered. Using the overrating procedure the actual dominant zeros are ±(60°+25%), i.e. ±75°. This specification requires complex zeros at −410±j 2813·28 and −410±j 2213·28 to give the zeros Z1, Z2, Z3 and Z4 of Fig. 4.

Assuming Z3 and Z4 are produced by the bridged-T filter connected to the output of the amplifier, then $410 = 1/C_3 R_3$ and $2213{\cdot}28 = (410)^2 - 410/C_3 R_3$. This also fixes poles P2 and P3 at −400 and −12 800. By a similar technique the bridged-T filter, used as the input impedance to the amplifier of Fig. 3 is designed to give the complex zeros Z1 and Z2 at −410±j 2813·28 and this also locates pole P1 at −820. Similarly the amplifier feedback filter is tuned to give poles P4 and P5 at −1000 ±j 4500 and zero Z5 at −10 600.

Practical filter responses from tests on an active filter built to this design are given in Fig. 5. These show the results for temperatures of −20°C, +20°C, and +60°C and a good linear phase response and a constant amplitude response over approx 400 rad/s are obtained. The results also demonstrate that temperature effects are relatively small.

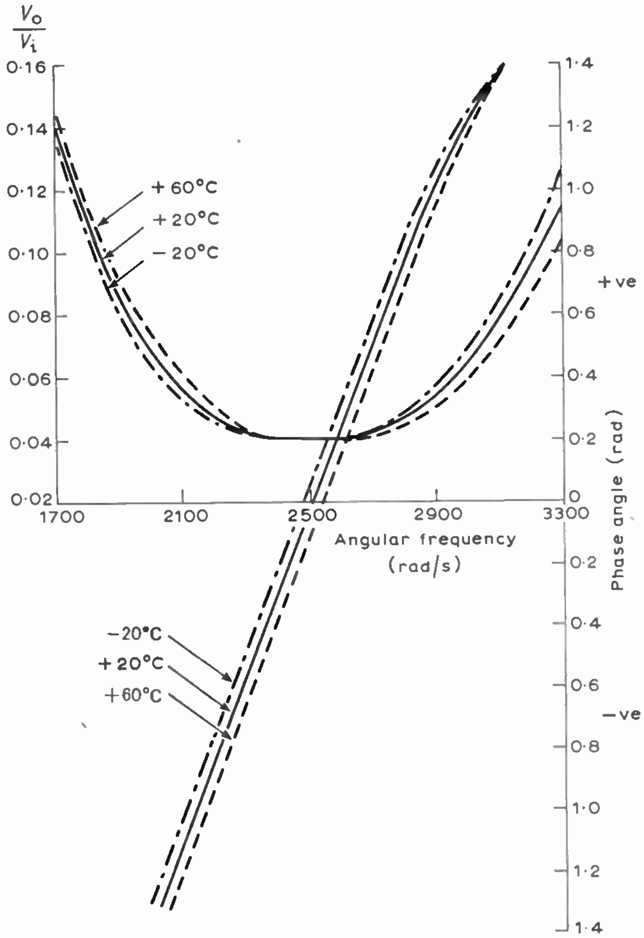

Fig. 5. Filter responses for temperature conditions.

When these results are presented as modulating frequency characteristics, similar to Fig. 2, there is no measurable deviation from the linear characteristic for modulating frequencies up to 400 rad/s at 20°C and at +60°C and −20°C only a 1·7% deviation from the linear characteristic results. These values contrast sharply with the experimental results obtained from a comparable passive bridged-T filter which gives a 21% deviation from the linear characteristic at +20°C for a modulating frequency of 400 rad/s and a 28% deviation at +60°C and −20°C.

The results for carrier drift effects for the active filter are similarly attractive, there is a 2% deviation from the

† A detailed analysis of the dominant zero location technique can be obtained from the authors on request.

ideal at 400 rad/s for $\pm 5\%$ carrier drift and only an 8% deviation for a $\pm 10\%$ carrier drift.

The active filter was constructed as Fig. 3 using the following components: R = 5·8 kΩ, R2 = 100 kΩ, R3 = 244 kΩ, R4 = 8·1 kΩ, C = C1 = C3 = 0·01 μF, C2 = 0·48 μF. The operational amplifier is Philbrick P65AU.

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A goniometer for use with high-frequency circularly disposed aerial arrays

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SUMMARY

The paper describes the development of a high-frequency spinning goniometer for use as a direction finding unit on a wide-aperture circularly disposed aerial array. The factors governing the design of the goniometer are presented and three different prototypes are discussed, the third being a miniaturized version.

Unlike previous goniometer designs, the beam forming network consists of delay lines and hybrid transformers mounted on the rotor assembly. This not only simplifies the electrical design and increases the operating frequency band but also enables the goniometer to work with arrays which exhibit standing wave ratios as large as 4:1 over the operating band. Previous designs of goniometer are limited to systems where the s.w.r. over the band remains below about 1.3:1.

Areas for further improvements are discussed including alternative beam forming configurations.

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1 Introduction

Circularly-disposed aerial arrays have been developed for reception in the high-frequency band, in which groups of adjacent elements are combined in phasing networks to provide a set of identical, equi-spaced, directional beams covering 360° of azimuth. In addition to the formation of fixed beams this type of array is frequently used for direction finding purposes, where a sector of elements is coupled to and combined in a commutating device, rotation of which produces a rotating aerial beam.

Such commutators, or goniometers, can function in two modes, continuously spinning or manually steerable. In the former case, the total energy within the pass-band of the receiving system can be displayed as a function of azimuthal angle of arrival, and in the latter case attention can be concentrated on any particular signal of interest.

Two outputs are normally obtained from a goniometer, a 'sum' output which provides maximum directivity for reception from any desired azimuth and a 'difference' output which produces a deep null in the direction of the received signal to provide bearing information.

Some typical wide-aperture receiving systems employing goniometers have been described by Wundt.[1] These systems may use three concentric rings of monopoles to cover the entire h.f. band. Each ring covers a different portion of the frequency range and requires a separate goniometer. The array elements exhibit non-linear frequency/admittance characteristics and are coupled to the goniometer stator circuitry via broadland amplifiers.

One function of the amplifiers is to present a constant drive impedance to the goniometer input circuitry over the frequency band, resulting in a constant reflected load impedance on the goniometer delay lines. The type of goniometer used with these large installations is complex and expensive to manufacture.

The three goniometers described in this paper are prototypes and were designed to provide a d.f. facility for existing circular h.f. arrays which were intended as receiving systems. These arrays provide 24 equi-spaced fixed beams[2] and are not equipped with aerial amplifiers. The absence of aerial buffer amplifiers implies that a goniometer must be capable of direct connexion to the non-linear admittance of the monopoles without detriment to the d.f. accuracy of the machine and without upsetting the polar diagram produced by the beam forming network. As conventional goniometer designs are unsuited to this application it was necessary to devise an alternative method of beam formation for the prototype goniometers.

A low insertion loss was not considered a prime requisite as external noise can usually be expected to predominate over system noise in the lower h.f. band. Exceptions to this can occur in the UK around noon in Winter and Spring when, assuming a receiver noise figure of about 7 dB, the maximum insertion loss of the goniometer should not exceed about 11 dB at 2 MHz to maintain an externally noise limited system. These figures are derived from expected values of atmospheric noise[3] and neglect man-made and galactic noise sources.

The major factors influencing the design decisions for

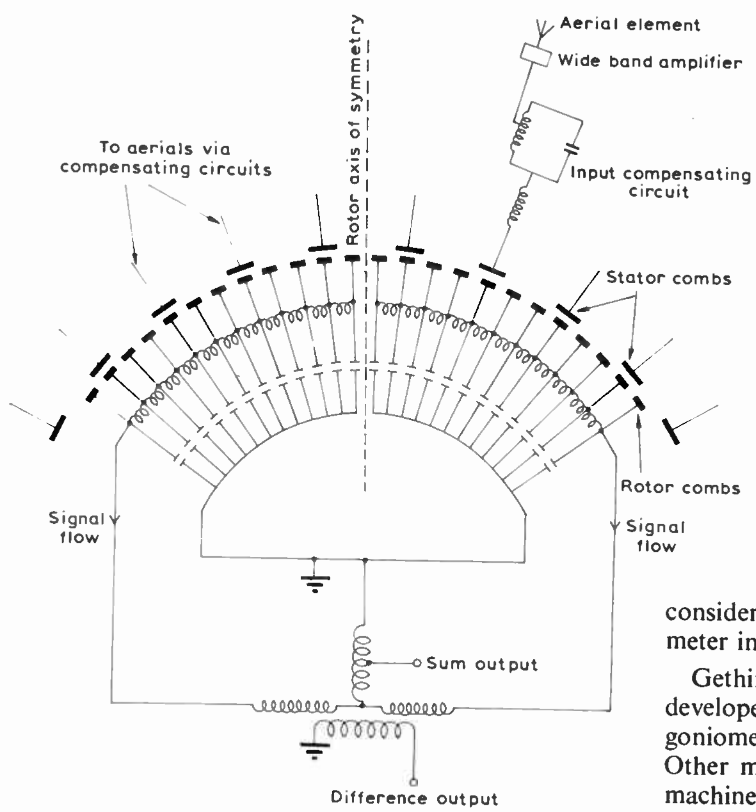


Fig. 1. Capacitance coupled goniometer using tapped lumped constant delay lines and input compensation circuitry.

the three prototype goniometers were accuracy of d.f. capability, economics and ease of manufacture. By choosing a simple mechanical arrangement the first prototype was made and tested in a relatively short period.

2 Historical Development of Wide-aperture D.F. Systems

It was shown by Stenzell[4] in 1929 that a directional aerial pattern could be obtained in a specific direction by suitably phasing and combining elements of a circular array. This technique was used by the Germans in World War II to produce several prototype direction-finding systems known as Wullenweber arrays. A typical Wullenweber system erected at Hjörring and described by Crampton[5] operated over the band 6–20 MHz and consisted of 40 wide-band monopoles equally spaced around a circle of diameter 100 m with a cylindrical reflecting screen of vertical wires located behind the monopoles. The monopoles were connected via amplifiers to a manually-controlled goniometer.

Rotor coupling to the goniometer stator was by parallel plate electrodes giving a coupling capacitance of about 10 pF. The 36 rotor-electrodes were connected to two sets of delay lines which were used to combine the outputs of 12 consecutive monopoles. The goniometer outputs were taken via slip-rings to a transformer unit which combined the rotor delay networks either additively to give a maximum in the direction of a signal for 'search' or differentially to give a polar pattern with a deep null for bearing information.

Very little has been published on the post-war development of Wullenweber systems but Wundt[1] shows that considerable improvements have been achieved in goniometer insertion loss.

Gething[6] has outlined a modern Wullenweber system developed at the University of Illinois[7] in which two goniometers are mounted on a common horizontal shaft. Other modern machines spin on a vertical shaft; most machines can be servo controlled in the manual mode to obtain an aural null. Modern Wullenweber arrays may employ 96 or more elements in a single ring of which about one third are used at any instant to synthesize a steerable beam in the goniometer.

3 Methods of Beam Rotation with Circular Arrays

Rotation of a directional beam can be achieved by suitably varying the phases of a group of aerial elements to be combined at one time. Some methods which have been considered in the past are outlined below.

3.1 *Direct Coupling*

A system can be envisaged where the elements of a circular array are directly coupled to phasing networks on a rotor by a system of brushes or switches. By using a single phasing network such a system can only be steered to the element positions (or intermediate prescribed positions) and in the case of a 40-element array beams could only be formed at 9° intervals. A reduction to 3° steps could be achieved by either trebling the number of aerial elements or including two additional sets of phasing networks for intermediate positions. This system is not suitable for continuously spinning goniometers unless a method of smooth transition from one element to the next can be devised.

3.2 *Inductive Coupling*

In an inductively-coupled system, beam rotation is accomplished by input transformers, the secondary windings of which are mounted on a rotor and can be moved to vary the coupling to the aerial elements.

In order to achieve a smooth coupling from one transformer primary to the next, shaping of the transformer cores is necessary because coupling through powdered iron or ferrite cores is not a linear function of core position. Shaping of cores inevitably reduces the efficiency of the transformer and increases insertion losses.

3.3 *Capacitive Coupling*

Capacitive coupling has proved the most successful method of coupling. The system illustrated in Fig. 1 is that described by Wundt[1] and developed by Dr. A. Curtis.

The aerial elements are connected via wide-band amplifiers to compensating circuits which are associated with capacitor combs equi-spaced around the stator. A rotor is similarly equipped with combs which mesh with those on the stator and occupy a sector of about one third of the periphery of the rotor. Two symmetrical phasing and combining networks are mounted on the rotor, the outputs of which can be represented by two identical linear arrays of total aperture equivalent to the chord of the sector of elements being used and orientated normally to the incident signal. A polar pattern is thus formed, the line of symmetry being normal to and bisecting the chord, and capable of rotation through any azimuth.

In order to obtain a maximum response to an incoming signal, the sector under consideration must be symmetrically aligned in the direction of the arriving energy. Under these conditions a maximum response for this signal will be obtained from the goniometer 'sum' output and the 'difference' output will produce a sharp null.

The phasing and combining networks used with this type of goniometer consist of two tapped, lumped-constant delay lines which are combined at their outputs to produce an algebraic 'sum' and 'difference' of the phased signals. The delay lines are inherently sensitive to changes in reflected load impedance resulting from the coupling of the monopoles. The capacitive component of the reflected load should be less than the smallest value of capacitance used in the delay line and the resistive component should be maintained at the correct delay line terminating impedance. Departures from these requirements will cause incorrect delay characteristics and result in break-up of the polar pattern. Compensating circuitry is therefore included which ensures an almost constant reflected load from the aerial wide-band amplifier over the rotor/stator comb coupling-capacitance excursion. It appears that compensation is feasible over a 4 : 1 frequency band.

4 General Design of the Prototype Goniometers

4.1 *Design Objectives*

Starbuck[2] has described the development and construction of the array with which the goniometers were to be used; variants of the original design have been produced to cater for alternative frequency bands. The original array consisted of 24 monopoles equi-spaced around a circle of 152 m (500 ft) diameter. The monopoles are 12·3 m (40 ft) high and have elevated feeds connected by equal length cables to a central hut housing passive beam-forming equipment which produces 24 fixed beams at intervals of 15°. The receiving system covers the frequency range 2–8 MHz.

The d.f. requirement is subordinate to the primary role of the system which is that of a receiving array and consequently it is desirable to keep the cost and complexity of the goniometer and associated equipment in proportion to its subsidiary role.

4.2 *Choice of Goniometer Design*

As a starting point, the possibility of designing a machine on the lines of that described in Section 3.3 was considered. To this end, some work on the analysis and design of suitable compensating circuitry was performed.

It was found that over a frequency band of 4 : 1 a circuit could be designed which presents a reasonably constant load impedance to the rotor delay lines over the rotor/stator comb coupling-capacitance excursion, provided the stator comb loads remained resistive at a constant value over the frequency range, i.e. when the goniometer is buffered from the aerial elements by aerial amplifiers.

The admittance/frequency characteristics of an aerial element plus feeder cable for the 152 m array is shown in Fig. 2. From this it is apparent that due to the widely

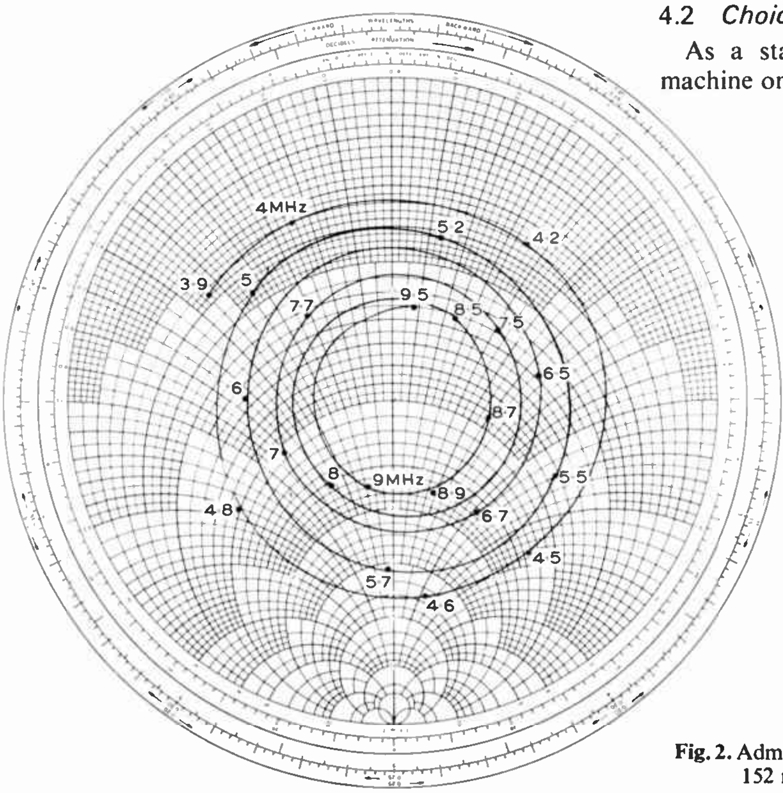


Fig. 2. Admittance/frequency curve for an element plus feeder for 152 m diameter array (normalized to 13·3 m Ω^{-1})

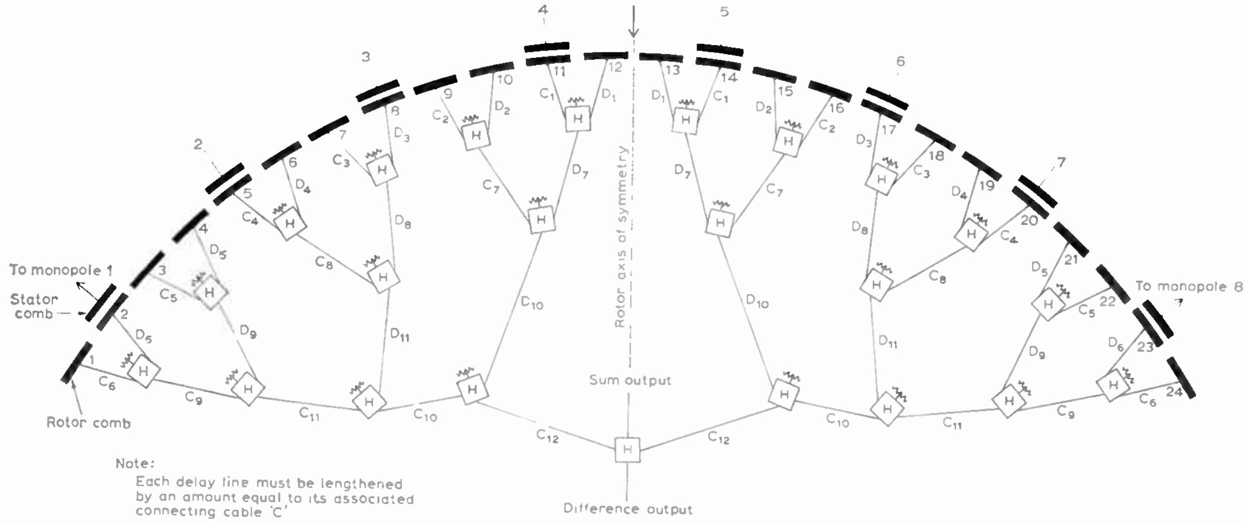


Fig. 3. Block diagram of hybrid goniometer

varying admittance over the band, broadband phase and gain matched amplifiers would be required for each element in order to present a constant impedance to the aerial compensating circuitry of a tapped delay line goniometer.

The added expense of providing amplifiers together with the inherently complex task of manufacturing a tapped, lumped-constant delay line goniometer prompted the investigation of a method of beam formation which remained relatively unaffected by large changes in impedance caused by rotor/stator coupling and non-linear element impedance.

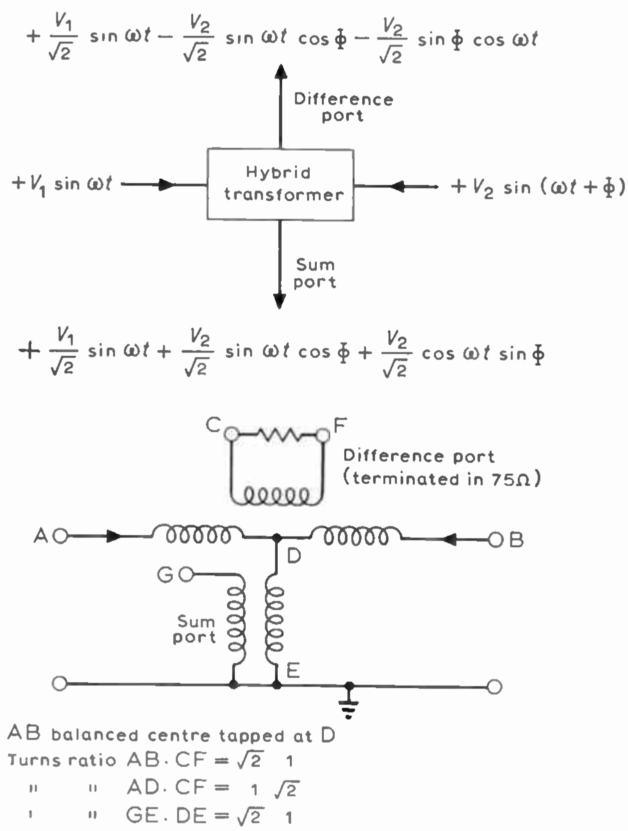


Fig. 4. Four-port hybrid transformer.

The beam forming method eventually devised for the three prototype goniometers (designated prototypes A, B and C) is shown in Fig. 3. This system consists of a twin hybrid-tree network with delay lines in certain branches. The major feature of this method is that the impedance terminating the final hybrid reflects throughout the branches, thus matching the delay lines and rendering them insensitive to changes of impedance at the coupling combs. The network is inherently broadband and it is possible to design a goniometer of this type to cover the whole h.f. band. Unfortunately the wide bandwidth characteristics of this goniometer cannot be fully exploited as the limiting factor in the system is the array which, at best, operates over a 5 : 1 frequency band. Use of the array below the design frequency range results in excessive broadening of the beam thus decreasing directivity; at frequencies beyond the upper limit grating lobes become troublesome. The usual way of extending the frequency band of these array systems is to include an additional concentric ring of monopoles for which a separate goniometer is required.

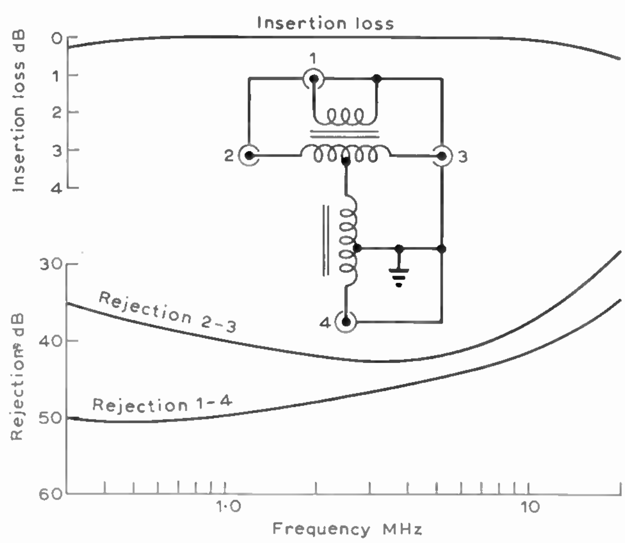


Fig. 5. Insertion loss and rejection curves for hybrid unit as used in prototypes A and B goniometers.

The delay elements in the models A and B are of miniature coaxial cable which gives an almost linear frequency/delay characteristic and provides good electrical screening. The prototype-C machine employs lumped constant delay lines.

The signal combining units are four-port hybrid transformers which resolve two input signals into their algebraic sum and difference. Details of these units are given in Fig. 4. When correctly terminated, isolations of the order of 30 dB exist between opposing ports. It is this last feature which enables the delay elements of the beam forming system to remain relatively isolated from changes in load impedance caused by rotor/stator coupling and the non-linear frequency/impedance characteristics of the monopoles. Graphs of insertion loss and isolation for the hybrid units are shown in Fig. 5.

4.3 *Choice of Rotor/Stator Comb Ratio*

A machine with rotor and stator combs mounted at the same angular spacings (i.e. 1 : 1 rotor/stator comb ratio) can be envisaged but this results in increased 'cogging' error. This source of bearing error manifests itself as a cyclic variation in indicated bearing between positions of coupling symmetry and can be decreased by increasing the rotor/stator comb ratio. This decreases the angular spacing between positions of symmetry and reduces the bearing error swing.

For the prototype machines the rotor/stator comb ratio was chosen to be 3 : 1, a ratio which gives considerably reduced cogging effects without imposing difficult mechanical design problems.

4.4 *Description of Operation*

At any instant, the goniometer synthesizes a beam from eight aerial elements which are coupled to the rotor via capacitor combs. Figure 3 shows the rotor symmetrically aligned between aerial elements 4 and 5. The purpose of the delay lines (marked 'D' on the diagram) is to delay all signals from the sector of elements being used to be in phase on a chord which can, for the purpose of this description, be considered to join rotor combs 1 and 24, e.g. input signals are phase referenced to each end rotor comb. Individual delay lines are such a length as to ensure co-phased signals at the input to each hybrid (marked 'H' on the diagram) only when the rotor is symmetrically aligned on a signal. The final hybrid combines the two halves of the rotor network, the sum output producing a maximum and the difference output a null for a signal on the axis of symmetry of the rotor.

Signals off-axis are not co-phased at the hybrid transformer inputs and their quadrature components are dissipated in the 75 Ω 'difference' port terminations. Photographs of typical 'sum' and 'difference' patterns as produced by the goniometers and displayed on a cathode ray tube are shown in Fig. 6.

The delay values depend primarily on the array geometry and, to a lesser extent, on the elevation angle of arrival of the signal. A satisfactory practical scheme can be achieved by assuming an average value of 15° for the elevation angle. Performance on signals at angles up to about 45° does not critically depend on the chosen value.

5 The Prototype-A Goniometer

The first prototype, shown in Fig. 7, was a test bed constructed in the simplest way to prove the viability of the goniometer design and intended for operation from 2 MHz to 8 MHz. Due to lack of rigidity of the structure the maximum speed of rotation was set to 150 rev/min.

A fully meshed rotor/stator comb capacitance of 100 pF was chosen; this was a compromise designed to balance the need for sufficient signal transfer from stator to rotor whilst maintaining a comb of reasonable physical dimensions. In choosing the blade running clearance, particular attention had to be given to the possibility of warpage in the comb material and also to the effects of possible aerodynamic flutter of the blades under dynamic conditions.

The rotary transformer is required to couple the sum and difference outputs from the rotating beam forming networks to static coaxial connectors. Figure 8 shows the results of measurements made on the rotary transformer and illustrates the improvement in return loss achieved by padding the transformer with fixed capacitors to shift the resonant frequency.

6 The Prototype-B Goniometer

The prototype-B goniometer was designed on the same beam forming principle as the previous machine but it is a more soundly engineered version. The extra rigidity of this structure enables the design rotational speed of 500 rev/min to be achieved, resulting in a more acceptable display. It is a continuously rated machine and intended for use with a 76 m (250 ft) diameter array having 24 elements and covering the frequency range 3–20 MHz. Figure 9 shows the general construction of the goniometer.

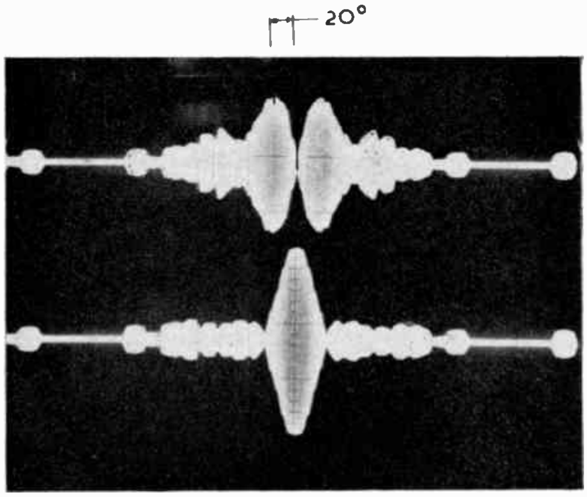
An approximation to the insertion loss of the goniometers was made with the aid of a wave-front generator. This unit represents a sector of the aerial array. Using this technique the insertion loss of the prototype-B machine was found to vary from 12 dB to 14 dB over its frequency range.

6.1 *Display System for the Prototype-B Goniometer*

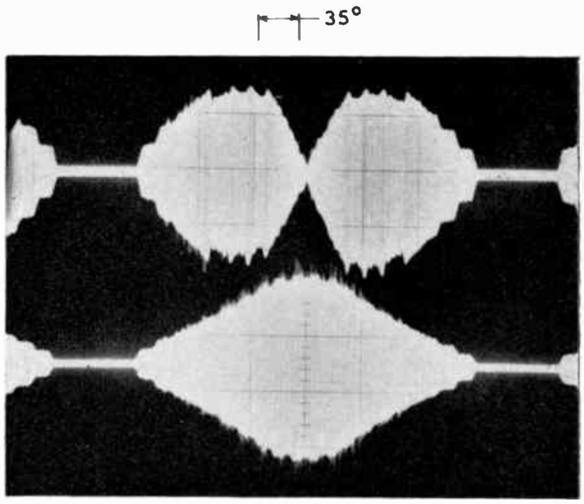
To give a better overall picture of the way in which this type of goniometer is used operationally, a brief description of the display equipment designed for the prototype-B goniometer will be given.

The goniometer, located in a small building at the centre of the array, provides two broadband r.f. outputs which are connected via coaxial feeders to a twin-channel receiver located some distance from the array.

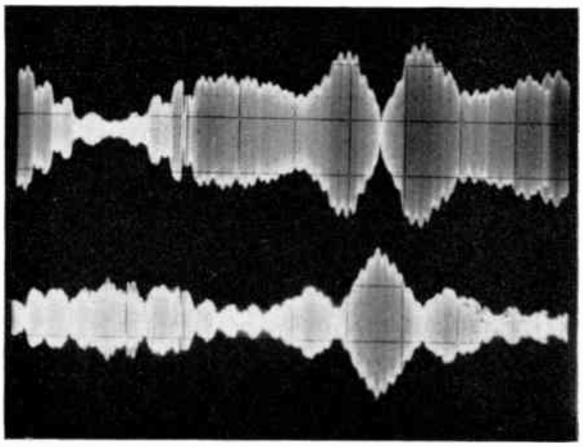
The 'sum' and 'difference' patterns of a selected signal are displayed from 0 to 360° on a cathode-ray tube at the receiver i.f. of 100 kHz. The 45° sector containing the null is recognized by the operator and expanded by a factor of four to fill the display; this is accomplished by operation of a sector selection control.



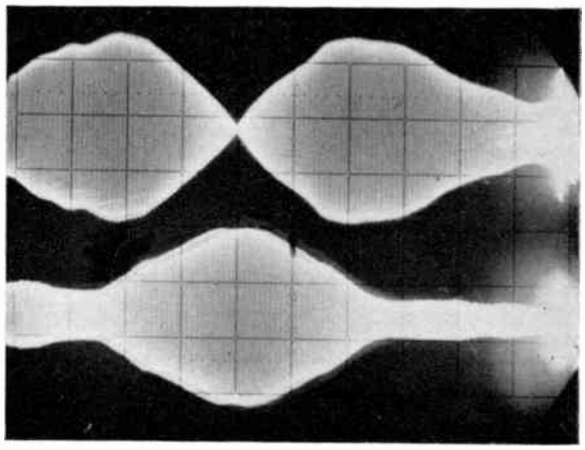
(a) 5MHz signal (using wavefront generator)



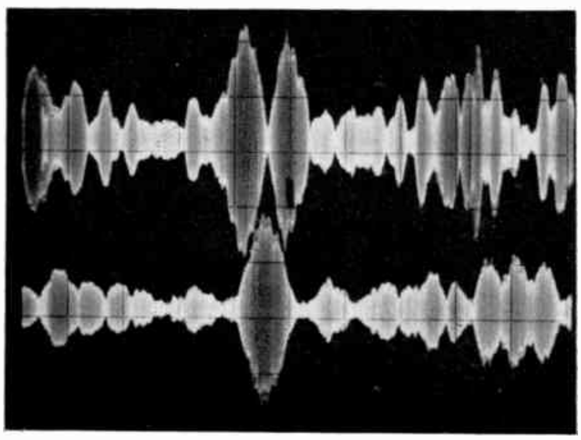
(b) 1MHz signal (using wavefront generator)



(c) 8·8 MHz c.w. transmission (receiver bandwidth 3kHz)



(d) 8·8 MHz c.w. transmission (receiver bandwidth 750Hz) Display expanded ×4.



(e) 16 MHz c.w. transmission.

Fig. 6. Typical sum and difference patterns from prototype goniometers.

A multi-turn precision potentiometer controls the position of an electronic cursor which appears on the displayed patterns as a narrow notch. When the cursor is aligned with the null of the 'difference' pattern the bearing of the signal is automatically indicated on a digital read-out which, in this case, changes in steps of one degree of arc.

The cursor is generated at the input to the receiver so that cursor and r.f. signal are subject to the same delay through the receiver irrespective of bandwidth setting.

A block diagram of the main parts of the display system is given in Fig. 10.

7 The Prototype-C Goniometer

The size of the goniometer is primarily determined by the rotor/stator comb ratio, comb size and pitch. This resulted, in the prototypes A and B, in bulky machines which pose machining problems and tend to conflict with two of the original design objectives of ease of manufacture and economy.

No problems arising from aerodynamic flutter or mechanical resonance of the comb blades had been detected on the previous two machines so it was decided to construct a third prototype goniometer with combs

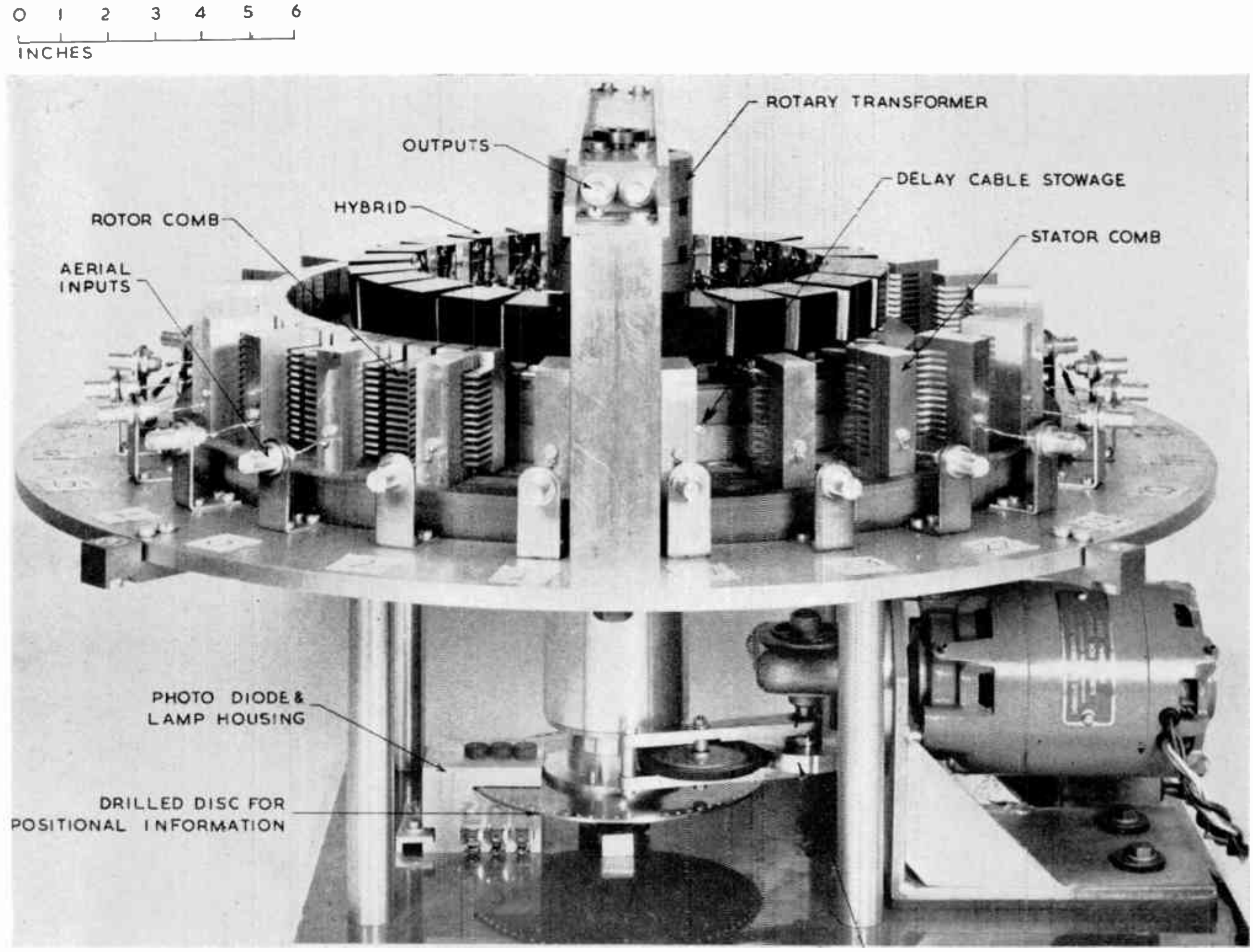


Fig. 7. Prototype A goniometer.

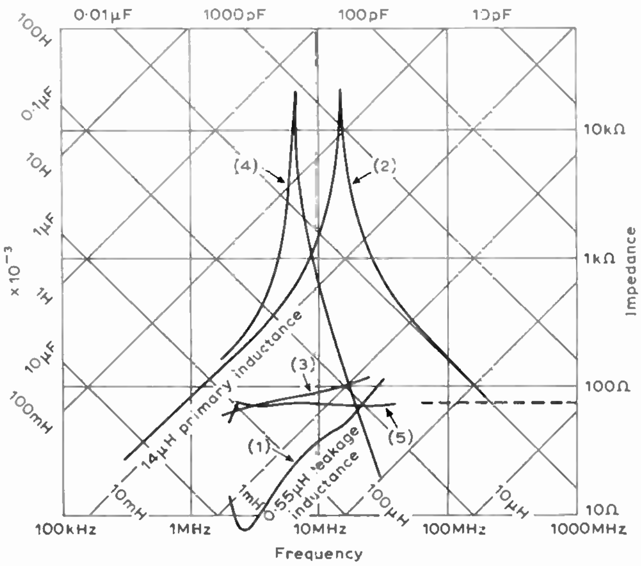


Fig. 8. Impedance measurements on goniometer rotary transformer. 4 turns solid copper enamelled wire (0·016 in dia) in 0·016 in groove on FX1588 core, running clearance between cores 0·003in. Impedance at primary with:

(1) Secondary short circuit
(2) Secondary open circuit
(3) Secondary terminated 75Ω
(4) Secondary with 49pF in parallel
(5) Secondary with 49pF and 75Ω all in parallel

halved in physical size and a reduced running clearance to maintain a fully meshed coupling capacitance of 100 pF. This enabled a drastic reduction in size, weight and complexity of the machine to be achieved.

The prototype-C goniometer is designed to work with the 152 m, 24-element array. Details of the construction are given in Fig. 11.

7.1 *Beam Forming Network*

The use of coaxial cable delay lines is impracticable due to the restricted space available on the prototype-C rotor. Alternative types of delay lines considered were printed strip line and lumped constant delay line.

Use of a printed strip line for this application has the disadvantage that, for a design impedance of 75 Ω, a track width and spacing of about 0·25 mm (0·01 in) would be required to accommodate the longest delay line within the rotor diameter. This leads to high losses which, due to the position of the long delay lines in the combining network, would produce an unwanted amplitude taper at the centre rotor combs, resulting in a broadening of the formed beam. Stacking this type of delay line modifies the impedance and effective delay and leads to problems in interconnexion to the hybrid transformers.

Use of lumped constant delay networks was considered a better approach.

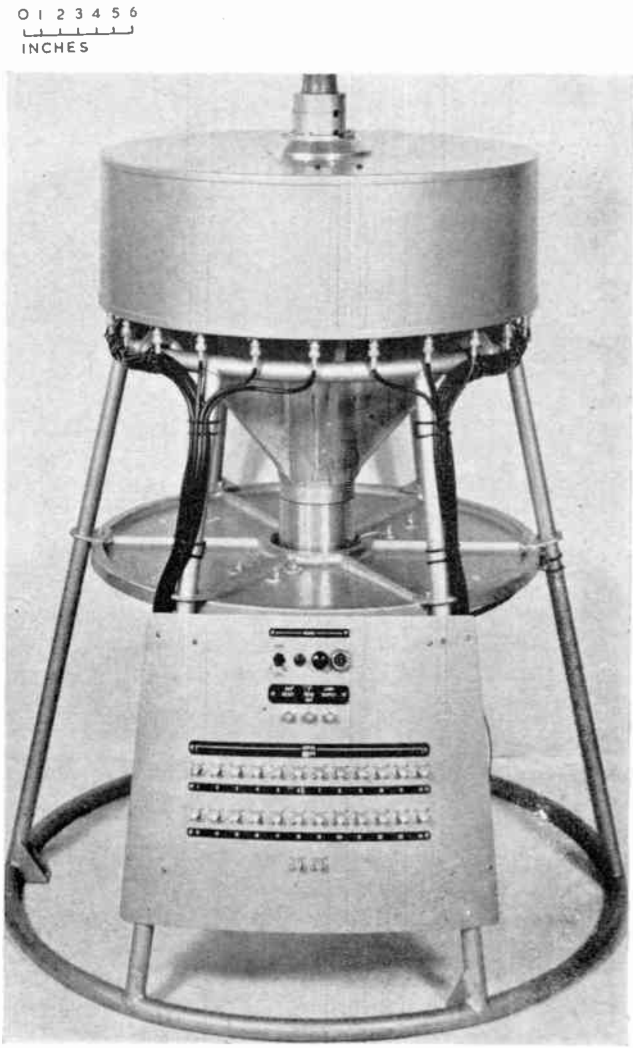


Fig. 9. The prototype B goniometer

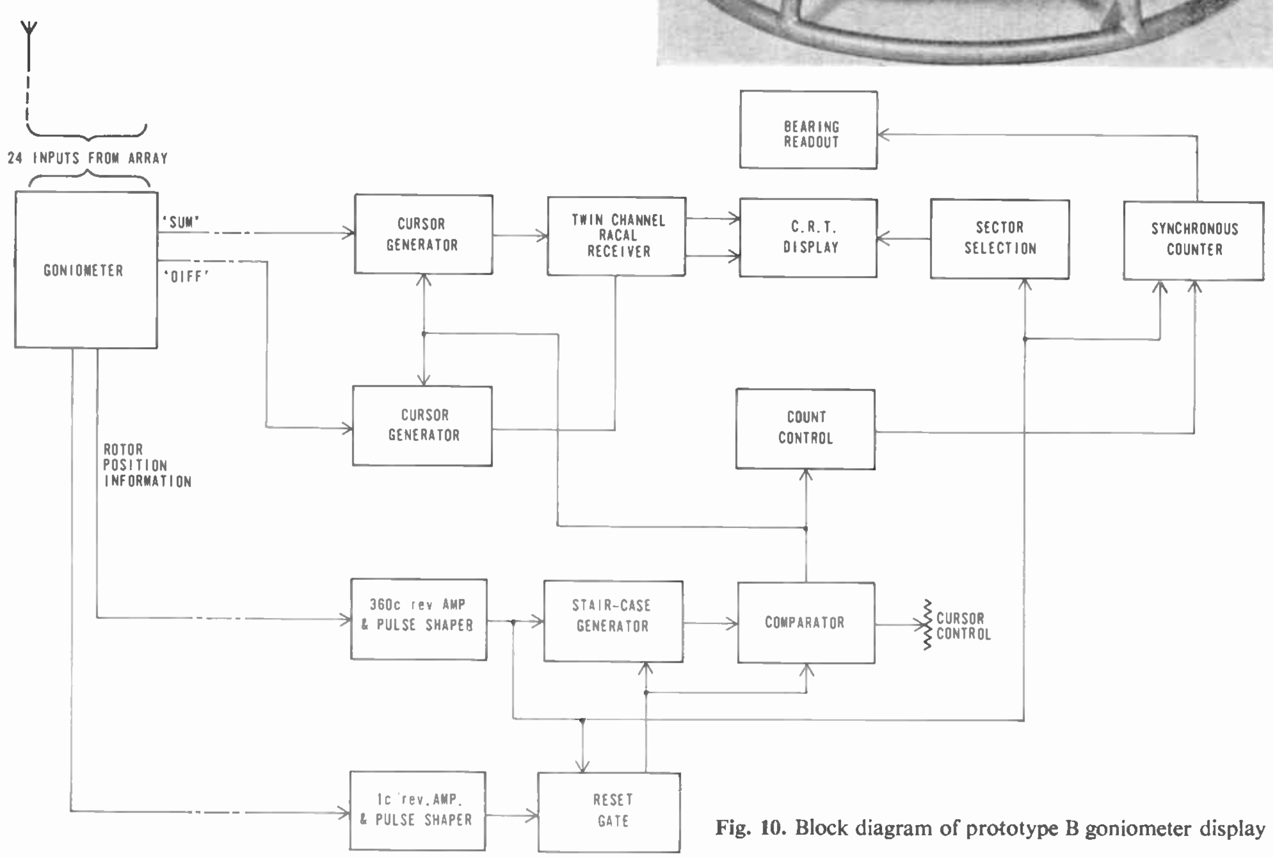


Fig. 10. Block diagram of prototype B goniometer display

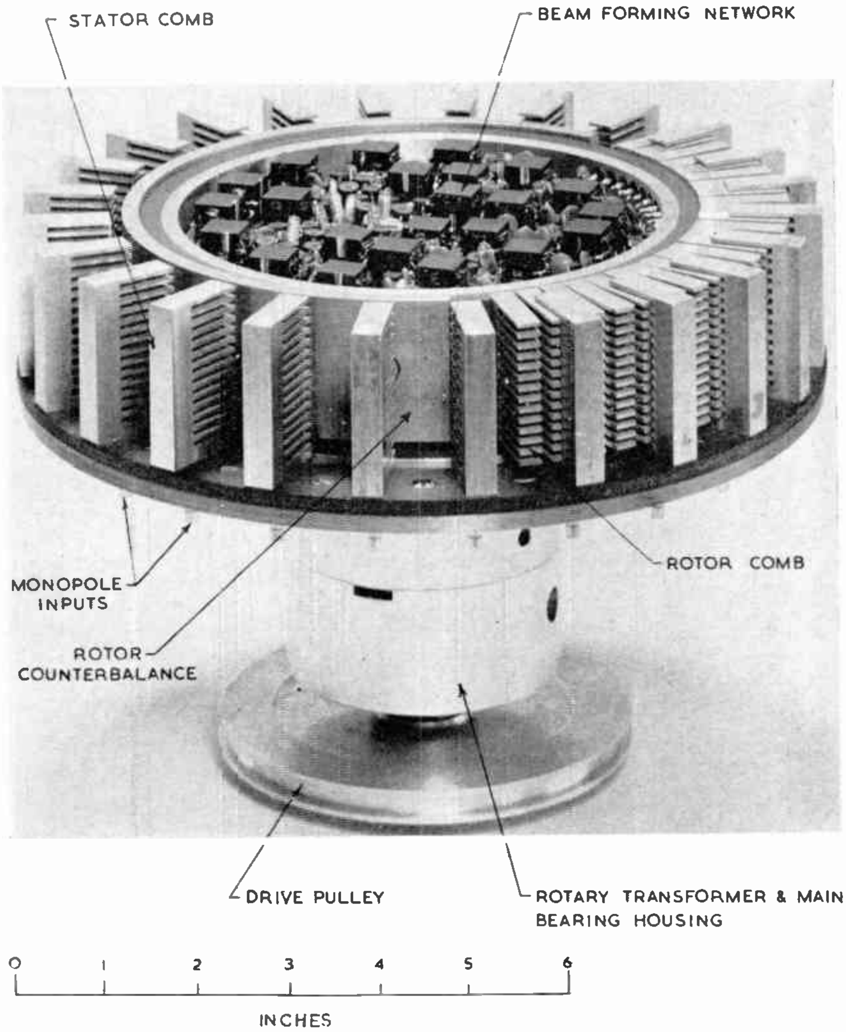


Fig. 11. Prototype C goniometer

7.2 *Choice of Lumped-Constant Network*

The selected network should, with the least number of components, produce a delay line which is easy to manufacture whilst exhibiting the following characteristics:

(a) Nominally linear phase shift over the operating frequency band.

(b) Low insertion loss, say less than 1 dB for the longest delay line.

(c) Reasonably constant impedance over the frequency band.

For the longer delay lines several sections connected in cascade in the form of a ladder network are required. These sections can be either equal or unequal depending on the type of network. In general the class of networks belonging to the former group are treated by image parameter methods whilst the latter type of ladders are treated by modern network theory.

7.3 *Equal Cascaded Delay Lines*

The constant-k, or prototype low-pass filter section, was not considered suitable for the required application as its characteristic impedance varies widely over the frequency range and would therefore require matching sections.

An m-derived low-pass filter section has improved impedance/frequency characteristics but requires at least one additional component. This section can be reduced to three components (as in the case of the constant-k section) by using mutual inductance between the coils. The mutual inductance is achieved by using a centre-tapped coil wound in the 'aiding' form. The disadvantage of this circuit is that phase response is not fully under control and requires bridging capacitors for final correction.

7.4 *Unequal Cascaded Delay Lines*

These networks have characteristics which are described by Butterworth, Chebyshev and Bessel polynomials and full consideration is given to keeping all parameters, e.g. bandwidth, impedance, group delay, etc., under control.

Tables have been devised[8,9] which greatly simplify the synthesis of these ladder networks and element values can be obtained for normalized low-pass ladders with the following characteristics:

(a) equal ripple magnitude (Chebyshev),

(b) maximally flat magnitude (Butterworth),

(c) maximally flat time-delay (Bessel).

The choice of network type for the delay lines was a compromise decision between having an acceptable group delay (linear phase shift) response and good pass-band amplitude characteristics in keeping with a minimum number of network components.

For a given number of elements, the Chebyshev filter gives better coverage of the pass-band with faster drop-off outside the band than either of the networks (b) and (c) above, however its phase characteristic is usually more non-linear than that of the Butterworth filter. The Butterworth is a limiting case of the Chebyshev class where the pass-band ripple has decreased to zero.

The Bessel class of filter network has a maximally flat group delay response but an amplitude response which falls off more rapidly than either the Chebyshev or the Butterworth networks. Delay lines based on the Bessel filter would require about thirty components for the longest delay elements in the combining network in order to provide acceptable amplitude characteristics over the frequency band.

A phase response with optimum linearity up to about (0·5 × cut-off frequency) may be achieved with a Chebyshev filter having a pass-band ripple of about 0·1 dB. A delay line of this description uses about half the number of elements compared with the equivalent Bessel filter and for equal input and output impedances has the added advantage of being symmetrical about the centre component, thus reducing the number of different element values required.

Due to the symmetrical arrangement of the two halves of the combining network, differences in phase-tracking between delay lines of different electrical length will result in an increased insertion loss in the combining network but will not degrade the null obtained. Degradation of the null would result if corresponding delay lines in each half of the combining network had dissimilar phase or amplitude responses.

Of the networks considered above the optimized Chebyshev design was considered the most suitable for the delay elements in the prototype-C goniometer.

The derived values of L and C for each delay line were checked with the aid of a computer to ensure the correct phase and amplitude relationship over the design frequency range. This precaution was taken to avoid effort being wasted in manufacturing delay lines if an error had been made in the design stage.

8 Future Development

8.1 *Reduction of Beam-forming Network Losses*

There appears to be no advantage in a further reduction in physical size of the prototype-C goniometer as any slight advantage gained in space utilization and weight will be more than offset by the degree of machining accuracy and component stability required. There is, however, scope for improvement of the beam forming network in terms of a reduction in the number of components used and a possible reduction of insertion loss. Referring to Fig. 4 it can be seen that, at any instant, the input levels to a hybrid will depend on the degree of coupling of each of its associated rotor combs to the monopoles. Even with a signal arriving on the axis of symmetry of the rotor, losses occur in the combining network due to unequal input levels to the hybrid transformers; this results in a net flow of current in the difference winding.

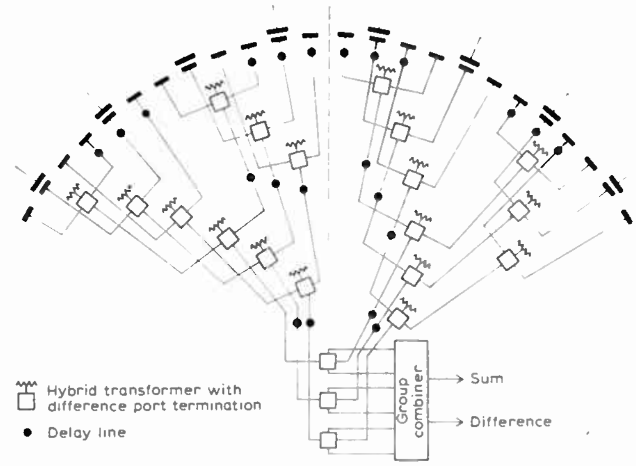


Fig. 12. Arrangement for reduction of beam forming network insertion loss.

Losses in the rotor combining network due to the method of rotor comb/hybrid connexion, were measured on the prototype-A machine using a wavefront generator input to eight stator combs. The results obtained showed a variation of insertion loss of between 6 and 8 dB, depending on rotor/stator position.

This source of insertion loss is avoided in the arrangement shown in Fig. 12 which basically consists of three separate groups of delay lines and hybrids. The angular spacing of the rotor combs within each group is such that for any position of the rotor, input levels to each hybrid are the same (neglecting signal-level gradient across the array).

Problems arise as a result of the need to provide a method of loss-less combination of the three groups of outputs (Fig. 12) which have a mutual phase relationship of 120° and a cyclic variation of amplitude with respect to each other. One method which might be considered is combination in an active network external to the goniometer; this would require a rotary transformer with six outputs.

8.2 *Simplification of Beam Forming Network*

During development of the goniometer, it was realized that the beam forming network could be simplified by using common delay lines in the manner shown in Fig. 13. With this arrangement the number of rotor combs must be an integral power of two. Any other arrangement will result in unequal amplitudes at the inputs to the final hybrid when the rotor is aligned on the direction of a signal of interest and therefore a null will not result in this position. This situation does not arise in the prototype goniometers due to the symmetry of the two halves of the rotor network.

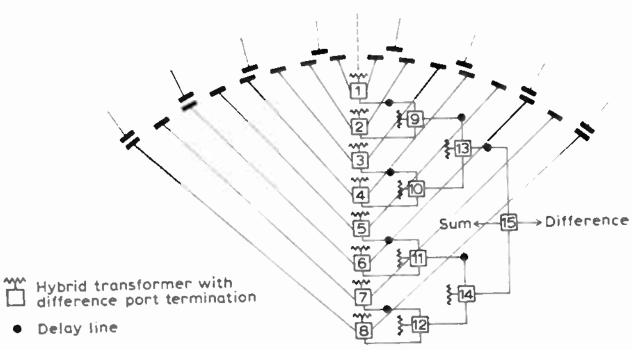


Fig. 13. Simplified beam forming network.

A further simplification can be achieved by the use of three-port hybrids in positions 9 to 14 inclusive (Fig. 13). These hybrid transformers are similar to those previously described except that the 'sum' output transformer is omitted and replaced by a 37·5 Ω resistor to maintain correct termination. This means that only the algebraic difference of two input signals can be obtained from the single output port.

With a combination of three-port and four-port hybrids, as outlined above, no output will be obtained from the three-port units when the rotor is aligned in the direction of a signal and consequently the final four-port hybrid will produce nulls from both the 'sum' and 'difference' ports for this rotor position. With this hybrid arrangement, it may be found that nulls and various minima occurring on the 'sum' and 'difference' patterns are only exactly coincident in the direction of a signal. If this is the case the outputs from hybrid 15 could be combined in a three-port unit mounted on the rotor (not shown in Fig. 13) to provide a single displayed pattern from which the required null could be distinguished from the various other, less well defined minima. With a pattern of this form it may be possible to use electronic null location techniques as part of an automatic bearing-measurement system. A single combined output further simplifies the rotary transformer as only one output channel is required.

It is not practicable to use three-port hybrids in positions one to eight (Fig. 13) as zero output would be obtained from these units in the direction of a signal and also at 180° to the true bearing. In these rotor positions the delay lines associated with hybrids one to eight would lose their 'sensing' capability as there would be no signal flow to produce phase coherence at succeeding hybrids. The result would be to produce reciprocal nulls in the direction of a signal source.

9 Conclusions

Throughout the development, the overriding objectives have been the economic production of an accurate direction-finding unit for use with a circular receiving array.

Operational results obtained with the prototype-A and B goniometers indicate that these compare very favourably with conventional narrow aperture d.f. systems of the Adcock type and represent a useful additional function for use with existing wide-aperture receiving systems. The advantages of wide-aperture systems over narrow-aperture installations lie in their increased effectiveness in reducing site errors, polarization errors and variations of bearings due to ionospheric roughness.

The experimental miniature goniometer has yet to undergo extensive field trials but it is anticipated that its performance will be similar to the two earlier machines. From economic and engineering considerations there are considerable advantages in adopting the miniature goniometer basic design. Further development of this machine lies mainly in simplification of the beam forming networks: this can be achieved by using common delay lines and three-port hybrid transformers.

10 Acknowledgments

The author wishes to acknowledge the assistance rendered by colleagues during the development of the goniometer.

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The assessment of connector reliability

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Based on a paper presented at an IERE Colloquium on 'Electrical Connectors—Applications and Reliability held in London on 15th May 1973.

SUMMARY

The simple 'U' curve concept used to express the mean time between failures (m.t.b.f.) of components as a means of estimating the m.t.b.f. of equipment is based upon a number of simplifying assumptions which are often forgotten when applying the simple rules which result.

While the simple rules adopted are sufficiently accurate to give a good working value for many components, they are unrealistic when applied to connectors. Those features in which a connector fails to approximate to the simple model normally adopted are considered, and their effects on connector reliability noted.

The operating conditions of connectors are grouped and analysed. From these considerations practical suggestions are made for obtaining an approximation to a value of connector reliability which would serve as a model for the forecasting of equipment reliability.

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1 Component Failure

Modern electronic equipment is used in spheres where continued satisfactory functioning is vital, and where a breakdown could endanger life, or else lead to an unacceptable financial loss. Some causes of breakdown are functions of the equipment design, but the greatest percentage are due to failure of a component to continue functioning in a satisfactory manner. Such a failure may be catastrophic, or merely a variation of some electrical parameter which is too great for the circuit of which it is a part. It is obvious that the value of variation which will constitute a network failure in the equipment will be different for any single component according to the critical nature of the circuit adopted by the equipment designer.

Failure in a component can result from any one or more of a number of causes. Such causes may be arbitrarily grouped as follows:

(i) A design which is unsuitable for the conditions of use. This is normally avoided by rigorous design testing at an approval stage, by a continuous series of quality control testing applied throughout the production process, and by skilful equipment design which does not expose the components specified to degrees of overstressing.

(ii) The occasional 'rogue' which has slipped through the statistical quality control net, and which has a manufacturing fault leading to early failure.

(iii) A component which has operated continuously throughout its expectation of life, and which has 'worn out'.

(iv) A component which has been subjected to a momentary high degree of overstress, either through faulty operation of the equipment, or through failure of another component in the same circuit.

(v) An occasional failure which cannot be neatly classified into any of the above four categories, and with which this paper, together with most reliability treatments, deals.

For the purpose of assessment it is normal to group all modes of failure together, to use as a measure the concept of the unit hour, which is the number of similar components employed multiplied by the number of hours during which they are exposed, and to express the reliability as the expected failure rate (the probability of failure of one component during one hour of operation). If we disregard categories (i) and (iv) above, the simplified characteristic which is usually taken as a model is as shown in Fig. 1.

A category (ii) failure occurs during the period marked as 'early failure', and for use in equipments where reliability is of paramount importance, some form of screening is employed to locate such members and remove them from the batch before inclusion in the equipment. Failures of category (iii) occur during the period marked as 'wear out', and either all components used must have a 'working life' in excess of the maximum life required for the equipment, or a replacement routine at suitable intervals must be implemented.

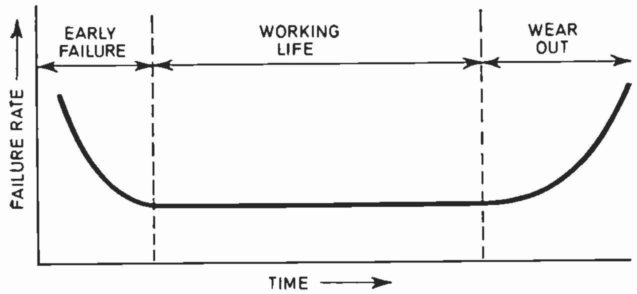

Fig. 1. Failure rate characteristic for a single component.

The failure rate during the working life is shown as constant, and it is that region of the characteristic that will form the main concern of this paper. The curve as shown results from a number of simplifying assumptions adopted to allow easy analysis of equipment performance, and these must now be considered.

2 Random Failure

The probability of failure, as of many other 'random' processes is covered mathematically by the Binomial Distribution. This distribution is a function of two parameters, a mean value, and a standard deviation. When the probability of failure is very small, as it will be in a high reliability component the distribution simplifies into one which is a function of one parameter only called the Poisson, in which the square of the standard deviation equals the mean value. This distribution is of great value in forecasting the reliability of a particular equipment in service because a number of batches of different components, each with its own curve of the form shown in Fig. 1 may be simply aggregated to form an overall curve of the same type which is the characteristic of the complete equipment.

The problem of forecasting the reliability of an equipment therefore reduces to that of determining the parameters which will allow a curve similar to that shown in Fig. 1 to be obtained for batches of all similar components used in the equipment. Unfortunately such treatment can never be 'exact', but at the best will only be an approximation based upon certain simplifying assumptions which are not true. In the case of very many of the component types however this approximation is sufficiently close to actual performance for a meaningful value to be obtained. Unfortunately in the case of electrical connectors the approximation as normally applied will not give a value of much use, and this paper is concerned with methods of improving the approximation.

The probability of failure for any single component having a high reliability, which is subjected to a constant set of stress conditions throughout its life, will remain constant, and its individual curve will approximate very closely to the curve of Fig. 1. For this single component however the stress pattern in an equipment will certainly vary with time, and such variation is likely to vary the value of the probability of failure with time, so that the base line will be a wavy line rather than a straight horizontal one. The solution in the case of the single component is simple; the stresses to which the component is subjected are limited to values which will not produce significantly large short-term variations of probability, so that the 'duty cycle' of the equipment will affect only the length of life between cut-off and wear-out, and this will be covered by a suitable replacement routine where necessary.

A single type of component however may be used in different circuits and where different values of parameter drift will constitute failure. The effect of this will be that for each type of circuit use, the same component will have a different value of probability. This is a practical case which occurs in accident insurance, where some people are found to be more 'accident prone' than others, and it has been treated statistically by use of a modified distribution similar to the Poisson, but with a value of probability which is itself distributed about a mean value. Such a distribution reverts to one with two determining parameters, the standard deviation being independent from the mean value. Unfortunately, for the high-reliability type of component where probability of failure is low and life is long, it is not practicable to determine empirically the values where more than one parameter governs the distribution.

A final departure from the simplifying assumptions is concerned with the fact that there will be a variation of the value of probability for the individual members of a batch of similar components, even when they are subjected to identical stresses in the same circuit location. This variation, in a well designed and carefully manufactured component, however, will be only a small percentage of the probability value; providing therefore that the distribution is determined from medium length tests of a large group of samples rather than from very long tests of a few samples, an average value will be obtained which may be employed meaningfully in reliability calculations.

3 Variability of Failure Probability

A single type of connector may be used in a wide variety of circuit conditions. Not only will conditions of use vary from one equipment to another, but even within one equipment the same type of connector may be used under more than one stress pattern, and in addition the criterion of failure may be significantly different for two circuit locations within the same equipment.

The patterns of stress which the connector may encounter may be arbitrarily grouped into five basic factors as follows:

(a) Use under static conditions (without mating operations) for long periods, and carrying only low-level signal currents.

(b) Frequent matings, particularly where significant levels of power are being carried at the time.

(c) Operation in an inclement environment such as a sulphur-laden atmosphere, one carrying salt spray, or one with a high level of relative humidity.

(d) Operation at a high electrical stress close to that obtaining at proof voltage, or at a high temperature close to the limiting value for the construction.

(e) Operation with frequent rapid transitions between very high and very low temperatures.

The above are only groupings of 'factors' of the complete stress pattern. The actual stress may be a combination of two or more of the above five, and may also have a 'duty cycle', that is, be applied periodically for periods of the life, and be replaced with a different one or ones for other portions of life.

In addition to the action of the above five in varying the probability of failure, the location of the connector in the circuit will give rise to different levels of failure criteria, and hence to different values of probability. The types of deterioration which can cause functional failure in the equipment may be arbitrarily grouped as follows:

(1) Increase in the fluctuation of contact resistance with time, resulting in an increase of 'noise' in the circuit.

(2) Decrease in the breakdown voltage between poles, or from poles to screen, resulting from chemical degradation of the dielectric.

(3) Increase in the average value of contact resistance due to degradation of the mating surfaces, leading to an unacceptable value of temperature rise caused by power dissipation in the current carrying circuit.

(4) Variation of the insertion impedance of the connector arising from mechanical deformation of the structural members.

(5) Mechanical fracture of structural members due to cyclic stresses which carry them beyond the yield point and cause fatigue, or from chemical degradation of organic resins.

The above factors are, in measure, correlated, and not only can their individual levels determine the value of probability, but also the combinations of more than one of them.

4 Working Life

It is obvious that if the curve of Fig. 1 is to be used for reliability prediction, the first measure which must be determined is the 'working life' of the connector. Where the reliability of the equipment must be predicted, it is necessary that a routine be used which will eliminate 'rogues' and remove all members causing the increased value of probability during the early failure portion of the curve. The details of such a routine will depend upon the design of the particular connector and will certainly give rise to an increase of manufacturing cost. Once this has been done, the horizontal portion of the curve may be considered to commence with the installation of the connector into the equipment, and the working life extends from value zero at that point.

The end point of the working life, where the probability increases sharply due to wear-out, will be a function of all ten of the factors (a) to (e) and (1) to (5) listed in Section 3. It is not practicable to evaluate performance for each of the thousands of combinations possible in use, and a practical compromise must be sought in certain standard combinations and levels which will not involve too great an increase in cost, but will cover most of the applications for which the connector is designed.

The criteria of failure may be arranged as three independently measured sets of values as follows:

(i) *Degradation of contact resistance:* A unique limit being chosen and specified for the value of fluctuation (1) and of average value (3), either of these limits being used to define the end of working life.

(ii) *Degradation of dielectric:* A unique limit being chosen for minimum breakdown voltage and for variation of insertion impedance from the design value, either limit being used to define end of working life.

(iii) *Mechanical failure:* An obvious termination of working life.

When using artificial application of stress combinations to determine working life, all five of the criteria (1) to (5) (see Section 3) are measured at suitable intervals, and the first of the five unique limits which is attained is noted for each of the group being tested. Application of standard statistical techniques to the group of lives thus obtained will enable a minimum value of working life to be stated to a calculated level of assurance.

The combinations of stress patterns (a) to (e) in Section 3 are too varied to allow of all of them to be artificially determined. A combination of 'over design' and of 'over stressing', while giving a small increase in cost, is the only way in which it is economical to design a connector which may be used for reliability prediction.

Degradation of contact resistance (i) can be a function of all five stress factors. One practical compromise is to adopt a test routine which combines (a), (b) and (c) in a predetermined combination which experience has shown to be a fair compromise for this purpose. A test batch is divided into six randomly chosen sub-batches, A1, A2, B1, B2, C1, C2. All batches are subjected to between 30 and 70% of the mating operations which previous tests have indicated to be the end of working life. Since it is bad practice continuously to mate and unmate connectors carrying significant levels of power through their poles, no power is carried during this test, and operational reliability is specified as being for mating under non-power-carrying conditions. Batches A are then subjected to IEC 68 test Ca for the correct period, half mated and half unmated; batches B to the salt spray test described in the British Standard BS 2011 test K half mated and half unmated; batches C to the two tests at present under discussion in IEC TC 50 for atmospheres containing the oxides of sulphur and for atmospheres containing the hydrogen sulphide, again with half mated and half unmated. The remainder of the mating tests are then continued up to failure. Measurements of contact resistance under low-level conditions are made at suitable intervals, and the point of failure, the nature of failure, and the portion of the overall test routine where failure occurred, are all noted. A statistical analysis of the results will allow a minimum life to be evaluated with a known value of certainty. It is important of course that a single 'random' failure due to the probability of random failure operating during the working life should be discounted by statistical means. The failure of a significant number resulting from the application of one of the three corrosive atmospheres, and before application of the second set of mating operations, should be taken as indication of an unsuitable design for high reliability use. This routine is considered to give length of life in terms of number of permissible mating operations.

Stress patterns (d) and (e) are most economically covered by a measure of over-design. A series of accelerated tests in the laboratory are used to determine that no deterioration leading to termination of life will occur at the maximum specified working stresses of this nature, at least up to the length of life which patterns (a) and (c) impose. The life which is to be determined for (a) and (c) presents by far the most difficult problem. The laboratory tests are all of an accelerated nature, and the exact correlation between the tests and operation in the field are not known. Practical experience with some of these routines over the past 35 years allows a fair degree of reliability to be established, but no firm quantitative figures can be established at present.

5 Probability of Failure

Where the working life is of the order of tens of years, and is characterized mainly by a rise in the value of probability of failure, it is obvious that this cannot be measured directly, but must be the subject of indirect calculations subject to confirmation from performance in the field. In such cases however, the value of probability of random failure which constitutes the height of the horizontal line in Fig. 1 will also present problems of measurement. The only practicable way is to subject a large batch or batches of similar components to the typical working stress for a period of up to a year, and record failures. Depending upon the total number tested, and the value of probability, it is quite possible for only one or two failures to be recorded; the only way of using such meagre data is to assume a Poisson distribution and calculate the mean value and the standard error of the result: quite often, unless the quantity tested is very large, it is found that no failure occurs, and in such a case the only solution is to calulate a maximum value for the probability on the false assumption that exactly one failure at an unspecified time had occurred during the test run.

The most practical test to establish a usable value of probability would seem to be one involving a combination of factors (a), (b) and (c) ennumerated in Section 3. It can be assumed that use involving only an occasional mating will give less probability of failure in an inclement environment than one involving static operation, and hence exposure to test atmospheres should be made on mated pairs of connectors, and involve measurement of contact resistance at appropriate intervals of time, with a very minimum of physical disturbance of the test samples. Eight batches of connectors are used, four batches without more than an initial mating, and four with approximately 30% of matings constituting a working life already performed to give typical physical abrasion of the contact surfaces. One pair of batches is exposed to each of four test atmospheres: one pair to high temperature, one to high humidity, one to a combination of sulphur oxides and hydrogen sulphide, and one to a standard salt mist and humidity cycle repeated until failure occurs. From these tests four pairs of values will be obtained, from which the effects of physical wear on failure rate may be statistically examined. The four pairs will also allow the probability of failure for each of the four test atmospheres to be compared; if they are all of the same order of magnitude, then they may be aggregated to obtain a greater degree of certainty for a single value; where they are of significantly differing order, then the four values may be recorded.

The method of using the values thus obtained for life and probability of failure is to obtain for a particular equipment a pessimistic figure of a maximum probability of failure, and feel reasonably certain that the performance will never be worse than that predicted from it. For the value of probability, the eight values obtained from the above test are taken, and from those conditions of the eight which may be experienced by the equipment during service, the maximum value of probability is taken and used. For operation at high temperature and at high humidity the value of probability measured will be a realistic maximum for actual operation; for salt mist and for sulphur contamination however a fair degree of acceleration is involved, and the weighting factor to be applied to the measured value of probability is one which is in process of being approximately assessed at the moment. In the same way, the length of working life in terms of exposure to all four of the atmospheres is one which must be judged on the past results in the field using equipments whose components have a known performance when subjected to these test atmospheres. The approximate frequency of mating in a given equipment may be estimated, and for each type of connector used in the equipment that one individual which has the greatest expected frequency should be used to calculate a pessimistic figure of life for all members of the group.

Stress factors (d) and (e) may be considered as affecting the life more than they affect the value of probability, and if they have been discounted as suggested by a degree of over-design, they may be ignored so far as their effect on probability is concerned. The measurements suggested above are all feasible in a modern test house, and the only reason which could prevent the necessary data from being given for connectors is the cost of making the measurements; where the assessed reliability of an equipment is of sufficient financial importance however to be a contract condition, the fairly reasonable cost of obtaining and guaranteeing these values would be justified.

6 Acknowledgments

Much practical experience of connector design and of performance assessment within the laboratories of Belling and Lee Ltd., and much discussion within National and International committees, has served to provide a basis on which the above paper has been written. There is, as yet, no generally agreed basis on which the failure rate of connectors should be calculated, and the author must bear the blame for the controversial suggestions presented.

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UDC 621.374.4

Use of switching circuits as redundant multiplier elements in canonic digital networks

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Based, in part, on a paper presented at the IERE Conference on Digital Processing of Signals in Communications held at Loughborough on 11th to 13th April 1972.

SUMMARY

Switching circuits are used to realize elementary multipliers whose coefficients are restricted to integer powers of 2. Modifications are given to accommodate signed magnitude, 1's complement and 2's complement binary codes.

The addition of a single elementary multiplier to a canonic digital network and its interchange with each conventional multiplier in turn enables the multiplier coefficients to be respecified with a corresponding change in gain (which need never exceed $\sqrt{2}$). The errors in the multiplier coefficient approximations may then be evaluated for the different sets of coefficients, and the most suitable set selected. A simple analysis procedure is given with an error criterion which provides a suitable assessment of the quantization errors resulting from multiplications. With fixed-point arithmetic, elementary multipliers provide scaling for conventional multipliers to enable the most significant bit in the coefficients to be used.

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1 Introduction

Conventional analogue networks contain 'impure' elements whose values vary with frequency, temperature and time; in particular, resistors are inductive and inductors have associated resistance and capacitance. Tolerancing errors reduce the accuracy still further. Inductors are not amenable to microminiaturization and their elimination in crystal and active networks results in additional problems; crystals have a three-element reactive equivalent circuit with a limited range of parameters, and active designs usually result in decreased stability.

An alternative solution makes use of the property that a signal sampled at more than twice the highest constituent frequency (the Nyquist rate) is completely and unambiguously specified by the samples, whose width may be arbitrarily small. For filters, it is worthwhile to band-limit the signal above the pass band. The binary representation of the amplitudes is clearly unaffected by ambient variations and the resulting digital networks[1,2] are therefore very stable with predictable properties. Linear phase is also possible. The networks are realizable using binary adders, multipliers and shift registers, fabricated using digital computer hardware.

Unfortunately, there are several problems associated with digital networks. One of the main disadvantages is the cost, especially for multipliers, but the situation is improving with advancements in mini-computers. Another problem is quantization errors resulting from both multiplications and terminating conversions. Further factors are dead bands[3] and limit cycling[4] resulting from quantization of the circulating numbers (and independent of the adder and multiplier coefficient errors); a total change in a recursive cycle of less than half the storage quantum† is lost so that a value which tends slowly towards a given limit is liable to terminate too soon, and for recursive networks of second and higher orders, small amplitude oscillations are liable to occur about the final value.

We are concerned here with the reduction of quantization errors resulting from multiplications. It was shown in a previous paper[5] that these errors can often be reduced without additional physical components, by introducing multipliers with coefficients set to integer powers of two. These elementary multipliers are treated here in greater detail with realizations for any type of binary arithmetic, and a simple analysis procedure is given enabling the most suitable branches for these multipliers to be easily determined.

2 Application of Redundant Multipliers

Since multipliers are expensive and slow in operation compared with other digital hardware, it appears that the fewer there are in a network the better. However, a single multiplier may be multiplexed, and the speed of operation can be increased if the coefficients are simplified. In particular, if a coefficient is set to an integer power of two, realization is possible simply by reordering the 'bits' of the binary-coded signals. This reordering to

† The storage quantum is the smallest recordable change.

Table 1: Examples of 9-bit 2-decimal place binary numbers

Decimal value	Positive	Negative		
		signed magnitude	1's complement	2's complement
3·25	0,0000 /11·01/	1,0000 /11·01/	1,1111 /00·10/	1,1111 /00·11/
6·5	0,000 /110·1/ 0	1,000 /110·1/ 0	1,111 /001·0/ 1	1,111 /001·1/ 0
13	0,00 /1101 /·00	1,00 /1101 /·00	1,11 /0010 /·11	1,11 /0011 /·00
26	0,0 /1101 /0·00	1,0 /1101 /0·00	1,1 /0010 /1·11	1,1 /0011 /0·00
52	0, /1101/ 00·00	1, /1101/ 00·00	1, /0010/ 11·11	1, /0011/ 00·00

multiply or divide an unsigned binary number by an integer power of two was given in a paper dealing primarily with quantization errors.[5] We consider here modifications to these elementary multipliers for different codes, namely signed magnitude, 1's complement and 2's complement, and also a switching arrangement for a general purpose multiplier whose binary code and value are readily altered.

There are $n-1$ multipliers in an nth order canonic† transversal digital network and twice this number in a recursive network (with both transversal and recursive sections). Scaling the coefficients only alters the gain so that one coefficient in both the transversal and recursive sections may be set to a predetermined value. An elementary multiplier may therefore be used in place of each conventional multiplier in turn, and this provides up to n sets of coefficients which are easily compared for assessing quantization errors. The integer powers of two for the elementary multipliers are chosen so that the digital system operates near the limit of its capacity under conditions which maximize the circulating binary values.

With fixed-point arithmetic, a further use of these elementary multipliers is to enable incoming signals to each conventional multiplier to be scaled so that the most significant bit assigned to its coefficient may be set (or unset for a negative number expressed in complementary arithmetic).‡

3 Realization of Elementary Binary Multipliers

Examples of positive and negative fixed-point 9-bit numbers to two binary places are given in Table 1, with the first bit denoting the sign. The coded values for any positive number (zero sign) are the same and when the bits are shifted due to multiplication or division by an integer power of 2, the newly created spaces in the least significant part as a result of multiplication, and most significant part due to division, are filled with zeros.

The sign bit is set for a negative number and it is here that the three codes vary.[6] With signed magnitude, the sign is followed by the modulus, as in conventional decimal notation. With 1's complement, positive and negative numbers have complementary bit patterns, and adding 1 to the least significant bit of a negative number in 1's complement gives the 2's complement version.§ When multiplying by 2, the space is filled with 0, 1, 0 for signed magnitude, 1's complement and 2's complement respectively. When dividing by 2, the space is filled with 0, 1, 1 respectively.

Examples of the reordering of bits corresponding to multiplication and division by an integer power of two are given in Fig. 1. When multiplying by 2^r, the r most significant bits must initially be zero otherwise an overflow will occur, and the most significant part of the new number will be lost. The realization of general-purpose multipliers using patch boards is given in Fig. 2. The patch boards have vertical and horizontal metallic strips on opposite faces and Fig. 2 shows the points of interconnexion for the different multiplying factors, e.g. to multiply by 2 using 1's complement, connection between the faces is made at the four points with '2' as a label. A general switching circuit is shown in Fig. 3 for enabling both the value (an integer power of two) and code to be varied; the given range, $\frac{1}{8}$ to 8, is easily extended.

4 Application of Elementary Multipliers to Digital Networks

The transfer function for an nth order recursive digital network may be expressed as follows:

$$G(z) = \frac{V_{out}}{V_{in}} = \frac{a_0 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_n z^{-n}}{b_0 + b_1 z^{-1} + b_2 z^{-2} + \ldots + b_n z^{-n}} \quad (1)$$

A conventional canonic realization is given in Fig. 4 with the gain altered by a factor b_0/a_0. The corresponding transfer function $G_1(z)$ is given by

$$G_1(z) = \frac{1 + \frac{a_1}{a_0} z^{-1} + \frac{a_2}{a_0} z^{-2} + \ldots + \frac{a_n}{a_0} z^{-n}}{1 + \frac{b_1}{b_0} z^{-1} + \frac{b_2}{b_0} z^{-2} + \ldots + \frac{b_n}{b_0} z^{-n}} = \frac{b_0}{a_0} G(z)$$

† Canonic is defined here as a minimum element representation.

‡ In positive logic binary arithmetic, 'set' denotes 1 and a positive signal; conversely, 'unset' denotes 0 and no signal. To allow for noise in practical systems, the given signal is compared with the threshold value required to operate the logic; this value is less than the given positive signal with the maximum expected noise subtracted, and greater than the noise alone. Note that in certain applications, including the processing of irregularly spaced pulse sequences, a negative signal is sometimes used in place of no signal to denote 'unset'.

§ 2's complement is usually considered the most suitable code for digital networks, partly because zero has a unique representation, and also because binary arithmetic using a complementary code is unaffected by temporary overflows. There are additional binary codes but these are usually unsuitable for arithmetic operations, e.g. Gray's code for counters with a difference of only one bit between adjacent integers.

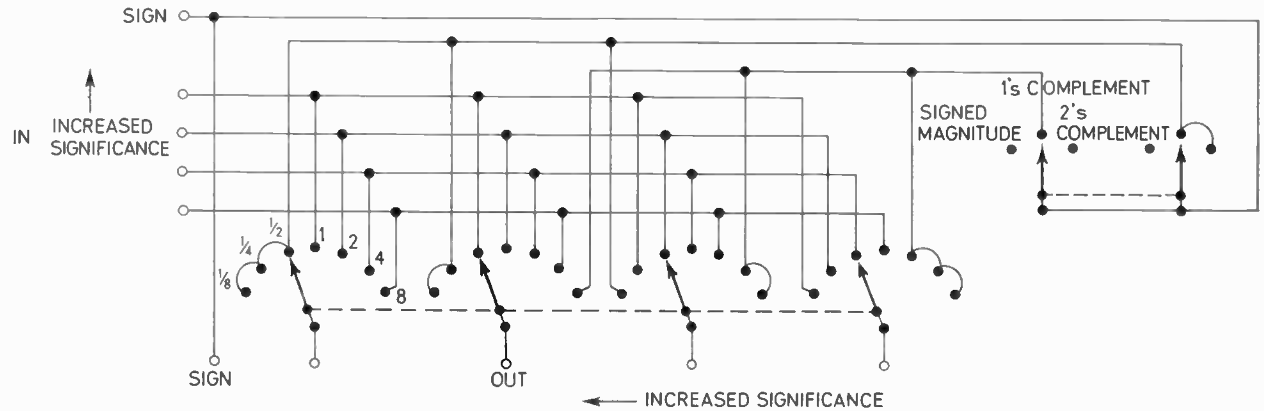


Fig. 3. General switching circuit for a binary multiplier.

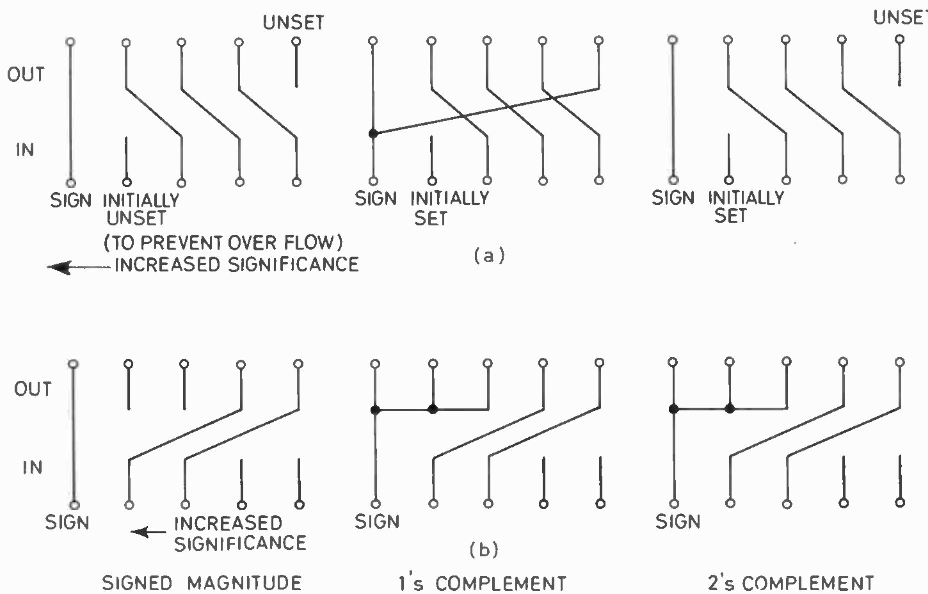


Fig. 1. Examples of binary multiplication by an integer power of 2.
(a) Multiplication by 2.
(b) Division by 4.

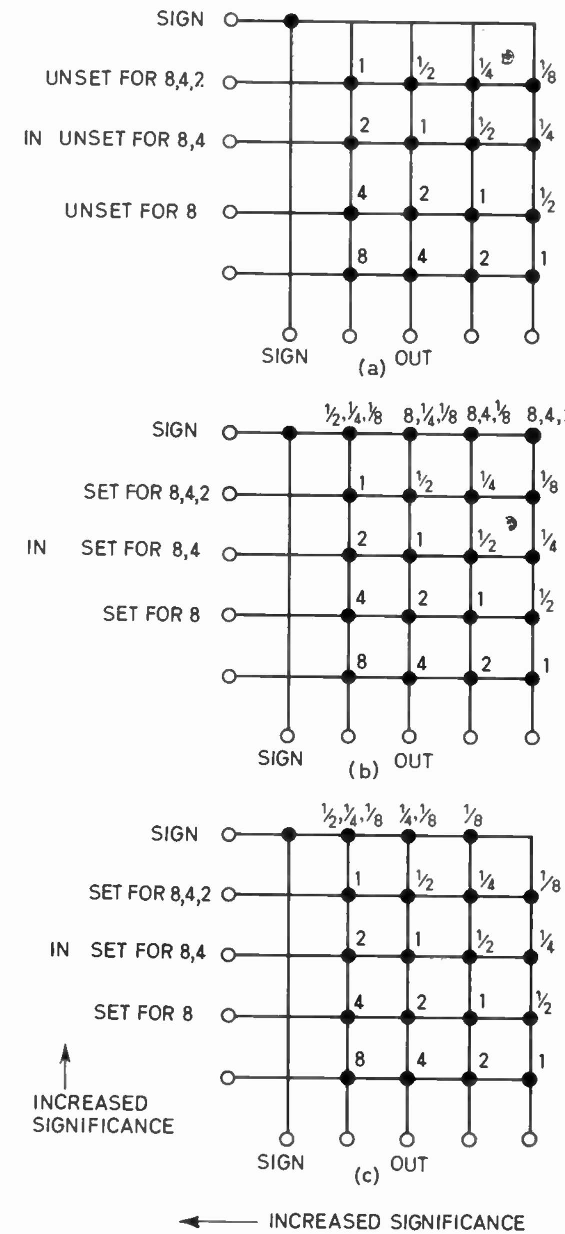
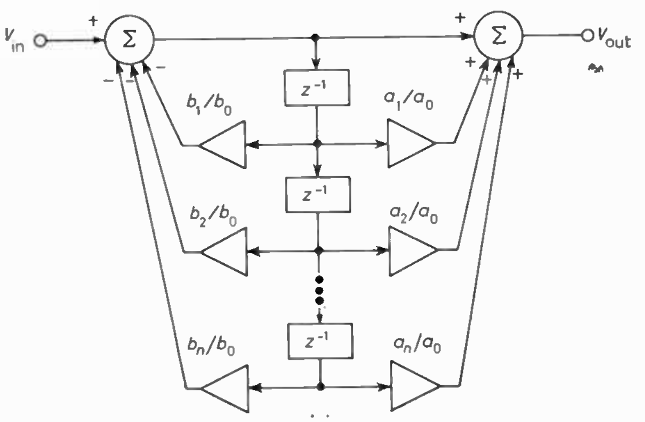
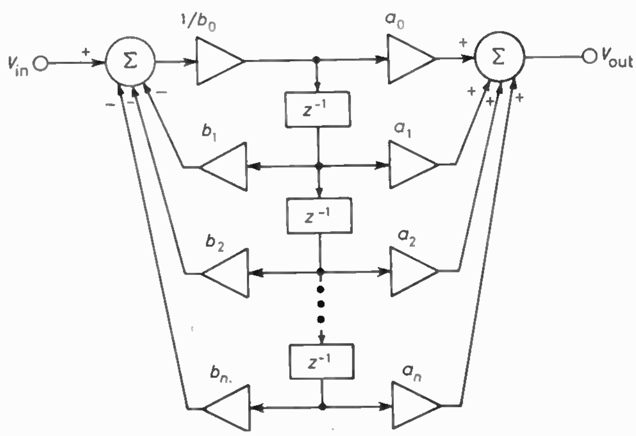


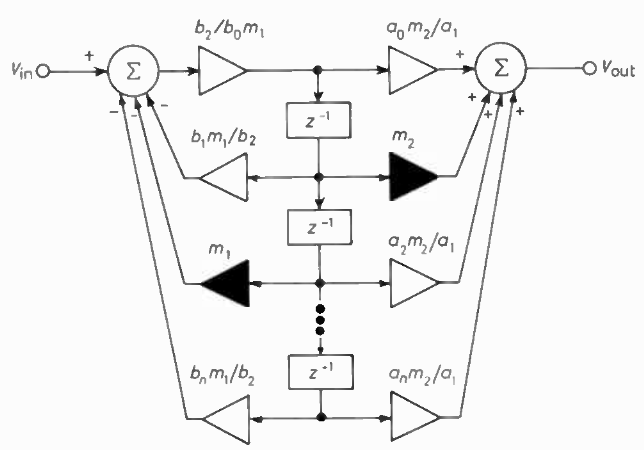
Fig. 2. Elementary multiplier realization using a patch board. (a) Signed magnitude. (b) 1's complement. (c) 2's complement.



(a) Canonic form.



(b) Addition of 2 multipliers to permit scaling.



(c) Coefficient scaling for realization with 2 elementary multipliers (shaded elements).

Fig. 4. Circuits for *n*th order recursive digital networks.

The addition of two extra multipliers, as shown in Fig. 4(b), increases the versatility and enables each coefficient in equation (1) to correspond directly to a separate multiplier. If we allow for a change in gain, the multiplier coefficients are no longer uniquely specified One coefficient in both the numerator and denominator of equation (1) may then be set to an integer power of two and realized with an elementary multiplier; its interchange with each conventional multiplier in turn provides a maximum of n sets of coefficients in both the transversal and recursive sections, corresponding to a change in the numerator and denominator coefficients, respectively, of the transfer function. Errors resulting from approximating these coefficients may then be compared. For the circuit in Fig. 4(c):

$$G_3(z) = \frac{\dfrac{a_0 m_2}{a_1} + m_2 z^{-1} + \dfrac{a_2 m_2}{a_1} z^{-2} + \ldots + \dfrac{a_n m_2}{a_1}}{\dfrac{b_0 m_1}{b_2} + \dfrac{b_1 m_1}{b_2} z^{-1} + m_1 z^{-2} + \ldots + \dfrac{b_n m_1}{b_2}}$$

$$= \frac{b_2 m_2}{a_1 m_1} G(z)$$

5 Comparison of Multiplier Approximations

The following method is suggested for determining the most suitable branch for an elementary multiplier whose coefficient is restricted to an integer power of 2. We will look firstly at the a coefficients. With a_0 to a_n specified, let a_0' to a_n' be binary approximations with the available multipliers. The deviation between each pair of coefficients with the same subscript consists of two parts, a scaling factor and an error. The scaling factor g is the change in gain which need never exceed $\sqrt{2}$; this change is unlikely to cause any problems, especially as in most instances the output is converted into analogue form where the gain may easily be readjusted, if necessary. The n coefficients may be related as follows:

$$\left.\begin{aligned} ga_0 + e_0 &= a_0' \\ ga_1 + e_1 &= a_1' \\ &\vdots \\ ga_n + e_n &= a_n' \end{aligned}\right\} \qquad (2)$$

We wish to minimize the error e. Using the principle of least squares, the value of

$$(a_0' - ga_0)^2 + (a_1' - ga_1)^2 + \ldots + (a_n' - ga_n)^2$$

is minimized when

$$\sum_{m=0}^{n} e_m = 0$$

Hence†

$$g = \frac{\sum_{m=0}^{n} a_m'}{\sum_{m=0}^{n} a_m}$$

† This expression for the gain may be obtained by an alternative argument. Let s be the mean amplitude of the signal approaching multiplier a_0; it will also be the mean value approaching the remaining a-multipliers which all receive the same signal with different delays. The mean 'ideal' output is $s \sum a_m$ and the mean value for the actual output is $s \sum a_m'$. The mean gain is therefore $\sum a_m' / \sum a_m$.

A suitable error criterion c is the mean fractional error in the rescaled coefficients, and is given as follows:

$$c = \frac{\frac{1}{n}\sum_{m=0}^{n}|e_m|}{\frac{1}{n}\sum_{m=0}^{n}|ga_m|} = \frac{\sum_{m=0}^{n}|e_m|}{\sum_{m=0}^{n}|a'_m|}$$

The error criterion is determined with the elementary multiplier in each branch in turn. The simplest procedure is to scale the multiplier coefficients so that the rth value is set to an integer power of 2 when the single elementary multiplier is in the rth arm. The remaining coefficients are approximated as closely as possible using conventional multipliers. In this instance, with $a_r = a'_r$ and $d_r = 0$,

$$\left.\begin{aligned} a_0+d_0 &= a'_0 = K_0\delta \\ a_1+d_1 &= a'_1 = K_1\delta \\ &\vdots \\ a_n+d_n &= a'_n = K_n\delta \end{aligned}\right\} \quad (3)$$

K_0 to K_n are integers and δ the coefficient storage quantum (the least significant storable digit). The value of d need not exceed $\frac{1}{2}\delta$ but minimizing $\sum_{m=0}^{n} d_m$ may not minimize $\sum_{m=0}^{n} e_m$. The variation of d_m/a_m should be minimized. If an elementary multiplier is introduced to increase the signal, it may be used to scale the incoming values so that all the bits in the standard multiplier are utilized. Otherwise, provided there is no risk of overload, the conventional multiplier should precede a signal-reducing elementary multiplier. Halving the signal before or after entering the standard multiplier, with its coefficient set to twice the specified value, effectively halves the storage quantum. If the risk of overload prevents a final reduction, there are two instances when scaling by 2^r should be avoided

(a) when $e \ll \delta/2^{r+1}$ so that the new coefficient is exactly 2^r times the original value, resulting in no benefit as regards multiplier coefficient approximation, and a degradation of the r least significant bits in the original signal;

(b) when the fractional improvement in the multiplier coefficient is less than the fractional degradation of the signal as a result of the initial division.

In other instances a partial reduction may be preferable. At first sight it may appear preferable to apply equation (2) to the coefficients of the conventional multipliers and disregard any initial or subsequent scaling; δ is then constant. Unfortunately, we would then be employing weighting inversely proportional to any scaling. To allow for this scaling, equation (3) should be replaced by

$$a_0+d_0 = a'_0 = K'_0\left(\frac{\delta}{2^{r_0}}\right)$$

$$a_1+d_1 = a'_1 = K'_1\left(\frac{\delta}{2^{r_1}}\right)$$

$$\vdots$$

$$a_n+d_n = a'_n = K'_n\left(\frac{\delta}{2^{r_n}}\right)$$

K'_0 to K'_n are new integers corresponding to coefficient storage quanta $(\delta/2^r)$ which are determined by the signal scaling. A negative value of r denotes an increase by an integer power of 2 which occurs when a coefficient is larger than the multiplier maximum.

The b coefficients are treated similarly, except that the first coefficient b_{01} $(= 1/b_0)$ varies in an inverse manner to the remainder. We therefore have

$$g\left(\frac{1}{b_{01}}\right) + e_0 = \left(\frac{1}{b'_{01}}\right) \quad (4)$$

Hence

$$gb_0+e_0 = b'_0$$

$$gb_1+e_1 = b'_1$$

$$\vdots$$

$$gb_n+e_n = b'_n$$

resulting in

$$c = \frac{\sum_{m=0}^{n}|e_m|}{\sum_{m=0}^{n}|b'_m|}$$

Having specified b_0, we determine the multiplier coefficient b'_{01} which best approximates $1/b_0$, consistent with the suggested value of g; these quantities are related by equation (4).

6 Example

We conclude with an example. For simplicity we will use multipliers with 4-bit coefficients and assume that either an overload will not occur as a result of using multipliers with coefficients larger than specified (followed by a division), or that the circulating numbers have a string length sufficiently long for the errors in multiplication to be due solely to the coefficient approximations.†

For a 2nd-order filter let $a_0 = 2{\cdot}0$, $a_1 = 1{\cdot}7$, $a_2 = 4{\cdot}2$ (the first three random numbers in the Cambridge Elementary Statistical Tables) and let the multiplier coefficients be fixed-point to two binary places, i.e. the range covered is 00·01 (0·25 decimal) to 11·11 (3·75 decimal). For analysis purposes it is more convenient to expand this range to extend from 1 to 15 and scale the coefficients so the branch containing the elementary multiplier has a coefficient of 8 (the largest integer power of 2 in the range). We therefore have

(a) $a_0 = 8{\cdot}000$ $a_1 = 6{\cdot}800$ $a_2 = 16{\cdot}800$

(b) $a_0 = 9{\cdot}412$ $a_1 = 8{\cdot}000$ $a_2 = 19{\cdot}765$

(c) $a_0 = 3{\cdot}810$ $a_1 = 3{\cdot}238$ $a_2 = 8{\cdot}000$

† To evaluate fully the effect of a truncation error in the incoming signal (resulting from an initial division) on the multiplication quantization error, it is necessary to specify the coefficient value, and the signal and multiplier coefficient string lengths, and analyse the multiplier output for a signal consisting of a random sequence of known mean amplitude and standard deviation; this is clearly beyond the scope of this paper.

Table 2: Values of error criterion, c, for example ($a_0 = 2{\cdot}0$, $a_1 = 1{\cdot}7$, $a_2 = 4{\cdot}2$)

			1st choice			2nd choice			3rd choice		
	Scaled value	δ	approx.	rescaled	c	approx.	rescaled	c	approx.	rescaled	c
a_0	8·0	1	8	7·848		8	7·722		8	8·354	
a_1	6·8	½	7	6·671	0·031	6½	6·563	0·018	7	7·101	0·028
a_2	16·8	2	16	16·481		16	16·215		18	17·544	
a_0	9·412	1	9	9·367		10	9·620				
a_1	8·000	1	8	7·962	0·020	8	8·177	0·020			
a_2	19·765	2	20	19·671		20	20·203				
a_0	3·810	¼	3¾	3·797		4	3·861				
a_1	3·238	¼	3¼	3·228	0·006	3¼	3·282	0·018			
a_2	8·000	1	8	7·975		8	8·108				

δ = coefficient storage quantum.

Taking the first set of values, $a_0' = 8$. If we set $a_1' = 7$, $a_2' = 16$, equation (2) then gives

$$\begin{aligned} 8{\cdot}0g+e_0 &= 8 \ldots \delta = 1 \\ 6{\cdot}8g+e_1 &= 7 \ldots \delta = \tfrac{1}{2} \\ 16{\cdot}8g+e_2 &= 16 \ldots \delta = 2 \end{aligned} \qquad (5)$$

Hence

$$g = \frac{31}{31{\cdot}6} = 0{\cdot}9810$$

Applying this value to equation (5) gives

$$\begin{aligned} 7{\cdot}848+e_0 &= 8 \\ 6{\cdot}671+e_1 &= 7 \\ 16{\cdot}481+e_2 &= 16 \end{aligned} \qquad (6)$$

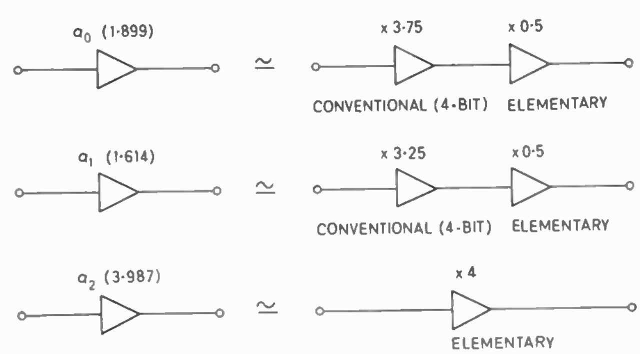
Hence

$$c = \frac{0{\cdot}962}{31} = 0{\cdot}031$$

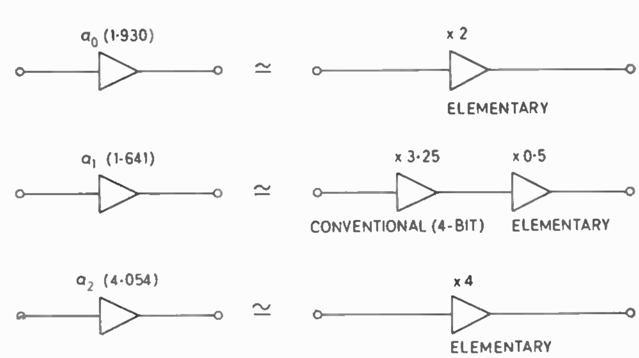
In branch 1 we are trying to realize 6·8 and since twice this value lies in the range 7·5 to 15 we approximate with an integer the coefficient 13·6; the signal is then halved to restore the multiplying factor and this halves the effective coefficient storage quantum (initially unity). In branch 2 the signal is doubled before or after entering the multiplier; δ is therefore 2. Our present choice of coefficients is poor for although we have minimized $\sum_{m=0}^{2} d_m$ by setting a_m' as close as possible to a_m, we have not minimized $\sum_{m=0}^{2} e_m$ (or more particularly, the error criterion c). At present, the first branch favours $g > 1$ and the second branch $g < 1$. As an alternative, both will favour a similar 'movement' of g if the coefficients are selected as follows, $a_1' = 6{\cdot}5$, $a_2' = 16$ or $a_1' = 7$, $a_2' = 18$. The corresponding values of c are 0·018 and 0·028. Equation (6) should therefore be replaced by

$$\begin{aligned} 7{\cdot}722+e_0 &= 8 \\ 6{\cdot}563+e_1 &= 6{\cdot}5 \\ 16{\cdot}215+e_2 &= 16 \end{aligned}$$

Results are given in Table 2 for different selections of coefficients. The best solution ($c = 0{\cdot}006$) is obtained with the simple multiplier in branch 2. The scaled coefficients 1·899, 1·614, 3·987 are approximated by 1·875, 1·625, 4, respectively as shown in Fig. 5. The second best solution has elementary multipliers in branches 0 and 2. The scaled coefficients 1·930, 1·641, 4·054 are approximated by 2, 1·625, 4. The rescaled values in Table 2 are subsequently scaled by a power of 2 to provide coefficients as near as possible to the original



(a) Solution with 2 conventional multipliers ($c = 0{\cdot}006$).



(b) Solution with 1 conventional multiplier ($c = 0{\cdot}018$).

Fig. 5. Realization of multipliers for numerical example.

set (the primary difference being a change in gain); this variation need never exceed $\sqrt{2}$. In the given examples the final coefficients are slightly smaller so there is no risk of overload.

7 Conclusions

We have shown that a general-purpose binary multiplier, whose coefficient may be set to any integer power of two, is realizable with a simple switching circuit, and a multiplier of given binary code and coefficient is realizable with a patch board.

A canonic digital network contains several parallel paths separated by different delays, and all but one contain a multiplier; by scaling the signal to provide a direct line in each of n paths in turn (unity gain), we obtain n sets of multiplier coefficients. The simple analysis procedure given here then determines the most suitable arrangement with the aid of an error criterion which is minimized to reduce quantization errors. Finally, the elementary multipliers enable the new coefficients to be rescaled so the deviation from the specified values (corresponding to a change in gain) is no more than $\sqrt{2}$.

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STANDARD FREQUENCY TRANSMISSIONS—June 1973

(Communication from the National Physical Laboratory)

June 1973	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)		June 1973	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)	
	GBR 16 kHz	MSF 60 kHz	Droitwich 200 kHz	*GBR 16 kHz	†MSF 60 kHz		GBR 16 kHz	MSF 60 kHz	Droitwich 200 kHz	*GBR 16 kHz	†MSF 60 kHz
1	−0·1	−0·1	0	715	625·0	**17**	0	0	0	725	633·9
2	−0·1	−0·1	−0·1	716	625·9	**18**	−0·1	−0·1	+0·1	726	634·7
3	−0·1	−0·1	0	717	626·8	**19**	0	0	0	726	634·9
4	−0·1	0	0	718	627·2	**20**	−0·1	0	0	727	635·3
5	0	−0·1	+0·1	718	627·8	**21**	−0·1	−0·1	+0·1	728	636·3
6	−0·1	−0·1	+0·1	719	628·3	**22**	−0·1	−0·1	+0·1	729	637·0
7	0	0	+0·1	719	628·6	**23**	0	0	+0·1	729	637·3
8	0	0	+0·1	719	629·0	**24**	0	0	+0·1	729	637·4
9	0	0	+0·1	719	629·4	**25**	0	0	+0·1	729	637·8
10	0	0	0	719	629·7	**26**	0	0	0	729	637·7
11	−0·1	−0·1	+0·1	720	630·5	**27**	0	0	0	729	638·0
12	−0·1	0	0	721	630·5	**28**	0	+0·1	0	729	637·5
13	−0·1	0	0	722	630·8	**29**	0	0	+0·1	729	637·5
14	−0·1	−0·2	+0·1	723	632·3	**30**	0	0	+0·1	729	637·1
15	−0·1	0	+0·1	724	632·7	**31**					
16	−0·1	−0·1	0	725	633·7						

All measurements in terms of H-P Caesium Standard No. 334, which agrees with the NPL Caesium Standard to 1 part in 10^{11}.

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

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

UDC 681.32

The use of logic simulation in the design of a large computer system

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and

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SUMMARY

By using a logic simulator, the designers of *MU5*, a large computer containing over 60,000 logic gates, have been able to commission their designs successfully prior to manufacture. A user's view of the simulator is given. This includes the structure of the simulator, the mechanisms for specifying and testing the networks and examples of the performance monitoring available. Typical results achieved are also discussed.

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1. Introduction

In common with designers in a number of widely differing areas, logic design engineers are making increasing use of computer-aided design systems to improve the accuracy of their design. Computer assistance in this field may be divided into three categories:

(i) logic generation

(ii) aids to manufacture

(iii) network simulation.

The research effort devoted to the automatic generation of logic[1,2] has resulted in the development of systems which impose severe restrictions on the designer. At present, these systems are useful when applied to small networks (for example, m.s.i. circuits), but are too limited for use in the practical design of large computers.

Automated manufacturing aids, however, solve many of the problems which arise during the detailed design and manufacture of large logic networks. This type of system[3] maintains files which the engineer updates with the details of the gates in his network and their logical interconnexions. From the files he can request logic diagrams, a breakdown of the number and types of gates used and listings showing, for instance, the physical arrangement of these gates. When the design phase is complete, wiring schedules are produced for use during manufacture. In more advanced systems, the information about the physical interconnexions between gates may be used to create masks from which multi-layer printed circuit boards are made. Although these systems ensure that the network manufactured is the same as that specified by the designer, there is no guarantee that the initial design is correct. Design errors, therefore, are not discovered until the commissioning stage when their detection is a time-consuming and costly process.

By the use of logic simulation, this difficulty is overcome and the time between the design of a computer and the manufacture of production models reduced. Tests to be applied to the network are specified by the designer who then obtains performance monitoring which allows the validity of the design to be checked prior to manufacture. Most design errors can be detected with a limited range of tests and, therefore, exhaustive testing of all input combinations is not necessary. In particular, data paths can be checked by simulation without using all input combinations. Thus, errors which may result in a considerable number of wiring changes, particularly in large parallel networks, are eliminated. Once the data paths are correct, the simulator can be used to validate the control circuits in the network until the performance of the design is satisfactory.

2 Logic Simulation

A logic simulator is a program which accepts a description of a logic network and exercises that network by applying to it a sequence of input patterns. To do this, a simulator requires three basic types of information: a list of the logic gates in the network and their interconnexions, details of the input patterns to be applied to the network and a precise description of the operation

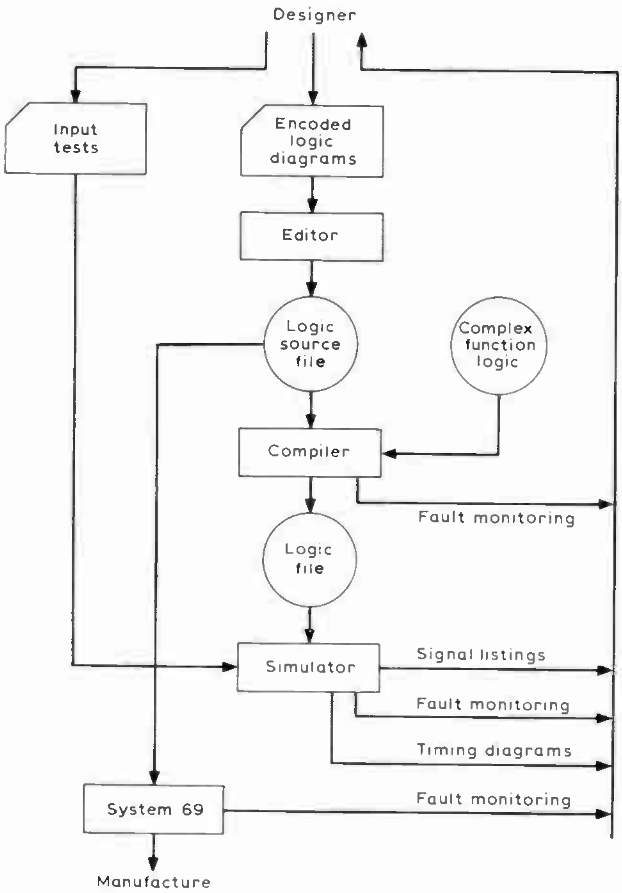


Fig. 1. Diagram of the complete system.

of each type of logic gate used. The exact form that this information takes depends on the type of network that the simulator is designed to handle.

If the network is synchronous, that is, it is controlled by external clock signals and contains no internal timing circuits, the input patterns consist of an initial setting of the data signals followed by a series of clock pulses. The simulator is required to propagate the signals through the logic levels using simple truth-table models to represent the operation of the different types of logic gate. Output is usually in the form of timing diagrams showing the state of signals at the end of each clock phase. In addition, fault monitoring may be provided to indicate, for instance, that the number of gate levels in a clock phase is too large.[4]

The operation of a logic simulator designed to test asynchronous networks is considerably more complex. In this case, the language used for the specification of input patterns must allow the sequencing of input data signals to be controlled both by external clock pulses and internal timing circuits. It is also necessary for the simulator to use more accurate gate models which can reflect the true operation of the gates by taking account of such details as pulse widths, set up times and gate propagation delays. Output from the simulator can take the form of timing diagrams, fault monitoring which identifies timing errors such as short pulses and detailed listings which show the changes of state of network signals as they occur. The logic simulator used by the designers of *MU5* is of this type.

3 The Simulation of *MU5*

The logic simulator used by the designers of the *MU5* research computer developed at the University of Manchester,[5] is written in SPG[6] for an ICL 1905E computer with 32k words of fast store, disk storage, line-printer and card and paper tape readers. The simple executive used leaves 25k words of store for the user program and its associated data space. *MU5* can be divided into a set of logically distinct units. Each unit, implemented by a group of design engineers, forms a network of about 2000 logic gates. After the networks have been validated by the simulator, information is passed (via a disk file) to System 69,[3] a design automation system developed by ICL. System 69 produces logic diagrams and initiates the physical manufacture of the hardware. Figure 1 gives an overall diagram of the complete system.

In order to use the simulator, the designer provides a specification of the network to be tested and a description of the input signals to be applied to it. The language used for the description of these signals allows the designer to initialize the network and then to exercise it in accordance with the requirements of its interface with other networks. Timing diagrams and detailed monitoring are produced as output from the simulator.

4 The Simulator

A time-ordered event list is the central feature of the simulator. Entries in this list indicate that, as a result of a change of state on the inputs to a gate, a new output state for that gate has been predicted. When an entry is removed from the top of the list, the predicted signal change 'occurs'. The simulator then examines the gates to which this signal is an input. This technique is particularly well suited to the efficient simulation of asynchronous networks, but may also be used for testing synchronous logic. The internal data structures used to represent a logic network reflect the direct logical connexion between a gate output and its fan-out. Signals within the network may assume one of two logical states, 0 and 1. Figure 2 shows a simple network and Table 1 sets out the essential features of the internal representation of part of that network.

If, at simulated time t, either of the inputs to G1 changes, an AND-gate routine will predict the new state of the output signal A. This prediction will then be entered in the time-ordered list with an associated time of t + propagation delay. When this prediction reaches the top of the list (that is, current time = t + propagation delay), a test is made to see if it involves a change

Table 1

Internal representation for G1.

Gate type	Output name	Input states	Fan-out	Fan-out details	
				INPUT 1	INPUT 0
AND	A		2	to G2	to G3

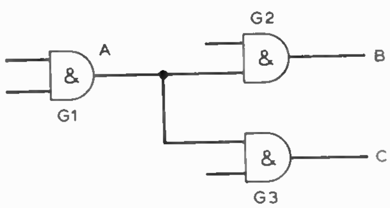


Fig. 2. A simple AND-gate network.

of state for A. If no state change will occur, the prediction is ignored; otherwise the states of the appropriate inputs to gates G2 and G3 are changed and further predictions made for signals B and C. Current simulated time is always set to the time associated with the entry at the top of the time-ordered list. Thus, if no signal changes are predicted for a long period, computer time is not wasted on the evaluation of signal states in the quiescent network.

The simulator uses 16 hand-coded routines which model the operation of the basic logic gates. These include AND-gates, OR-gates, AND–OR-gates, flip-flops and pulse generators. For each gate-type, the routines assume a suitable propagation delay. For example, the delay for a three-input AND-gate is 5 ns. The operation of the more complex functions (macros) is represented by suitable combinations of the basic gates. This representation is substituted in the network when a macro is encountered in the network description.

5 Network Description

The design engineer specifies his logic network by using a simple logic description language. As this specification is to be used both by the simulator and for the initiation of the manufacturing procedures (see Fig. 1), it must allow the user to specify a logic network completely. When defining a network the designer first draws logic diagrams on paper marked out in a special 26 × 26 grid. The network is then encoded and input to the logic source file via a simple editing system. Each logic gate is coded in the following format:

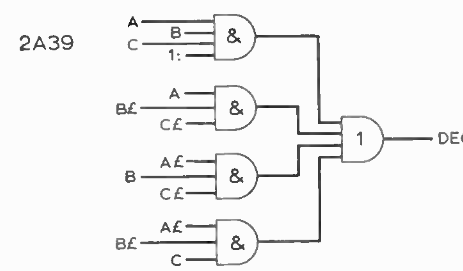
GRID REFERENCE
GATE TYPE PHYSICAL PLACEMENT
OUTPUT NAME(S)
INPUT NAME(S)
:
INPUT NAME(S)

The use of this language is illustrated in Fig. 3 which shows the encoding of the gates in Fig. 4.

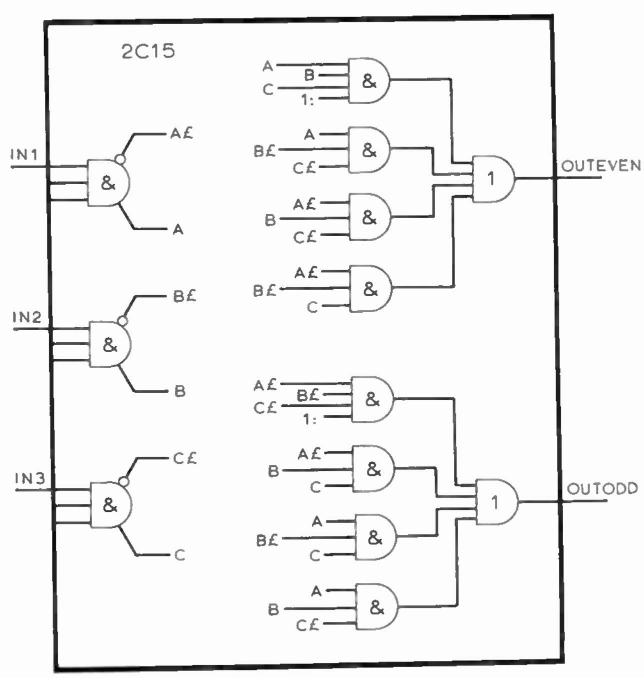
Some of the information supplied by this encoding is not required by the simulator (for example, the physical placement) but it must be provided for other programs in the system. The information essential for the simulator is the gate type, and the output and input names, which may be up to 7 characters long. The use of unique names for each gate output allows the logical connexions between different gates to be deduced. Any gate inputs which do not have names may be tied to logical 1 or logical 0 using 1: and 0: respectively. The symbol £ is used to indicate the inverse phase of a signal. The physical placement specifies the position of the gate on a large multi-layer printed circuit board. Each board, identified by a number, has 5 rows (A–E) and 40 columns.

(a) coding of a basic AND-OR gate	(b) coding of a parity generator macro
CD	RE
B7 2A39	U2 2C15
DECA	OUTEVEN OUTODD
A B C 1:	IN1 IN2 IN3
A B£ C£	
A£ B C£	
A£ B£ C	

Fig. 3. Examples of the network description language.



(a) Basic AND-OR gate (Type B7).



(b) Parity macro (Type U2).

Fig. 4. Typical logic gates.

Before the logic is tested by the simulator, the network specification is checked in order to ensure that the encoding is syntactically correct. This validation is done by a 'compiler' which produces the compiled logic files. It is at this stage that a circuit consisting of basic gates is substituted for the more complex macros. After the compiled logic files have been created or updated, the simulator extracts information about the gates and their interconnexions and forms its own internal representation of the network.

Simulation is then initiated and controlled by a program of 'driving instructions' supplied by the user.

6 Driving Instructions

The program of driving instructions simulates the interface between a network and the rest of the computer. It allows the user to set up input data signals and to control their timing both explicitly and implicitly. The implicit timing involves the examination of the states of signals in the network or on the interface.

6.1 *Assignment Instructions*

Assignment instructions are used to set input signals to a specified state. The basic form of the instruction is ⟨signal name⟩ = ⟨logical value⟩; for example, A = 0 or STROBEX = 1. An alternative form of this instruction is used for assigning states to wide data paths. The format is ⟨signal name⟩[⟨lower limit⟩ – ⟨upper limit⟩] = ⟨bit pattern⟩. An example of this is HWY[00–15] = 1100110011001100. The only rule associated with the use of assignment instructions is that the specified signal name must refer to a network input. This is not restrictive, as it would be incorrect to allow the user to override the state generated by the simulator for an internal network signal.

Normally, assignments are obeyed at the simulated time at which they are encountered. An exception to this is an assignment following an instruction of the form AFTER ⟨delay⟩. In this case, the new signal state is regarded as a state change prediction and will be entered in the time-ordered list with an associated time of current simulated time + delay. The state change occurs when the entry reaches the top of the list. Thus, the following instructions

```
SIGNAL = 1
AFTER 25 SIGNAL = 0
```

will produce a 25 ns pulse on the input SIGNAL. This mechanism is used to provide input clock signals.

6.2 *Timing Instructions*

The explicit timing of input patterns is controlled by an instruction, WAIT ⟨delay⟩. When this type of instruction is obeyed, the path of the driving instructions is suspended until the specified delay has elapsed. The sequence

```
A = 1
WAIT 15
B = 1
```

will ensure that there is a 15 ns separation between the setting of A and B.

When the timing of signals across the interface is dependent upon the states of signals within the network itself, the driving instruction path must be suspended for an undefined period until the specified network state is reached. This is done by the instruction WAIT UNTIL ⟨condition⟩ which is illustrated by the following example.

```
A = 1
WAIT UNTIL C AND D OR E
B = 1
```

Here, B will only be set to 1 after a specified network state occurs. In this case, the network state is defined by either C = 1 and D = 1 or by E = 1. If, for instance, E = 1 when the WAIT UNTIL is encountered, both A and B will be changed at the same time.

6.3 *Control Instructions*

The instructions in a driving instruction program are obeyed in sequence unless an explicit control transfer instruction is encountered. To alter the normal sequence, the user labels the instruction to be obeyed and specifies a jump instruction, –⟩⟨label⟩. For example,

```
1:  A = 1
    AFTER 10  A = 0
    WAIT 20
    –⟩ 1
```

This sequence produces a continuous series of 10 ns pulses on A. When simulating an asynchronous network, it is frequently the case that groups of networks inputs are notionally independent and operate in parallel with each other. To achieve this effect, a multi-way jump instruction is used. This instruction is defined as –⟩⟨label⟩, ⟨label⟩ . . ., ⟨label⟩. For instance,

```
    –⟩ 1, 2
1:  A = 1
    AFTER 20  A = 0
    .           .
                .
2:  B = 1
    AFTER 15  B = 0
                .
                .
```

When the multi-way jump is obeyed, control will be transferred to the instructions A = 1 and B = 1 at the same instance of simulated time. From then on the two parallel paths (labelled 1: and 2:) will operate quite independently. A STOP instruction is also provided; this allows a path in the driving instruction program to be terminated without necessarily terminating the simulation process.

6.4 *Conditional Instruction*

The conditional instruction allows the user to alter the action of the driving instruction program if some predefined network state exists when the instruction is obeyed. The format is IF ⟨condition⟩, ⟨instruction⟩. The following sequence illustrates its use:

```
1:  A = 1
    WAIT 10
    A = 0
    WAIT 10
    IF B, –⟩ 1
    C = 1
```

The effect of this sequence is to produce a 10 ns pulse on A. After a delay of 10 ns, the current state of signal B is tested. If B = 1, control is transferred to label 1: and a new pulse generated on A. If B = 0 when the conditional instruction is reached, the loop is broken and C set to 1.

7 Output from the Simulator

A number of different types of output are available. This output is produced at two quite distinct stages of the simulation process.

7.1 *General Network Information*

Before any instructions in the driving instruction program are obeyed, print-outs are produced listing the names of all network input and output signals. This enables a quick visual check of the network interface to be made. In addition, the user may request a listing showing the initial logical states assumed by the simulator for all signals in the network. This list of signal names is sorted into alphabetical order for ease of reference. The states shown are equivalent to a settled network after powering up. If a free-running oscillator exists in the network, the names of the affected signals are listed and the network is assumed to have settled down as much as possible.

7.2 *Network Performance Monitoring*

The second stage of output provides full monitoring of the performance and state of the network as it reacts to the driving of interface signals. Two different types of print-out are available.

The first, the State Print, allows the user to monitor the states of up to 300 selected signals. This monitoring is carried out at regular time intervals as specified by the user. It produces on the line-printer what is in effect a timing diagram for each of the selected signals. The main purpose of the State Print is to allow the designer to check the accuracy of his network as quickly and easily as possible. It has, however, also proved to be a valuable reference guide during the commissioning of the hardware. The State Print is illustrated in Fig. 5.

The second type of output provides a complete record of every state change that occurs during the simulation and the time at which that change occurred. In addition, any fault conditions detected by the simulator are monitored on this print-out. These errors, which include attempting to set and reset a flip-flop simultaneously (CLASH OF INPUTS) or to propagate unacceptably narrow pulses (DRIVE TOO SHORT), can therefore be pinpointed without difficulty. The main purpose of this very detailed information is to allow the designer to trace the logical or timing errors which may have arisen during the simulation. An example of this print-out is given in Fig. 6.

8 Conclusions

The effectiveness of any system is directly related to the way in which it is used. The simulator described in this paper is intended as a means of checking the accuracy of the design of a network, not as an aid to the design process. The successful use of simulation by the designers of *MU5* indicates that it played a significant part in minimizing the number of faults remaining at the commissioning stage.

Although the checking of data paths is the simplest task required of the logic designer, any errors that remain after the hardware is built invariably result in a large number of modifications. In *MU5* about 80% of the 100,000 network interconnexion wires carry data path signals. As a result of simulation, no errors have been found during the comissioning of the data paths within individual networks.

The validation of control networks poses a more complicated problem for the designer. In this area, too, simulation has proved valuable. For example, a 500-gate network which contains part of the control for the operand buffer store was found to contain 25 logical errors during simulation. When the hardware was commissioned, a further 6 errors were detected in an area which the designer did not simulate. During simulation of a 2200-gate fixed point arithmetic/logical unit 46 logical errors were found. If the discovery of these faults (which include data path errors) had been left until the commissioning stage, over 500 wiring changes would have been necessary.[7] When the network was built one further fault was found and the commissioning phase completed in a week.

Most of the difficulties which arose during commissioning centred around the network interface. A simulator check on the correct operation of the interface signals would be very useful here. This was not possible because of the limitation on the size of network handled by the *MU5* simulator. The restriction to a maximum of 2500 logic gates is imposed by the store size of the ICL 1905E and is not inherent in the system. In order to improve the communication between different groups of designers, automatically produced documentation would also be helpful.

As a result of experience gained from the use of this simulator, a new simulator is now being developed as part of a fully-integrated design system. This system will run on *MU5* and has as its central feature a general data base capable of supplying information to a wide variety of application programs. The applications currently under development include automatic, interactive placement and routing suites, fan-out and load checks, a wiring scheduler and a graphics package for use with the c.r.t. facilities being incorporated into the *MU5* system.

A number of changes to the logic simulator itself are also proposed. The instruction set of the driving instruction language is being enhanced to provide mechanisms for easier loop control, the specification of common input sequences and more comprehensive monitoring. In addition, because m.s.i. functions are now readily available in most logic families, a new internal network structure will be used. This will allow complicated multi-output devices to be simulated as efficiently as simple gates. Finally, instead of using fixed hand-coded routines, the designer will be able to describe the operation of logic gates and complex functions in a specially developed high-level language. In this way the features of a network considered important by the designer can be included in the formulation of the simulator routines. It is expected that these developments will

	PA	PB	PCVAL	RIMA	RIMB	RPAX	RPBX	RPBL	COUNTA	COUNTB	GPAX	&1215FF	XSY	COUNTA	COUNTB	&1215FM	&1215IG	RSYB	RCNTA	RCNTB
1530	.		1	1	1	1		.	1	.	1	1	.	1	.	.	.	.	1	.
1532	.		1	1	1	1		.	1	.	1	1	.	1	.	.	.	.	1	.
1534	.		1	1	1	1		.	1	.	1	.	.	1	.	.	1	.	1	.
1536	.		1	1	1	1		.	1	.	1	.	.	1	.	.	1	.	1	.
1538	.		1	1	1	1		.	1	.	1	.	.	1	.	.	1	.	1	.
1540	1		1	1	1	1		.	1	.	1	.	.	1	.	.	1	.	1	.
1542	1		1	1	1	.		.	1	.	1	.	.	1	.	.	1	.	1	.
1544	1		1	1	1	.		.	1	.	1	.	.	1	.	.	1	.	1	.
1546	1		1	1	1	.		.	.	.	.	.	.	.	.	.	1	.	.	.
1548	1		1	1	1	.		.	.	.	.	.	.	.	.	.	1	.	.	.
1550	1		1	1	1	.		.	.	.	.	.	.	.	.	.	1	.	.	.
1552	1		1	1	1	.		.	.	.	.	.	.	.	.	.	1	.	.	.
1554	1	1	1	1	1	.		.	.	.	.	.	.	.	.	.	1	.	.	.
1556	.	1	1	1	1	.		.	.	.	.	.	.	.	.	.	1	.	.	.
1558	.	1	1	1	1	.		.	.	.	.	.	1	.	.	.	1	.	.	.
1560	.	1	1	1	1	1		.	.	.	.	.	1	.	.	.	1	.	.	.
1562	.	1	1	1	1	1		.	.	.	.	.	1	.	.	.	1	.	1	.
1564	.	1	1	1	1	1		.	1	.	1	.	1	1	.	.	.	.	1	.
1566	.	1	1	1	1	1		.	1	.	1	.	1	1	.	.	.	.	1	.
1568	.	1	1	1	1	1		.	1	.	1	.	.	1	.	.	.	.	1	.
1570	.	1	1	1	1	1		.	1	.	1	1	.	1	.	.	.	.	1	.
1572	.	1	1	1	1	1		.	1	.	1	1	.	1	.	.	.	.	1	.
1574		1	1	1	1	1		1	1		1			1			1		1	

Fig. 5. State print.

```
1540  PA        0 1
1541  RPAX      1 0
1544  &1215MH   0 1    RCNTA    1 0
1545  &1208ED   0 1
1546  GPAX      1 0    COUNTA   1 0    &1215CG   1 0
1548  &1215IJ   0 1
1551  &1215CF   0 1
1554  PB        0 1    &1208ID  0 1
                RPAX            CLASH OF INPUTS
1555  PA        1 0
1556  &1208LC   1 0
1557  XSY       0 1
                RCNTA           CLASH OF INPUTS
1559  &1215MF   1 0    &1208FH  0 1    RPAX      0 1
1560  &1208FD   1 0
1562  RCNTA     0 1
1564  GPAX      0 1    COUNTA   0 1    &1215IG   1 0    &1215CG   0 1
1565  &1208ID   1 0
1566  &1215IJ   1 0
1568  XSY       1 0    &1208IH  0 1
1569  &1215CF   1 0    &1215FF  0 1
1573  RPBL      0 1    RPBX     0 1
1574  &1208LC   0 1    &1215MH  1 0    &1215FF   1 0    &1215IG   0 1
1577  &1215MF   0 1
1578  COUNTA    1 0    COUNTB   0 1
1579  &1208IH   1 0
                &1215IG         DRIVE TOO SHORT
                RSYB            DRIVE TOO SHORT
```

Fig. 6. Detailed monitor listing.

greatly improve the flexibility and power of the simulation system.

9 Acknowledgments

Support for the *MU5* project was provided by the SRC and ICL. The work described here benefited from discussions with members of the *MU5* team led by Professor T. Kilburn, in particular Professor D. B. G. Edwards and Dr. D. J. Kinniment.

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MEETING REPORT

X-Ray Image Intensifier Systems

W. G. GORE, C.Eng., M.I.E.R.E.*

A COLLOQUIUM organized jointly by the Medical and Biological Electronics Group Committees of the IERE and the Institution of Electrical Engineers, with the association of the British Institute of Radiology, the Hospital Physicists Association, and the Biological Engineering Society, entitled 'X-ray Image Intensifier Systems' was held at University College London, on 14th June 1973. Over 190 were present to hear nine papers.

The morning session, chaired by Professor R. E. Steiner (President of the British Institute of Radiology), was opened with introductory papers on the medical aspects by Dr. F. R. Airth (Southmead Hospital) and the technical aspects by Dr. G. A. Hay (University of Leeds). Dr. Airth gave a brief history of intensifier systems since their introduction 20 years ago, showing the growth in size of the intensifier tube and the improved ergonomic design of the systems over the years. He then suggested the following basic requirements:

(1) Adequate brightness gain.
(2) Low quantum noise.
(3) Good definition and contrast over the whole area.
(4) Optimum size of 25 cm diameter.
(5) Long useful life of intensifier.
(6) Better presentation of results.
(7) Maximum reduction in X-ray dose.
(8) Minimum number of voids in the viewing area.
(9) Insensitivity to equipment position.

Dr. Hay described the construction and operation of modern image intensifier systems and the various means of observing and recording the results. The following limitations of a system were discussed:

(1) Geometric distortion.
(2) Non-linearity in the intensity transfer characteristic from the X-ray input to the recorded output.
(3) Unsharpness of the image which can be described by the modulation transfer function.
(4) Lag on a moving image which can be described by the temporal modulation transfer function.
(5) Noise and its effects in perception of detail.

Experience with X-ray Intensifier Systems in Hospitals

The morning session continued with four papers which considered the routine testing of complete intensifier systems, either to confirm that they met the manufacturer's specification or to determine if they had deteriorated in use.

Dr. G. M. Ardran (Nuffield Institute for Medical Research) discussed the need to know the radiation quality when making measurements or comparisons on intensifier systems. Because the intensifier is not usually energy independent, radiation dose rate measurements alone are insufficient and experience has shown that the indicated voltage on the generator is not reliable. The use of the penetrameter cassette,† which can measure the effective voltage to 1 kV and the effective filtration to 0·1 mm of aluminium was discussed. This can be used to indicate degradation of the high voltage generator or X-ray tube.

The practical difficulties of routine testing were discussed by Dr. M. D. Davison (Western Regional Hospital Board, Glasgow) who pointed out that a measurement of the dose used for a particular examination is not a good indication of the efficiency of the system because of the wide variation found in normal practice. A thick phantom was described which gave an indication of resolution, linearity, noise and scatter. Because testing of the many factors influencing picture quality is time consuming, a photographic record of the image of this phantom is used as the primary check on the complete system. More detailed tests of the separate factors were discussed and the need for improved test instruments such as dose rate meters and photometers, to measure the light output from the intensifier, was stressed. Prototype models of these instruments were described.

Dr. Hay showed a number of thin test objects that he used. To check the overall usefulness of a system detail detectability was measured with a dot pattern. To investigate changes in the system performance it is preferable to measure separate parameters. Thus to measure unsharpness, for example, a repetitive resolution chart is used as the eye is more sensitive to repetitive than single patterns.

Mr. P. Jilbert (Atomic Weapons Research Establishment, Aldermaston) described a range of instruments that had been developed for the Department of Health and Social Security, to enable checks on the efficiency of the individual parts of the system to be made by non-technical staff. They were an X-ray exposure rate meter with a flat energy response from 60 kV to 140 kV; a photometer based on a blue sensitive photo-voltaic silicon cell that could measure the light output from the intensifier tube with a given level of X-ray input; and a video waveform analyser that could be used to measure the amplitudes of the various parts of the video waveform and to check the circular blanking in the television camera and the setting of the brightness control on the monitor.

Design Aspects of X-ray Intensifier Systems

The afternoon session, chaired by Professor F. T. Farmer (Regional Medical Physics Department, Newcastle General Hospital) consisted of three papers describing recent advances in image intensifiers and laboratory testing. Professor F. Gudden (Siemens Ltd.) described the development of a high resolution intensifier. This started with a search for a converter to match the energy spectra of the X-ray source. An evaporated CsI screen was found suitable and had the added advantages that the light output was a good spectral match for the S11 photocathode, and the crystal structure reduced

*Atomic Weapons Research Establishment, Aldermaston, Reading, RG7 4PR.

†Ardran, G. M. and Crooks, H. E., 'Checking diagnostic X-ray beam quality', *Brit. J. Radiol.*, **41**, pp. 193–8, 1968;

—— 'Some technical problems with diagnostic radiology at 20 to 40 kVp', *Brit. J. Radiol.*, **44**, pp. 625–30, 1971;

—— 'Measurement of inherent filtration in diagnostic X-ray tubes and the effect of target angle on X-ray quality', *Brit. J. Radiol.*, **45**, pp. 599–602, 1972.

the sideways diffusion of the light so maintaining a good resolution. The cathode shape was chosen, after computer design, to give a substantially flat image plane so that pin cushion distortion and vignetting were reduced. With these intensifiers a dose of 100 μR at the tube was recommended to overcome quantum noise, but the high resolution and picture quality obtained with doses as low as 30 μR were illustrated. Thus a dose from 3 to 10 times less than with standard screen film combinations could be used.

Another design of intensifier with a CsI screen, developed by NV Philips, was described by Dr. W. Kuhl, in which, to reduce the halation at the output of the intensifier, absorbing glass or fibre optics are used for the output screen. The need to reduce the number of stages in the system and to improve the remainder was stressed, and results obtained with a 2 in system which had the output screen directly coupled by fibre optics to the television camera input phosphor were shown. This enabled 30 μm vessels to be observed. High resolution intensifiers systems have their resolution limited by the television chain, therefore a larger number of line pairs per millimetre can be obtained with smaller tubes. To maintain the full resolution the system bandwidth would need to be 15 MHz for a 6 in diameter tube and 30 MHz for one of 9 in diameter.

Mr. F. Timmer (NV Philips) described a method of determining the modulation transfer function (m.t.f.) and the phase transfer function (p.t.f.) of a complete intensifier system except for the television monitor. The test object used is a thin gold or tungsten wire mounted perpendicular to the television line scan direction. The line spread function due to this object is obtained from the video signal of a television line. To improve the signal/noise ratio the signals from a number of lines are averaged in a signal averager after being transformed to a lower frequency band by a sampling oscilloscope. The line spread function is transferred to a computer where the m.t.f. and p.t.f. are obtained by a fast Fourier transform. Results for the test system alone and for a typical image intensifier system were presented.

The colloquium closed with a panel discussion chaired by Professor J. F. Fowler (Mount Vernon Hospital). Dr. G. R. Burfield (Royal Berkshire Hospital) remarked that no tests for time lag had been considered by the speakers. The consensus of opinion was that image intensifiers would not contribute significantly to this and that the most likely cause of excessive lag would be the television camera tube. For dynamic measurements a plumbicon should be used rather than a vidicon. Dr. T. J. Tulley (Hull Royal Infirmary) asked if any use might be found for a short pulse of X-rays followed by image storage techniques. The panel agreed that as intensifiers are quantum noise limited the total dose might not be reduced, but that some use might be found for such a technique for long-term observation of patients and where rates of change are slow.

The panel agreed that with CsI intensifiers the results obtained on 70 or 100 mm film are as good as on full-size film, and that such systems could become much more popular. Dr. Airth stressed the saving that would ensue on the cost of film and volume of storage space needed to keep results. It was generally agreed that emphasis was needed on test methods to determine deterioration in intensifier systems, and that every effort must be made to reduce the radiation dose to the patient.

European Stereophonic Music Links

An international stereophonic sound link was provided by the Post Office for the BBC to bring a live two-hour performance of music from Vienna recently. The occasion was the BBC Symphony Orchestra's live opening performance at the Vienna Festival. Special equipment was installed in Vienna and at Faraday international telephone exchange in London—with the broadcast coming in over international telephone circuits. The transmission was routed through Paris to Fiennes near Lille and beamed across the Channel on a 30-mile microwave radio link to the Post Office's radio station at Tolsford Hill, near Dover. From there the transmission was routed to the Post Office's international sound programme centre at Faraday exchange—which handles all international radio broadcasts—and passed to the BBC.

The dedicated UK and Continental networks for carrying monophonic sound of the quality required for radio programmes provide channels at 10 kHz bandwidth. Although adequate for normal mono transmissions, this is not wide enough for the higher-quality transmissions in stereo. A further essential requirement for stereo transmission is that phase stability must be maintained between the two programme channels and this cannot be readily guaranteed in the present network.

For the stereo transmission from Vienna the Post Office isolated a group of 12 ordinary telephone channels of 4 kHz each, giving a total bandwidth of 48 kHz. The equipment used for the input of the two stereo signals accepts them and modulates each into a single sideband form. One channel utilizes an upper sideband based on a carrier of 86 kHz, the other a lower sideband based on a carrier of 82 kHz. The total signal occupies a band of 65·2–102·8 kHz, which is within the normal telephony carrier group of 60–108 kHz. A 16·8 kHz audio pilot signal is used to ensure that proper phase stability between the two signals is maintained. At Faraday exchange in London similar equipment was used to restore the stereo signals.

Broadcasting in stereo is being used increasingly in Britain and other countries with the spread of stereo radio receivers. Although this is not the first international stereo broadcast by the BBC, it is the first made over international Post Office links. At the moment, the Post Office has no plans to provide permanent international routes capable of carrying stereophonic sound but this broadcast showed that it can be done.

The Post Office handles nearly 1500 international monophonic sound broadcasts a month between the UK and other countries. In Britain and on the Continent these travel over a special network which carries only the sound transmissions for radio programmes.

IERE News and Commentary

Dinner of Council and Committees

Members are reminded that the Dinner of Council and its Committees will take place at the Savoy Hotel, London, on Wednesday, 21st November 1973. Further details, including application forms for tickets, will be sent out with the September issue of the Journal.

Formation of New Zealand Division

Following a visit to New Zealand by the Director of the Institution in 1966, a New Zealand Advisory Council was formed. Despite the comparatively small number of IERE members in that country, the Advisory Council has been very active and has made a considerable impact on electronic engineering in New Zealand. It was a prime mover in the formation of the National Electronics Development Association (NZ) which is modelled on the UK National Electronics Council. It was also instrumental in sponsoring the NELCON series of exhibitions and conferences which are now a biennial feature of the New Zealand Electronics Industry. At the same time it has formed strong links with the New Zealand Engineering Institutions.

The Institution's Council has now agreed to the request from the Advisory Council to enable it to advance further by bringing its organization into line with that of other IERE Divisions and Sections. Accordingly, a Division of the Institution has been formed in New Zealand under the Interim Chairmanship of Professor Leslie Kay, Ph.D. (Fellow), Head of the Department of Electrical Engineering at the University of Canterbury, Christchurch. Professor Kay has taken an active part in the Institution's affairs in New Zealand ever since he took up his appointment in 1966.

Other members of the Committee are as follows:

T. J. Seed, Ph.D. (Member); G. C. Mowat (Member); J. C. Conyers-Brown (Member); J. J. Tait, M.Sc. (Member), Honorary Treasurer; A. H. Barth (Member), Honorary Secretary.

The Divisional Council is sending a newsletter to all members informing them of the formation of the New Zealand Division and asking them for nominations for two further members to be elected at the Annual General Meeting to be held in August, when the membership of the Council will be confirmed.

The Administrative Secretary of the Division will continue to be Mrs. E. M. Keating and the office of the Division is c/o The Department of Electrical Engineering, University of Canterbury, Private Bag, Christchurch 1, New Zealand.

East Midland Section Members and the Schools

Members in many parts of the country help to bring to the notice of school leavers the opportunities which are offered in electronics. There is now a call for further assistance in this work in the East Midlands and graduate members are required to speak about their training and experience to upper schools and colleges at careers meetings in the Leicestershire area. Members who would like to participate in this important function should write to, or telephone, the Honorary Secretary, Mr. E. R. Hack, 7 Frampton Avenue, Leicester LE3 0SG. (Telephone (Home): Leicester 858714.)

Guidance for Authors

A new edition of the Institution's booklet 'Guidance for Authors' has just been published and intending authors of papers are invited to write to the Editor for copies. The booklet identifies the various types of papers, including short contributions, and gives brief hints on points which the author should bear in mind in preparing a paper. Requirements and advice in connection with the preparation of the manuscript and illustrations are also given and a bibliography of publications which will be found helpful by authors is included.

Institution Christmas Cards

Special Institution Christmas cards will again be available this year. Details including order forms will be contained in the September issue of the Journal. The proceeds from the sale of these cards goes to the Institution's Benevolent Fund which for last year received nearly £100 and all members are asked to give this venture their fullest support.

Two Further DTI Requirements Boards

The newly created Metrology and Standards Requirements Board has held its first meeting in London under the Chairmanship of Mr. Ewen McEwen, F.R.S.E., Vice-Chairman (Engineering), Joseph Lucas Ltd. The setting up of this Board was referred to by Mr. Michael Heseltine, Minister for Aerospace and Shipping, when he announced details of five other Requirements Boards. (See Journal for March 1973, p. 232.) Subsequently, it has been decided to set up an additional Board, the Fundamental Standards Requirements Board.

Membership of the Metrology and Standards Requirements Board is made up of independent members from industry, commerce and the universities, and official members from interested Government Departments.

The Requirements Boards have been set up to implement the customer/contractor principle in DTI-funded research and development. The purpose of the Metrology and Standards Requirements Board will be to determine, subject to the agreement of the Minister for Aerospace and Shipping, the objective and balance of the Department's intra-mural and, where appropriate, extra-mural R and D programmes, in the fields of metrology and industrial reference standards relating to mechanical, electrical, optical and radiation science, flow measurement, and reference materials.

The new Fundamental Standards Requirements Board will be chaired by Dr. Ieuan Maddock, C.B., O.B.E., F.R.S., Chief Scientist of the DTI (President-elect of the IERE). Membership will include representatives nominated by the Royal Society, the Advisory Board on Research Councils, the Science Research Council, and the Council of Engineering Institutions. The Director of the National Physical Laboratory will also be a member.

Winston Churchill Travelling Fellowships

The Winston Churchill Memorial Trust, established as a result of the National Appeal in 1965, is a unique form of memorial. It enables men and women who might never otherwise have the chance, to travel abroad, to widen their knowledge not only in their own field of activity, but also of other peoples' lives and work in different parts of the world, and as a result of the experience they gain, to contribute more effectively to their profession, community and country.

Each year a number of subjects in which Awards are to be offered for the year are chosen in turn from a much longer list. For 1973, for instance, several Fellowships were granted to men and women wishing to study various aspects of telecommunications in Europe, Canada, the USA and Japan. Among the 13 subjects for 1974 are five which could well be of interest to members of this Institution. These include:

Design of aids and facilities for the handicapped.

Health and safety in the ports.

Coastal rescue and patrol.

Intensive care in hospitals.

Control of noise and litter.

The distinctive features of these awards are that there are no age limits, and academic or professional qualifications are not needed. Candidates, however, must be citizens of the United Kingdom and must be able to convince the selectors of the worth of their project and that they have the ability and initiative to make full use of the Fellowship both while they are abroad and when they come back.

The Grants cover all Fellowship expenses, the average length of which is three months. Interviews will be held in London in January 1974 and successful candidates will be expected to start their travels during that year.

To apply, send your name and address only on a postcard *in September* to the Winston Churchill Memorial Trust, 10 Queen Street, Mayfair, London W1X 7PD. You will receive an explanatory leaflet and a form to complete which must be returned before 5th November 1973.

The I.M.C. Thomson Lecture 1973

Dr. B. J. Mason, C.B., F.R.S., Director-General of the Meteorological Office, will deliver the above Lecture at the Royal Institution of Great Britain, 21 Albemarle Street, London W.1, at 6.0 p.m. on Tuesday, 2nd October 1973. His subject will be 'The Contribution of Satellites to the Exploration of the Global Atmosphere and to the Improvement of Weather Forecasting'.

Admission will be by ticket only, available from The Institute of Measurement and Control, 20 Peel Street, London W8. (Telephone: 01-727 3755/9156).

Assistance for Travel to International Standards Meetings

For many years heavy costs have been incurred by industrial companies and professional bodies in manning the delegations which represent the United Kingdom on the several bodies concerned with international standards work. Recognizing the importance of lowering technological trade barriers by way of international harmonization of standards, the British Overseas Trade Board has agreed that a contribution towards the costs would be justified. The Board's contribution caters for the travelling costs of leaders of British delegations to meetings of committees and working groups of the main international standards organizations; and when the Chairman of any such group or committee is British his costs will be similarly met. This assistance will be administered by the British Standards Institution, as the United Kingdom member of the organizations in question, e.g. IEC and ISO, and the scheme was brought into operation from the beginning of August 1973.

The Institution has raised this matter on numerous occasions with both BSI and Government Departments as it was considered unsatisfactory that engineers who were acting as representatives of the United Kingdom should be dependent on essentially non-public funds to meet the high costs of air fares and accommodation—meetings have not infrequently been as far away as the USA or even Japan. This long overdue easement in official policy is therefore warmly welcomed.

Obituary

The Council has learned with regret of the deaths of the folllowing members.

Colin Clark Richardson, B.Sc.(Eng.), F.I.E.E. (Fellow 1966, Member 1959) died suddenly on 28th June at the age of forty-seven whilst visiting The College, Swindon, where he was an external assessor. He leaves a widow.

Born in Glasgow, he was educated at Worthing High School and from 1943 to 1947 was a Laboratory Assistant at the Admiralty Signal Establishment, Witley. He took an honours degree at Brighton Technical College in 1950 and was then employed as a Development Engineer with Muirhead & Co., Beckenham, working on picture telegraphy apparatus. Mr. Richardson also organized courses for junior staff and took a part in the teaching.

In 1953 he was appointed an Assistant Lecturer in the Engineering Department at Reading College of Technology, being promoted to Lecturer in 1955, and Senior Lecturer in 1957. He was made Head of the Department of Electrical and Electronic Engineering on its formation in 1960, the appointment he held at the time of his death.

Colin Richardson will be remembered for his great contribution over many years to the work of the Institution's Examinations Committee and the Thames Valley Section Committee, on both of which he had served as Chairman. He was the Institution representative on the CEI Exemptions Sub-Committee, had represented the IERE on the Joint Committee for H.N.D. and H.N.C. Awards in Electrical and Electronic Engineering, served as an assessor and examiner for the Institution's own Graduateship examination, and was an expert on Indian qualifications.

He was also a member of the Southern Regional Council for Further Education and had recently been in close co-operation with the Post Office in the development of their training programme in the Reading area.

His Principal has written that 'Colin Richardson was respected by all for his mastery of his chosen field of work, was known regionally and nationally as a fair-minded examiner and administrator and will be sorely missed by his colleagues'. Those who were associated with him in his Institution activities will surely echo this tribute.

Geoffrey Victor Ager (Graduate 1968) died on 27th June, aged 29 years. He leaves a widow.

After attending Kilburn Grammar School, Mr. Ager undertook further studies at the Willesden and Hendon Colleges of Technology, completing these in 1968. From 1960 to 1966 he was at the Post Office Research Station, Dollis Hill, as a Youth-in-Training and Technical Officer, and from there he went to the Independent Television Authority as a Technical Assistant, subsequently being promoted to Junior Engineer in the Video and Colour Section. In September 1969 he joined Plessey Radar as a Senior Engineer at Addlestone where he worked on the development of radar display equipment. Early in 1971 he joined Semiconductor Specialists Limited where, after a period in regional sales management, he was appointed their UK Manager in August of last year, the position he held at the time of his death.

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

Notice of Annual General Meeting

NOTICE IS HEREBY GIVEN that the TWELFTH ANNUAL GENERAL MEETING of the Institution since Incorporation by Royal Charter will be held on THURSDAY, 25th OCTOBER, 1973, at 6 p.m. at the London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C.1.

AGENDA

1. To receive the Minutes of the Eleventh Annual General Meeting of the Institution since Incorporation by Royal Charter held on 7th December 1972 (Reported on pages 160–163 of the January/February 1973 issue of *The Radio and Electronic Engineer.*)
2. To receive the Annual Report of the Council for the year ended 31st March 1973. (To be published in the September 1973 issue of *The Radio and Electronic Engineer.*)
3. To receive the Auditor's Report, Accounts and Balance Sheet for the year ended 31st March 1973. (To be published in the September 1973 issue of *The Radio and Electronic Engineer.*)
4. To confirm the election of the Council for 1973–4.

In accordance with Bye-law 49 the Council's nominations were sent to Corporate members by a Notice dated 26th June 1973 included with the June 1973 issue of *The Radio and Electronic Engineer.* As no other nominations have been received under Bye-law 50, a ballot will not be necessary and the following will be elected:—

The President

For Election: I. Maddock, C.B., O.B.E., D.SC., F.R.S.

The Vice-Presidents

Under Bye-law 46, all Vice-Presidents retire each year but may be re-elected provided they do not thereby serve for more than three years in succession.

The following must retire: J. Bilbrough; Prof. W. A. Gambling, PH.D., D.SC.; Gp. Capt. C. K. Street, M.B.E.

For Re-Election: Air Cdre. S. M. Davidson, C.B.E.; Prof. W. Gosling, B.SC.; A. St. Johnston, B.SC.

For Election: P. A. Allaway, C.B.E., D.TECH.; Prof. G. B. B. Chaplin, M.SC., PH.D.

The Honorary Treasurer

G. A. Taylor (Fellow) is retiring after 20 years service in this Office.
The Council recommends the election of S. R. Wilkins (Fellow).

Ordinary Members of Council

Under Bye-law 48, Ordinary Members of Council are elected for three years and may not hold that office for more than three years in succession.

FELLOWS

The following must retire: H. Arthur, PH.D.; Prof. G. B. B. Chaplin, M.SC., PH.D.; Maj. Gen. P. H. Girling, O.B.E.; R. T. Lakin, M.B.E.; R. Larry; D. Simpson.

For election: R. C. Hills, B.SC.; H.R.H. The Duke of Kent, G.C.M.G., G.C.V.O.; P. L. Mothersole; K. G. Nichols, B.SC., M.SC.; J. Powell, M.SC.

MEMBERS

The following must retire: W. J. Fry.

For Election: H. Blackburn; Prof. D. W. Lewin, M.SC.; M. M. Zepler, M.A.

ASSOCIATE

For Election: G. Phillips

ASSOCIATE MEMBER

For Election: C. R. Fox

The remaining members of Council will continue to serve in accordance with the period of office laid down in Bye-law 48.

5. To appoint Auditors and to determine their remuneration. (Council recommends the re-appointment of Gladstone, Jenkins & Co., 42 Bedford Avenue, London, W.C.1.)
6. To appoint Solicitors. (Council recommends the re-appointment of Braund and Hill, 6 Gray's Inn Square, London, W.C.1.)
7. Awards to Premium and Prize Winners.
8. Any other business. (*Notice of any other business must have reached the Secretary not less than forty-two days prior to the meeting.*)

By Order of the Council.
GRAHAM D. CLIFFORD, *Secretary.*

3rd August 1973

NOMINATIONS FOR ELECTION TO COUNCIL

Brief Biographical Notes

In accordance with Bye-Law 43 the Council's nominations for election to the 1973–74 Council were circulated with the June issue of the Institution's *Journal*.

FOR ELECTION AS PRESIDENT OF THE INSTITUTION

Ieuan Maddock, C.B., O.B.E., D.Sc., F.R.S. (Fellow 1955, Member 1943) was appointed Chief Scientist in the Department of Trade and Industry in 1971. Before moving to the then Ministry of Technology in 1965, where he was latterly Controller, Industrial Technology, Dr. Maddock had been associated with the British nuclear weapons project since its inception.

Born in 1917 he was educated at Gowerton County Intermediate School (Glamorgan) and University College of Wales, Swansea, where he graduated with first class honours in physics in 1938. During the war he was engaged on research work in the explosives field, and in 1947 he joined Lord Penney (then Dr. Penney) in the team which was set up to produce the British atomic bomb. He was Assistant Director at the first British nuclear weapon test at the Montebello Islands in Australia in 1952 and subsequently supervised several of the nuclear tests carried out in Australia, the Pacific and the test site at Nevada in the USA. He was appointed an O.B.E. in 1953 and a C.B. in 1968.

Dr. Maddock moved to Aldermaston in 1955 and subsequently became Head of Field Trials at AWRE. Later he became Chief of Applied Physics and Assistant Director of AWRE. In 1959 he started work on the detection of nuclear explosions fired in space and underground and was a British delegate to the Geneva Conference with Russia and the USA on the abolition of nuclear tests. He directed this work up until 1965, when he was loaned to the Ministry of Technology by the UK Atomic Energy Authority to act as Deputy Controller in charge of the newly-created Industry Divisions. He was appointed Controller in February 1967.

Dr. Maddock was elected to Fellowship of the Royal Society in 1967, and in 1970 he received an Honorary Doctorate of Science of the University of Wales. He has served on many scientific and technical committees and among his most recent appointments was that of Chairman of the Fundamental Standards Requirements Board (See p. 506).

For several years Dr. Maddock served on the Programme and Papers Committee and he was later chairman of the Organizing Committee for the 1961 Convention on Radio Techniques and Space Research. He was elected a member of Council in 1960 and has served terms of office as a Vice-President from 1963–1966 and from 1969–1972. He is the author of numerous papers and articles on a wide variety of scientific and technological matters and these include two which have been published by the Institution.

FOR RE-ELECTION AS VICE-PRESIDENTS

Air Commodore Sinclair Melville Davidson, C.B.E., R.A.F. (Fellow 1971, Member 1951) has held the appointments of Station Commander R.A.F. St. Athan and Air Officer, Wales, since January 1972. He has had a varied and distinguished career in the Royal Air Force, which he joined in 1939, and prior to taking up his present post he was Director of Signals (Air) at the Ministry of Defence. Air Cdre. Davidson who is a member of the Management Techniques Group Committee, was appointed a member of the Council in 1971, and elected a Vice-President in 1972.

Professor William Gosling, B.Sc. (Fellow 1968) will shortly take up the newly founded Chair of Electronic Engineering at Bath University of Technology. Professor Gosling went to the University College of Swansea in 1958 and in 1960 he was appointed to its Chair of Electrical Engineering. He is Chairman of the Professional Activities Committee and served as Chairman of the organizing committee for the 1972 Conference on Radio Receiver Systems. He was elected a member of Council in 1970 and a Vice-President in 1972.

Andrew St. Johnston, B.Sc. (Fellow 1960) is a director of Vaughan Programming Services. He has been concerned with the development and applications of electronic digital computers since 1949 when he joined Elliott Brothers (London) Ltd. He subsequently held the appointment of Joint Managing Director of Elliott Automation Computers Ltd. Between 1960 and 1965 Mr. St. Johnston was a member of the Computer Group Committee. He was a member of the Council in 1963–1965 and has served as Vice-President from 1967–1970 and since 1972. Since 1971 he has been a member of the Professional Activities Committee.

(For fuller biographies of these Vice-Presidents see the *Journal* for September 1972).

S. R. Wilkins

G. B. B. Chaplin

R. C. Hills

H.R.H. The Duke of Kent

FOR ELECTION AS VICE-PRESIDENTS

Percy Albert Allaway, C.B.E., D.Tech. (Fellow 1971) is Chairman of EMI Electronics Ltd. and is Chairman or a member of the board of numerous associated and subsidiary companies. He first joined the group in 1930 and returned to it in 1939 to work on military radar systems following some five years in other parts of the radio industry. He is a member of numerous industrial and government committees including the National Electronics Council on which he represents the Conference of the Electronics Industry. He has been closely associated with Brunel University since its formation and the University conferred its Honorary Degree of Doctor of Technology on him on July 14th. A fuller note on his career appeared in the *Journal* for September 1972 on the occasion of his election to Council.

Professor George Brian Barrie Chaplin, M.Sc., Ph.D. (Fellow 1967) is Professor and Chairman of the Department of Electrical Science at the University of Essex, to which he was appointed in 1966. His earlier experience, following five years as a lecturer at the University of Manchester, was at the Atomic Energy Research Establishment, Harwell, between 1955–1959 and with the Plessey Company as Chief Scientist between 1959–1966. Professor Chaplin is the author of numerous papers and holds many patents. He is a member of the National Electronics Council and he represents this Council on the Parliamentary and Scientific Committee. He has also been particularly concerned with the Link Scheme for the Electronics Industry. He served on the IERE Council from 1971 to 1973.

FOR ELECTION AS HONORARY TREASURER

Sydney Rutherford Wilkins (Fellow 1942, Member 1935, Associate 1934) has an impressive record of service to the Institution. He has served on the Membership, Programme and Papers, Education and Training, and Finance Committees; he has been an Institution Examiner and has represented the IERE on BSI technical committees and on a consultative committee of the S.E. London Technical College. He was a member of the Council from 1968–1972 and was elected a Vice-President in 1972. (A fuller note on his career was published in the *Journal* for September, 1972.)

FOR ELECTION AS ORDINARY MEMBERS

From the Class of Fellows

Raymond C. Hills, B.Sc. (Fellow 1972, Member 1961) is currently Head of Station Design and Construction Department, Independent Broadcasting Authority and will take up the newly-created post of Chief Engineer (Transmitters) in October. Before joining the Independent Television Authority in 1966 Mr. Hills held various engineering appointments in the British Broadcasting Corporation. He served on Council as a Member from 1969 to 1972, and is currently on the Communications Group Committee. He has also served on Conference Organizing Committees.

H.R.H. The Duke of Kent, G.C.M.G., G.C.V.O. (Fellow 1973, Companion 1972) was educated at Eton and Le Rosey, Switzerland, and entered the Royal Military Academy in 1953. He was commissioned as a Second Lieutenant in the Royal Scots Greys in 1955, promoted to Lieutenant in 1957, Captain in 1960, and Major in 1967. He has wide interests at home and overseas and is at present serving in the Ministry of Defence Procurement Executive. His Royal Highness has a considerable interest in electronics and is an active member of the National Electronics Council.

Peter L. Mothersole (Fellow 1961, Member 1957, Graduate 1952) is Commercial Chief Engineer of Mullard Limited. From 1969 to his present appointment in March 1973 he was Engineering Manager and a member of the Executive Management team of Pye TVT. He was previously with the Central Research and Application Laboratories of Mullard Ltd. Mr. Mothersole has represented the Institution on the Management Committee of the International Broadcasting Convention since 1968 and is currently Chairman of its Papers and Programme Committee. He has served on the Communications Group Committee since its formation and was Chairman from 1964 to 1969. He has contributed numerous papers to the Institution's *Journal* and other publications.

Kenneth G. Nichols, B.Sc., M.Sc. (Fellow 1966, Member 1960) is Reader in the Department of Electronics at the University of Southampton. Before joining the staff of the University in 1961 he was a Senior Lecturer at Letchworth Technical College. Previous industrial appointments were with EMI Research Ltd. and STC Ltd. Mr. Nichols has served on the Examinations Committee and the Education and Training Committee. He has also represented the Institution on

P. L. Mothersole

K. G. Nichols

J. Powell

H. Blackburn

technical committees of the British Standards Institution and on working parties of the Council of Engineering Institutions. He has published a number of papers in the Institution's *Journal*.

John Powell, M.Sc. (Fellow 1965, Member 1957, Graduate 1953, Student 1948) is Head of Corporate Planning, Cable & Wireless Limited. Prior to his present appointment he has held a number of engineering appointments in Cable and Wireless at home and overseas since 1946; he became an Assistant Engineer-in-Chief in 1965. Mr. Powell was a member of the former Technical Committee from 1958–59 and he was the IERE representative at International Switching Conferences in Paris in 1965 and London 1968. Mr. Powell has served on the Membership Committee since 1966 and was appointed Chairman of that Committee in December 1972.

From the Class of Members

Harold Blackburn (Member 1966, Graduate 1964) is a Development Engineer at the Allen Clark Research Centre of the Plessey Company, where he has been employed since 1958. He serves on the Institution's Components and Circuits Group Committee and was a member of the Organizing Committee for the Conference on 'Infra Red Techniques'. He is an author of several papers which have been published in the Institution's *Journal*.

Professor Douglas W. Lewin, M.Sc. (Member 1960, Graduate 1957) is Professor of Electronics at Brunel University. Prior to his present appointment in January 1972 he was a Senior Lecturer in the Department of Electronics at the University of Southampton. He has served as a member of the Southern Section Committee and has been a member of the Computer Group Committee since 1970 and of the Papers Committee since 1971; he has represented the Institution on the Organizing Committees for several joint Conferences. He has contributed papers to the *Journal* and is author of several books.

Martin M. Zepler, M.A. (Member 1967, Graduate 1961, Student 1959) is a Group Leader with Plessey Avionics and Communications at Roke Manor. Mr. Zepler graduated from Cambridge and subsequently obtained the Southampton University Diploma in Electronics. The whole of his professional career has been spent with the Plessey Company. He has served on the Communications Group Committee since 1969 and on the Membership Committee since August of last year.

From the Class of Associates

Graham Phillips, (Associate 1972) is Managing Director, Harland Simon Ltd. Educated at Manchester Technical College he is an accountant by profession with a strong bias towards engineering. Initially experienced in mechanical engineering, he joined an electronics company in 1958, originally as chief accountant and company secretary, becoming general manager in 1964. Mr. Phillips was appointed Director and General Manager of Harland Simon Ltd. in 1970, succeeding Sir Leonard Atkinson as Managing Director in January 1973.

From the Class of Associate Members

C. Reginald Fox (Associate 1959) joined the R.A.F. as a wireless apprentice in 1939 and subsequently served in various parts of the world until 1953. This was followed by two years as a civilian instructor at the R.A.F. Radio School, Locking. In 1955 he joined the Air Technical Publications branch of what is now MOD(PE) and he is in charge of a Section based at the Royal Aircraft Establishment, Farnborough. Mr. Fox has served on the Southern Section Committee of the Institution since 1963 and was Honorary Secretary from 1964 to March of this year.

D. W. Lewin

M. M. Zepler

G. Phillips

C. R. Fox

Industrial News

PAL Tolerances and Television Receiver Design

The United Kingdom adopted the PAL system of colour television as its national standard in 1966 after the most exhaustive testing and international discussion. It was seen to offer important advantages over the American NTSC system although it differs very little in most respects: it was also preferred to the SECAM system.

In a statement issued jointly by the BBC and the IBA, it is pointed out that the advantages of the PAL system depend upon the incorporation of special circuit techniques in the colour receiver which confer upon the picture an almost complete immunity to various forms of colour distortion. These can arise from unwanted changes in the transmitted signals during their passage from the television studio to the home. British receiver manufacturers have consistently designed and manufactured receivers to take advantage of the immunity of the PAL system to colour errors arising from this cause and the signals transmitted throughout the United Kingdom by both the BBC and the IBA have tolerances based upon the assumption that the receiver specification is in accordance with the established principles of the PAL system.

It is, however, possible to design and manufacture a colour television receiver which does not take advantage of the special qualities of the PAL system. Very often the performance of receivers designed and manufactured in this way is perfectly adequate, but circumstances may arise where they do not give a fully satisfactory colour reproduction although the broadcast signals are still within the accepted tolerances. The Broadcasting Authorities of the UK strive to ensure that the transmitted signals remain within tolerance at all times, but they cannot take into account receivers which have not been designed to take advantage of the PAL system.

New Defence Supply Quality Requirement

New quality requirements for the procurement of defence supplies and services have been adopted by the British Ministry of Defence from 1st April this year.

Most invitations to tender issued after that date, and the resulting contracts, will invoke the requirements of one of three Defence Standards based on existing NATO Allied Assurance Publications. These Standards prescribe the kind of quality arrangements a contractor must have to ensure the quality of his products and to enable the customer to have confidence that his requirements will be met adequately. In addition the Ministry will progressively assess the ability to conform with the new quality requirements of each firm wishing to obtain Defence orders.

These changes follow the recommendations of the Raby Committee on Defence Equipment Inspection Policy, which were underlined in the Rayner Report and are being made after consultation with Industry through the Defence Industries Quality Assurance Panel. Their aim is to improve the quality of defence supplies, and to unify and simplify the arrangements by which firms and the M of D assure quality. The fact that NATO requirements are the basis will be of assistance in the European context.

Initially firms which have undertaken, or bid for Defence orders in the recent past will, without action on their part, be registered on a provisional Defence Contractors List pending assessment by a Ministry team to the new standards. Firms subsequently assessed as satisfying a standard will have their registration confirmed. New applicants will be similarly assessed and registered to the new standards if they offer supply capacity needed by the Ministry and satisfy in all respects its requirements as to their suitability for registration.

Assessment of the large number of firms involved will take some two to three years. It will be undertaken by small teams of specially trained staff who will consult and advise firms as necessary on requirements and standards of compliances. Firms registered on the provisional Defence Contractors List will, while awaiting assessment, continue to receive invitations to tender for Ministry orders to the same extent as hitherto.

The booklet explaining the changes in detail has been prepared by the Ministry of Defence and is being made widely available within Industry. This booklet as well as the supporting Defence Standards and their Guides are available for reference in the Institution's Library.

Further information, and copies of the booklet, which is entitled 'The New Quality Requirements for Defence Procurement', may be obtained from: The Secretariat, Defence Quality Assurance Board Executive, Turnstile House, 94–99 High Holborn, London WC1V 6LL.

EEA Publication on EEC

The Electronic Engineering Association's Publication 'Rules of Competition in the European Economic Community', first introduced in January, has already been reprinted. The Publication, which has received a favourable acceptance by Industry, was produced as an aid to all those who are responsible for negotiating or considering commercial contracts affecting trade between Member States of the Common Market, so that they may have a closer understanding of the EEC Rules of Competition.

The Publication is available from: The Electronic Engineering Association, 8 Leicester Street, London WC2H 7BN, at a cost per copy of £2·50.

Shipboard Selective Calling Equipment

A new selective calling receiving equipment, which will greatly increase the efficiency of the shore-to-ship radio service by reducing the time taken by coast stations to establish contact with ships, has been introduced by Marconi Marine. Known as Seacall, it will permit the automation of shore-to-ship radio calling functions so that 'on demand' contact can be made with vessels 24 hours a day.

Its introduction follows the agreement reached on the techniques and parameters of a selective calling system at the International Radio Consultative Committee (CCIR) conference's Plenary Assembly in 1970. In the agreed system, each ship is allotted a five-figure identification code, similar to the present lettered call-sign system now in use. Coast stations are given a four-figure code identification.

The radio frequencies over which the selective code is to be transmitted are in each of the marine frequency bands. The two m.f. channels are the international distress and calling frequencies of 500 kHz and 2182 kHz. All coast stations will use these specially allocated frequencies so that all ships monitor the same channels for calls. Some coast stations will transmit their calls on one or more channels to ensure reception by the ship stations.

By using five sequential figures for ship identification, nearly 100 000 combinations are possible, more than adequately serving the requirements of world shipping. The code is transmitted by converting each figure, by use of an encoder, to a specific audio frequency. A repeat tone is required when two figures are repeated sequentially. The audio tones used to identify the figures of the code numbers are arranged so that harmonic and intermodulation problems are eliminated. As a safeguard against interference, the complete code sequence is repeated twice in quick succession, the transmission taking less than two seconds.

On reception of the ship's identification code, Seacall indicates the frequency on which the call was made. It also sounds an audible alarm to attract the attention of the radio or deck officer. In addition to alerting the ship, provision is also made for advising which coast station made the call. This is achieved by transmitting, after the ship's selective code, the coast station's own four-digit code number. The ship's Seacall decoder, as well as incorporating facilities for reception of its own code, has additional circuitry which detects and displays the coast station's code number. The coast station's identity can then be found by simply referring to a reference list. With this additional information following the ship's code a complete transmission takes just three seconds.

Seacall equipment will also respond to the 'all stations' call where all eleven tones are radiated sequentially for a period of five seconds. As the 'all stations' call is transmitted for at least 5 seconds, the Seacall will be actuated three to five times, thus the signal can be easily distinguished from a normal call and so displayed appropriately.

The entire ship-borne Seacall equipment, comprising multi-channel receiver decoder and coast identification display, is contained in one compact unit.

Electronics Assembly as a 'Cottage Industry'

A Blackburn company, Mellor Electrics Ltd., specializes in employing people in their own homes to assemble electronic circuits and mechanical components. Only certain types of work are suitable for assembly in this way, but provided care is taken in selecting the right type of orders the results are excellent, and it is claimed that productivity is higher than comparable work carried out in a factory.

The company also points out that there are large numbers of people available so that they never experience labour shortage, and delivery times can be strictly adhered to. It has been the experience of Mellor Electrics, that once a suitable person has been recruited, this person is efficient and reliable and remains so over a long period.

Conference Public Address Control System

Claimed to be one of the most flexible and sophisticated installations for conferences in the world, the SNS Sound System being supplied to Cunard International Hotels has fifteen microphone inputs, each with individual bass and treble controls (± 15 dB) and slider control faders.

The gram/tape pre-amplifiers using Garrard decks have individual bass, treble and slider gain controls, plus scratch and hiss filters. Each pre-amplifier input is individually selectable to any one of seven 100 watt r.m.s. amplifiers and has its own master volume control. A standby amplifier with similar controls and specifications is incorporated. Recording facilities are available on any output.

The amplifier outputs can be directed into any one of six output groups, each with its own output meter. The five conference/banqueting channels are controlled by individual loudspeaker, volume and on/off controls in nine groups. Five monitor stations giving post-fade listen are switchable to each of the eighteen pre-amplifier outputs. Visual and audible (headset) indications are provided for all outputs.

Forthcoming Conferences

1973 Microwave Power Symposium

The International Microwave Power Institute (of Edmonton, Alberta, Canada) will hold its 8th Annual Technical Symposium from 10th to 13th September 1973 at the Loughborough University of Technology. Engineers, scientists and users of microwave energy from many different nations will attend the meeting to hear papers and exchange ideas on the latest developments in the industrial microwave field. The programme has sessions covering Microwaves in the Food Industry, Biological Effects and Safety, Microwave Heating Applications, Instrumentation Systems, Power Generation and Transmission, Ovens and Medical Applications.

A feature of every annual meeting of IMPI is the Short Course intended to be of a tutorial nature for persons from diverse processing industries who have little or no background knowledge of microwaves but who are potential users of this unique form of energy.

Programme and registration details can be obtained from Mr. H. Barber, Department of Electronic and Electrical Engineering, Loughborough University of Technology, Loughborough, Leicestershire, LE11 3TU.

Non-Destructive Testing

NDT '73, the 10th Annual Conference of the Non-Destructive Testing Society of Great Britain, is to be held from 11th to 14th September 1973 at the University of Bath, Somerset. This series of annual Conferences has become the established meeting place for scientists, engineers, technicians and management to discuss the latest developments in applications of non-destructive testing and related subjects, and the programme for NDT '73 will include papers on a wide range of techniques. Also included in the programme will be a revision course on radiography, a technical visit to the British Aircraft Corporation, Filton, and demonstrations by the Central Electricity Generating Board, Ministry of Defence (Navy), Westland Helicopters Ltd. and Henry Wiggins Ltd.

The President's Honour Lecture will be presented this year at the Conference by Mr. Paul Dick (General Electric, Space Division), President of the American Society for Non-destructive Testing. The theme of his lecture will be 'Non-destructive Testing of Space Systems during the past Decade'.

Further information may be obtained from The Non-Destructive Testing Society of Great Britain, Maitland House, Warrior Square, Southend-on-Sea, Essex SS1 2JY. (Telephone: Southend-on-Sea (0702) 610131-2).

Digital Computers in Measurement

A wide range of measurement applications to which computers can contribute will be discussed during a conference entitled 'The Use of Digital Computers in Measurement' to be held at the University of York from 24th to 27th September 1973. Such applications vary from the control of measurement to the processing of data, and include fault location and mathematical, statistical and modelling techniques.

The Conference is being organized by the Science, Education and Management Division and the Control and Automation Division of the Institution of Electrical Engineers in association with the IERE, the British Computer Society, the Institute of Mathematics and its Applications, the Institute of Measurement and Control, the Institution of Mechanical Engineers, the Institute of Physics, and the National Physical Laboratory.

Those working in many different fields of measurement will have the opportunity to exchange information on new techniques and to discuss common problems. In the past, full use of data available from measurements has often been restricted by the impossibility of processing it in reasonable time. Computers have now gone a long way towards remedying this; during the conference the associated advantages and difficulties will be discussed.

Speakers from the United Kingdom and from overseas will present papers during the nine sessions which will deal with such varied subjects as computer analysis of the performance of chronometers, on-line analysis of Brownian motion of a suspended mirror, methods of digital data preprocessing in surface metrology, cross-correlation flow measurement and the detection of malfunction.

Provisional programmes, registration forms and further details are available from the Manager, Conference Department, IEE, Savoy Place, London WC2R 0BL.

Mathematics of Telecommunications Traffic

The Institute of Mathematics and its Applications is organizing a Symposium on The Mathematics of Telecommunications Traffic to be held at the Institution of Electrical Engineers, Savoy Place, London W.C.2, on 9th November 1973.

The Symposium is devoted to the interesting and difficult mathematical problems to be faced in the planning and operation of a telecommunications system and some of the techniques used to deal with them. Papers will be as follows:

'Mathematical problems in telecommunications networks'—J. A. Pevey (Post Office Telecommunications Headquarters). (A survey defining teletraffic activities and problems).

'Complex random phenomena as a challenge to mathematics'—Professor J. F. C. Kingman, F.R.S. (Mathematical Institute, University of Oxford).

'The development of teletraffic theory'—A. C. Cole (Teletraffic Branch, Post Office Telecommunications Headquarters). (Major solved and unsolved mathematical problems and techniques used in dealing with them).

'Teletraffic studies in the development of a crossbar telephone switching system'—J. R. W. Smith (Plessey Telecommunications Research, Taplow, Bucks).

'A telephone exchange dimensioning problem'—D. J. Songhurst and C. Harvey (Teletraffic Branch, Post Office Telecommunications Headquarters). (Studies of the new cordless switchboard combining analytical and simulation techniques).

'The application of graph theory to a telecommunications network'—Professor K. W. Cattermole (Department of Electrical Engineering, University of Essex).

The Symposium will be introduced by the Chairman—Professor Sir James Lighthill, F.R.S. (University of Cambridge and Part-Time Member of the Post Office Board), and closing remarks will be made by Professor J. H. H. Merriman (Board Member for Technology and Senior Director, Development, Post Office Telecommunications).

Application forms and further details may be obtained from the Secretary, The Institute of Mathematics and its Applications, Maitland House, Warrior Square, Southend-on-Sea, Essex SS1 2JY.

Frontiers in Education

Papers are invited for the Frontiers in Education Conference to be held in London from 15th to 19th July 1974. The Conference aims to increase understanding of educational technology with particular reference to engineering education and training.

The scope of the Conference includes distant study systems, systems planning, information systems, self-teaching systems, multi-media systems, task analysis, computer-assisted learning, evaluation of system performance, assessment of student performance, resource centres, effective utilization of professional manpower, training and educational schemes for technically educated personnel and the problems of national shortages of professional manpower.

Contributions are invited in these areas and intending authors should send a 250-word synopsis to the 1974 Frontiers in Education Secretariat not later than 5th October 1973. Authors whose synopses are selected will be invited to submit for further consideration a contribution in typescript of 2000 words by 18th February 1974.

Organized by the Institution of Electrical Engineers, the conference will be the annual meeting of the Education Group of the Institute of Electrical and Electronics Engineers. It is the first time that this American-based group has met in another country. Also associated with the conference are the IERE, the American Society for Engineering Education, the Department of Trade and Industry, the Industrial Council for Education and Training Technology, the Institute of Electrical and Electronics Engineers (UKRI Section), the Ministry of Defence and the Open University.

The Conference will be held at City University, London, where some residential accommodation will be available. There will be a non-commercial display of relevant exhibits and the programme will include a series of workshops, seminars, demonstrations and technical visits.

Further information is available from the 1974 Frontiers in Education Secretariat, c/o Conference Department, Institution of Electrical Engineers, Savoy Place, London, WC2R 0BL, England.

1974 IFAC Symposium on Multivariable Technological Systems

Organized by the Institute of Measurement and Control under the aegis of the United Kingdom Automation Council (to which the IERE belongs), the principal theme of this IFAC Conference will be the development and application of design techniques for the feedback control of multivariable technical systems.

Subsidary themes related directly to the Conference will be:

The construction of models for a wide range of engineering multivariable systems.

Techniques of identifying and validating such models.

Comparisons of different types of design technique applied to industrial problems.

Use of computer-aided design techniques for multivariable feedback system design.

Applications of multivariable feedback control to a wide range of industrial processes.

Other subsidiary themes will be:

Multilevel and hierarchial control.

Adaptive control.

Application of design techniques for large systems.

Man-machine problems in multivariable systems.

Industrial applications are especially sought in the fields of the control of process industries, prime movers, electrical power plant, aircraft and helicopters, electrical drives, surface transportation systems, communication and information processing systems, ship systems and energy distribution systems.

A general criterion which will be applied to theoretical papers is that they must be associated with the development of design techniques, or deal with some other specific aspect of multivariable technological systems with an immediate or near-future possibility of application. A general criterion for applications papers (which are especially desired) is that they have some clearly-defined multivariable aspect.

Prospective contributors are invited to submit abstracts in English (of approximately 250 words length) of papers offered in any of these areas. Technical papers will be classified into two categories: full and short. Full papers will be of 3000 words length and will be presented by the author. Short papers will be of 1000 words length and will be grouped into sets around which discussion meetings will be organized. The working language for the conference will be English and all papers should be in English with abstracts in English, French and German submitted with the final version of the paper.

The closing date for submission of abstracts is 30th September 1973. Final version of accepted papers, to be prepared by the authors on special forms for offset litho reproduction, will be required by 31st March 1974. The symposium will be held in the Owens Park residential and conference complex of the University of Manchester from 16th to 18th September 1974.

All correspondence and enquiries should be addressed to: 3rd IFAC Symposium on Multivariable Technological Systems, Institute of Measurement and Control, 20 Peel Street, London W8. (Telephone 01-727 3755/9156).

Power Electronics—Power Semiconductors and their Applications

The specification, operation and application of all forms of power semiconductor devices will be covered during an international conference to be held at the IEE, London, from 3rd to 5th December 1974. The Conference is being organized by the Power Division and Control and Automation Division of the Institution of Electrical Engineers in association with the IERE, the Institute of Electrical and Electronics Engineers (United Kingdom and Republic of Ireland Section) and the Institute of Physics.

The particular advantages of the various forms of power semiconductor devices now available will be discussed and examples of recent trends in the utilization of these devices will be described. The sessions will include:

(i) devices, gating and control.

(ii) applications: domestic, lighting and heating; electrolytic; industrial power control and conversion; machine control; traction; and transmission.

The Organizing Committee invites offers of contributions not exceeding 3000 words (i.e. a maximum of six A4 pages including typescript and illustrations) for consideration for inclusion in the conference programme. Those intending to offer a contribution should submit a synopsis of approximately 250 words to the Conference Department, IEE, Savoy Place, London WC2R 0BL, by 1st January 1974. The full typescripts will be required for assessment by 24th May 1974.

Registration forms and further programme details will be available a few months before the date of the conference from the IEE Conference Department.

Members' Appointments

CORPORATE MEMBERS

Mr. A. J. Davidson (Fellow 1964) has been seconded by the Foreign & Commonwealth Office (Overseas Development Administration) as Electronic and Electrical Adviser to the Jamaican Government on the Joint Industrial Development Council. His previous appointments, both in Zambia, were as Director of Engineering with the Ministry of Transport, Power and Communication and as General Manager of the Kariba North Bank Co. Ltd.

Mr. E. G. Lamb, B.Sc. (Eng.) (Fellow 1965) who has been Principal of Bell College of Technology, Hamilton, Lanarkshire, since January 1972, has been appointed an educational member of the Iron and Steel Industry Training Board for an initial period of three years. Mr. Lamb was previously Head of the Department of Electrical Engineering at the City of Liverpool College of Technology. He is a past Chairman of the Merseyside Section of the Institution.

Commander R. J. Record, RN (Fellow 1965, Member 1950, Associate 1946) has taken up the appointment of Assistant Personnel Superintendent with London and Overseas Freighters on his retirement from the Navy. Commander Record joined the Navy in 1942 and was granted a Temporary Commission in the RNVR, as an Air Radio Officer, in 1944. He subsequently was granted a permanent commission in the Electrical Branch. Prior to retirement, he held a Staff appointment in the Directorate of Naval Manpower Planning, Ministry of Defence, dealing with officer structure matters.

Mr. D. J. Cairns, Ph.D., (Member 1964) who was previously Principal Lecturer and Head of the Division of Construction Science and Mathematics at the Polytechnic of the South Bank has taken up a Lectureship in Computer Science at Birkbeck College (University of London).

Mr. K. W. Lambert (Member 1971, Graduate 1960) has been appointed Chief Engineer of the Television Production and Recording Studios of Trans-World Communications which is a division of Columbia Pictures based in Las Vegas, Nevada, U.S.A. Mr. Lambert was with the BBC before moving to the United States in 1967; he subsequently held appointments with RCA and Ampex.

Mr. K. G. Lockyer, B.Sc. (Member 1948, Associate 1944) who has been Senior Lecturer in Management Studies at Loughborough University of Technology since 1966, has been appointed to the new Chair of Operations Management at the University of Bradford. Before entering technical education at the Polytechnic, Regent Street, London in 1961, Mr. Lockyer held various industrial appointments, mainly in production engineering. He was a member of the Programme and Papers Committee from 1950 to 1951 and for several years was an examiner for the Institution's Graduateship Examination.

Mr. J. M. Lowe (Member 1971) who was formerly a Higher Scientific Officer at Daresbury Nuclear Physics Laboratory, has been appointed a Principal Engineer with Plessey Interconnect in Northampton.

Mr. E. McFall (Member 1971, Graduate 1963) has been appointed an Electrical Engineer Surveyor at the Belfast Office of Lloyd's Register of Shipping. He was previously with the Ministry of Defence (Procurement Executive) as a Professional and Technical Officer II concerned with quality assurance and inspection of avionics equipment installations.

Mr. D. G. Pinder (Member 1971, Graduate 1966) has joined Selection Trust Ltd. as a Process Control Engineer. He was previously an engineer responsible for instruments projects with Roan Consolidated Mines Ltd. in Zambia.

Mr. T. Scott (Member 1973, Graduate 1968) has been promoted to Signals Officer in the Directorate of Data Processing of the Civil Aviation Authority.

Mr. K. R. Thrower (Member 1967, Graduate 1965) has been appointed Director of Advanced Development with Racal Group Services Ltd. Mr. Thrower joined the Racal Group in 1960 and prior to taking up his present appointment was Technical Director of Racal Instruments Ltd.

Wing Cdr. D. R. Wood, RAF (Member 1971) has been posted to the Ministry of Defence as Elect. Eng. 10 (RAF). Wing Cdr. Wood has recently completed a course at the RAF Staff College, Bracknell.

NON-CORPORATE MEMBERS

Mr. P. Blakeborough (Associate 1971) who was previously a Broadcasting Engineer from 1965 to 1970 with the BBC and from 1970 to 1972 with the Jamaica Broadcasting Corporation, has joined Link Electronics Ltd. as Senior Engineer for Systems.

Mr. S. Christie (Associate 1970) has been seconded by the BBC where he is a Senior Engineer, to the Malaysian Department of Broadcasting as an advisor on colour television under the Colombo Plan.

Mr. C. W. Parsons (Associate 1972) is now a Maintenance Engineer with the Arabian American Oil Company, Dhahran, Saudi Arabia. He was previously Director of a company producing technical publications for industry.

Mr. P. Rivkin (Associate 1962), who joined the Central Electricity Board a year ago, has recently been promoted 3rd Assistant Engineer (Control and Instrumentation) at Hartlepool Nuclear Power Station.

Mr. B. R. Sudbury (Associate 1969) is now Technical Instructor on Flight Simulators in the Link-Miles Division of Singer (Gt. Britain) Ltd., Lancing, Sussex.

Mr. M. O. Barlow (Graduate 1958) is now Chief Engineer for motor design and associated industrial control systems with Normand Electrical Co. Ltd., Cosham, Portsmouth.

Mr. Chung Chok Hin, B.Sc. (Eng.) (Graduate 1971) has been awarded the degree of M.Sc. of the University of London for a Dissertation entitled 'Investigation of Transistor Model Parameters from Transient Response'.

Mr. Chung Sam Yeun (Graduate 1971) is now a Production Supervisor with Litronix Ltd. in Mauritius.

Mr. R. F. Eunson (Graduate 1966) has been promoted to Executive Engineer in the Post Office Engineering Department and is now with the Wales & The Marches Telecommunications Board in Cardiff. Prior to his promotion he was in the Swansea Telephone Area.

Mr. M. R. Hill (Graduate 1970) has joined the British Steel Corporation as a Senior Electrical Designer in the Rolling Mill Design Section of the Special Steels Division at Rotherham. He was previously with Davy and United Engineering Company working on the design and installation of steel mills.

Mr. J. Lincoln (Graduate 1972) who joined the London College of Furniture as a Technician in the Department of Musical Instrument Technology, has now been appointed Lecturer in Electronics and Musical Acoustics.

Mr. I. B. Osman (Graduate 1971) is now a Technical Assistant with the National Electricity Board of the State of Malaysia, Kuala Lumpur, following a period of five years in the United Kingdom when he gained a Higher National Diploma in Electrical and Electronic Engineering at Kingston Polytechnic.

Mr. M. S. Siddiqi, B.Sc., B.Sc.(Tech.) (Graduate 1972) has joined Litton Systems (Canada) Ltd., Toronto, to work on aircraft navigational systems. He completed a sandwich course for his degree in electronics last summer at UWIST; his industrial training was obtained with Racal Research Ltd.

Mr. M. D. Stephenson, M.Sc. (Graduate 1968) is now Senior Systems Engineer in the Flight Automation Research Laboratories of Marconi-Elliott Avionics Ltd. From 1969 to 1972 he was carrying out research on integrated circuits at Southampton University for his higher degree.

Sqdn. Ldr. T. H. W. Wilson (Graduate 1970) has taken up a staff appointment in the Directorate of Engineering Policy at the Ministry of Defence (Air). He was previously Officer Commanding Air Electrical Engineering Flight at RAF Odiham and from 1969 to June 1972 he was on the Staff of the Engineering Management Wing at the RAF College, Carwell.

Tin—its Role in Soldering and Plating

One of the most important primary materials used in electronic engineering is tin—and it is probably one that is therefore most taken for granted. The source of much expertise on the multitudinous uses of this metal is the Tin Research Institute, in Greenford, Middlesex, maintained by the International Tin Research Council, which is financed by the major producers of the world (Bolivia, Indonesia, Malaysia, Nigeria, Thailand and Zaire). The ITRC has other organizations for information, service and technical development in several industrial countries, e.g. USA, Belgium, Brazil, Germany, Holland, Italy, Japan and Australia.

The Annual Report of the TRI for 1972 describes the development and research activities and its account of work on soldering and on the properties of tin plated coatings in electronic equipment will be of considerable interest to electronic engineers, particularly those concerned with production of equipment and components.

Solders and Solderability

Impurities. The presence of impurities in tin-lead solders can have an important effect on their performance in specific applications. An extensive programme of research has been in hand at TRI for some time to establish for a number of elements the impurity levels that can be tolerated without detriment. This work is now almost complete.

During the year, detailed investigations have been carried out on the influence of antimony, copper, cadmium, bismuth and arsenic in 60% tin–40% lead solder. Using copper, brass or mild steel as the basis metal, the time required for the solder to wet these has been determined and any tendency for dewetting of the solder has been noted. It has, for example, been found that bismuth additions up to 2·5% do not affect the wetting properties of 60/40 solder, although they do cause a noticeable loss of brightness of the surface. The presence of arsenic up to 0·1% does not appear to affect the ease of wetting of copper and mild steel, whereas only 0·015% arsenic appears to cause severe dewetting on brass substrates.

In addition to carrying out rotary-dip and area-of-spread tests as a measure of solderability, the effect of impurities on surface tension has also been studied using an instrument which permits sensitive measurements to be made of the wetting time, the rate of wetting and the wetting force, when a sample is immersed in molten solder.

The British Standards Institution is currently revising its specifications for soft-solders and the Institute's work on the influence of impurities in solder is being used as guidance for this revision.

Properties. A programme of creep testing of bulk solders was commenced in 1971 and has been continued. Complete data have now been obtained for 60% tin–40% lead solder tested at room temperature, at 80°C and at 100°C. For economic and design reasons, electronic assemblies are being required to function at ever-increasing temperatures and operation at up to 140°C is likely to be commonplace in the near future. Creep data at these higher temperatures are now being obtained and the programme includes alloys such as tin-antimony and tin-silver, currently used commercially to obtain higher joint strengths at elevated temperatures. These data will be valuable in advising on the correct material for arduous service conditions.

Roller Coating. During 1972 the Institute's study on the roller-coating of printed circuit boards with 60% Sn–40% Pb alloy has been completed. Tests have been made using two different helical-groove patterned tinning rolls, the first having grooves with a square cross-section and the second a V-section. The average thickness of the coatings obtained with the first roll on unetched laminate was greater than for a plain roll profile, but the coating was not uniform and the solder tended to solidify in uneven ridges along the board. The second grooved roll, with a truncated V-shaped groove to facilitate solder spread, produced on plain laminate a thicker, more uniform coating. However, on the tracks of boards having an etched circuit pattern the coating was still very uneven. A number of reflowing techniques have been tried in an attempt to improve the uniformity of the coating, with only limited success. Some of these experimental results have now been published.

Testing. Two aspects of the testing of solders and fluxes have received attention at TRI: the artificial ageing of surfaces to be soldered, and the assessment of the corrosion produced by flux residues. The object of artificial ageing is to provide a means of assessing whether a particular coating or metal is likely to retain adequate solderability over a long period of storage. Exposure to steam appears to be the most convenient and generally applicable method, and further attention is being given to standardization of the procedure to be used.

The examination of flux residues is also aimed at standardization of test procedures. Most of the work carried out to date has been concerned with the examination of soldered joints after exposure for appropriate test periods to atmospheres of controlled humidity. This is an old-established method but it is not wholly satisfactory because of difficulties and uncertainties of observing the small visual indications of corrosion. Attention has therefore been given to the alternative of measuring the conductivity of water extracts of the flux residue. Results of these tests have the advantage of giving numerical values but much care is required to produce reliable, reproducible results and there is some doubt as to whether all materials yielding large water extracts represent a corrosion danger. More information is needed about the hazards of flux residues in service.

Intermetallic Compound Growth in Plated Coatings

Modern electronic components and assemblies frequently undergo elevated temperature conditions either during production processes or in service. As would be expected from a relatively low melting-point metal such as tin, solid-state diffusion between tin and tin alloy coatings and their substrates becomes significant at 100°C or above. This results in loss of the tin coating thickness, as it forms an interfacial layer of compound, with possible reduction in solderability and increased brittleness of soldered joints. The results of the present investigation at Greenford are providing quantitative information on the rate of growth of such compounds and will enable the Institute to provide considerable help and advice to industrial users of these coatings.

Detailed results have already been obtained for the rates of growth of intermetallic compounds for coatings of tin and various tin-lead alloys on copper (in both hard and soft conditions), silver and brass. In all the systems so far studied, there is a period of up to about one day when the rate of growth is rapid, followed by a reduction which continues thereafter at a steady rate. In industry, it is generally believed that the presence of a significant percentage of lead reduces considerably the rate of compound growth at the interface, but, at the temperature studied, the rate of growth of compound was not very dependent on the composition of the coating. Quantitative results have already been reported to a meeting of the American Society for Metals.

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

Applicants for Election and Transfer

THE MEMBERSHIP COMMITTEE at its meeting on 26th June 1973 recommended to the Council the election and transfer of 48 candidates to Corporate Membership of the Institution and the election and transfer of 6 candidates to Graduateship and Associateship. In accordance with Bye-law 21, 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 communications from Corporate Members concerning these proposed elections must be addressed by letter to the Secretary within twenty-eight days after the publication of these details.

***Meeting: 26th June 1973** (**Membership Approval List No. 161**)*

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Member to Fellow

WILLISON, William Ernest *Barnet, Hertfordshire.*

Transfer from Graduate to Member

ALLAN, William *Rosyth, Fife.*
ATTWOOD, Michael *Poynton, Stockport, Cheshire.*
AXFORD, David James *Faversham, Kent.*
BAYLY, Michael Richard John *Stourport-on-Severn, Worcestershire.*
BINGLEY, Benjamin Arthur *Chelmsford, Essex.*
BLANCHFORD, Nigel Bruce *New Malden, Surrey.*
BROXTON, Anthony Charles *Wallington, Surrey.*
BUCHANAN, Charles Ronald *Orpington, Kent.*
CASLING, Colin Arthur *Bedford.*
DALY, John Leonard *West Harrow, Middlesex.*
DULEY, Richard Keith *Romsey, Hampshire.*
EVANS, Robert Alun *Binley Woods, Coventry.*
GILLIS, Ian James *Danbury, Essex.*
HARDWICK, Edward Arthur *Shirehampton, Bristol.*
HARVEY, Peter Alan, M.Tech. *Hinckley, Leicester.*
JONES, Frank *Chorley, Lancashire.*
KEMP, Francis Finlay *Rushden, Northampton.*
KING, Clifford Robert David *Rotherfield, Sussex.*
LEWIS, John Henry *Frodsham, Cheshire.*
LEWIS, William Peter *Stockwood, Bristol.*
MARCHANT, Peter James *Kingsclere, Berkshire.*
MAWDSLEY, Brian *Stevenage, Hertfordshire.*
McGOVERN, Alan John *Brownhills, Stafford.*
MONK, Colin Leslie *St. Albans, Hertfordshire.*
MORGAN, Geoffrey John *Headcorn, Kent.*
NICHOLAS, Gordon Alan *Greasby, Cheshire.*
NWEBUBE, Victor Eluemuno *Croydon, Surrey.*
POORE, Norris George. B.E.M. *Felpham, Sussex.*
POTHECARY, Kenneth *Botley, Hampshire.*
PRATT, Ian Wilfred *Marlow, Buckinghamshire.*
SCOTT, Peter Edward *Seven Kings, Essex.*
STEVENS, John Francis *Dollar, Clackmananshire.*
TREVITT, Ronald Brian *Addlestone, Surrey.*
WHARTON, Leonard *Lymm, Cheshire.*
WILLCOX, Douglas Arthur *Bolton, Lancashire.*
WILLIAMS, Robert Geoffrey *Rugby, Warwickshire.*

Transfer from Associate to Member

STONE, Frederick John *London Colney, Hertfordshire.*

Direct Election to Member

BARNETT, Malcolm John, B.Sc. *Trentham, Stafford.*
GRIMSTON, Derek Frederick, Squadron Leader RAF *Wilton, Wiltshire.*
HOLROYD, Malcolm, M.Sc. *Oxford.*
MEARNS, James Alfred, M.Sc. *Thingwall, Cheshire.*
MOULT, Alan Stanley *Welwyn, Hertfordshire.*
SHEPHARD, Ian, Flight Lieutenant, RAF, *Farnborough, Hampshire*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

GORDON, Robert Gourlay, B.Sc. *Chatham, Kent.*

Direction Election to Graduate

BILLINGTON, Geoffrey Richard, B.Sc. *Nelson, Lancashire.*
DURRANI, Abdul Sattar Khan *Woking, Surrey.*
HILTON, Michael William *Bramford, Ipswich, Suffolk.*
MATTHEWS, John Charles, Major, R.A. *Tonbridge, Kent.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Graduate to Member

ADEIFE, Mrs. Olatoun Taiwo, *Yaba, Nigeria.*
HALES, Rodney *Mufulira, Zambia.*
JONES, Robert Hugh *Uithoorn, Holland.*
STROOBANT, Anthony David *Auckland 7, New Zealand.*

NON-CORPORATE MEMBERS

Direct Election to Graduate

FAIYAZ, Muhammad *Bangalore, India.*

STUDENTS REGISTERED

TEO, Kian Sing *Singapore 15.*
TEO, Tee Seng *Singapore 12*

Notice is hereby given that the elections and transfers shown on List 158 have now been confirmed by the Council.

Forthcoming Institution Meetings *(cont. from p. 520)*

South Western Section *(cont.)*

Thursday, 18th October

JOINT MEETING WITH IEE

Optical Fibre Communications

By F. F. Roberts (*Post Office Research Department*)

Lecture Room 4E3, 10, University of Bath, 6 p.m. (Tea 5.45 p.m.)

A rapid survey will first be given of the development of existing cable communication systems. The relative repeater cost contributions for optical fibre and coaxial cable systems will then be estimated with stated assumptions about attenuation in relation to communication rate per pathway. Finally after a summary of cable make-up requirements the materials contribution to fibres and coaxial cables of equal transmission capacity will be compared on defined bases. It is concluded that fibre systems will have good prospects of competing with coaxial cables systems under conditions likely eventually to be met, but that considerable further R & D is still required.

Merseyside Section

Wednesday, 17th October

The Semiconductor Story

By Dr. K. J. Dean (*South East London Technical College*)

Department of Electrical Engineering and Electronics, University of Liverpool, at 7 p.m. (Tea 6.30 p.m.)

South Wales Section

Wednesday, 10th October

New Integrated Circuits for Television Receivers

By G. Baskerville (*Plessey Semiconductors*)

Department of Applied Physics, UWIST, Cardiff, 6.30 p.m. (Tea in College Refectory from 5.30–6 p.m.)

Wednesday, 24th October

JOINT MEETING WITH IEE

Recent Developments in the Design of Transfer Function Analysers

By W. A. Evans (*University College of Swansea*)

University College, Swansea, 6.15 p.m. (Tea 5.30 p.m,)

Northern Ireland Section

Wednesday, 10th October

Annual General Meeting followed by a talk on

'T. Eng. and All That'

By J. T. Attridge, C.Eng., M.I.E.R.E.

Board Room, Ashby Institute, Queens University, Belfast, 6.30 p.m.

A discussion on the recent changes in the rules relating to Technician Engineering qualifications.

Forthcoming Institution Meetings

London Meetings

Wednesday, 10th October

AEROSPACE, MARITIME AND MILITARY SYSTEMS GROUP

Colloquium on ELECTROMAGNETIC COMPATIBILITY OR CONFUSION ON LAND, IN SHIPS AND IN AIRCRAFT

IERE Lecture Room, 2.30 p.m.

Advance Registration necessary. Apply for details and registration forms to Meetings Secretary, IERE.

Wednesday, 17th October

EDUCATION AND TRAINING GROUP

The Feedback Classroom

By K. Holling (*Chesterfield College of Technology*)

IERE Lecture Room, 6 p.m. (Tea 5.30 p.m.)

The Feedback Classroom is a group teaching/testing machine in which each student in a class is provided with a response unit so that responses to objective type questions can be made by the operation of switches. The responses are displayed to the teacher on a control console. This lecture will describe the design and construction of a Feedback Classroom and its use for teaching and testing purposes. Examples will be shown of the objective test questions suitable for use at various levels ranging from craft to degree type courses.

Thursday, 25th October

ANNUAL GENERAL MEETING at 6 p.m. (Members only).

Followed at 6.45 p.m. by

Presidential Address

Dr. I. Maddock, C.B., O.B.E., F.R.S. (*DTI*). London School of Hygiene and Tropical Medicine (Tea 5.30 p.m.).

Wednesday, 31st October

AUTOMATION AND CONTROL SYSTEMS GROUP

Colloquium on REMOTE CONTROL SYSTEM ORGANIZATION

The Middlesex Hospital Medical School, 10.15 a.m.

Advance Registration necessary. Apply for details and registration forms to Meetings Secretary, IERE.

Error detecting codes and their application.
By J. D. Martin (*Bath University*)

Bandwidth and speed requirements for binary command signalling.
By F. D. Pullen (*CEGB*)

Adaptive sampling in telemetry systems.
By I. G. Dewis (*National Physical Laboratory*)

An optimum solution for security, speed and communication channel for general purpose telemetry—some basic considerations.
By G. White (*GEC-Elliott Process Automation*)

Optimizing the bandwidth–security–access time merry-go-round.
By P. D. Cooper (*Westinghouse Brake & Signal*)

Operational integrity in supervisory control systems.
By D. Keast (*Intelogic Ltd.*)

The design and applications of a general-purpose telemetry system.
By M. S. Jennions (*Kent Automation Systems*)

Remote supervisory control—some aspects of system security.
By C. J. Williams (*Quinder Wirral*)

A secure data link between autonomous data handling systems in CAMAC.
By J. A. Laver (*CEGB*)

Organizing a telecontrol system for distribution network control.
By T. D. Dawson (*Terminal Display Systems*)

A simple data transmission system for use in area traffic control systems.
By J. T. M. Garrioch and P. C. M. Kay (*Plessey*)

East Anglian Section

Tuesday, 25th September

JOINT MEETING WITH IEE

An Anti-collision Radar employing Storage of Radar Pictures on Tape

By J. Watt (*Marconi Communication Systems*)

Civic Centre, Chelmsford, 6.30 p.m. (Tea 6 p.m.)

The introduction of radar has far from eliminated collisions at sea and the shortcomings of radars in general use are discussed. A radar display system which provides to the navigator a service of an entirely new order, including the ability to pre-test the effects of a proposed anti-collision manoeuvre, is described.

Wednesday, 17th October

JOINT MEETING WITH IEE

Radio Astronomy

By Dr. R. S. Booth (*Jodrell Bank Observatory*)

The Civic College, Ipswich, 6.30 p.m. (Tea 6 p.m.)

Wednesday, 24th October

JOINT MEETING WITH IEE

Sonar and Underwater Communications

By Dr. V. G. Welsby (*University of Birmingham*)

Assembly House, Norwich, 7 p.m. (Refreshments 8 p.m.)

A review is given of modern techniques based on the use of sound waves in the sea and in lakes, rivers, etc. Systems for diver communication and navigation are described. High resolution sonars, sometimes using focused acoustic arrays, have uses which range from the study of the behaviour of fish shoals to aiding police searches in muddy canals. Acoustic telemetry is used to control submersible vehicles and to channel collected information back to the surface. Acoustic waves can also be used to count migrating fish in rivers.

Thursday, 25th October

JOINT MEETING WITH IEE

Situation Display—A New and Unique Approach to Radar Presentation

By F. K. H. Birnbaum (*Kelvin Hughes*)

The University Engineering Laboratories, Trumpington Street, Cambridge, 6.30 p.m. (Tea 6 p.m.)

The whole philosophy of 'Situation Display' is based on the fact that the officer responsible for conning and navigating the ship is perfectly able to make correct decisions in complex situations when the weather is clear and he can see for himself what is happening, without making recourse to prediction apparatus and similar aids. Many years of experience accumulated in clear weather navigation have proved the human brain to be the best possible 'computer' in this application. The real difficulties arise in fog and low visibility conditions when the navigator has to rely on radar. Kelvin Hughes' approach is to present him in these conditions with the same information that he would obtain for himself in clear weather, in a way that is simple to understand and easy to assimilate, thereby enabling him readily to determine for himself the correct collision avoidance manoeuvres.

Friday, 26th October

Annual Dinner/Dance

The Meads Ballroom, Brentwood.
Details to be circulated to members.

Kent Section

Wednesday, 3rd October

Recent Advances in Radio Navigation

By J. E. Viles (*Marconi-Elliott Avionic Systems*)

Medway and Maidstone College of Technology, Chatham, 7 p.m.

Thames Valley Section

Wednesday, 10th October

Digital Phase Lock Loops

By K. Thrower (*Racal*) and P. Atkinson (*University of Reading*)

J. J. Thomson Physical Laboratory, University of Reading, Whiteknights Park, Reading, 7.30 p.m.

The digital phase-locked loop is widely used for frequency synthesis and control. The lecture is concerned with the design, performance and practical applications of the loop. The shortcomings of the conventional Type 1 loop are discussed and it is shown how the Type 2 loop, which has integral control, overcomes these. In considering the applications of the digital phase-locked loops the problems of oscillator design, noise, jitter and frequency range are considered.

Southern Section

Wednesday, 10th October

CEI LECTURE

Carry On Civil Engineering

By Sir Harold Harding, F.C.G.I. (*Consulting Engineer*)

Portsmouth Guildhall, 7 p.m.

Wednesday, 17th October

Charge Coupled Devices

By J. D. E. Beynon (*University of Southampton*)

Lanchester Theatre, University of Southampton, 6.30 p.m. (Tea served in Senior Common Room from 5.45 p.m.)

Although the charge-coupled device was conceived only three years ago it is already challenging many conventional integrated circuit techniques, particularly in the memory and solid state imaging field. This is because of the device's extreme simplicity which is leading to circuits having high packed density, low power dissipation and low cost per function. The lecturer will explain the operation of the charge-coupled device and describe some of the techniques used for fabricating c.c.d. circuits. Some of the c.c.d.'s many present and future applications will be discussed.

Wednesday, 24th October

Multiphonic Organs

By J. H. Asbery

Queen's Hotel, Farnborough, 7 p.m.

The principle of the multimonophonic organ (usually abbreviated to multiphonic), involves the use of a small number of oscillators, the frequency of these being determined according to the keys pressed. Attention will be drawn to the relative advantages of a.c. resistance, a.c. capacitive and d.c. keyboard switching and to systems using the divider principle. Aperiodic frequency multipliers may be used as an alternative to dividers. Tone forming by use of non-linear elements and modulation of one footage by another will be mentioned. Some of the techniques can be used where a conventional melodic section is provided in a polyphonic organ. While the concept of the multiphonic organ is over a quarter of a century old its commercial exploitation has hitherto been inhibited by lack of inexpensive components of sufficient stability. The lecture will be supported by comprehensive demonstrations.

Wednesday, 31st October

JOINT MEETING WITH IEE

Exploring the Deep Oceans

By K. Haigh (*HMS Vernon*)

Portsmouth Polytechnic, 6.30 p.m.

Yorkshire Section

Thursday, 20th September

Modern Developments in Hi-Fi Reproduction

By Dr. A. R. Bailey (*University of Bradford*)
University of Bradford, 7 p.m. (Refreshments 6.30 p.m.)

The lecture investigates the recent claimed advances in high-fidelity reproduction and attempts to derive a balanced view of the present systems and possible future developments. The main topics to be covered will be disk and tape systems, multichannel recording systems including 'quadrophony', loudspeaker systems and room acoustics. The lecture will be accompanied by demonstrations.

Friday, 19th October

CEI LECTURE

Suspension Bridges

By Dr. O. A. Kerensky, C.B.E., F.R.S. (*Freeman, Fox and Partners*)

City Hall, Sheffield, 7 p.m.

West Midland Section

Tuesday, 16th October

The Electronic Control and Communication Network Employed on the Midland Links Motorways

By Chief Inspector W. A. Hambrey (*Midland Links Motorway Police Group*)

RAF Cosford, Albrighton, Wolverhampton, 7 p.m.

As part of a national programme for the control and signalling of motorways, the Department of the Environment has equipped the Midlands section with a computer-based signal and surveillance system. Some of the control and communications aspects of the system will be dealt with by the lecturer, including the functions of the Perry Barr control room.

East Midland Section

Wednesday, 10th October

Delta Modulation Systems

By R. Steele (*Loughborough University*)

Lecture Theatre 'A', Physics Block, Leicester University, 7 p.m. (Tea 6.30 p.m.)

The lecture will describe how the basic linear delta modulator works and discuss factors which limit its performance. In particular, quantization, noise, slope overload noise and signal to noise ratio will be examined.

The second half of the lecture will deal with companded delta modulators. Syllabically companded delta modulators are used for speech encoding, and analogue and digital versions will be considered. Instantaneously companded delta modulators which can be used to encode television signals will be reviewed. Comparisons will be made between delta modulation, pulse code modulation and differential pulse code modulation in order to give some perspective to the relatively complex subject of digital encoding in telecommunications.

Wednesday, 24th October

Space Instrumentation

By R. Young and B. R. Kendall (*Hawker Siddeley Dynamics*)
RAF College, Cranwell, 7.30 p.m. (Tea 7 p.m.)

South Midland Section

Thursday, 20th September

Colour Television Displays—The Next Stage

By W. W. Wright (*Thorn Colour Tubes*)
BBC Evesham Club, 7.30 p.m.

The paper deals with the movement towards 110° deflexion with large-screen tubes and traces the two approaches to this problem. The evolution of the precision toroid yoke as a tool to enable the 110° system to be more economical is described as are the convergence problems of wide angle scanning. Turning to medium-sized tubes the evolution of line screens with the Sony Trinitron and the Linytron tube is mentioned. With the combination of line screen and precision toroid yoke it is shown that an inherently self-converging system can be designed and a description is given of the features of an integral tube component which needs no setting up.

Thursday, 18th October

Provision of Communications for Remote Clustered Visual Display Units

By F. B. Sanders (*West Midlands Gas Board*)

Gloucester College of Technology, 7.30 p.m.

West Midlands Gas today makes extensive use of visual display units v.d.u. and typical applications include information retrieval and data input to assist in the administration of accounts and service work in an area containing 1¼ million gas consumers (domestic and commercial). The v.d.u.s are connected into the central computer hardware via a communications network shared by other systems. The paper includes a description of the computer and communications system and details the evolution of v.d.u. systems from the design to post-design stages. Storage media, c.p.u. message transmission and multiplexing, microwave network, u.h.f. scanning techniques, P.O. lines, modems, and polling techniques are discussed for the hardware aspects while network planning, implementation and support including project co-ordination, system acceptance, commissioning and maintenance are also covered. Mention will also be made of future developments.

South Western Section

Thursday, 19th September

Yacht Electronics

By N. T. J. Bevan (*Marconi*)
Lecture Room 2E3. 1, University of Bath, 7 p.m. (Tea 6.45 p.m.)
The lecture will include discussion of the following: receivers and transmitters, electronic chronometers, v.l.f. direction-finding receivers, electronic compass, passive radar warning devices, self-steering gear and autopilots and power supplies (batteries, thermo-electroeic generator, and ships' motion generator).

(*cont. on p. 518*)