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The Radio and Electronic Engineer

The Journal of the Institution of Electronic and Radio Engineers

Exploiting Research

TWO recent annual reports from the Science Research Council (SRC)* and the National Research Development Corporation (NRDC)† respectively, present a broad and fascinating view of some of the research and development effort in the United Kingdom which is of interest to the radio and electronics engineer. All the various classifications of 'R and D' identified by a distinguished committee under Lord Zuckerman in 1961‡ can be noted in the reports: pure basic research, objective basic research, applied project research, applied operational research, and development.

The main interests of the SRC are summed up in the names of its four Boards—Astronomy, Space and Radio; Nuclear Physics; Science; Engineering—but it should not be assumed that the work which the first three supervise is predominantly pure basic research. Admittedly the optical and radio astronomical work may be regarded, primarily, as the search for knowledge for its own sake, but the wider implications of space research need no more spelling out in this Journal than do the radio wave propagation investigations by the Appleton Laboratory and its collaborating university departments. Nuclear physics, too, has its pure, objective and applied research aspects, and the high energy particle installations represent electronic engineering of a particularly exacting nature. Computer techniques, based mainly on the Atlas Computer Laboratory, fall within the Science Board's responsibilities as well as laser work‡ and materials studies. Computing science, and especially computer-aided design is the concern of the Engineering Board, as are control engineering and electrical and system engineering.

Post graduate education in universities is a complementary purpose of the SRC and in 1973 some 3,500 research studentships and advanced course studentships were taken up. This investment in present and future research represents 11% of the SRC's 1973/4 expenditure of £74M.

The report of the NRDC—which celebrates its 25th anniversary this year—points out that nearly a half of the inventions communicated to it came from Government departments or the universities, and well over 90% of the patent rights assigned to it came from these sources. A clear relationship therefore exists between the SRC (and the other Research Councils) and the universities on one hand, and NRDC on the other. In the electronics field may be noted new computer peripherals and stores, an instrumentation tape recorder and an ambisonic sound system; the first three are in fact from industry, the fourth is a university project.

NRDC operates on a commercial basis and has been self-financing for several years—it has drawing rights with the Treasury under its constitution of which £25M is at present unused. Its success can be judged from the 15 other countries which, in recent years, have taken up the concept of such an organization to exploit inventions.

While many university inventors assign patent rights to NRDC, there is considered to be a need for greater effort in developing their inventions and £1M has been earmarked for this purpose in the coming year. The NRDC is anxious to stimulate its services to industry which are regarded as being poorly utilized. The Chairman, Sir Frank Schon, has launched a new advertising campaign aimed specifically at small and medium sized companies who, he believes, may be reluctant to pursue development projects in the prevailing economic conditions.

With justification, the NRDC can claim that it provides finance necessary to back innovations by Government establishments and university researchers (not to mention a handful of private inventors) and especially by industry itself, which could not be supported by more orthodox methods. With its technical expertise and financial resources it forges the final decisive link between the laboratory and the factory, and enables inventive achievement to be realized effectively.

* Science Research Council, Report of the Council for the year 1973–74 (HMSO, price 73p).

† National Research Development Corporation 25th Annual Report and Statement of Accounts 1973–74 (NRDC, 66–74 Victoria Street, London SW1E 6SL).

‡ 'The Management and Control of Research and Development' (HMSO, 1961).

Contributors to this issue



Professor Leslie Kay (Fellow 1965) graduated from King's College, University of Durham, in 1948 and spent the following 10 years in the Royal Naval Scientific Service working on the development of active and passive sonar systems. In 1958 he joined the Department of Electrical Engineering at the University of Birmingham as a lecturer where he continued research on underwater sound and

also commenced studies on air sonar for the blind and ultrasonics in solids. He gained his Ph.D. from the University in 1962 and in the following year he was appointed Head of the Electrical Engineering Department at Lanchester Polytechnic. In 1966 he took up the Chair in Electrical Engineering at the University of Canterbury, Christchurch, New Zealand where he has continued to direct research into the applications of sonar systems in air, water and solids. He also has a research interest in diagnostic cardiology.

In 1971-1972 he spent 18 months on special leave as Visiting Professor at Boston College, evaluating the sensory aid for the blind which is the subject of the paper published in this issue.

From 1970-1974 Professor Kay was Dean of the School of Engineering at Canterbury and in May 1971 he was elected to Fellowship of the Royal Society of New Zealand, the only engineer so far to be thus honoured.

In 1969 Professor Kay took part in the New Zealand National Development Conference and for the past 5 years he has served on the Electronics Advisory Committee of the Minister of Trade and Industry. He is a Founder Member of New Zealand's National Electronics Research Council, (patterned on the British National Electronics Council) which is now known as the National Electronics Development Association. He is also a member of the Regional Development and Fuel and Power Committees of the Canterbury Chamber of Commerce.

Soon after going to the University of Canterbury, Professor Kay became actively involved in the affairs of the Institution in New Zealand and he was subsequently appointed first Chairman of the New Zealand Division. In 1962 he received the Institution's Vladimir K. Zwoykin Premium for a paper reporting on his earlier researches and he has contributed numerous other papers to this Journal and to other scientific and technical journals.



Dr. J. K. Stevenson is a Lecturer in the Department of Electronics and Electrical Engineering in the Polytechnic of the South Bank, London. Before taking up this appointment in the autumn of 1973 he was with the General Electric Company. A fuller biography was published in the August 1973 issue of the Journal.



Mr. Verner McKinley entered the Department of Electrical and Electronic Engineering, Queen's University of Belfast in 1968, graduating with B.Sc. in 1971. Since then he has carried out research in the Department on adaptive and learning systems and their implementation using small processors.



Dr. Fabian C. Monds obtained his Doctorate from Queen's University of Belfast in 1965. From 1966 to 1967 he was a Visiting Assistant Professor in the Electrical Engineering School of Purdue University, Lafayette, Indiana. In 1968 he was appointed to a Lectureship in the Department of Electrical and Electronic Engineering at Queen's University. He is author of some 20 papers on communications, pattern recognition, hospital laboratory data processing and e.m.g. signal processing.

tion, hospital laboratory data processing and e.m.g. signal processing.

*See also page 596.

Unsupervised learning and detection of pulse signals

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SUMMARY

This paper describes an adaptive learning system for the estimation and detection of a pulse type signal of known duration but unknown shape or epoch, randomly occurring in white Gaussian noise. A combination of energy detection and cross-correlation is used to build up estimates of the signal. Results are presented for different signal shapes showing that the error rate approaches that of the ideal matched filter. The system is intended for on-line real-time implementation. The system has potential applications to medical signal processing.

List of Symbols

T	decision threshold
α	probability of a false alarm
β	probability of a miss
M_i	values of the transmitted signal samples ($i = 1-8$)
a_i	'tap weights' of the matched filter ($i = 1-8$)
x_i	samples of signal plus noise ($i = 1-8$)
α_N	variance of the additive Gaussian noise
C_α	cost of a false alarm
C_β	cost of a miss
q_0	<i>a priori</i> probability of no signal transmitted
q_1	<i>a priori</i> probability of a signal transmitted
u	mean of the matched filter output ($= \sum_{i=1}^8 a_i M_i$)
σ^2	variance of the matched filter output ($= \sigma_N \sum a_i^2$)
K	$q_0 C_\alpha / q_1 C_\beta$
E_i	sample estimates of the signal ($i = 1-8$)
A_i	accumulator register samples ($i = 1-14$)
D_i	delay line samples ($i = 1-20$)
C_i	cross-correlator register samples ($i = 1-14$)
N_{TR}	tracking length, the number of estimation detections before upgrading estimates
N_{AMF}	number of estimation detections before the system takes up an adaptive matched filter configuration
L	duration of pulse in sample intervals

1 Introduction

The purpose of this work has been to design, develop and assess a learning system for the estimation and detection of one pulse-type signal, occurring randomly in white Gaussian noise. The shape and epoch of the signal are unknown but the duration is known *a priori*. It is assumed that the noise is stationary and that the signals cannot overlap. In the investigation, a signal duration has been chosen at 8 sample intervals giving a time-bandwidth product of up to 4. The adaptive system also has the capability of tracking a signal whose shape is slowly varying, relative to the frequency of occurrence of the signal.

One objective of this work has been to produce a practical system which could be implemented using digital techniques. Because of the inevitable limitations on a practical system, design was strongly influenced by practical considerations rather than by a strictly theoretical derivation of an optimum system and computer simulations have been extensively used in the development of the system. Optimum systems derived from theory tend to be very difficult if not impossible to implement in real time, because of either the complexity of calculations or the quantity of storage required.¹

The practical system has potential application in the areas of radar, sonar and medical signal processing. In the medical field, the pulse-type electrocardiogram (e.c.g.) lends itself to processing in this way. For example, the exact e.c.g. waveform varies from subject to

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subject and is further dependent on electrode configurations.² As the subject's heart condition varies, the tracking capability of the system can accommodate the e.c.g. variations and sudden changes (e.g. due to ectopic beats) can be detected. The foetal electrocardiograph (f.e.c.g.) is also a very useful signal because its characteristics are useful in determining foetal life, foetal maturity and the existence of foetal distress of congenital heart disease.²⁻⁷ Despite its usefulness, the techniques used for detecting and estimating the f.e.c.g. are relatively simple and of poor performance. The signal/noise ratio is sometimes so poor that the foetal signal cannot even be detected by visual analysis of a pen recording.⁷

2 Review of Learning Techniques

General reviews of learning techniques have been published by Nilsson,⁸ Fu,⁹ Nagy¹⁰ and Spraggins.¹¹ Unsupervised learning has been studied by Glaser,¹ Fralick,¹² Spiker and Luby,¹³ Patrick Costello and Monds¹⁴ and McCudden and Stewart.^{15,16}

Glaser¹ developed equations for the likelihood ratio in the case of adaptive detection of one unknown signal of unknown epoch and showed that they could be interpreted as an energy detector and cross-correlator. The calculations involved were extremely complex and it is unlikely that this system could be implemented on anything short of a full-sized computer.

Fralick¹² devised a recursive equation for the calculation of the *a posteriori* probability density required, for an optimum Bayes solution to the learning problem. This equation describes a machine of finite size that may be realized in delay feedback form, but it would be difficult to implement if the signals were multi-dimensional.

Spiker and Luby¹³ produced a digital system for detecting and estimating one unknown binary waveform of unknown epoch using an energy detector-correlator. The system usually converged but some situations were found when it did not. The incoming signals had 1000 dimensions and were quantized to three levels so that a polarity coincidence correlator could be used. It could handle signals at the rate of one every two seconds.

Patrick, Costello and Monds¹⁴ produced a self-contained portable learning system called *DEMO I*. This was the first system which was decision directed, i.e. the estimates are sample means where the samples have been classified by the system. Two unknown signals of known duration and epoch could be learned and each signal had four dimensions.

McCudden¹⁵ and Stewart¹⁶ continued the work of Patrick *et al.*¹⁴ and built an experimental digital system, which could operate either in a supervised or unsupervised (decision directed) mode.

Favret and Cuputo,¹⁷ Van Bommel,¹⁸ Van Bommel and Van der Weide,¹⁹ Rhyne²⁰ and Favret²¹ have carried out work on the detection of foetal e.c.g. signals.

Favret and Caputo¹⁷ used autocorrelation techniques, processing the signals using a digital computer, but little improvement over visual detection was obtained.

Van Bommel¹⁹ devised a technique for the detection

of f.e.c.g. signals by autocorrelation and cross-correlation of envelopes but it could not be used on line.

Van Bommel and Van der Weide¹⁹ produced an on-line digital system which filtered the signal, used amplitude detection and then made use of the periodic nature of the f.e.c.g.

Rhyne²⁰ produced an on-line digital system which adds each sample to the previous three samples and if the output lies between two thresholds the signal is gated into a digital averaging device.

Favret²¹ used a matched filter technique for the detection of the foetal signal. The cross-correlator had 13 samples and a computer was used for processing.

It can be seen that there is a considerable gap between the complex systems, many of which are impractical for on-line implementation, devised by researchers in signal detection and the relatively simple methods used by researchers in f.e.c.g. detection where a practical on-line system is desirable.

3 Theoretical Considerations

The optimum method of detecting a known signal of known epoch occurring in additive Gaussian noise is the matched filter, the output of which is $\sum_{i=1}^L x_i a_i$ where

x_i represents the sampled signal plus noise and a_i are the sampled time-inverse of the signal waveform and are known as 'tap-weights'. Correlation is only effectively performed at certain points where it is known a signal may occur, i.e. the output is only examined at these points. The theoretical performance can be readily derived²² and the boundary is given by equation (1):

$$T = \frac{u}{2} + \frac{\sigma^2}{u} \log_e K \quad (1)$$

The probability of a false alarm (α) or a miss (β) is given by equations (2) and (3) respectively:

$$\alpha = \frac{1}{2} \left\{ 1 - \operatorname{erf} \left(\frac{u}{(2\sqrt{2})\sigma} + \frac{\sigma}{(\sqrt{2})u} \log_e K \right) \right\} \quad (2)$$

$$\beta = \frac{1}{2} \left\{ 1 - \operatorname{erf} \left(\frac{u}{(2\sqrt{2})\sigma} - \frac{\sigma}{(\sqrt{2})u} \log_e K \right) \right\} \quad (3)$$

where

$$u = \sum_{i=1}^8 a_i M_i$$

$$\sigma^2 = \sigma_N^2 \sum_{i=1}^8 a_i^2$$

$$K = \frac{q_0 C_\alpha}{q_1 C_\beta}$$

If synchronism is not known then the matched filter output is continuously examined and a series of correlation outputs is obtained. These outputs are not statistically independent of each other and are correlated one to another. It would appear that this type of situation could be analysed using the *k*-variate normal distribution.²³ In practice however this is complex to evaluate, e.g. an 8-sample correlation would require $k = 15$.

If the signal is initially unknown then initial estimates are required in order to initiate an adaptive matched filter. An energy detector $\sum x_i^2$ does not require *a priori* knowledge of signal shape for detection. Its output when no signal is present can be described using the chi square distribution²³ but a theoretical solution has not been found for the output if any of the inputs are of non-zero mean. The summer $\sum |x_i|$ is also capable of detection without *a priori* knowledge of signal shape but theoretical probability density functions for its output are also difficult to obtain.

In both cases an expression for the output could be obtained by building up a histogram of the distribution in a computer simulation but it would still be necessary to develop a *k*-variate distribution.

4 Development of the System

The use of the energy detector to produce the estimates required for the adaptive matched filter was investigated in a computer simulation program. In this program the samples of detected signals were averaged to improve the effective signal/noise ratio and the 'goodness' of the estimate was examined after 50 transmitted signals. The 'goodness' of the estimate was measured by obtaining the average mean square difference between the estimate and the noiseless transmitted signal, i.e. for an 8-sample signal m.s.d. = $\sum_{i=1}^8 (E_i - M_i)^2 / 8$ where $\sum_{i=1}^8 M_i^2 / 8 = 1$ and E_i are estimates of the signal.

The process was repeated 100 times to produce a reliable overall average m.s.d. and the results for various detection techniques are shown in Table 1. The energy

detector and summer had a similar performance with a m.s.d. greater than 0.8, i.e. extremely poor, almost non-existent estimates. The matched filter which was used for comparison gave an m.s.d. of 0.025.

In order to investigate the very poor performance of the energy detector and summer, error rates were taken using a computer simulation and are shown in Fig. 1 for a signal/noise ratio of 3 dB and the threshold which gave minimum total error. The error rates are expressed as probabilities per transmitted signal and a near miss occurs when a signal is not detected at its point of occurrence but within 7 sample intervals.

It can be seen from Fig. 1 that the majority of signals detected by the summer or energy detector were not detected at their exact time of occurrence but within a few sample intervals before or after it. This means that when the samples of signals detected by the energy detector are read out, stored and averaged, a very poor estimate of the transmitted signal is obtained. In an attempt to synchronize the samples of detected signals before they are averaged, each detected signal is cross-correlated with the current average of detected signals and shifted to the point of maximum correlation before being averaged.

An experimental system using this technique was simulated on the computer in the following manner. The first signal is detected by energy detection but instead of reading out and storing 8 samples which would contain the signal if the read-out time were correct, 7 samples on either side of the 8 are also read out and stored, i.e. a total of 22 samples. The threshold for this first detection is set at a very high value so as to make it highly probable that a signal is contained somewhere within the 22 stored samples. The next signal is detected by energy detection and 22 samples read out, but instead of averaging the 2 detections immediately, cross-correlation and shifting are repeatedly carried out to move the second signal to the position of maximum correlation before they are averaged to form a new estimate. This is then repeated for each detected signal so that the cross-correlation aligns it with the current average

Table 1. M.s.d. of estimates

Mode of Detection	M.S.D.
Summer	> 0.8
Energy detection	> 0.8
Energy detection plus correlation	0.08
Matched filter	0.025

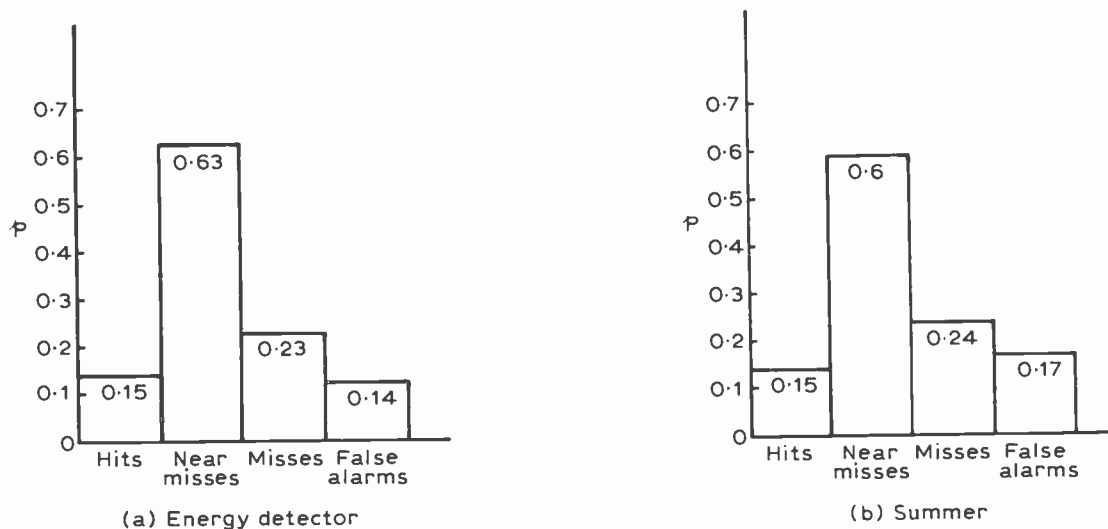


Fig. 1. Error rates for energy detector and summer based on a computer simulation

before the overall average is formed.

Table 1 shows that this system of energy detection plus cross-correlation produced considerably improved estimates (average m.s.d. of 0.08) over the basic energy detector estimates. This system however was purely experimental and would be inefficient and difficult to implement in practice because of the number of multiplications and the quantity of storage required. One of the practical modifications of the system is the reduction of the number of samples stored and used as an estimate in the cross-correlation process from 22 to 14. This means that if the transmitted signal is to be contained in the 14 samples read out during the first detection, the maximum allowable error in read-out time is reduced from 7 to 3 sample intervals. As most of the near misses are concentrated close to the transmitted signal this was felt to be acceptable considering the substantial reduction in storage and multiplication requirements.

The system was also modified into a more practicable form for real-time operation utilizing the same basic principles to build up an estimate of the signal. This final system model is described in detail in the following Section and flow charts of the system are shown in the Appendix.

5 The Final System Model

The block diagram in Fig. 2 shows the delay line and relative positions of the energy detector, cross-correlator and accumulator register. A delay line of 20 sample intervals is required and samples are entering from the right and moving towards the left in shifts of 1 sample interval. The incoming waveform of signal plus noise has been sampled and binary coded to produce the incoming samples. Positions in the delay line are labelled D_1 to D_{20} , position D_{20} holding the most recent sample. The energy detector output equals the sum of the square of the samples in positions D_{13} to D_{20} , i.e. $\sum_{i=13}^{20} D_i^2$. The cross-correlator is a 14-sample storage and multiplication register, the output of which equals $\sum_{i=1}^{14} C_i D_{i+6}$ and gives a measure of the correlation between the

cross-correlator samples, i.e. C_i and the input samples in D_7 to D_{20} . In general the cross-correlator samples will be an estimate of signal waveform formed from previous detections. The accumulator register is a 14-sample register used to sum, store and average recently detected signal estimates until the average is used to upgrade the cross-correlator samples.

5.1 Detection of the First Signal

The first signal is detected purely by energy detection as there is no *a priori* knowledge of its waveform. The system detects the first signal at a peak in energy detector output greater than the initial energy detector threshold and followed by 9 lower values. The energy detector output is compared with the initial energy detector threshold and if it exceeds it then that output value is stored. The following energy detector outputs are compared with this stored value and if greater, then the stored value is replaced by the new maximum. When the delay line samples have been shifted 9 sample intervals since the last maximum then the samples in positions D_1 to D_{14} are read into the accumulator register positions A_1 to A_{14} .

It can be seen from Fig. 2 that those 8 samples which caused the peak in energy detector output will now be in positions A_4 to A_{11} of the accumulator register. As 3 samples before and after the detected signal are also stored in the accumulator register then provided the error in detecting the signal is not greater than 3 sample intervals the accumulator register will contain all 8 samples of signal plus noise and 6 samples of noise.

5.2 Detection of Following Signals

Following signals are detected by a combination of energy detection and cross-correlation. The approximate position of a signal is determined by the energy detector and then the cross-correlator is used to ensure that the signal is detected accurately, relative to the cross-correlator estimates by finding the position of maximum correlation.

The energy detector output is compared with the energy detection threshold (a lower threshold than the initial one) and once this is exceeded the cross correlator

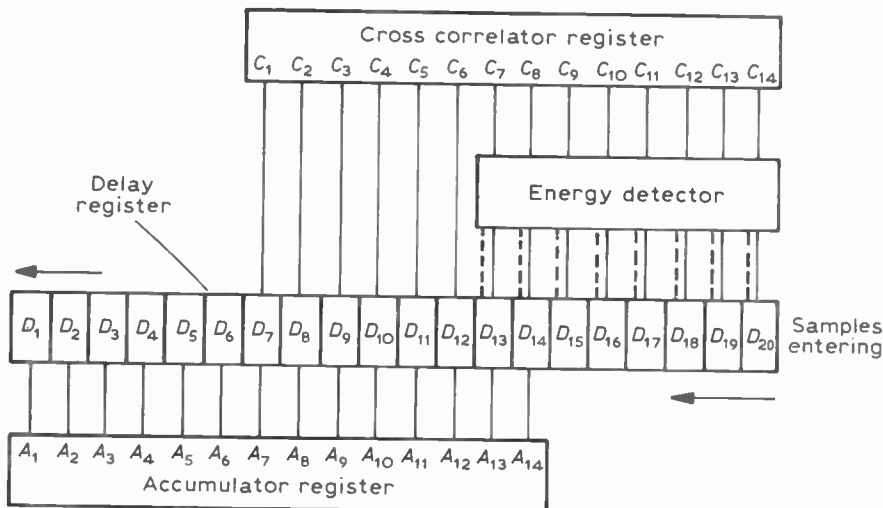


Fig. 2. Layout of the system.

is brought into action correlating the estimate of signal shape with delay line samples D_7 to D_{20} . The criterion for a detection is a peak in cross-correlator output, greater than the cross-correlator estimation threshold and followed by 6 lower values. It can be seen from Fig. 2 that since the cross correlator and accumulator register are displaced by 6 sample intervals then after 6 shifts of the delay line samples since a maximum those 14 samples which were highly correlated with the cross correlator estimates will be in positions D_1 to D_{14} and can be read out into the accumulator register.

5.3 Upgrading of Cross Correlator Estimates

Initially estimates are formed from the equally weighted average of all detected signals. In order to simplify averaging of detected signal samples, upgrading does not take place after each detected signal but rather at those times when the total number of detections is a power of two, i.e. after 1, 2, 4, 8 detected signals. New estimates are formed from the sum of all detected signals divided by a power of 2 and as each sample is a binary coded value this is easily accomplished by a right shift of the bits within each sample. The accumulator register holds the sum of all detected signal samples and as each new detection is made it is read out of the delay register and added to the previous contents of the accumulator register. When upgrading occurs the accumulator register sample bits are temporarily shifted to perform the division and copied into the cross correlator register. The bits of the accumulator register samples are shifted to the left back to their original position so that the accumulator register still contains the sum of all detected signals.

When the cross correlator register has been upgraded after N_{TR} detected signals (where N_{TR} is the tracking length and is a power of 2) the upgrading pattern changes. The accumulator register is now cleared after each upgrading and the number of detections between upgradings is now held constant at N_{TR} detections, i.e. new estimates are formed from the equally weighed average of the last N_{TR} detections.

5.4 Formation of the Adaptive Matched Filter Configuration

After N_{AMF} detections the energy detector is no longer used and the cross correlator alone is used for estimation and detection. The system has now become an adaptive matched filter. The value of N_{AMF} is not critical as will be seen from the results in the next section.

6 Results

6.1 Test Parameters

All results are from computer simulations on the University's ICL 1907 and 1906S computers. The samples of white Gaussian noise are uncorrelated random numbers with a normal distribution and were generated from ICL subroutines and stored on a 2400 ft magnetic tape which holds approximately 1.1 million numbers. The variance (σ^2) of the noise is unity and the transmitted signal samples are scaled to give the required signal/noise ratio which was defined as:

$$S/N \text{ ratio} = \frac{\sum_{i=1}^8 M_i^2}{\sigma^2}$$

In order to compare different detection systems the total error rate is used and is defined as the sum of the number of false alarms and misses, divided by the number of transmitted signals. A miss is said to occur if a signal is not detected within 7 samples from its point of occurrence and a false alarm is said to occur if a detection is claimed which is not within 7 sample intervals of the point of occurrence of a transmitted signal. Confidence limits of 95% have been placed on these results where necessary, i.e. where two quite close values are being compared. These imply that the true value will lie within the limits 95% of the time.

The two thresholds for the energy detector are set to a high value to ensure a low false alarm rate as all detected signals are used to form estimates. A false alarm will cause a deterioration in estimates while a miss is relatively unimportant and only slows up the learning system. It is particularly important that the first detection be correct and a value of 30.0 was chosen for the initial energy detection threshold and this effectively gives a constant false alarm rate of 0.050 at a mark/space ratio of 1 : 4 irrespective of S/N ratio and signal shape. If this threshold was chosen any lower the false alarm rate would be higher while if it were chosen higher there would be an excessive time delay before the system makes the first detection. The latter factor is particularly important at lower S/N ratios.

The energy detection threshold is chosen somewhat lower at 22.0 to allow the learning process to progress at a reasonable speed while maintaining a fairly low false alarm rate of 0.086.

There are two cross correlator thresholds, the cross-correlator detection threshold which is set to give a minimum total error rate, and the cross-correlator estimation threshold which is set rather higher to lower the probability of false alarms 'damaging' the formation of estimates. The equation for the minimum total error threshold level for the synchronized matched filter (equation (1)) is used in this system to determine the threshold setting. Computer simulations have shown this to yield a close approximation to the minimum total error boundary. This value is multiplied by a factor F where

$$F = \frac{\sum_{i=1}^{14} C_i^2}{\text{energy of transmitted signal}}$$

This is to compensate for the fact that the energy of the cross-correlator estimate samples may vary and avoids the necessity of normalizing these estimate samples.

6.2 Performance

The performance of the learning system was investigated in a computer simulation by evaluating the total error rate after each upgrading of the cross-correlator register. The error rate of the system remains constant between upgradings. In order to improve the confidence

limits on the error rates the system is effectively 'frozen' at the desired point in the learning process while 30 signals are transmitted and the system attempts to detect them. The whole process is repeated 500 times, the learning system starting from the beginning with no *a priori* knowledge of signal waveform, each time, and the overall total error rate evaluated. Results were taken for a S/N ratio of 3 dB, $N_{TR} = 8$ (a tracking length of 8) and several values of N_{AMF} (where N_{AMF} is the number of estimation detections before the system becomes an adaptive matched filter). Before N_{AMF} detections the system is making detections purely for estimation and the total error rate will be high as a high threshold is being used resulting in a high miss rate. An extra lower energy detection threshold could be introduced in an attempt to give minimum total error detection during this period before N_{AMF} estimation detections. In this case the system would have similar performance (as far as detection is concerned) as an energy detector, i.e. at a S/N ratio of 3 dB and a mark/space ratio of 1 : 4 a total error rate of approximately 0.38. These results are shown on Table 2. The confidence limits on the results in Table 2 are ± 0.006 .

In order to compare the learning system with other possible detection procedures for different signal waveforms, five different groups of eight samples were used as test signals and the samples of these are shown in Table 3 together with an approximate analogue reconstruction of signal shape for each group. Results were taken as before for a S/N ratio of 3 dB, a mark/space ratio of 1 : 4, $N_{TR} = 8$ and $N_{AMF} = 4$ and the total error rates are shown in column 6 of Table 4. The first four columns in Table 4 show the total error rates for detection of the test signals by cross-correlation with either of four groups of samples representing basic signal shapes (these are identical to signals 1-4, Table 3). Column five gives the minimum total error rate for an energy detector while column seven shows the same for a matched filter.

The performance of the adaptive learning system over a range of S/N ratios for a mark/space ratio of 1 : 4 is shown in Fig. 3. These total error rates were

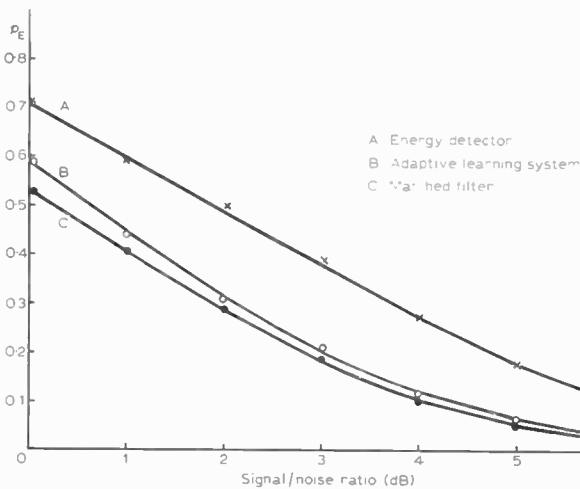


Fig. 3. Total error rates.

Table 2. Total error rates S/N = 3 dB

N_{AMF}	After 0 detections	After 1 detection	After 2 detections	After 4 detections	After 8 detections	After 16 detections
1	~0.38	0.388	0.323	0.265	0.237	0.215
2	~0.38	~0.38	0.332	0.291	0.238	0.211
4	~0.38	~0.38	~0.38	0.277	0.238	0.208
8	~0.38	~0.38	~0.38	~0.38	0.223	0.213

Table 3. Test signal waveforms

Sample values of test signals	Analogue representation
10 10 10 10 10 10 10 10	
0.16 0.32 0.72 0.95 0.95 0.72 0.32 0.16	
-0.7 -1.0 -0.2 1.6 1.7 -0.2 -0.7 -0.4	
0.38 0.92 0.92 0.38 -0.38 -0.92 -0.92 -0.38	
10 -10 10 -10 10 -10 10 -10	

Table 4. Total error rates

Test signals transmitted	Detection by cross-correlation with				Energy detector	Adaptive learning system (after 16 detections)	Matched filter
	0.12	0.16	>0.9	>0.9	0.39	0.14	0.12
	0.16	0.13	0.54	0.72	0.38	0.14	0.13
	>0.9	0.54	0.14	0.57	0.40	0.18	0.14
	>0.9	0.73	0.57	0.18	0.38	0.21	0.18
	>0.9	>0.9	>0.9	>0.9	0.40	0.17	0.14

obtained from a computer simulation as before with $N_{TR} = 8$ and $N_{AMF} = 4$ and the transmitted signal samples were -0.6, -1.0, -0.2, 1.6, 1.7, -0.2, -0.6, -0.4. The total error rates for the energy detector and matched filter under the same conditions are also shown. The rate of learning of the system is of importance and the number of signals transmitted before the 1st and before the 16th estimation detection occurred are given in Table 5.

Table 5. Rate of learning of the adaptive system

S/N ratio (dB)	Number of transmitted signals before 1st detection	Number of transmitted signals before 16th detection
0	17.0	57.2
1	9.4	42.2
2	5.2	31.5
3	3.6	25.0
4	2.2	20.7
5	1.6	18.5
6	1.2	16.8

7 Discussion of Results

Each line in Table 2 gives the total error rate as the number of estimation detections increase for a S/N ratio of 3 dB and a mark/space ratio of 1:4, the minimum error rate is initially that of an energy detector, i.e. 0.38, but after 16 estimation detections (on average 25 transmitted signals) the total error rate has dropped to approximately 0.20 indicating that the system is successfully learning the signal waveform and adapting itself to it. The total error rate will converge towards a value which depends on the tracking length as a long tracking length will lower the variance of the estimate samples (assuming a non-varying transmitted signal waveform) and give an improvement in performance. However, a long tracking length will detract from the ability of the system to detect time varying signals. The value of N_{AMF} is not critical as after 16 estimation detections the differences in total error rate are within the confidence limits. Lower values of N_{AMF} give some improvement in total error rate for the first few transmitted signals.

Reading across each line in Table 4 it can be seen that the adaptive learning system is approaching the matched filter performance for all the test signal waveforms although it has no *a priori* knowledge of any of these. The energy detector produces consistent results also without *a priori* knowledge of signal waveform but the total error rate is high compared with the adaptive learning system. Detection by cross-correlation with one of the basic waveforms will only produce good results when detecting a signal of similar waveform and is unreliable if the transmitted signal waveform is unknown.

The adaptive learning system is capable of learning and detecting a pulse signal at a S/N ratio as low as 0 dB after 16 estimation detections while over the range 0 dB to 6 dB the system shows considerable improvement over the energy detector and approaches the performance of the matched filter. The latter of course makes full use of the knowledge of signal waveform. Table 5 shows the effect of S/N ratio on rate of learning and at lower S/N ratios the system learning rate is appreciably slower.

8 Implementation

As already mentioned the system has been designed to be implemented as a hardware system which could be used on-line. However, it is also ideally suited for

on-line implementation using a general-purpose mini-computer. Storage requirements for the program and its execution are less than 1000 words. Sampling rates up to 1 kHz could be accommodated if the mini-computer had a hardware multiplier and a cycle time of 1.6 μ s.

9 Conclusions

The adaptive learning system is capable of estimating an unknown signal occurring randomly in white Gaussian noise and detecting it with an error rate approaching that of the ideal matched filter. The system also has the capability of tracking slowly-time-varying signals.

The system is especially useful in that it is suitable for on-line implementation as special-purpose hardware or using general-purpose mini-computer.

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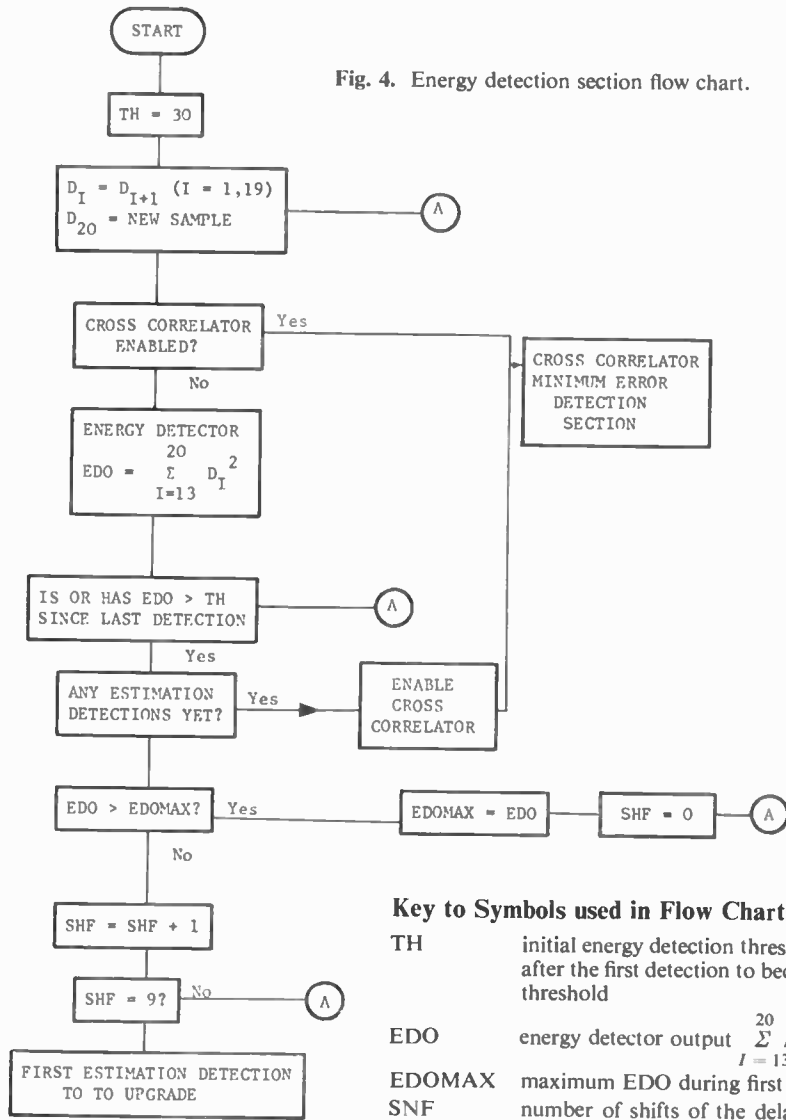


Fig. 4. Energy detection section flow chart.

Key to Symbols used in Flow Charts

- TH initial energy detection threshold but value is changed after the first detection to become the energy detection threshold
- EDO energy detector output $\sum_{I=13}^{20} D_I^2$
- EDOMAX maximum EDO during first detection
- SNF number of shifts of the delay line samples since the last peak in EDO during first detection
- TD minimum error cross-correlator detection threshold
- CCO cross-correlator output $\sum_{I=1}^{14} D_{I+6} C_I$
- CCOMAX maximum CCO during a minimum error detection
- SHFD number of shifts of the delay line samples since the last peak in CCO during a minimum error detection

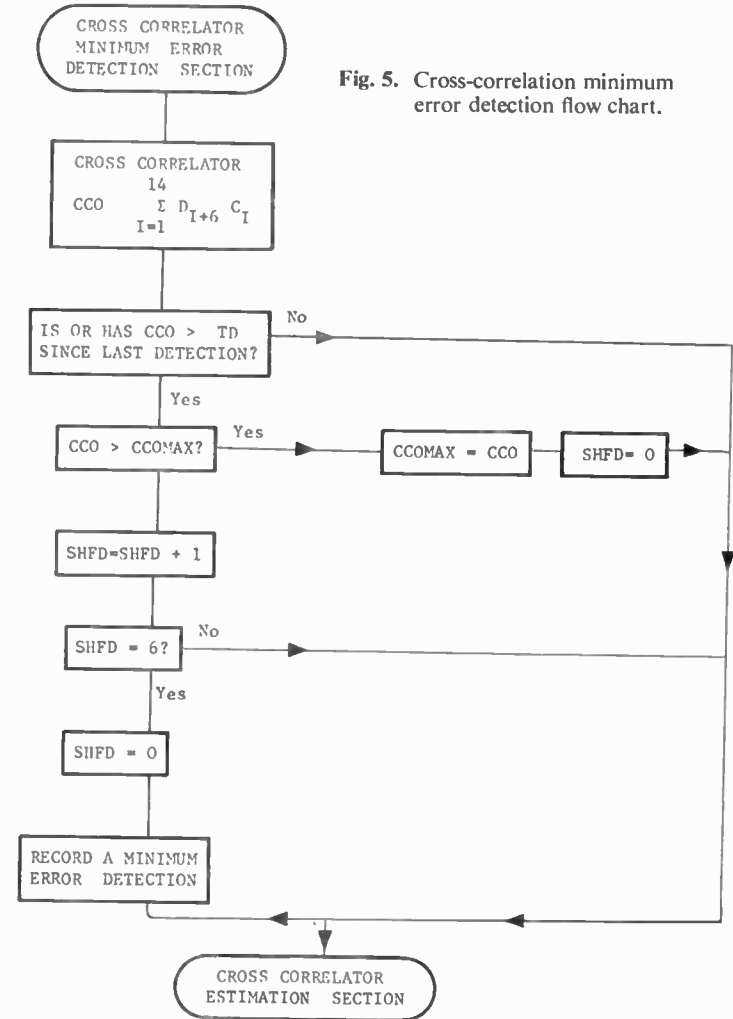


Fig. 5. Cross-correlation minimum error detection flow chart.

- TE cross-correlator estimation threshold
- CCOMAXE maximum CCO during an estimation detection
- SHFE number of shifts of the delay line samples since the last peak in CCO during an estimation detection
- TR tracking length, number of estimation detections before upgrading estimates
- EDET number of estimation detections (used by the system while there are less than TR estimation detections)
- EDETSU number of estimation detections since upgrading (used by the system when there are more than TR estimation detections)

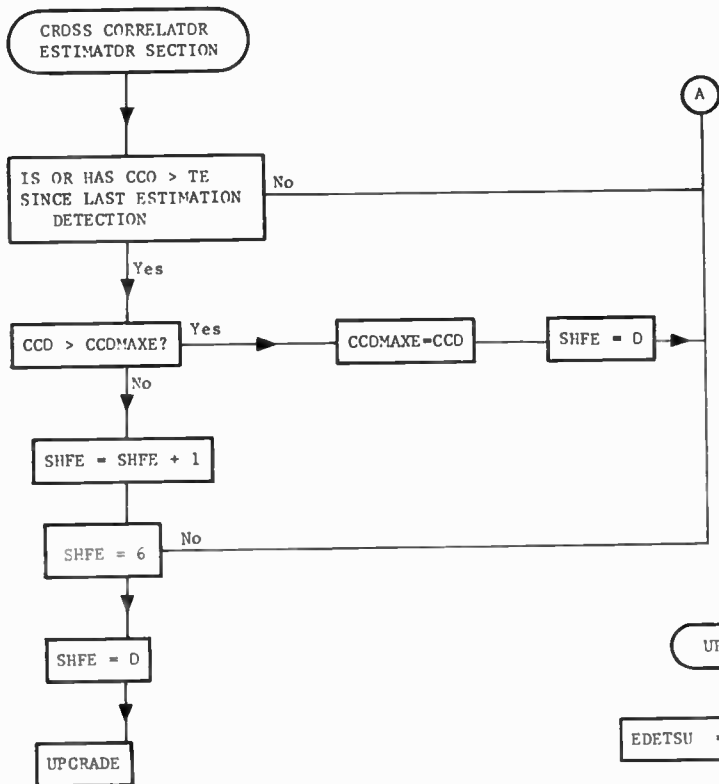
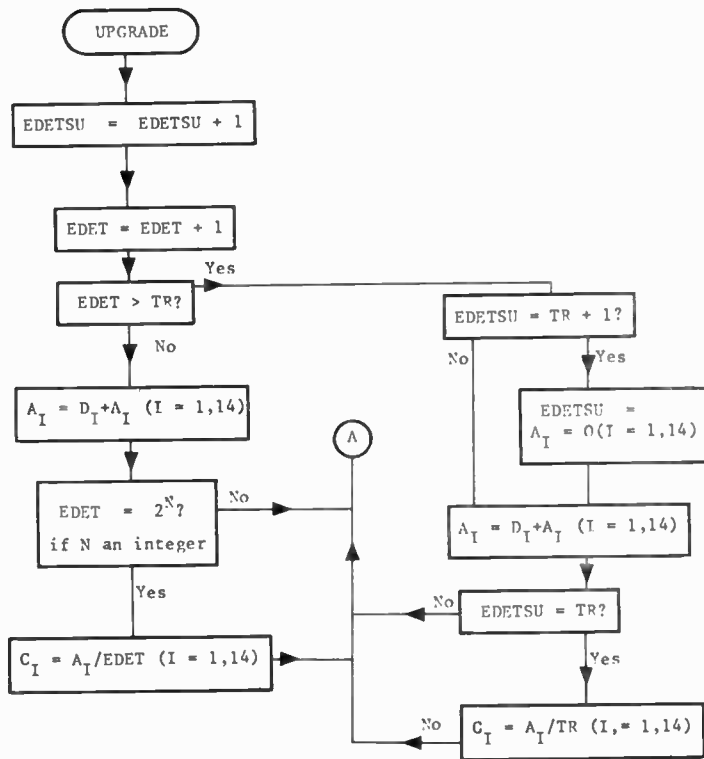


Fig. 6. Cross-correlation estimation detection flow chart.

Fig. 7. Upgrading section flow chart.



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11 Appendix

Figures 4-7 show flow charts of the adaptive learning system and an additional list of symbols used in the flow charts is provided. These flow charts have been considerably simplified and have been written so as to aid understanding of the system rather than to give a rigid or very detailed representation.

Manuscript first received by the Institution on 16th May 1973, in revised form on 2nd January 1974 and in final form on 17th April 1974. (Paper No. 1610/CC215.)

Company Financial Performance in the British Electronics Industry

The 1974 edition of 'Company Financial Performance in the Electronics Industry', covering the latest available results of over 300 of the industry's major companies, has recently been published*: it reveals how the consumer goods sector grew fastest of all up to 1972/73, while growth in the capital equipment sectors was very much slower.

The report provides an insight into the performance of 338 companies in the industry, each with an annual turnover in excess of £½M. It also enables comparisons to be made between companies in the five sectors of the industry covered and for the industry's results as a whole to be compared with previous years. The five sectors are based on Minimum List Headings of the Standard Industrial Classification as revised in 1968, namely Scientific and industrial instruments and systems, Radio and electronic components, Broadcast receiving and sound reproducing equipment, Electronic computers, and Radio, radar and electronic capital goods. (A sixth relevant sector in the Minimum List Headings is Telegraphic and telephone apparatus, but full financial data could not be obtained on the UK divisions of the few companies in this field.)

The latest available information has been included for sixteen financial key items and ratios, and a four-year view is given for four items—sales, exports, pre-interest profits and net capital employed. Altogether some 223 companies' results for 1972/73 are included and 318 for 1971/72.

The report shows that the decline in the industry's profitability from 1969 halted in 1971/72 when pre-interest profits as a percentage of net capital employed reached 13.5%. By 1972/73 this had recovered to 20.1%. Only the computer

sector recovered less strongly, although the instruments sector did not experience good profitability throughout the whole period covered. The consumer goods sector generated a consistently high return while the communications and other capital equipment sector recovered strongly in 1972/73. It is noticeable that the sector with the highest profitability—consumer goods—achieved the lowest export/sales ratio, while the reverse was true for the computers sector.

The export performance of the industry as a whole was creditable with 40% between 1969/70 and 1972/73. Exports by instruments companies showed the highest growth, although exports of consumer goods substantially increased in 1972/73. Two companies are singled out as influencing the export performance of their respective sectors: communications by Marconi, and the components sector by BSR whose principal products are now more related in fact to the consumer sector.

The picture for net capital employed is complicated by the effects of inflation. The very low figures for net capital employed in consumer goods are partly explained by the accounting practices in that sector.

From the analysis of the structure and ownership of the industry in 1971/72, some 35% by numbers were foreign-owned and accounted for 34% of total sales. In computers foreign-owned companies accounted for 58% of sales and 49% in components. The instruments sector was clearly the most fragmented with 135 companies all with a turnover in excess of £½ M. The component sector, however, had the lowest average annual sales of £4 M per company. In contrast the computer companies had average sales of £22.6 M.

The Electronics EDC expresses the hope that this annual survey, together with the 'Annual Statistical Survey of the Electronics Industry', will facilitate and stimulate improved performance by the industry.

* 'Company Financial Performance in the Electronics Industry 1969/70-1972/73' is available, price £1.00 postage paid from Neddy Books, NEDO, Millbank Tower, London SW1P 4QX.

STANDARD FREQUENCY TRANSMISSIONS—September 1974

(Communication from the National Physical Laboratory)

Sept. 1974	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)		Sept. 1974	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	0	-0.1	700		601.2	17	0	0	-0.2
2	0	0	-0.2	700	601.2	18	0	0	-0.2	700	601.9
3	0	0	-0.1	700	601.3	19	0	0	-0.1	700	601.9
4	0	0	-0.1	700	601.4	20	0	0	-0.1	700	601.9
5	0	0	-0.1	700	601.6	21	0	0	-0.1	700	602.0
6	0	0	-0.1	700	601.5	22	0	0	-0.1	700	602.1
7	0	0	-0.1	700	602.1	23	0	0	-0.1	700	602.3
8	0	-0.1	-0.1	700	601.7	24	0	0	-0.1	700	602.4
9	0	0	-0.1	700	602.0	25	0	0	-0.1	700	602.6
10	0	0	-0.1	700	601.7	26	0	0	-0.1	700	602.6
11	0	0	-0.1	700	601.7	27	0	0	-0.1	700	602.8
12	0	0	-0.1	700	601.7	28	0	0	-0.1	700	602.9
13	0	0	-0.2	700	601.6	29	-0.1	0	-0.2	701	603.1
14	0	0	-0.1	700	601.7	30	0	0	-0.2	701	602.8
15	0	0	-0.2	700	601.6						
16	0	0	-0.2	700	601.4						

All measurements in terms of H-P Caesium Standard No. 334, agrees with the NPL Caesium Standard to 1 part in 10¹¹.

* 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.

Eigenvalues for a trapezoidal waveguide

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and

Professor M. A. K. HAMID, Ph.D.*

SUMMARY

The eigenvalue solution for modes propagating in a trapezoidal waveguide is derived using Schwarz's iterative method of overlapping regions. The technique involves matching the field expansion of each two overlapping regions on one boundary of the overlapping region and using field continuity on the other boundary to couple the successive iterations. The method is efficient and provides accurate results for the eigenvalues of the dominant and first few higher order modes. Numerical results are presented for the isosceles trapezoidal waveguide case, where the solution is simplified by making use of symmetry planes.

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1 Introduction

The problem of field distribution in waveguides of non-conventional cross-sections has been treated by various methods including ray optics, conformal mapping and many numerical techniques.¹⁻⁵ In particular, waveguides of trapezoidal cross-section have been solved by applying the transverse resonance method with a three-step deformation in each lateral side⁶ and by approximating the lateral sides of the uniform isosceles trapezoidal cross-section by three steps, thus forming five rectangular waveguides.⁷

In this paper, we employ Schwarz's method of overlapping regions⁸ to obtain an eigenvalue solution for trapezoidal waveguide of arbitrary dimensions. The solution is simplified by symmetry considerations, since it will be only necessary to solve for a right-angled trapezoid. Example calculations for the cut-off wavenumbers for isosceles trapezoidal waveguide are presented.

2 Formulation

A schematic diagram of a trapezoidal waveguide of arbitrary dimensions is shown in Fig. 1. The cross-section is divided into three overlapping regions: Region I is a wedge-shaped region OAC, Region II is a rectangular

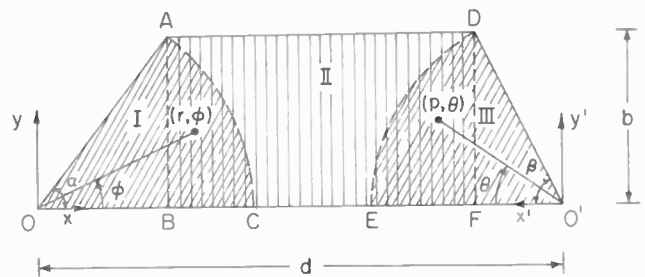


Fig. 1. Schematic diagram of trapezoidal waveguide sub-regions.

region ABFD, and Region III is a wedge-shaped region O'DE. The excitation corresponds to TE modes, while the solution for TM modes can be derived in a similar fashion.

For the TE modes (or H waves), $E_z = 0$ while $\partial H_z / \partial n = 0$ on all metal boundaries with normal n . Thus the magnetic fields in the three regions are given by the eigenfunction expansions:

$$H_{zI} = \sum_{m=0}^{\infty} A_m J_\nu(K_c r) \cos \nu \phi \quad (1)$$

$$H_{zII} = \sum_{s=0}^{\infty} \cos \left(\frac{s\pi y}{b} \right) [B_{1s} \cos \gamma_s x + B_{2s} \sin \gamma_s x] \quad (2)$$

$$H_{zIII} = \sum_{p=0}^{\infty} C_p J_\mu(K_c \rho) \cos \mu \theta \quad (3)$$

where

$$\nu = \frac{m\pi}{\alpha}, \quad \mu = \frac{p\pi}{\beta} \quad \text{and} \quad \gamma_s^2 = K_c^2 - \left(\frac{s\pi}{b} \right)^2$$

In order to employ Schwarz's iterative procedure and to apply the continuity condition on the tangential fields

across the boundaries between regions II and III, we describe the field expansion in region II with respect to the origin O' in the form

$$H_{zII} = \sum_{s=0}^{\infty} \cos\left(\frac{s\pi y'}{b}\right) [B'_{1s} \cos \gamma_s x' + B'_{2s} \sin \gamma_s x'] \quad (4)$$

where $y = y'$, $x' = d - x$ and the coefficients B'_{1s} and B'_{2s} are related to B_{1s} and B_{2s} by

$$B'_{1s} = B_{1s} \cos \gamma_s d + B_{2s} \sin \gamma_s d$$

$$B'_{2s} = B_{1s} \sin \gamma_s d - B_{2s} \cos \gamma_s d$$

Applying the continuity condition on the tangential fields across the boundary $x = g = b \cot \alpha$, we have

$$\frac{\partial H_{zI}}{\partial x} \Big|_{x=g} = \frac{\partial H_{zII}}{\partial x} \Big|_{x=g} \quad (5)$$

$$\sum_{s=0}^{\infty} \cos\left(\frac{s\pi y}{b}\right) [-\gamma_s B_{1s} \sin(\gamma_s g) + \gamma_s B_{2s} \cos \gamma_s g] = \sum_{m=0}^{\infty} A_m \frac{\partial [J_v(K_c r) \cos v\phi]}{\partial x} \Big|_{x=g} \quad (6)$$

$$H_{zI} \Big|_{x=g} = H_{zII} \Big|_{x=g} \quad (7)$$

$$\sum_{s=0}^{\infty} \cos\left(\frac{s\pi y}{b}\right) [B_{1s} \cos \gamma_s g + B_{2s} \sin \gamma_s g] = \sum_{m=0}^{\infty} A_m [J_v(K_c r) \cos v\phi] \Big|_{x=g} \quad (8)$$

Employing the orthogonality of the trigonometric functions on the left-hand side of equations (6) and (8), we get

$$B_{1s} \sin \gamma_s g - B_{2s} \cos \gamma_s g = \sum_{m=0}^{\infty} A_m V_{sm} \quad (9)$$

$$B_{1s} \cos \gamma_s g + B_{2s} \sin \gamma_s g = \sum_{m=0}^{\infty} A_m W_{sm} \quad (10)$$

where

$$V_{sm} = \frac{-2}{\gamma_s b} \int_0^b \cos\left(\frac{s\pi y}{b}\right) \times [J'_v(K_c \sqrt{g^2 + y^2}) \frac{K_c g}{\sqrt{g^2 + y^2}} \cos v(\tan^{-1} y/g) + J_v(K_c \sqrt{g^2 + y^2}) \sin v(\tan^{-1} y/g) \frac{vy}{y^2 + g^2}] dy$$

$$W_{sm} = \frac{2}{b} \int_0^b \cos\left(\frac{s\pi y}{b}\right) \times [J_v(K_c \sqrt{g^2 + y^2}) \cos v(\tan^{-1} y/g)] dy$$

An additional equation, which will be used to couple the successive iterations, is obtained by applying the continuity of E_ϕ at the boundary AC. Hence

$$\frac{\partial H_{zI}}{\partial r} \Big|_{r=T} = \frac{\partial H_{zII}}{\partial r} \Big|_{r=T} \quad (11)$$

$$\sum_{m=0}^{\infty} A_m K_c J'_v(K_c T) \cos v\phi = \frac{\partial}{\partial r} \sum_{s=0}^{\infty} \cos\left(\frac{s\pi y}{b}\right) [B_{1s} \cos \gamma_s x + B_{2s} \sin \gamma_s x] \Big|_{r=T} \quad (12)$$

Using the orthogonality property of the trigonometric

functions on the left-hand side, we obtain

$$A_m = \sum_{s=0}^{\infty} B_{1s} U_{1sm} + B_{2s} U_{2sm} \quad (13)$$

where

$$U_{1sm} = \frac{-2}{\alpha K_c J'_v(K_c T)} \int_0^\alpha \cos v\phi \times \left[\frac{s\pi}{b} \sin \phi \sin\left(\frac{s\pi}{b} T \sin \phi\right) \cos(\gamma_s T \cos \phi) + \gamma_s \cos \phi \left(\frac{s\pi}{b} T \sin \phi\right) \sin(\gamma_s T \cos \phi) \right] d\phi$$

$$U_{2sm} = \frac{-2}{\alpha K_c J'_v(K_c T)} \int_0^\alpha \cos v\phi \times \left[\frac{s\pi}{b} \sin \phi \sin\left(\frac{s\pi}{b} T \sin \phi\right) \sin(\gamma_s T \cos \phi) - \gamma_s \cos \phi \cos\left(\frac{s\pi}{b} T \sin \phi\right) \times \cos(\gamma_s T \cos \phi) \right] d\phi$$

and

$$T = b \operatorname{cosec} \alpha$$

Similarly, we follow the same procedure to apply the continuity condition on the tangential fields across the boundaries between regions II and III and using field expansions expressed with respect to the origin O' we have, respectively

$$B'_{1s} \sin(\gamma_s a) - B'_{2s} \cos(\gamma_s a) = \sum_{p=0}^{\infty} C_p V'_{sp} \quad (14)$$

$$B'_{1s} \cos(\gamma_s a) + B'_{2s} \sin(\gamma_s a) = \sum_{p=0}^{\infty} C_p W'_{sp} \quad (15)$$

and

$$C_p = \sum_{s=0}^{\infty} B'_{1s} U'_{1sp} + B'_{2s} U'_{2sp} \quad (16)$$

where V'_{sp} and W'_{sp} are given respectively by V_{sm} and W_{sm} with v replaced by μ and g by a , while

$$U'_{1sp} = \frac{-2}{\beta K_c J'_\mu(K_c R)} \int_0^\beta \cos \mu\theta \times \left[\frac{s\pi}{b} \sin \theta \sin\left(\frac{s\pi}{b} R \sin \theta\right) \cos(\gamma_s R \cos \theta) + \gamma_s \cos \theta \cos\left(\frac{s\pi}{b} R \sin \theta\right) \sin(\gamma_s R \cos \theta) \right] d\theta$$

$$U'_{2sp} = \frac{-2}{\beta K_c J'_\mu(K_c R)} \int_0^\beta \cos \mu\theta \times \left[\frac{s\pi}{b} \sin \theta \sin\left(\frac{s\pi}{b} R \sin \theta\right) \cos(\gamma_s R \cos \theta) - \gamma_s \cos \theta \cos\left(\frac{s\pi}{b} R \sin \theta\right) \cos(\gamma_s R \cos \theta) \right] d\theta$$

$$R = b \operatorname{cosec} \beta$$

and

$$a = b \cot \beta$$

The solution of the given set of equations (9), (10) and (13-16) is obtained by the iterative method, starting with assigned arbitrary values for any two sets of the unknowns B_{1s} , B_{2s} , A_m , C_p and K_c . Typically one can start by assuming a series of coefficients A_m and the ratio B_{1s}/B_{2s} . Although the initial values may be completely arbitrary, the successive approximations constructed according to Schwarz's method will converge to some limit function which satisfies the wave equation and the boundary conditions.⁸

If the waveguide has a longitudinal plane of symmetry as shown in Fig. 2 (i.e. an isosceles trapezoidal cross-section) then the problem can be reduced to two cases, one for magnetic symmetry wall and the other for electric symmetry wall. It is clear that in this case we have to solve only for a right-angled trapezoidal waveguide with an electric or magnetic conducting wall at the symmetry plane and consequently the ratio B_{1s}/B_{2s} will not be initially assumed but will be determined depending on the boundary condition on the symmetry plane.

For an electric symmetry plane

$$\left. \frac{\partial H_{z11}}{\partial x} \right|_{x=d/2}$$

and hence

$$B_{1s}/B_{2s} = \frac{\cos(\gamma_s d/2)}{\sin(\gamma_s d/2)}$$

For magnetic symmetry plane

$$H_{z11}|_{x=d/2} = 0$$

and

$$B_{1s}/B_{2s} = -\frac{\sin(\gamma_s d/2)}{\cos(\gamma_s d/2)}$$

Therefore, for the isosceles trapezoidal waveguide, the set of equations (9), (10) and (13) are iterated simultaneously only with the series of coefficients A_m are initially assigned arbitrarily.

The accuracy of the iterative method has been verified with computations of cut-off wavenumbers for the dominant modes in isosceles trapezoidal waveguides. Table 1 shows the calculated values along with available results in the literature.^{6,7}

Table 2 shows the cut-off wavenumbers for higher order TE modes. It is to be noted that on substituting the B_s coefficients from (9) to (10) to obtain a characteristic equation for the unknown eigenvalues K_c for certain A_m coefficients, the resulting equation has singularities in addition to the desired roots. Since most standard root finding techniques are locally convergent, the procedure followed here was first to solve a low-order approximation by scanning the characteristic equation against K_c , and the zeros are used as the basis for a more accurate solution.⁹

3 Discussion and Conclusion

An eigenvalue solution for modes propagating in a trapezoidal waveguide of arbitrary dimensions has been presented using Schwarz's method of overlapping

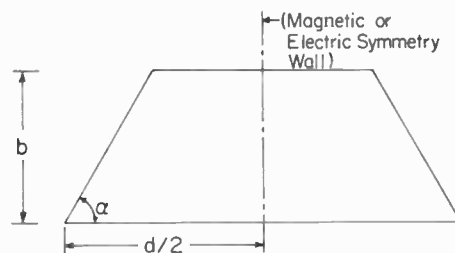


Fig. 2. Schematic diagram of isosceles trapezoidal waveguide with a symmetry plane.

regions. The main advantage of the method is that it describes the modal fields in terms of a rapidly converging series, especially for narrow angle wedged-shaped regions, due to the large orders and small arguments of the Bessel functions. Thus truncation of the infinite series in equations (9), (10) and (13) up to the first five terms is found adequate for all cases in Table 1 except the last case where only the first four terms in equations (9) and (10) are used. The required number of iterations is basically dependent on the assumed field on the boundary AC, namely on the initially assigned values of the coefficients A_m . In fact the first term $A_0 = 1$ is quite appropriate and the number of iterations is typically three. The validity of these truncations is evident from Table 1 where the deviations from previous solutions by Yashkin and Uptain^{6,7} are typically less than 1% except for the $\alpha = 30^\circ$ case where larger deviations are observed. However, Uptain pointed out certain difficulties of his method for this case whereas our method suffers from

Table 1. $\eta(2d/\lambda_c)$ calculated for the dominant mode in trapezoidal waveguides with $b/d = 0.25$ for different values of α .

α	Yashkin ⁷	Transverse resonance ⁶	Proposed method
80°	1.04	1.05	1.04
70°	1.10	1.10	1.10
60°	1.17	1.16	1.16
50°	1.26	1.25	1.26
40°	1.33	1.36	1.37
30°	1.36	1.45	1.62

Table 2. Values of η calculated for the dominant and higher order TE modes in isosceles trapezoidal waveguides with $b/d = 0.25$. The M and E notation in the brackets denote magnetic and electric symmetry walls respectively.

α	Mode			
	1st	2nd	3rd	4th
80°	1.04(M)	2.08(E)	3.12(M)	4.14(E)
70°	1.10(M)	2.18(E)	3.25(M)	4.32(E)
60°	1.16(M)	2.31(E)	3.44(M)	4.54(E)
50°	1.25(M)	2.48(E)	3.65(M)	4.75(E)

truncation errors associated with small values α . As far as the computation time is concerned, the proposed method is found to be quite adequate compared with other numerical techniques. Thus, while Beaubien and Wexler's finite difference algorithm³ needs about 8 minutes for each waveguide mode using an IBM 360/65 computer, and Bates⁴ requires about 0.5 minute on an IBM 360/44 computer using the straightforward point matching technique, our results require 1.5 minutes using an IBM 360/65 computer for each case in Table I. However, the proposed iterative method as well as the point matching technique require more computation time for higher-order modes. In fact, the iterative method was found more efficient¹⁰ where no numerical integrations are involved. Typically, 8.5 seconds are required for accurate calculation of the dominant modes, while up to three times this figure is needed for higher-order modes. This compares favourably with 0.5 minute using the straightforward point matching technique and 5.5 seconds using the extended point matching technique⁴ for the eigenvalues of each mode.

4 Acknowledgment

This research was supported by the National Research Council of Canada, Grant A-3326 and the Defence Research Board of Canada, Grant 3801-42.

*Manuscript received by the Institution on 18th February 1974
(Paper No. 1611/CC216).*

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Tabulation of characteristics and active network design values for Cauer elliptic function filters of order 2 to 9

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SUMMARY

Design values are given for active elliptic function filters realized with biquadratic sections in tandem; for networks of odd-order there is an additional linear section. The complete set of tables contains sixteen separate designs for filters of each order from second to ninth, with attenuation and phase characteristics for each design. Only one network order (8th) is included here: the full paper containing all the tables is published separately.

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List of Principal Symbols

$-a_0$	real zero $H(s)$ for network of odd order
$-a_i$	real part of complex zero of $H(s)$, corresponding to i th biquadratic section
b_i	imaginary part of complex zero of $H(s)$, for i th section
C	constant term in expression for $H_1(s)$
$H_1(s)$	transfer-loss function; ratio of load voltage with source and load coupled for maximum power transfer, to actual load voltage
$H(s)$	transfer-loss function scaled so $H(0) = 1$ to give zero attenuation at zero frequency; $H(s) = H_1(s)/H_1(s) _{s=0} = V_{out}(s) _{s=0}/V_{out}(s)$
H_e	real part of $H(j\omega)$, given by coefficients of even-order
H_{o0}	imaginary part of $H(j\omega)$, given by coefficients of odd-order
$n \equiv N$	order of network
p	reflexion coefficient
$Q_i \equiv Q$	Q -factor of i th biquadratic section; design parameter
s	complex frequency variable; $s = \sigma + j\omega$
$V_{out}(s)$	output voltage for network
α	insertion loss relative to zero frequency value, in decibels
$\alpha_p \equiv A(P)$	pass-band ripple
$\alpha_{min} \equiv A(MIN)$	minimum attenuation in stop band, relative to zero frequency value
$-\beta$	phase shift in radians
$\omega \equiv W/WO$	angular frequency (normalized with respect to pass-band cut-off frequency)
$\omega_{r0} \equiv W(R)$	design frequency for linear section of odd-order network
$\omega_{ri} \equiv W(R)$	design frequency for i th biquadratic section
$\omega_s \equiv W(S)$	stop-band cut-off frequency; lowest frequency at which attenuation equals α_{min}
$\omega_\infty \equiv W(INF)$	frequency of infinite attenuation; design parameter

1 Introduction

Tables of design values are readily available for elliptic function filters realized with passive elements,¹⁻⁵ but not with active elements; tables giving attenuation and phase characteristics are also deficient. For this reason, a program was written in *Fortran IV* for implementation on a Honeywell time-sharing computer to generate sets of tables giving design values for low-pass active sections, and attenuation and phase characteristics. The filters are initially specified by zeros and poles of the transfer-loss function,⁶ defined as the ratio of the load voltage with the source and load coupled for maximum power transfer,

to the actual load voltage. The active sections are in biquadratic form, each relating to a complex conjugate pair of zeros and a positive-negative pair of attenuation poles. For networks of odd-order, there is an additional linear section resulting from a single real zero, and this produces a single attenuation pole at infinite frequency. Four tables, each with four pass-band ripple values, have been calculated for filters of each order from second to ninth. Band-pass filters may be synthesized by applying a frequency transformation directly to the factorized terms in the transfer-loss function (or alternatively, the voltage transfer ratio);^{7,8} high-pass and band-stop filters result from inverting the normalized frequency variable for low-pass and band-pass filters, respectively.

The tables resulted from a requirement at the Admiralty Underwater Weapons Establishment (A.U.W.E.) for design values and characteristics of representative elliptic function filters.

2 Theory

Tabulated values for the normalized zeros and poles of the transfer-loss function $H_1(s)$ are given in Christian and Eisenmann's tables.⁶ The zeros are in complex conjugate pairs with an additional real zero for networks of odd order. For an n th order network,

$$H_1(s) = (1 + C^2)^{\frac{1}{2}} \prod_{i=1}^{\frac{1}{2}n} \frac{(s^2 + 2a_i s + a_i^2 + b_i^2)}{(s^2 + \omega_{\infty i}^2)} \quad \dots n \text{ even}$$

$$H_1(s) = C(s + a_0) \prod_{i=1}^{\frac{1}{2}(n-1)} \frac{(s^2 + 2a_i s + a_i^2 + b_i^2)}{(s^2 + \omega_{\infty i}^2)} \quad \dots n \text{ odd}$$

By inspection, the zeros occur at $s = -a_i \pm jb_i$, and also at $s = -a_0$ for odd orders, and poles at $s = \pm j\omega_{\infty i}$ (or $\omega = \pm \omega_{\infty i}$).[†]

It is usual to define attenuation relative to the minimum value, but for active networks it is generally more convenient to give attenuation relative to the d.c. value ($\omega = 0$). As a result, we will define $H(s)$ as follows.[‡]

$$H(s) = \left. \begin{aligned} & \frac{V_{out}(s)|_{s=0}}{V_{out}(s)} \\ & = \prod_{i=1}^{\frac{1}{2}n} \frac{s^2 + \frac{2a_i s}{a_i^2 + b_i^2} + 1}{\frac{s^2}{\omega_{\infty i}^2} + 1} \quad \dots n \text{ even} \\ & H(s) = \frac{V_{out}(s)|_{s=0}}{V_{out}(s)} = \left(\frac{s}{a_0} + 1 \right) \times \\ & \times \prod_{i=1}^{\frac{1}{2}(n-1)} \frac{s^2 + \frac{2a_i s}{a_i^2 + b_i^2} + 1}{\frac{s^2}{\omega_{\infty i}^2} + 1} \quad \dots n \text{ odd} \end{aligned} \right\} \quad (1)$$

$V_{out}(s)$ is the output voltage for the network, and $H(s)$ has been scaled so that its value is unity at zero frequency. Clearly, $H(s)$ is equal to $H_1(s)$ for responses with mini-

[†] We have preserved the original notation (in Reference 6) but for simplicity have defined a and b as positive constants. Christian and Eisenmann define as zeros $s = a_0, a_1 + jb_1$; the negative values of a are then subtracted in the formulae for $H_1(s)$.

mum attenuation at zero frequency, including Causer filters of odd-order and class-c even-order. The attenuation α , and phase shift, $-\beta$, both relative to zero frequency, are given by the following,

$$\alpha = 10 \log_{10} (H_e^2 + H_0^2), \quad \beta = \tan^{-1} \frac{H_0}{H_e}$$

where

$$H(j\omega) = H_e + jH_0$$

In computer analysis programs with a range of frequencies in ascending order, it is preferable to determine the first value of β in this manner and subsequent values from the previous plus the phase difference. The range of values for β is then no longer restricted to 2π . Defining

$$\beta_1 = \tan^{-1} \frac{H_{01}}{H_{e1}}, \quad \beta_2 = \tan^{-1} \frac{H_{02}}{H_{e2}}$$

we obtain

$$\beta_2 = \beta_1 + \tan^{-1} \frac{H_{e1}H_{02} - H_{01}H_{e2}}{H_{e1}H_{e2} + H_{01}H_{02}}$$

At real frequencies, with $s = j\omega$,

$$H(j\omega) = \prod_{i=1}^{\frac{1}{2}n} \frac{\left(1 - \frac{\omega^2}{a_i^2 + b_i^2}\right) + j \frac{2a_i\omega}{a_i^2 + b_i^2}}{1 - \frac{\omega^2}{\omega_{\infty i}^2}} \quad \dots n \text{ even}$$

$$H(j\omega) = \left(1 + j \frac{\omega}{a_0}\right) \times \prod_{i=1}^{\frac{1}{2}(n-1)} \frac{\left(1 - \frac{\omega^2}{a_i^2 + b_i^2}\right) + j \frac{2a_i\omega}{a_i^2 + b_i^2}}{1 - \frac{\omega^2}{\omega_{\infty i}^2}} \quad \dots n \text{ odd}$$

Let H_{em} and H_{0m} denote the values of H_e and H_0 for the m th biquadratic section, and H_{em}^t and H_{0m}^t the value of H_e and H_0 resulting from a network consisting of the first m biquadratic sections (plus the linear section for n odd). i.e.

$$H_{em}^t + jH_{0m}^t = \prod_{i=0}^m (H_{ei} + jH_{0i})$$

Also,

$$H(j\omega) = H_e + jH_0 = \prod_{i=0}^{\frac{1}{2}n} (H_{ei} + jH_{0i}) \quad \dots n \text{ even}$$

$$= \prod_{i=0}^{\frac{1}{2}(n-1)} (H_{ei} + jH_{0i}) \quad \dots n \text{ odd}$$

Commencing with $H_{e0} = 1, H_{00} = 0$ for n even, and $H_{e0} = 1, H_{00} = \omega/a_0$ for n odd, a simple recursive formula which avoids using complex arithmetic in a computer program is given by separating the real and

[‡] Note that the voltage transfer ratio is usually used for expressing the characteristics of active filters. Nevertheless, the transfer-loss function, which is inversely proportional to this ratio, has been used instead for two reasons; firstly, the original roots are given for this function⁶ which is used extensively in filter theory, and secondly, there is less likelihood of ambiguity when describing attenuation poles and zeros, i.e. attenuation poles are the same as transfer-loss function poles and voltage transfer ratio zeros.

imaginary parts in

$$H'_{ei} + jH'_{oi} = \frac{\left(1 - \frac{\omega^2}{a_i^2 + b_i^2}\right) + j \frac{2a_i\omega}{a_i^2 + b_i^2}}{1 - \frac{\omega^2}{\omega_{\infty i}^2}} [H'_{e(i-1)} + jH'_{o(i-1)}]$$

$$\text{i.e. } \left. \begin{aligned} H'_{ei} &= \frac{\left(1 - \frac{\omega^2}{a_i^2 + b_i^2}\right) H'_{e(i-1)} - \frac{2a_i\omega}{a_i^2 + b_i^2} H'_{o(i-1)}}{1 - \frac{\omega^2}{\omega_{\infty i}^2}} \\ H'_{oi} &= \frac{\frac{2a_i\omega}{a_i^2 + b_i^2} H'_{e(i-1)} + \left(1 - \frac{\omega^2}{a_i^2 + b_i^2}\right) H'_{o(i-1)}}{1 - \frac{\omega^2}{\omega_{\infty i}^2}} \end{aligned} \right\} \begin{aligned} 1 \leq i \leq \frac{1}{2}n \quad \dots n \text{ even} \\ 1 \leq i \leq \frac{1}{2}(n-1) \quad \dots n \text{ odd} \end{aligned}$$

A useful realization in active form consists of linear and biquadratic sections in tandem, characterized by ω_r and Q , which are included in the Tables. These parameters are defined by the following expressions for the transfer-loss function $H(s)$:

$$\left. \begin{aligned} H(s) &= \prod_{i=1}^{\frac{1}{2}n} \frac{\left(\frac{s}{\omega_{ri}}\right)^2 + \frac{1}{Q_i} \left(\frac{s}{\omega_{ri}}\right) + 1}{\left(\frac{s}{\omega_{\infty i}}\right)^2 + 1} \quad \dots n \text{ even} \\ H(s) &= \left(\frac{s}{\omega_{r0}} + 1\right) \times \prod_{i=1}^{\frac{1}{2}(n-1)} \frac{\left(\frac{s}{\omega_{ri}}\right)^2 + \frac{1}{Q_i} \left(\frac{s}{\omega_{ri}}\right) + 1}{\left(\frac{s}{\omega_{\infty i}}\right)^2 + 1} \quad \dots n \text{ odd} \end{aligned} \right\} (2)$$

The values of ω_r and Q are independent of the circuits used for implementing the filters. The linear section is realized most simply using a first-order passive RC circuit consisting of a series resistor R and shunt capacitor C (nearer the load), where $\omega_{r0} = 1/CR$. The biquadratic sections should have large input and small output impedances to minimize the interaction between sections; one of the most suitable realizations is the low-sensitivity active RC circuit of Lim.^{9,10}

3 Results

Sixteen designs for each order are contained in the Tables, and the following points relate to their interpretation and the selection procedure used.

3.1 Selection Procedure

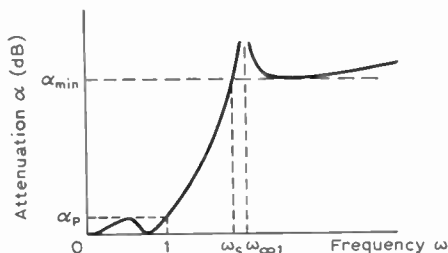
(i) *Pass-band attenuation, α_p*

In Christian and Eisenmann's tables of roots, pass-band ripple is expressed in terms of the reflexion coefficient p . The corresponding attenuation α_p , as defined in Figs. 1 and 2, is given as follows:

$$\alpha_p = 10 \log_{10} (1-p^2)^{-1} \text{ dB}$$

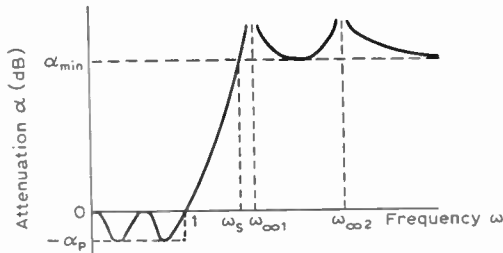
Hence,

$$\left. \begin{aligned} p &= 0.05, 0.10, 0.15, 0.25, 0.50 \\ \alpha_p &= 0.0109, 0.0436, 0.0988, 0.2803, 1.2494 \text{ dB} \end{aligned} \right\}$$



$$\frac{V_{out}(s)|_{s=j\omega}}{V_{out}(s)|_{s=0}} = \frac{1 - \frac{\omega^2}{\omega_{\infty 1}^2}}{\left(1 + j\frac{\omega}{a_0}\right) \left(1 - \frac{\omega^2}{a_1^2 + b_1^2} + j\frac{2a_1\omega}{a_1^2 + b_1^2}\right)}$$

Fig. 1. 3rd-order filter.



$$\frac{V_{out}(s)|_{s=j\omega}}{V_{out}(s)|_{s=0}} = \frac{\left(1 - \frac{\omega^2}{\omega_{\infty 1}^2}\right) \left(1 - \frac{\omega^2}{\omega_{\infty 2}^2}\right)}{\left(1 - \frac{\omega^2}{a_1^2 + b_1^2} + j\frac{2a_1\omega}{a_1^2 + b_1^2}\right) \left(1 - \frac{\omega^2}{a_2^2 + b_2^2} + j\frac{2a_2\omega}{a_2^2 + b_2^2}\right)}$$

Fig. 2. 4th-order filter (class a).

The last four values were considered the most useful and are used in the tables (given to two decimal places).

(ii) *Stop-band attenuation, α_{min}*

For each set of α_p terms, values of ω_s were selected such that α_{min} is closest to 30, 40, 50 and 60 dB when $\alpha_p = 0.28$ dB.

(iii) *Class of Caer functions*

The even-order filters are class a, as distinct from the degenerate forms b and c. For given values of α_p and α_{min} , class a has the smallest ω_s and the maximum number of turning points in a plot of attenuation against frequency. The class b characteristic is similar, with the highest ω_∞ removed to infinite frequency to facilitate passive LC realization, and class c is similar to b with one less turning point in the pass-band for maximum transmission at zero frequency. Class a has finite attenuation at infinite frequency, and cannot be realized in passive LC form without mutual inductances. Only one classification (class a) is provided for odd-order functions which are always realizable, and have attenuation characteristics similar to the class c even function one order higher.

(iv) *Frequencies selected for tabulation*

α and β are tabulated for the normalized frequencies 0 to 1 in 0.1 steps in the pass-band; also given are the initial stop-band frequency, ω_s and each value of ω_∞ . Additional frequencies are provided as follows, rounded as stated to reasonable values for measurement purposes:

- (i) Four frequencies are given in the transition band, namely $1+x, 1+2x, 1+3x, 1+4x$, where $x \approx (\omega_s - 1)/5$. The increment x is rounded initially to one decimal place and more are added, if required, until the final step, $\omega_s - (1+4x)$, lies between $\frac{1}{2}x$ and $2x$.
- (ii) Mid-way between adjacent values of ω_∞ and at twice the maximum value of ω_∞ , a frequency is given rounded to sufficient decimal places, with a minimum of one, for the increase from the previous frequency to be significant.
- (iii) For odd orders only, two frequencies are given above the attenuation minimum which follows the highest finite attenuation pole. The frequencies selected are the integral values at which the attenuation is nearest to $\alpha_{min} + 10$ dB, $\alpha_{min} + 20$ dB when $\alpha_p = 0.28$ dB. The final increase in attenuation is 6 dB per octave due to the single pole at infinite frequency.

3.2 Interpretation of Tables

(i) *Redefinition of α_{min}*

Stop-band attenuation is usually defined relative to the pass-band minimum, whereas it is generally more convenient with active filters to express attenuation relative to the zero frequency value (as in the present Tables). For odd orders there is no difference as the pass-band minimum occurs at zero frequency, as shown in Fig. 1. For even orders, our values of α_{min} are slightly less than

those in the original Tables, the difference being α_p . Negative attenuation in our Tables denotes gain; see Fig. 2.

(ii) *Phase discontinuity at α_∞*

An increase in β of π occurs from just below to just above an attenuation pole, and the lower of these two values is given in the tables. At the i th attenuation pole, $s = j\omega_{\infty i}$, and therefore

$$\left(\frac{s^2}{\omega_{\infty i}^2} + 1\right)$$

changes from positive to negative (with increasing frequency) resulting in a sign change for both the real and imaginary parts of H ; this corresponds to a phase change of π radians, since β is given by the inverse tangent of this ratio.

(iii) *Maximum phase shift resulting from sections*

The effect on the maximum phase shift of an additional linear and biquadratic section is an increase of $\frac{1}{2}\pi$ and 2π radians, respectively; the transfer-loss function $H(s)$, as given in equation (2), is multiplied by the following factors,

$$\frac{s}{\omega_{r0}} + 1 \quad \dots \text{linear section}$$

$$\frac{\left(\frac{s}{\omega_{ri}}\right)^2 + \frac{1}{Q_i}\left(\frac{s}{\omega_{ri}}\right) + 1}{\left(\frac{s}{\omega_{\infty i}}\right)^2 + 1} \quad \dots \text{ith biquadratic section}$$

Each second-order section has two zeros and two finite poles, each contributing $\frac{1}{2}\pi$ radians to the maximum phase shift, and the first order section has a single zero. The single pole at infinite frequency for the first-order section results from the numerator being one degree in s higher than the denominator (which is unity and therefore of degree zero).

(iv) *Linear and biquadratic active sections*

ω_r and Q form pairs and each pair is associated with a separate value of ω_∞ , the three parameters defining a biquadratic section. The values of ω_∞ are freely interchangeable since they are not associated with specific ω_r and Q values. For odd-order networks there follows in the Tables an additional ω_r term which is associated with $\omega_\infty = \infty$, and realizable with a linear section.

4 Example

Using the Tables given here, determine the most suitable filter for satisfying the following specification: attenuation less than 1 dB at frequencies below 10 kHz and greater than 45 dB above 11 kHz

With parameters expressed in computer notation, we require $A(P) < 1$ dB, $A(MIN) > 45$ dB, $W(S) \leq 1.1$ ($= 11/10$). From the index there are seen to be seven possible solutions, two of eighth order and five of ninth order.† The eighth-order networks have parameters as

† Only the set of four tables for the eighth order are included in this abridged version of the paper: the full set of 32 tables is published, with the text, as a 'Designers' Monograph', price £1.00.

follows:

$$\left. \begin{aligned} A(P) &= 0.10 \text{ dB}, A(\text{MIN}) = 45.03 \text{ dB} \\ A(P) &= 0.28 \text{ dB}, A(\text{MIN}) = 49.47 \text{ dB} \end{aligned} \right\} W(S) = 1.07853$$

The second solution is preferable, with good pass-band and stop-band clearances. The design values for the individual sections are as follows:

2nd-order sections				
$\omega_r \equiv W(R)$	1.00580	0.95812	0.80926	0.50785
Q	30.97393	6.85318	2.07675	0.66925
$\omega_\infty \equiv W(\text{INF})$	3.66620	1.47790	1.16156	1.08568

The values of ω_∞ , which are interchangeable, are given here in descending order.

Element values for a filter realized using the Lim circuit in Fig. 3 are contained in the following Table.† C was set to 2.7 nF and, to simplify subsequent adjustment, resistors were chosen to satisfy the condition $R_5 \gg R_3 R_4 / (R_3 + R_4)$.

Table 1

2nd-order sections				
R_1 (k Ω)	5.8606	6.1523	7.2840	11.6070
R_2 (k Ω)	11.7213	12.3046	14.5679	23.2140
R_3 (k Ω)	0.1	0.47	0.56	1.0
R_4 (k Ω)	9.1922	9.1930	2.9289	1.0078
R_5 (k Ω)	1.8546	1.6036	1.9579	3.3671
C_{1A} (nF)	2.4968	1.5652	1.3894	2.1092
C_{1B} (nF)	0.2032	1.1348	1.3106	0.5908
C_2 (nF)	2.7	2.7	2.7	2.7
C_3 (nF)	2.7	2.7	2.7	2.7

5 Acknowledgments

The author would like to acknowledge helpful discussions with Dr. W. Saraga and Mr. D. G. Haigh of the Electrical Engineering Department, Imperial College and Mr. R. G. Barker of the Admiralty Underwater

† Design equations for the 'equal capacitor' low-pass Lim circuit are as follows¹⁰, $R_1 = R$, $R_2 = 2R$, $R_4/R_3 = 3Q-1$, $R_5 + R_3 R_4 / (R_3 + R_4) = R/3$, $C_{1A} + C_{1B} = C_2 = C_3 = C$, $C_{1A}/C_{1B} = (\omega_\infty/\omega_r)^2 - 1$, $RC = 1/\omega_r$. Since these element values are denormalized, ω in the design tables must be multiplied by $2\pi \times 10^4$, the cut-off frequency in rad/s.

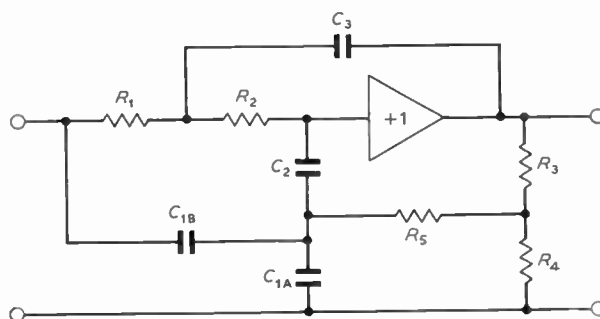


Fig. 3. Low-pass Lim circuit.

Weapons Establishment. The work was supported by a contract from the Ministry of Defence, Navy, sponsored by the Director, A.U.W.E.

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Manuscript first received by the Institution on 7th January 1974 and in final form on 14th August 1974 (Paper No. 1612/CC217).

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INDEX

ORDER	W(S)	PASS-BAND RIPPLE, A(P) (DB)				TABLE
		0.04	0.10	0.28	1.25	
		MIN. STOP-BAND ATTENUATION, A(MIN) (DB)				
2	28.65370	50.32	53.84	58.28	64.30	1
2	19.10720	43.28	46.80	51.24	57.26	2
2	9.56675	31.23	34.75	39.18	45.20	3
2	5.75877	22.35	25.85	30.28	36.30	4
3	6.39245	52.31	55.88	60.50	67.49	5
3	4.44541	42.66	46.24	50.86	57.85	6
3	2.92380	31.29	34.86	39.48	46.47	7
3	2.13005	22.27	25.83	30.44	37.43	8
4	2.92380	52.33	55.85	60.29	66.31	9
4	2.20269	41.60	45.12	49.56	55.58	10
4	1.74345	32.10	35.62	40.06	46.08	11
4	1.39016	21.70	25.20	29.63	35.65	12
5	1.88708	52.32	55.90	60.51	67.50	13
5	1.55573	41.90	45.48	50.10	57.09	14
5	1.32501	32.00	35.57	40.19	47.18	15
5	1.16663	22.28	25.85	30.46	37.44	16
6	1.43956	51.14	54.66	59.10	65.12	17
6	1.28676	42.32	45.84	50.28	56.30	18
6	1.15470	31.95	35.47	39.91	45.93	19
6	1.07114	22.04	25.55	29.98	36.00	20
7	1.25214	51.98	55.56	60.18	67.17	21
7	1.14335	41.36	44.94	49.56	56.55	22
7	1.07853	32.36	35.94	40.55	47.54	23
7	1.03061	21.79	25.35	29.96	36.94	24
8	1.14335	51.79	55.32	59.75	65.77	25
8	1.07853	41.51	45.03	49.47	55.49	26
8	1.04030	32.53	36.05	40.49	46.51	27
8	1.01543	22.79	26.30	30.73	36.74	28
9	1.08636	52.41	55.98	60.60	67.59	29
9	1.04569	42.36	45.93	50.55	57.54	30
9	1.01872	31.61	35.18	39.80	46.79	31
9	1.00551	21.02	24.58	29.19	36.17	32

Table 25

ORDER = 8

W(S) 1.14335
W(INF) 1.15364 1.25829 1.66203 4.27916

A(P)	0.04 DB	0.10 DB	0.28 DB	1.25 DB
A(MIN)	51.79 DB	55.32 DB	59.75 DB	65.77 DB
W(R)	1.02464	1.01652	1.00758	0.99793
Q	16.90576	18.75670	22.46442	33.61832
W(R)	0.97630	0.95978	0.94171	0.92232
Q	4.09154	4.53352	5.42025	8.09351
W(R)	0.84329	0.80503	0.76350	0.71915
Q	1.43405	1.57293	1.85499	2.72001
W(R)	0.62050	0.54416	0.45698	0.35366
Q	0.59525	0.61517	0.65900	0.81414

W/WO	PASS-BAND RIPPLE (DB)							
	0.04	0.10	0.28	1.25	0.04	0.10	0.28	1.25
	ATTENUATION (DB)				PHASE (DEG)			
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	-0.01	-0.03	-0.08	-0.34	22.11	23.40	24.73	24.61
0.2	-0.04	-0.08	-0.24	-1.03	44.76	47.57	50.90	53.89
0.3	-0.04	-0.09	-0.27	-1.19	68.35	72.90	78.90	88.59
0.4	-0.02	-0.04	-0.12	-0.50	93.18	99.48	107.95	122.45
0.5	0.00	0.00	0.00	0.00	119.80	127.73	137.94	152.79
0.6	-0.02	-0.05	-0.13	-0.56	149.43	159.21	171.44	186.83
0.7	-0.04	-0.10	-0.28	-1.23	184.11	196.54	212.66	236.67
0.8	0.00	-0.01	-0.02	-0.09	226.51	242.14	262.54	293.35
0.9	-0.04	-0.10	-0.27	-1.20	284.07	304.27	330.40	367.73
1.0	0.00	0.00	0.00	0.00	388.35	421.86	468.48	545.49
1.030	3.04	5.16	8.65	14.20	455.87	497.02	547.34	613.49
1.060	12.66	16.05	20.41	26.40	510.15	542.25	580.75	632.73
1.090	23.67	27.19	31.62	37.64	538.45	565.11	597.84	642.98
1.120	36.24	39.76	44.19	50.22	556.25	579.87	609.17	649.94
1.14335	51.79	55.32	59.75	65.77	566.61	588.56	615.92	654.13
1.15364	INF	INF	INF	INF	570.54	591.88	618.50	655.74
1.210	53.54	57.06	61.50	67.52	767.66	786.39	809.86	842.84
1.25829	INF	INF	INF	INF	778.49	795.61	817.12	847.41
1.500	54.64	58.16	62.59	68.61	990.44	1002.95	1018.73	1041.06
1.66203	INF	INF	INF	INF	1002.71	1013.48	1027.09	1046.36
3.000	55.38	58.90	63.34	69.36	1221.64	1226.96	1233.70	1243.26
4.27916	INF	INF	INF	INF	1233.66	1237.31	1241.94	1248.50
8.600	54.67	58.19	62.63	68.65	1427.08	1428.87	1431.14	1434.36

Table 26

ORDER = 8

W(S) 1.07853
W(INF) 1.08568 1.16156 1.47790 3.66620

A(P)	0.04 DB	0.10 DB	0.28 DB	1.25 DB
A(MIN)	41.51 DB	45.03 DB	49.47 DB	55.49 DB
W(R)	1.01824	1.01237	1.00580	0.99859
Q	23.96053	26.22304	30.97393	45.71817
W(R)	0.98828	0.97399	0.95812	0.94084
Q	5.31043	5.80784	6.85318	10.10155
W(R)	0.89230	0.85262	0.80926	0.76269
Q	1.63733	1.77815	2.07675	3.01707
W(R)	0.69740	0.60818	0.50785	0.39083
Q	0.60696	0.62596	0.66925	0.82534

W/WO	PASS-BAND RIPPLE (DB)							
	0.04	0.10	0.28	1.25	0.04	0.10	0.28	1.25
	ATTENUATION (DB)				PHASE (DEG)			
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	-0.01	-0.02	-0.07	-0.28	18.87	20.18	21.54	21.62
0.2	-0.03	-0.07	-0.21	-0.91	38.21	41.01	44.29	46.89
0.3	-0.04	-0.10	-0.28	-1.25	58.42	62.95	68.79	77.36
0.4	-0.03	-0.07	-0.18	-0.79	79.85	86.20	94.70	109.22
0.5	0.00	-0.01	-0.03	-0.10	102.99	111.10	121.70	138.22
0.6	-0.01	-0.02	-0.04	-0.18	128.89	138.82	151.31	167.74
0.7	-0.04	-0.09	-0.26	-1.13	159.61	172.04	187.82	209.20
0.8	-0.02	-0.05	-0.13	-0.55	198.53	214.47	235.36	267.92
0.9	-0.03	-0.06	-0.16	-0.70	253.70	274.22	300.42	336.24
1.0	0.00	0.00	0.00	0.00	370.83	406.83	456.56	537.93
1.016	1.52	2.88	5.58	10.59	418.50	462.70	519.56	596.55
1.032	7.65	10.73	14.93	20.84	469.01	508.19	554.85	616.96
1.048	16.53	20.00	24.41	30.41	500.84	533.59	573.40	627.79
1.064	26.98	30.50	34.93	40.95	520.66	549.68	585.49	635.09
1.07853	41.51	45.03	49.47	55.49	533.60	560.40	593.71	640.13
1.08568	INF	INF	INF	INF	538.89	564.83	597.13	642.24
1.120	42.24	45.77	50.20	56.22	738.50	761.36	790.00	830.26
1.16156	INF	INF	INF	INF	754.92	775.31	800.96	837.13
1.300	42.08	45.61	50.04	56.06	966.89	982.65	1002.55	1030.76
1.47790	INF	INF	INF	INF	988.90	1001.55	1017.54	1049.26
2.600	45.22	48.75	53.18	59.20	1215.28	1221.46	1229.29	1240.45
3.66620	INF	INF	INF	INF	1229.15	1233.41	1238.81	1246.51
7.300	44.41	47.94	52.37	58.39	1424.81	1426.91	1429.57	1433.35

Table 27

ORDER = 8

W(S)	1.04030			
W(INF)	1.04501	1.09801	1.34287	3.18529
A(P)	0.04 DB	0.10 DB	0.28 DB	1.25 DB
A(MIN)	32.53 DB	36.05 DB	40.49 DB	46.51 DB
W(R)	1.01252	1.00862	1.00415	0.99915
Q	37.19450	39.95564	46.32250	67.13263
W(R)	0.99758	0.98594	0.97274	0.95807
Q	7.39099	7.93730	9.19758	13.31959
W(R)	0.94061	0.90082	0.85675	0.80884
Q	1.95268	2.08846	2.40346	3.44357
W(R)	0.79415	0.68776	0.57029	0.43586
Q	0.62456	0.64159	0.68357	0.84045

Table 28

ORDER = 8

W(S)	1.01543			
W(INF)	1.01793	1.04921	1.22094	2.70618
A(P)	0.04 DB	0.10 DB	0.28 DB	1.25 DB
A(MIN)	22.79 DB	26.30 DB	30.73 DB	36.74 DB
W(R)	1.00686	1.00483	1.00243	0.99963
Q	75.79510	78.69678	88.24956	123.87357
W(R)	1.00441	0.99636	0.98688	0.97595
Q	12.65761	13.14145	14.73464	20.67665
W(R)	0.99240	0.95552	0.91331	0.86607
Q	2.64688	2.74466	3.06739	4.27734
W(R)	0.94803	0.81267	0.66676	0.50424
Q	0.66191	0.67291	0.71066	0.86747

W/W0	PASS-BAND RIPPLE (DB)							
	0.04	0.10	0.28	1.25	0.04	0.10	0.28	1.25
	ATTENUATION (DB)				PHASE (DEG)			
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	-0.01	-0.02	-0.06	-0.22	15.67	17.00	18.41	18.70
0.2	-0.03	-0.06	-0.18	-0.77	31.74	34.54	37.79	40.16
0.3	-0.04	-0.10	-0.27	-1.22	48.57	53.07	58.73	66.17
0.4	-0.04	-0.08	-0.24	-1.04	66.53	72.88	81.27	95.12
0.5	-0.01	-0.03	-0.09	-0.36	86.05	94.28	105.15	122.89
0.6	0.00	0.00	0.00	0.00	107.98	118.12	131.06	149.47
0.7	-0.02	-0.05	-0.15	-0.65	134.16	146.64	162.29	182.49
0.8	-0.04	-0.09	-0.26	-1.13	168.25	184.32	205.14	236.60
0.9	0.00	-0.01	-0.02	-0.09	218.88	239.89	266.73	304.44
1.0	0.00	0.00	0.00	0.00	348.91	388.02	441.65	528.49
1.008	0.79	1.62	3.53	7.79	382.18	428.44	490.28	577.85
1.016	4.24	6.74	10.54	16.27	423.48	469.65	525.37	599.12
1.024	10.78	14.09	18.42	24.39	457.27	497.34	545.52	610.61
1.032	19.30	22.79	27.21	33.23	479.68	515.13	558.54	618.27
1.04030	32.53	36.05	40.49	46.51	495.74	528.17	568.35	624.18
1.04501	INF	INF	INF	INF	502.95	534.12	572.89	626.96
1.070	33.60	37.12	41.56	47.58	709.84	736.69	770.38	817.79
1.09801	INF	INF	INF	INF	729.07	753.01	783.18	825.80
1.200	33.01	36.53	40.97	46.99	947.28	965.69	989.00	1022.10
1.34287	INF	INF	INF	INF	973.99	988.64	1007.22	1033.65
2.300	36.51	40.03	44.47	50.49	1208.79	1215.84	1224.79	1237.56
3.18529	INF	INF	INF	INF	1224.30	1229.21	1235.45	1244.35
6.400	35.33	38.85	43.29	49.31	1422.70	1425.08	1428.10	1432.41

W/W0	PASS-BAND RIPPLE (DB)							
	0.04	0.10	0.28	1.25	0.04	0.10	0.28	1.25
	ATTENUATION (DB)				PHASE (DEG)			
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	-0.01	-0.01	-0.04	-0.17	11.89	13.24	14.72	15.29
0.2	-0.02	-0.05	-0.14	-0.61	24.08	26.89	30.13	32.44
0.3	-0.04	-0.09	-0.25	-1.09	36.88	41.34	46.80	53.06
0.4	-0.04	-0.10	-0.28	-1.23	50.60	56.90	65.04	77.33
0.5	-0.03	-0.07	-0.19	-0.79	65.63	73.91	84.85	102.84
0.6	-0.01	-0.01	-0.04	-0.16	82.61	92.96	106.45	127.34
0.7	0.00	-0.01	-0.02	-0.10	102.89	115.56	131.58	153.40
0.8	-0.04	-0.09	-0.24	-1.07	129.68	145.70	165.96	193.40
0.9	-0.01	-0.02	-0.07	-0.27	171.78	193.40	221.45	263.73
1.0	0.00	0.00	0.00	0.00	313.96	358.02	417.86	513.42
1.003	0.39	0.83	2.01	5.26	335.22	384.71	452.03	552.06
1.006	1.93	3.54	6.54	11.77	363.50	416.49	483.34	573.46
1.009	5.69	8.50	12.53	18.37	394.14	444.42	504.92	585.78
1.012	11.83	15.19	19.54	25.52	419.29	464.55	519.37	593.97
1.01543	22.79	26.30	30.73	36.74	439.66	480.58	531.02	600.78
1.01793	INF	INF	INF	INF	450.64	489.41	537.61	604.71
1.030	23.16	26.67	31.10	37.12	663.72	696.97	738.80	797.72
1.04921	INF	INF	INF	INF	692.85	721.67	758.13	809.80
1.140	24.99	28.50	32.93	38.95	929.84	950.54	976.83	1014.28
1.22094	INF	INF	INF	INF	953.24	970.65	992.80	1024.43
2.000	27.05	30.57	35.00	41.02	1199.76	1208.04	1218.55	1233.57
2.70618	INF	INF	INF	INF	1217.53	1223.34	1230.75	1241.34
5.400	25.54	29.05	33.49	39.51	1419.57	1422.33	1425.88	1430.99

A sonar aid to enhance spatial perception of the blind: engineering design and evaluation

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SUMMARY

The design of an air sonar device with a new form of binaural display is described which aids the blind in perceiving their environment. Some of the limitations of knowledge of human perception and the influence this has on a specification for the device are discussed. Inherent limitations in the binaural aid both in terms of technology development and performance are also explained. The paper described what is expected of the man-machine control system in a mobility setting and discusses the technique of evaluating a man-machine system so as to assess the machine performance.

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Part 1. THE DESIGN

1 Introduction

A major evaluation of the Ultrasonic Binaural Sensory Aid for the Blind illustrated in Fig. 1 passed a critical stage in July 1972 when replies from questionnaires, sent to 96 blind users and their 24 teachers, were processed. The device, more commonly known as the 'Sonic Glasses', appears to be of significant value to blind people. This finding is the justification for discussing the design of an apparently simple sonar system which nevertheless has taken some 12 years to develop and introduce to a unique user population.



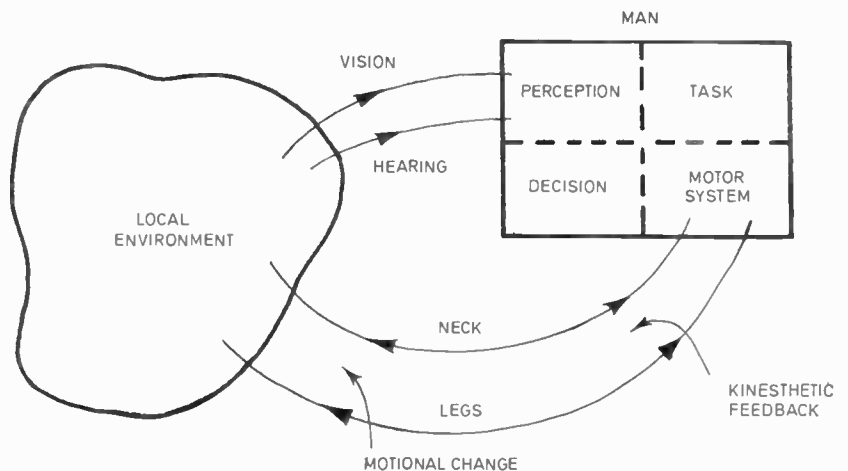
Fig. 1. Binaural sensory aid for the blind.

Many complex factors involved in the design are not ones commonly met by engineers, since in this system the human brain forms part of the signal processor prior to the 'display'—which can only be described as the *percept* of the user. It may perhaps be said that the system as a whole forms a new sense and as such its development had to be evolutionary in character.

2 The Designer's Task

A model of man and his environment is illustrated in Fig. 2. From this it will be noted that when a person is blind, a complex control system is deprived of a vital complex feedback link—that of vision—through which most of the information about the environment is apparently transmitted. The complexity of the link may not be

Fig. 2. Elementary model of man and his environment.



fully appreciated without a study of the process of visual perception.¹

Before some form of replacement link can be systematically designed, the task of man in his environment needs to be determined, and the total information which is necessary to execute this task has to be specified. At the time of commencing the development of the Binaural Sensor (1959) there was virtually no background on which to build and little was known about mobility for the blind. Even today, the literature is vague on the blind man's task in moving from one place to another, and the information required to execute this has not been determined in an objective form. In fact, a *theory of mobility* has yet to be evolved.

3 The User's Task

Few sighted people understand the real problems which face a blind person trying to be mobile, otherwise the fallacy that '... a blind man needs to avoid obstacles in his path ...' would not be so prevalent. *Above all a blind person wants to move about in his environment confidently and gracefully so that he appears to be sighted.*

3.1 Mobility by the Blind

One of many mobility tasks facing a blind person may be to travel from home to the local shopping area. The reader can readily construct a cognitive map of the route, as it would apply to him, and he may have already experienced a mental glimpse of the shopping area itself. It is probably not difficult to trace, in one's mind, the path which would normally be taken in walking there. The blind person does not have this same facility since visual reinforcement of the cognitive map is denied him. Only if newly blinded, or if the area in which he lives has not changed over the years, can a blind person use visual memory.

Nevertheless, a prime requirement of any traveller is a mental map of some kind and this a blind person must acquire in order to travel effectively.² The sighted person usually supplements the memory through conventional maps, as required, but the blind traveller has to rely almost entirely upon verbal instructions. These are useful only if some means are available for recognizing one's relationship with the cognitive map through the remaining sensory channels.

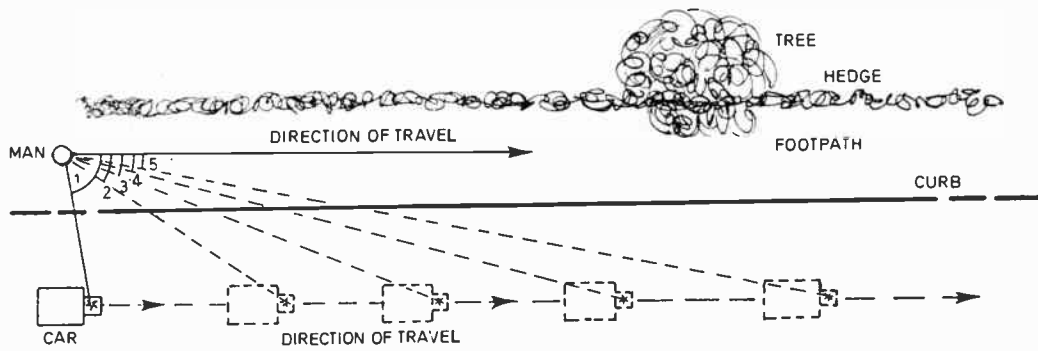


Fig. 3. Angular change of environmental noise provides direction of travel path. Change in relative angle of traffic noise indicates direction of roadway and required travel path of man. At (5) rate of angular change is small and traveller knows direction of sound is nearly direction of road.

A simple instruction for finding a specific shop may be '... two doors past the telephone booth ...' It is necessary to be able to recognize a phone booth and a doorway reliably if this instruction is to be of value. This clearly involves more than the concept of *obstacle detection*, thought by so many to be the primary need of the blind man.

Only two of the remaining sensory channels available to a blind person appear to have the potential necessary for conveying spatial information—those of hearing and touch. Natural unaided hearing provides a blind person with important orientation and navigation cues, such as the position of a road intersection in the distance, perceived through the stopping and starting of traffic. The direction of a roadway along which one is travelling on foot may be perceived through the changing sound of a car as it passes by. Both the gradual change in direction of the car, and the loudness and character of the engine noise provide surprisingly accurate 'long range' information, as shown in Fig. 3. In general the unaided sense of hearing may be considered to provide distant orientation and environmental information, which the blind are well able to use after an adequate period of training.

Throughout history the staff, or long stick, has provided the blind man with information about his immediate surroundings and protected him against collisions with objects. In recent times (since World War II) the Long Cane³ (50 inches or more) has been used by blind travellers to scan the terrain ahead and now (since 1960) special courses of training in its use are provided at numerous rehabilitation centres.⁴ The skill which may be acquired in the use of both the cane and long range auditory cues has enabled many blind people to travel relatively safely. This, together with locomotive feedback from the feet, is known as the Long Cane System of Travel.

What has been most significantly missing in this form of travel is reliable information about the middle distance, which may conveniently be thought of as stretching from 'touch' distance to some 6 metres or so. Rice, through his experiments⁵ on the ability of blind persons to perceive objects within this range, observed that those congenitally blind, who seemed good at locating the objects, were also regular travellers on foot. This led him

to suggest that an ability to echo-locate leads to superior mobility in the blind. Whilst echo-location using audible sound cannot be very meaningful, simply from a consideration of the basic physics involved (long wavelength and poor directivity), what little information that is gathered by this means appears to make a significant difference to blind travellers. Leonard and Carpenter⁶ found that some blind boys had an uncanny ability to negotiate a complex environment through natural echo-location; so much so that they felt this facility should be developed in preference to electronic sensory aids.

It is well known of course that bats echo locate with remarkable precision⁷ and it has often been suggested that some blind people have developed a similar ability, because of their apparent ease in determining their surroundings through audible sounds. Unfortunately, no satisfactory means for training many blind people to use natural echo-location effectively has yet been developed. It is not surprising therefore that much effort has been concentrated on devices designed to bridge the gap between 'touch' distance and some longer useful range, since these were seen as being more tangible than human echo-location—and of course more useful.

If a satisfactory technical solution were to be found it would appear from this meagre evidence that adventitiously blind people, once able to sense their environment as well as the congenitally blind, could then travel just as efficiently without training—or at least with very little. After all, the congenitally blind did not have the training.

There is however a terrible fallacy here. The more one learns about blindness and the blindness system⁸ the more it becomes apparent that the congenitally blind are at a disadvantage in this respect. True, the congenitally blind person has in the past been the one who was most likely to travel—but very poorly and exhibiting many blindisms in his behaviour; but now that mobility is taught by orientation and mobility specialists through the long cane system, the adventitiously blind often succeeds in achieving greater skill of travel coupled with a grace not often seen in the 'congenital'. The literature does not have much to say about this, but it certainly appears that the cognitive map of the 'adventitious'

together with some visual concepts and a well developed gait, more than compensates for the limited echo-location facility of the 'congenital'.

Because of the limited understanding in this field and the negligible research in mobility, there has been considerable controversy over the past decade about the type of sensory aid which is needed to *supplement* existing aids (Long Cane and Guide Dog). No one now sees any electronic aid *supplanting* these.

3.2 Sensory Aid Controversy

The majority of those who have been involved in sensory aid development have seen a need for a simple 'obstacle detector' which would warn the user of an imminent collision with an object.⁹⁻¹² A very cogent argument in favour of this concept was the ease with which it was thought a blind person could learn to use such a device. There has been much discussion on the form of *display* required and there have been frequent references to complex computer systems for simulating all kinds of devices and their displays, so as to find the optimum form.¹³⁻¹⁵ Built into this concept for device development is the tacit assumption that the most complex part of some systems—the man-machine interface—is easily produced. Some tactile imaging displays¹⁶⁻¹⁸ have however taken many years to develop. It was also assumed that in searching for the optimum display, the limited learning-time available in a major computer simulated experimental system would be adequate for the testing processes.

An opposing viewpoint is that of developing a device which would present to the brain the maximum amount of environmental information which the auditory sensory channel could effectively transmit, and in such a way that the user could readily disregard both redundant and unwanted information merely by switching his attention. Two arguments were used by the writer in support of this approach.

(1) Non-visual animals (particularly bats) exhibit remarkable skill in negotiating their environment and can readily recognize their prey against a complex background through the use of very wide band high frequency sound waves.⁷ The system they use goes well beyond the capability of a simple 'obstacle detector' and must provide a high degree of spatial perception.

(2) The congenitally blind have developed an uncanny ability to perceive their environment through the limited information provided by audible sound. Whilst this is not easily learned because of the near threshold level at which perception is possible, this may not apply if artificially enhanced to the maximum possible level. Learning the use of an enhanced sense was not considered to be a serious limitation because the use of ambient travel cues and physical skill of mobility has to be taught. This should be made easier by the addition of an effective sensory aid.

The design of the system described here was supported by an extensive study of animal echo-location,¹⁹⁻²² behaviour of congenitally and adventitiously blind people,⁶ and an extensive knowledge of complex high resolution

sonar systems.²³⁻²⁷ (It is however only proper to say that the study grew from an original concept²⁸ triggered by a chance reference to blind children in a swimming pool.)

4 A Solution

The *concept* of the Binaural Ultrasonic Sensory Aid which forms the basis of a solution to the problem of sensing the 'middle distance' is basically simple. The environment to be sensed is irradiated continuously by ultrasound. Reflexions are converted to audible sounds in such a way that the pitch of an echo is made proportional to the distance from which it originates, and direction is determined binaurally by the auditory neural system which compares the signals from the two ears. The use of pitch to indicate distance arises from the known fact that the ear can recognize the source of a sound from its character (timbre), and several sounds (provided they each have different spectral characteristics) may be heard simultaneously and often discriminated with relative ease. There is only one form of coding of the irradiating energy which provides this cue simply—that of a continuous transmission frequency-modulated (c.t.f.m.) wave as used in some earlier sonar experiments (1952).^{23, 24, 29} It is also known that we determine the direction of audible sound through the binaural processing of differences in the sound in one ear relative to the other. The difference in amplitude between the ears is used as the direction cue.³⁰ This basic concept is simply illustrated in Fig. 4.

4.1 Description of the System

A diagram of the sensory aid as redesigned from the original³¹ by Martin³² is given in Fig. 5, and the principle of operation is illustrated through the waveforms of Fig. 6. A detailed analysis of this c.t.f.m. system may be found in reference 37. The returning echos are mixed

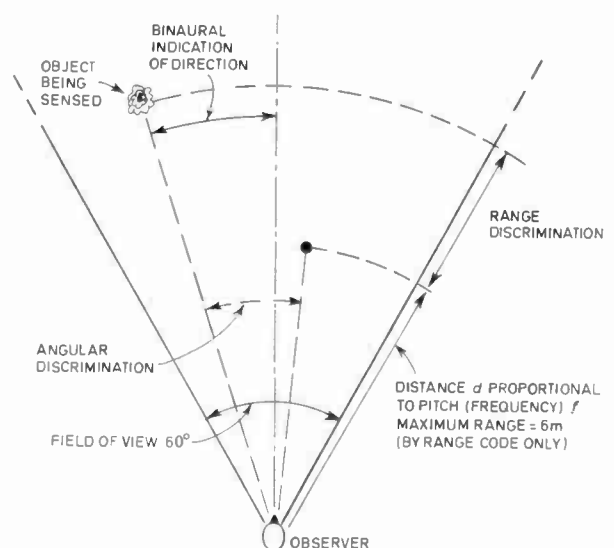


Fig. 4. Basic concept of sensory aid. Note: Range and angular discrimination are illustrative only. Degree to which these are usable varies with conditions and situations.

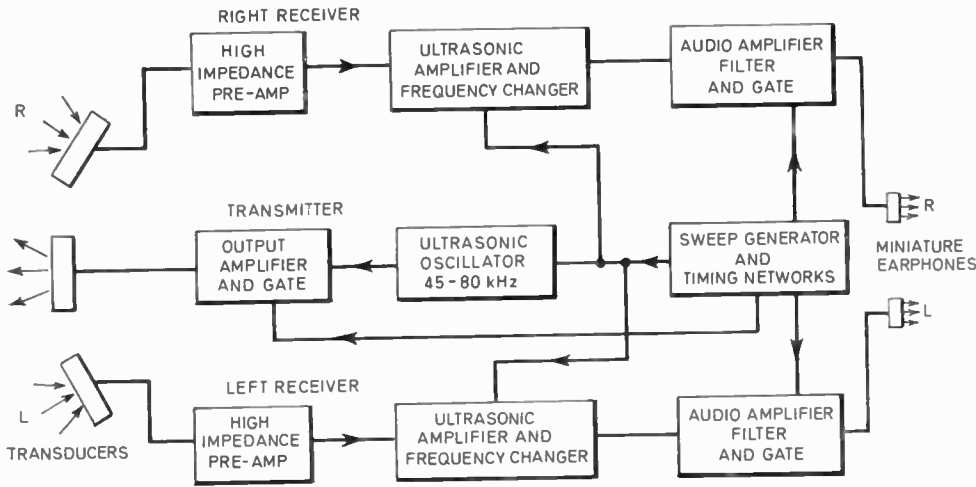


Fig. 5. Schematic of Binaural Sensory Aid.

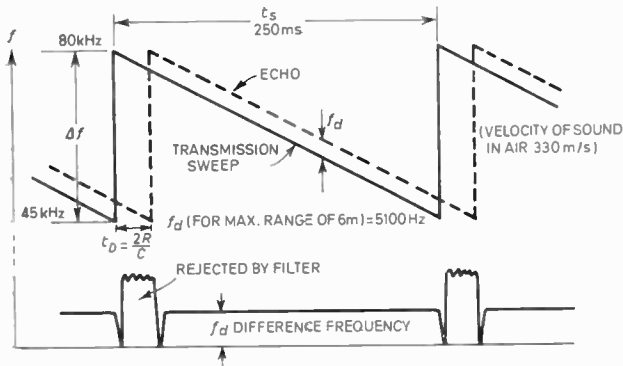


Fig. 6. Frequency-time functions for binaural aid.

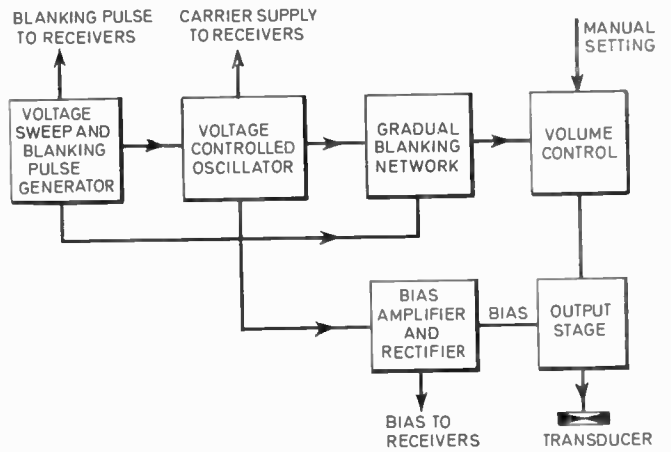
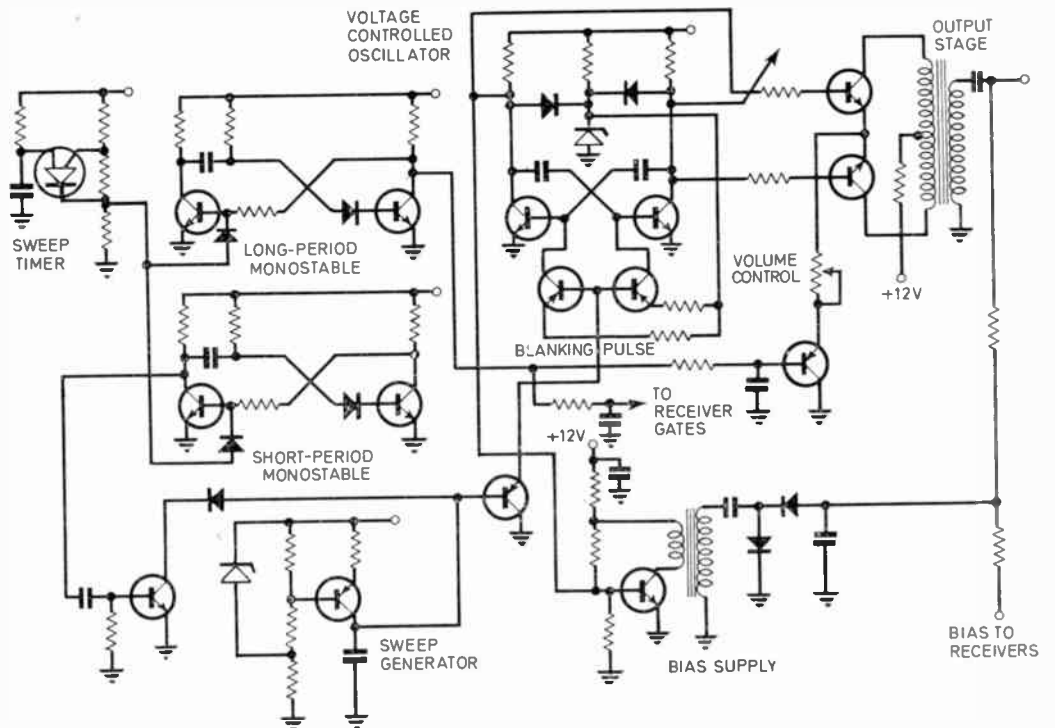


Fig. 7. Detailed schematic of the transmitter.

Fig. 8. Transmitter electronics as used in initial evaluation (1969-70).



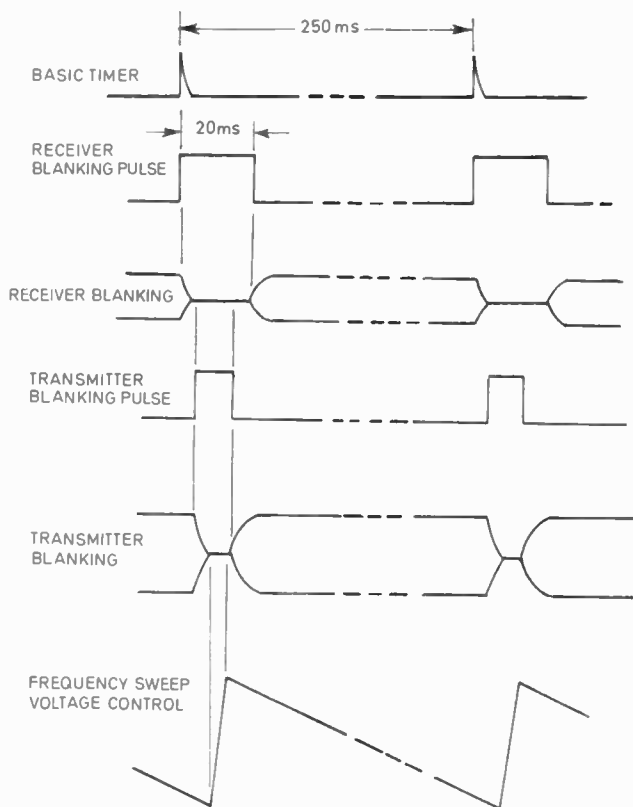


Fig. 9. Timing sequence of blanking arrangement as required for major evaluation programme.

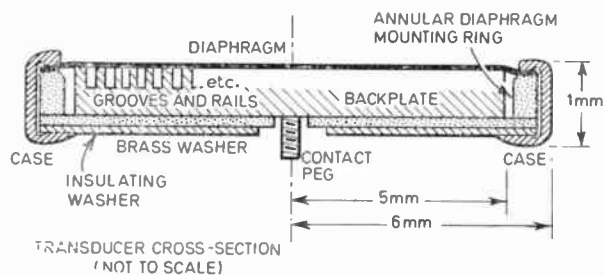


Fig. 10. Solid dielectric transducer.

flyback, the transmitter output stage is gated off so as to eliminate undesirable transients appearing at the receiver output (see Sect. 4.1.3). This is accomplished with the timing network (long period monostable) driven from the master timing unit; ideally, a timing sequence shown in Fig. 9 is required; this is discussed in Section 4.1.4.

4.1.2 Transducers

Solid dielectric transducers, as illustrated in Fig. 10, were used for both the transmitter and the receivers.^{34, 35} The characteristics of these are shown in Fig. 11 and 12, where it will be seen that the frequency response in the operating band is a slope of approximately 12 dB per octave. The receiver transducers are matched pairs and splayed apart at an angle $\pm\alpha^\circ$ from the median plane so as to produce a predetermined amplitude difference function between channels as the azimuth angle is varied, shown ideally in Fig. 13. This provides the binaural direction cue.

4.1.3 Receivers

The two receiver channels (of which one is shown in Fig. 14) are similar in gain and frequency response within close tolerances, and use low-noise, high-impedance

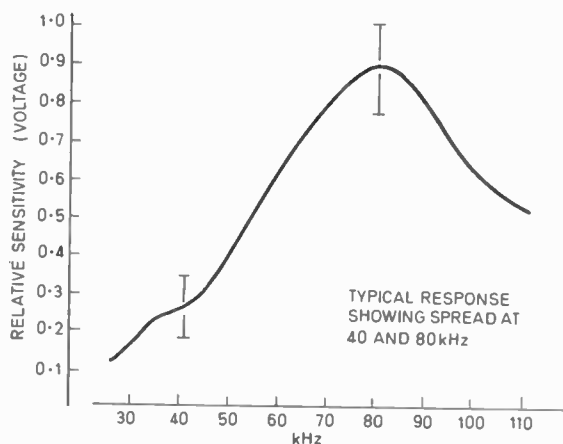


Fig. 11. Transducer sensitivity as a transmitter. (Measured as a voltage output from Bruel and Kjaer microphone 4135.)

with the transmitter signal in a linear modulator to produce a difference frequency which is proportional to distance. Two channels of reception are used, one for the right ear and one for the left.

4.1.1 The transmitter

This is shown in detail in Figs. 7 and 8. The saw-tooth frequency modulated output from the transmitter varies linearly between 80 and 45 kHz during the sweep period of 250 ms (various values have been used up to 330 ms). It is arranged that the output voltage increases 6 dB during the downward frequency sweep to compensate for the increase in radiation field of the transducers. An output power control is provided as a volume control—the reason for this unusual feature is explained in the Section dealing with the receiver. During the sweep

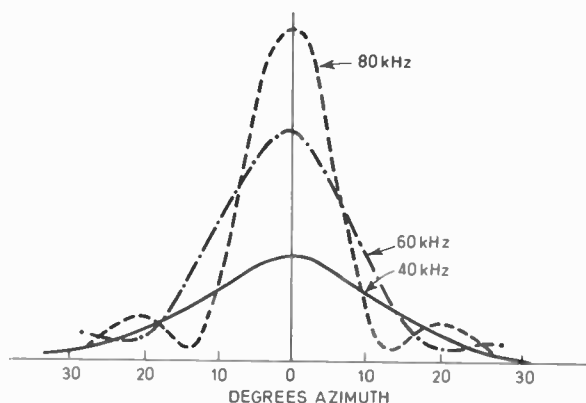


Fig. 12. Typical polar response of transducer (cf. Fig. 11). (Note: maxima vary with frequency response.)

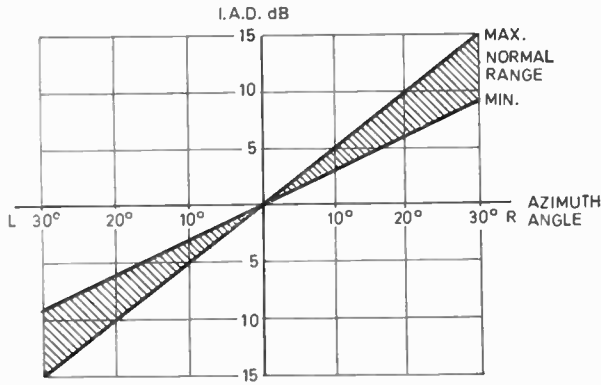


Fig. 13. Interaural amplitude difference (i.a.d.) as azimuth indicator (ideal response).

inputs. So as to maintain a balance of better than 1 dB over a wide dynamic range in the output volume, two switched gain settings were used with a difference of 20 dB between levels. High quality miniature ganged potentiometers with differential attenuation of less than 1/2 dB were not available at the time of designing the electronics, and ordinary ganged potentiometers had such large tolerances that the required output balance could not be assured. The volume control was therefore provided by varying the transmitter output power. This varied the signal/noise ratio of the system but a workable arrangement was found possible.

Linear balanced series modulators (used in the main evaluation models), produced both sum and difference frequencies, but only the difference frequencies were fed to the audio stage to provide the range code.

(i) From Fig. 6 the slope of the frequency sweep is

$$\frac{df}{dt} = \frac{\Delta f}{t_s} \text{ Hz/second}$$

If D = object distance and c velocity of sound then the frequency of the echo

$$f_D = \frac{\Delta f}{t_s} t_D$$

$$= \frac{2\Delta f D}{t_s c} \text{ Hz.}$$

The range code f_r is simply given by f_D/D . Thus for a choice of sweep period $t_s = 250$ ms and a frequency sweep $\Delta f = 35$ kHz, the range code $f_r = 2\Delta f/t_s c = 850$ Hz/metre (using a figure of 330 metres/second for the velocity of sound).

In practice, the frequency sweep is adjusted to maintain reasonable control on the sweep period and the range code.

Ideally, the echo from a single specular reflector, such as a sphere, produces a narrow spectrum of lines spaced $1/t_s$ Hz with an envelope given by

$$\frac{\sin\left(\frac{n\pi t_B}{t_s}\right)}{\frac{n\pi t_B}{t_s}} \quad n = 0, 1, 2.$$

$$t_B = t_s - t_D$$

shown in Fig. 15.

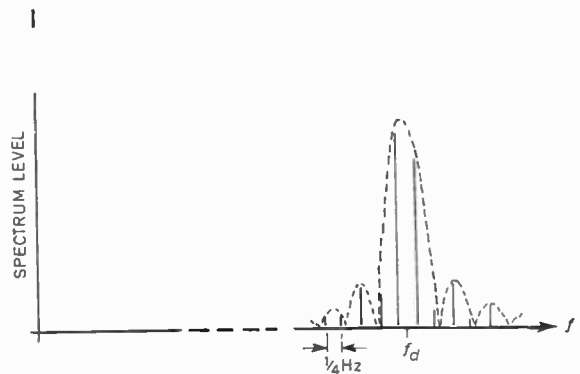


Fig. 15. Spectrum of audio echo signal from single specular reflector.

This of course is for rectangular 'blanking', which is undesirable since it produces unpleasant 'thumps', due to the energy in the side-lobes. In the device design, the side-lobes are reduced by envelope shaping, and of course only slight departure from linearity in the frequency sweep produces considerable blurring of the audio spectrum. It is not possible, in fact, to obtain a pure pulsed tone without accompanying soft 'thumps' and a fully continuous pure note from an object seems to be theoretically impossible, highly desirable though this would be.

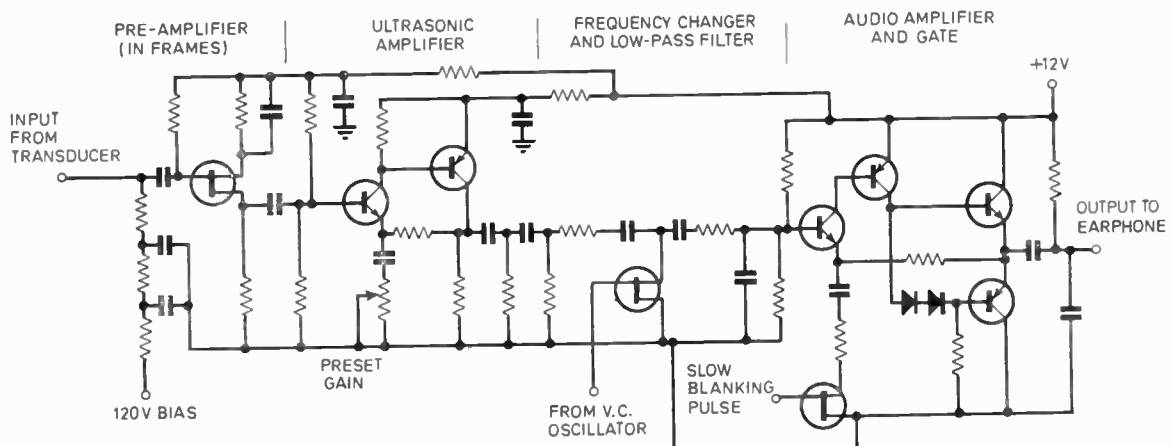


Fig. 14. Receiver electronics as used in initial evaluation (1969-70).

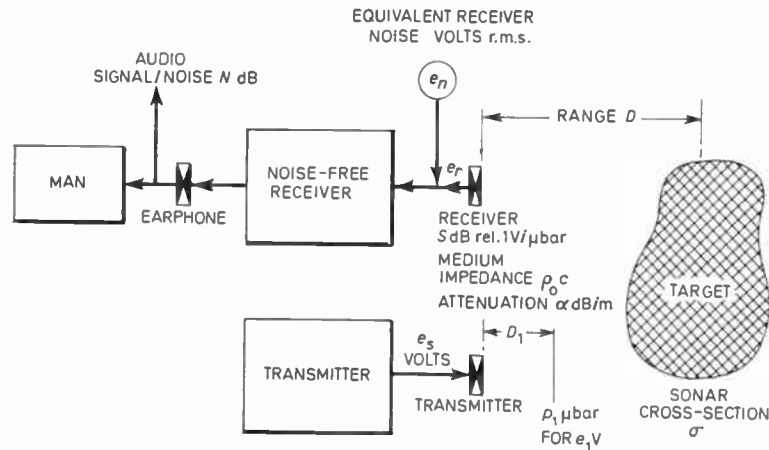


Fig. 16. Schematic of sonar performance.

Miniature earphones mounted in the temples of the spectacle frames were coupled to the ears by short lengths of plastic tubing. To keep the tube in place a special frame was designed which had no noticeable effect on the user's natural ability to hear and locate ambient sounds.

The audio output was adjusted on 'high gain' to be 100 dB relative to 0.0002 dyne/cm² when using a 2.54 cm diam. wood pole at 1 metre as a target, and the earphone outlet was tightly coupled to a 2 cm³ cavity. (Since the earphone normally operated open-ended, this sound level could not be obtained in general use.)

4.1.4 Timing sequence

This is shown in Fig. 9 and is used for controlling the blanking of the transmitter and the receivers during the flyback period so as to avoid undesirable clicks or thumps in the audio output. The receiver is fully 'off' before the transmitter is gated 'off', and this has zero output during the sweep flyback.

Several features in the design are discussed in Section 7.

4.1.5 Performance as a sonar system

The sonar performance is related to the ability to detect a specified target determined by the sonar equation.

This may be written, from Fig. 16, as

$$\sigma = \pi e_n^2 \frac{4D^2}{D_1^2} \left(\frac{e_1}{p_1 e_s} \right)^2 10^{(2\alpha D + N - S)/10} \tag{1}$$

- where σ = sonar cross-section
- e_n = noise voltage in the relevant audio band
- D = distance to the object
- D_1 = reference distance at which the source level was measured
- e_1 = transmitter voltage to produce a pressure p_1 at D_1
- e_s = transmitter voltage normally used
- α = frequency dependent attenuation of sound in air
- N = signal/noise ratio
- S = sensitivity of the microphone

Substituting a typical set of values we can calculate the minimum object cross-section for a target at 2 metres

range to produce an audio signal/noise ratio of 3 dB.³² $D = 2\text{m}$; $D_1 = 0.4\text{m}$; $\alpha = 1 \text{ dB/m}$ (60 kHz); $N = 3 \text{ dB}$; $S = 62 \text{ dB}$ relative to $1 \text{ V}/\mu\text{bar}$; $e_n = 1 \times 10^{-6} \text{ volts}$ †; $p_1 = 0.4 \mu\text{bar}$ for $e_1 = 4 \text{ V p-p}$; $e_s = 100 \text{ V p-p}$.

Then

$$\sigma = 4 \times 10^{-4} \text{ m}^2$$

The sonar cross-section of a rigid sphere of radius a is πa^2 (circumference $> 5\lambda$)

Hence we obtain

$$2a = 1.1 \text{ cm approximately.}$$

This order of performance was subjectively checked by three observers.

In many situations where the ambient audible noise was not high, the transmitter voltage could be reduced to 2 V p-p and the usual signal would still be well above the receiver noise level.

5 Some Experimental Investigations

Some early experiments showed that pulsed echo-location systems do not provide an auditory cue to distance which is read as easily as the distinctive pitch-distance cue of the c.t.f.m. system.²⁹ Because of the precedence effect^{36,37} only the first echo in a pulsed system may be heard; the ear is inhibited for subsequent sounds unless they are highly dominant, in which case attention is centred on them. This makes natural (i.e. non-processed) pulsed echo-location systems 'single-object' detectors. Some complex form of processing is required to convert them to multiple object detectors using an auditory display. C.t.f.m. systems, operating in the frequency domain can, on the other hand, provide multiple target detection capability with ease through the use of an auditory display.

It was found, however, that pulsed systems give a good indication of direction through the use of interaural time difference (i.t.d.) when they utilize the spacing between the ears. The c.t.f.m. system can provide both a time difference and, directly related to this (since f_D is proportional to t_D , Fig. 6), a frequency difference between

† Minimum r.m.s. tone injected at the input which can be aurally detected against the system noise—used as the noise reference level.

the ears when using spaced receiver transducers. But it was found during early experiments that an interaural amplitude difference (i.a.d.)—produced by directing the left transducer to the left slightly and the right transducer to the right by an equal amount—gave a more definite indication of direction.³¹

The reason for this was investigated in detail by Rowell³⁸ when it was discovered that a simultaneous interaural frequency difference and time difference destroys the ability of the ear to use i.t.d. The signals in the left and right ears had to be almost identical in frequency before a time difference could be used to indicate direction. In addition, it was found that whereas some subjects could fuse two slightly different sounds, one in the left ear and one in the right, into one and localize this, others had great difficulty.

The conclusion was drawn that only an interaural amplitude difference was usable and meant removing the spacing between the transducers eliminating the i.t.d. and i.f.d. together with any information, theoretically, they may provide. This result did, however, substantiate the earlier findings³¹ which seemed to be so contrary to experience in auditory localization.

A study undertaken by Rowell³⁸ led to a specification for the i.a.d. cue which follows the long established form:³⁹

$$\theta_E = K \log \left(\frac{I_R}{I_L} \right)^2 + \theta_0 \quad (2)$$

where θ_E is the estimated azimuth, I_R and I_L are the stimulus intensities in the right and left ears respectively, K is a constant defining the activity of the cue, and θ_0 is the value of θ_E when the i.a.d. is zero.

This function may be approximated by taking the difference between two identical polar responses splayed by a total angle 2α . The ideal polar response of each receiver transducer may be shown to be³⁸

$$I(\theta) = C \exp \left(\frac{-\theta}{K} \right)^2 \quad (3)$$

where C is a constant, but this polar response is impossible to produce over the octave frequency range with disk transducers which must be mounted in spectacle frames.

Two disturbing features arose from these experiments.

(1) The i.a.d. direction cue required by an individual varied with the pitch of the stimulus. This implied that the *position* of a stationary object would be perceived to change as the relative distance and direction varied; clearly an undesirable feature since perceptual constancy would be poor.⁴⁰

(2) The localization function of equation (2) varied with individuals, and the i.a.d. should therefore be matched to them. This meant it should be carefully controlled. Ideally, this requires the use of a narrow band echo-location system so as to maintain a constant well-defined radiation pattern from the transducers. The distance cue on the other hand demands a wide band echo-location system.

These two features would seem to indicate the system was unusable, and it is worth noting in passing that had

this been the only information available to us—such as when using only a simulated system so often proposed—it is unlikely that the system would have been developed.

6 Optimizing the Direction Cue with a Wide Bandwidth Constraint

It is fortunate that through exploratory usage of the system in a mobility setting, employing a portable device throughout the period of controlled experimentation discussed in Section 5, it was found that the i.a.d. direction cue did not exhibit the undesirable characteristics found in the experiments using simple simulation. The i.a.d. produced by splaying the transducers $\pm\alpha$ could be adjusted to suit an individual by varying the value of α .

It was possible to arrange that, as the head of a user wearing the 'glasses' was rotated from side to side through about $\pm 30^\circ$, the user perceived

- either (a) objects remained stationary in space (i.e. perceptual constancy was good)
- or (b) objects appeared to move in the opposite direction to which the head was turned
- or (c) objects seemed to move in the same direction as the head was turned.

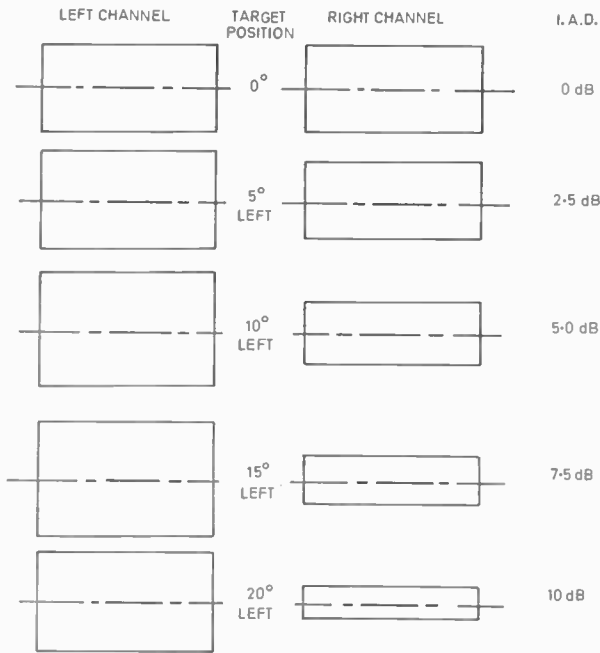
In (a) the i.a.d. could be said to be matched to the user, in (b) the i.a.d. was too large, and in (c) it was too small.

A careful investigation of the frequency response of the transducers revealed that a marked variation between transducers was possible through very small changes in physical dimensions. This caused considerable departure from the desired audio envelope shape of the device output, particularly as the azimuth angle changed. Such a change in envelope shape, which because of the splay angle α could not be identical in the two receiver outputs, indicated a varying i.a.d. during the frequency sweep for any specified angle, illustrated in Fig. 18(a). Users, however had not observed this, suggesting that some form of integration in the auditory system caused the user to perceive only the total energy in each sweep pulse.

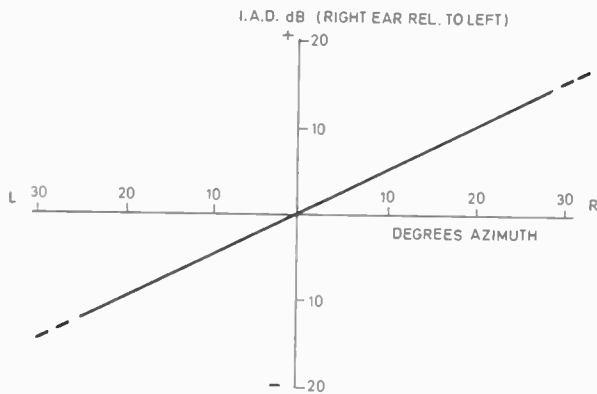
It was evident, nevertheless, that the best performance would be obtained by choosing the most suitable frequency response. This undoubtedly seems to be a self-evident statement but the reasons are not. In Fig. 17, is depicted the ideal system output for a change in azimuth angle. Since the angular sensitivity of the receivers and transmitters varies with frequency, it is not possible to maintain a constant output volume throughout the sweep and some compromise is necessary.

Factors which must be considered are:

- (1) change of angular sensitivity of the transducers over the frequency range;
- (2) frequency response of the transducers;
- (3) increasing differential attenuation with range over the wide frequency band of the system;
- (4) variation in the attenuation characteristics of the propagation medium with atmospheric conditions;
- (5) minimum acceptable signal/noise ratio limiting the beam width which in practice may be used;
- (6) frequency dependent target strength of objects.



(a) Idealized output envelope of audio amplifier for frequency-independent target and propagating medium (constant beamwidth arrays).



(b) I.a.d. for idealized audio output.

Fig. 17. Idealized system performance for direction cue.

The latter factor may be looked upon as useful information, but an inappropriate compromise may result in a device having an unpleasant tonal characteristic.

At this stage of the art it is not possible to present a theory of optimization; the only satisfactory approach is one of trial and error within the various constraints. The ultimate choice of performance is shown in Figs. 18 and 19.

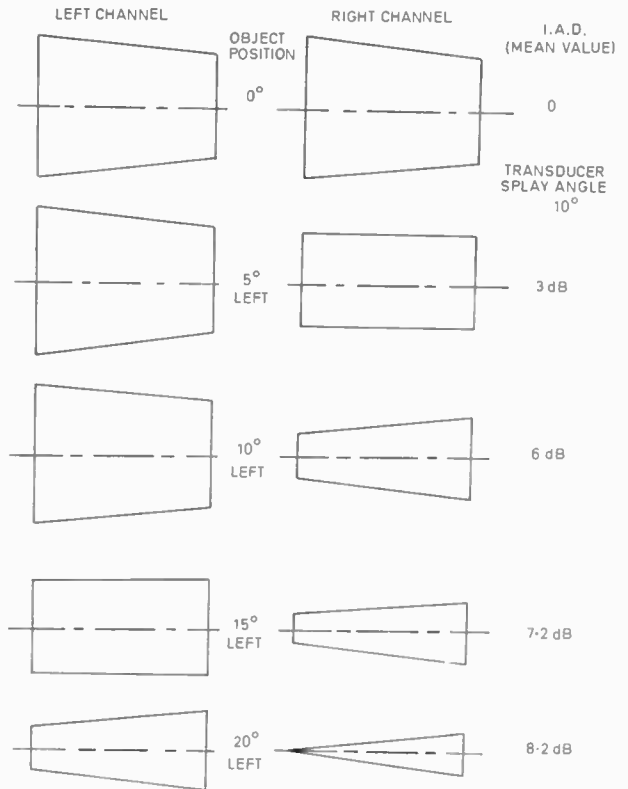
A number of alternatives were available but the evidence in favour of these was less than for the one selected, mainly through experience gained during the development process. Only after the evaluation was it thought possible to determine which changes would be most effective for the majority of people.

It will be observed that the variation in envelope shape during the sweep period is considerable for some angles even though the target chosen has a frequency independent target strength. Objects with frequency sensitive

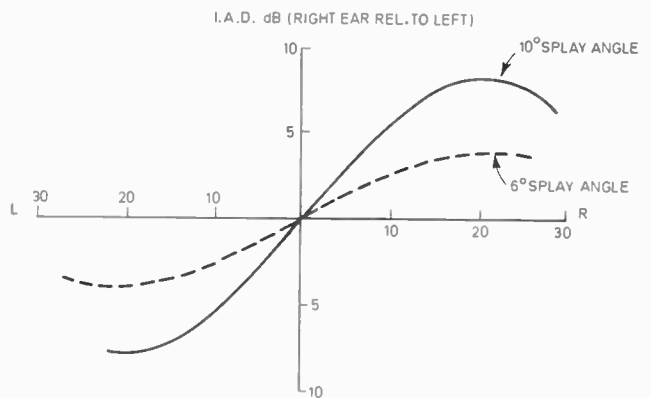
target strengths produce even greater variation in the output envelope and multiple scatterers clustered together produce a noise-like signal. Even so, the system remains workable.

7 Some Design Problems

The device does not have an output which can be called a display in the conventional sense. Viewing the two audio outputs on an oscilloscope, for example, is rather like looking at the signal waveform at the earphones of a stereophonic reproduction system to determine the



(a) Compromise audio output for frequency-independent target, propagating medium, and beam width.



(b) I.a.d. response (mean) from compromise direction stimulus for splay angles of 6° and 10°.

Fig. 18. Compromise system performance showing non-ideal output audio envelope, varying i.a.d. with input signal frequency, and non-linear i.a.d. with azimuth angle.

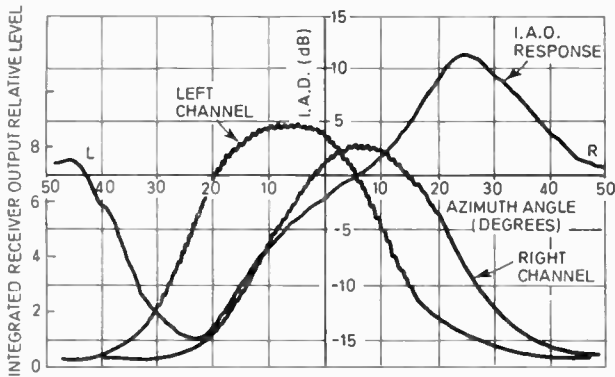


Fig. 19. Measured polar response of system (integrated output) and resultant i.a.d. (typical curves).

sound one would hear when listening binaurally to the music producing the signals. This—in the first instance—without having had some prior experience of music. In other words, to an engineer still unfamiliar with the device, the waveforms it produces are meaningless.

When listening to the sounds of the device monaurally, i.e. using only one ear at a time, the range cue is quickly appreciated and the variation in character of the sounds from different objects is observed to carry meaningful information almost immediately.

When the two outputs are heard binaurally from the device worn on the head, and free head movement is allowed to control the change in the i.a.d. of the signals, the direction cue is readily perceived. The auditory neural channels must first operate on the signals before the direction of an echo can be perceived. Hence, since signal processing must continue beyond the sound output of the device, this cannot form the display.

The reaction of sighted and blind to the binaural effects when trying the device is one of considerable enthusiasm; this applies even when the device is operating only poorly, is relatively noisy, and the sound output contains extraneous but regular clicks and thumps. In other words, new inexperienced subjects are uncritical of the sounds produced by the system.

Two conflicting questions had to be resolved.

(1) At what degree of sophistication in the electronics and mechanical design will the user population accept the device as such, and concentrate on its performance as an aid?

(2) Will the device be acceptable as an aid to mobility—the use to which it is most likely to be put—and thereby confirm the concept?

The former question may best be resolved by further increased expenditure to improve the overall quality of the product, but the cost per unit then rises rapidly without the certainty of acceptance as an aid. The latter question could not be answered until the former was resolved; and without adequate funds in a university setting, well removed from the main user population, this posed unusual problems.

It was appreciated that whilst the initial reaction to the main cues to perception may be enthusiastic, after a

period of training the user becomes much more critical of the sound quality. Noise, clicks, thumps, or roughness in the character of the sound becomes objectionable. Unfortunately, none of these defects can be removed—only reduced, and at considerable cost. (Price for the evaluation device was \$600 U.S.)

Thus at a point in the development programme when the effectiveness of the display in a mobility setting had been questioned by many in the field and more engineering seemed desirable, it was necessary to involve a significant number of people in a major exercise just to establish—through an adequately reliable sample of the blind population—the validity of the concept—something one can usually do in a laboratory. It is normally after the concept of a device has been shown to be viable that expensive engineering development takes place and quantity manufacture is considered seriously.

Factors which are important in determining the performance of the device simply as an electronic system are:

- (1) frequency response of the transducers;
- (2) polar response of the transducers;
- (3) ultrasonic frequency range of operation;
- (4) linearity of frequency sweep;
- (5) repetition period of sweep;
- (6) blanking period of transmitter;
- (7) shaping of the envelope of the ultrasonic output of the transmitter;
- (8) noise balance in the receivers;
- (9) gain balance in the ultrasonic and the audio frequency amplifiers;
- (10) equality in the frequency response of the ultrasonic and audio amplifiers;
- (11) linearity of frequency changers;
- (12) blanking of receivers during sweep flyback;
- (13) shaping of audio envelope during blanking period—equality of onset and decay times;
- (14) balance in earphone response over the frequency band of 5 kHz;
- (15) stability of transducer mounting;
- (16) independence of battery voltage;
- (17) stable sensitivity in detecting objects;
- (18) independence of environmental conditions:
 - 20° to +40°C temperature
 - 0 to 100% humidity
 - 0 to 60 mile/h (96 km/h) winds
- (19) reliable operation in ambient noise from 40 dB to 100 dB relative to auditory threshold;
- (20) no effect on the natural perception of ambient sounds by the user.

It must be evident that some engineering compromises were necessary if the device were to be produced at all and be carried conveniently. We were in fact proposing to give any blind person who could be trained, a very complex, delicate, and expensive device.

7.1 The Transducer

The most delicate and most difficult component to manufacture was the electrostatic transducer. No other type of transducer will provide the sensitivity, yet after very many years of development the literature indicated that these elements of the system cannot be adequately

controlled in production and must be individually made and tested. They are normally bulky and very expensive. Unless these transducers could be mass produced and controlled within reasonable tolerances, the price of the device would be prohibitive and the cosmetics unacceptable.

Through intensive development by G. Clark (Senior Technical Officer on research team), the size of the transducer was reduced to a disk, 1 mm thick and 14 mm in diameter. The sensitivity was adequate, the beam width controllable within reasonable limits but the frequency response remained variable (see Fig. 11). It has already been shown that this had to be within quite small tolerances so a high rate of rejection was anticipated. This appeared to be the weak link in the system and demanded great care.

The requirement was that the receiver transducers be matched pairs for frequency response and beam width, the transmitter transducer have a good low frequency response.

7.2 Tolerancing of System

To ease the manufacturing problem at this early stage of development fairly wide tolerances were allowed on some of the features listed, but in certain critical areas, particularly those which could cause rejection of the device, tight control was specified. These were:

- (1) matched frequency response for receiver transducers;
- (2) matched polar response for receiver transducers (usually correlated with (1));
- (3) frequency response of transducers to be +12 dB per octave between 40 kHz and 80 kHz.
- (4) noise output balance to be better than 1 dB;
- (5) audio output balance to $\frac{1}{2}$ dB;
- (6) blanking of receivers to be complete whilst transmitter is blanked off;
blanking of transmitter to be complete during sweep flyback;
blanking period not to exceed 25 ms;
- (7) envelope shaping to be sufficient to avoid observable thumps in sound output (see subjective tests 8.1).

8 Performance Tests

As the device was to be evaluated both by blind people carrying out their normal daily routine, and their mobility teachers, its performance had to be checked in the field by non-instrumented means (Part 2). It has already been emphasized that in terms of auditory performance, instrumentation in the laboratory or factory could not test the system—only the user can do this adequately—until the required auditory performance had been fully determined by trials.

We had no means of correlating user perception with instrumented measurements until user tolerance had been assessed and verbal feedback was adequately meaningful.

The writer therefore devised a subjective test which he believed, if passed, would ensure high user acceptance and at least adequate performance of the man-machine system.

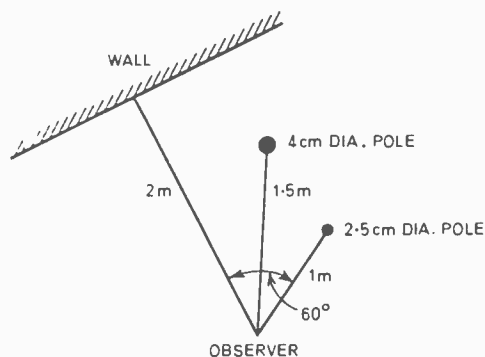


Fig. 20. Arrangement of objects for subjective testing of device output.

8.1 Subjective Testing of Device Performance at Factory

The following tests were specified and personnel (one blind user and two engineers) trained to carry them out wearing the Glasses.

(1) Noise—(a) With the transmitter volume at maximum and the receiver gain on LOW there should be no hiss or clicks heard when looking into free space.

(b) With the gain on HIGH and the transmitter volume at maximum there should be only a faint pulsation in the background hiss. This should be equal in both ears.

(2) Balance—Stand 6 ft (2 m) from a 3.5 cm diameter metal pole placed in a clear area. Look at the pole and check that with the sound centralized on the median plane you are looking directly at the pole and not to one side.

Rotate the head to left and right to check that equal amount of movement left and right is necessary for the sound to shift an equal amount left and right. Check that the quality of the note is tonal and not accompanied by a thump.

(3) Range—Face a concrete wall, free from doors and windows, and walk backwards from a distance of about 2 m until the echo just merges with the increasing background signal from the ground. The range at which this happens should be at least 6 m.

(4) Sound quality—place a 3.5 cm diam. metal pole 0.7 m (2 ft) from a concrete wall; stand 2 m (6 ft) from the wall facing both the pole and the wall. The two signals, one from the pole and one from the wall, should be distinct. In order that the pole does not mask the wall the line of sight should be slightly to the side of the pole. Both notes should have clear quality and it should be noted that a third 'ghost' signal caused by intermodulation is not heard corresponding to a weak echo from 0.7 m (2 ft).

(5) Angle of perception—to test the angle of perception set up a 2.5 cm diam. wooden pole and a 3.5 cm metal pole in proximity to a concrete wall as shown in Fig. 20. Standing at the apex as shown, check that signals from the wall, metal pole, and wood pole can be heard simultaneously as all three are brought into the field of view as the head is turned anti-clockwise.

These tests were given to all teachers so that they could use the same checks in the field.

9 Effect of Movement in the Environment

Only stationary conditions have so far been discussed, when in practice continuous relative movement with the environment takes place during travel on foot. This introduces a complex pattern of change in the signal due to Doppler effect.

The change in frequency due to movement takes place in the ultrasonic frequency range, and whilst the proportional change is small, the effect on the audible difference frequency is considerable. In Fig. 23 is shown the effect of Doppler shift due to a relative velocity of 10 km/h (6 miles/h)—pedestrian approaching a blind traveller, each walking at 5 km/h—computed from

$$f_a = D_0 K_D + \frac{2V_t f_{2/1}}{c} - V_t K_D t_i - V_t K_D t_s \quad (4)$$

static range code	initial Doppler shift	change in static range as target approaches	change in Doppler shift as frequency alters
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- where f_a = audio frequency output
 D_0 = initial distance
 K_D = range code
 c = velocity of sound in air
 f_2 = upper limit of frequency sweep
 f_1 = lower limit of frequency sweep
 V_t = relative velocity
 t_i = time measured from when range is D_0
 t_s = sweep time (sawtooth function resetting to zero at the start of each sweep)

It will be noticed that the range is constantly overestimated but the rate at which the audio frequency changes indicates the degree of overestimation—an advantage of the very wide bandwidth.

From equation (4) the rate of change of audio frequency is:

(quasi-static) $\frac{df_a}{dt} = -V_t K_D$

(Doppler) $\frac{df_a}{dt} = -2V_t K_D$

thus

(Doppler) $\frac{df_a}{dt} = 2 \times \frac{df_a}{dt}$ (quasi-static)

As the range is reduced the percentage overestimation increases to a maximum at zero range. In practice, of course, the change takes place so rapidly that accuracy in range estimation is not an important factor; rate of change of range is, however, and this is accentuated by the Doppler effect. Its effect is considered under 'Evaluation'.

An equally—and sometimes more—important effect of movement is change in angle. In experimental situations when the direction of a signal is held static, it can be difficult to determine this direction with confidence. The moment there is angular movement, however, this change is immediately perceived and the sense of direction

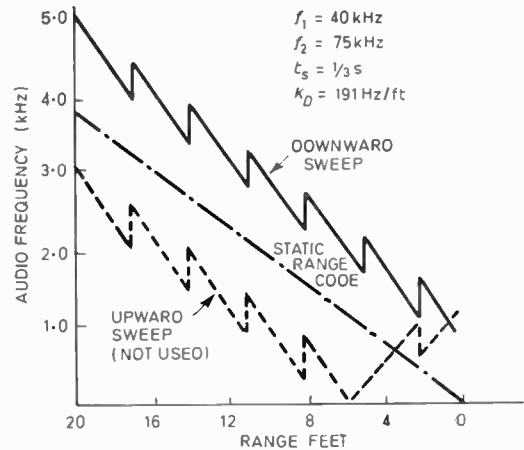


Fig. 21. Doppler effect for a closing velocity of 6 miles/h (9 ft/s). (After G. Martin.)

appears to be sharper. Angular velocity and acceleration both seem to be readily perceived and provide excellent feedback for the motor system.

Consider, for example, the simple task of passing a pole by about 1 metre, starting from a distance of about 5 metres. Two possible courses of action are illustrated in Fig. 22(a) and (b).

(a) One may estimate the angle $\theta = \tan^{-1}(1/5)$, face in the direction θ° to the left or right of the direction of the pole and, maintaining a straight course, pass the pole at a distance of 1 metre.

(b) Alternatively, one may continue towards the pole constantly monitoring its position, and gradually change course so as to make the pole appear to move to one side with an increasing angular velocity. When this approaches a maximum, the pole will be passing from the field of view; and by constant monitoring of the distance arrange that when the rate of change of range approaches zero, the almost constant distance is 1 metre.

Strategy (a) seems to be the simplest approach to the problem but none of us use it in practice. We naturally use (b) even though on paper it appears to be more difficult. We are operating a closed-loop control system which gives us greater confidence in our performance; this is constantly monitored and adjustments to our curved course enable us to achieve considerable precision in the result.

We require accurate judgment of neither distance nor

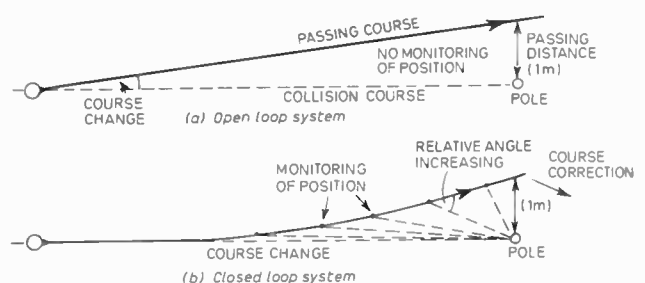


Fig. 22. Strategies for passing pole.

angle until the task is almost completed when it is necessary to judge the 1 metre at which the pole has to be passed. But we do require good judgment in assessing the rate of change of angle as well as distance because these seem to provide vital control information. Nevertheless, all four parameters R , dR/dt , θ , $d\theta/dr$ are needed, and we probably make good use of $d^2\theta/dr^2$ too. (r = distance moved as registered by feet).

The sensory aid provides this information very effectively. Neither R nor θ can be judged accurately but dR/dt and $d\theta/dr$ seem to be readily perceived.

10 Angular Judgment and Discrimination

It was a hypothesis of the writer that if a binaural sensory aid could be made to match the auditory system of the user he 'would have the impression that objects in the environment were themselves making sounds'.³¹ For example—the sensory aid may be indicating an object at 2 metres, at 'one o'clock' to the direction in which the user is looking. If, at the same time, a tapping sound comes from the same object (a flag-pole with the rope flapping in the breeze) this should also indicate an object at a distance of 2 metres and a direction corresponding to 'one o'clock'. The sensory aid and the natural perception of space would then be matched.

Rowell has defined matching of the binaural system to the auditory system as arranging for the i.a.d. of the device to be equal to the i.a.d. the user requires in order that his estimate of angle θ is correct over the range of angles of interest.

Thus from equation (2)

$$\theta = \theta_E = K \log_e \frac{A_R}{A_L} \quad (5)$$

where A_L = amplitude of the sound in the left ear and A_R = amplitude of the sound in the right ear.

Experiments were conducted⁴¹ using a simulated arrangement where it was found that subjects learned to respond accurately to direction stimuli when the value of the localization constant K was both smaller and larger than that thought to correspond to the users localization constant. *Those using the large i.a.d.* (corresponding to large device splay angle) *found the task easier.*

There was no evidence of adaptation but the experiments were not conducted for a long enough period for this to be established. Thus, on the basis of successful user experience up to that time, it was initially determined that the splay angle remain at 10° as set up at the factory for the mini-evaluation, and plans for the adjustment of this in the field, as necessary, were made. Such a splay angle was to produce an i.a.d. slope of approximately 0.5 dB/deg which agreed with Rowell's findings that an i.a.d. slope of between 0.4 and 0.5 dB/deg would suit the majority of people. Some, however, would require much less.³⁸

Under these circumstances, where possibly too great an i.a.d. slope was being used, learning the direction stimulus would be somewhat easier, if not faster, and the discrimination of objects would be better than if one

erred towards too small an i.a.d. Also, provided proprioceptive feedback was used during the training, the ultimate accuracy in determining direction with the sensory aid would be good.

It was also felt that, provided the accentuation in the direction cue by a larger i.a.d. than perhaps required for 'matching' was not too great, the enhanced ability to perceive angular velocity would aid in negotiating objects, and discrimination between two objects in azimuth would be easier.

A further important factor which influenced the decision to use an accentuated i.a.d. is the increased ability to shoreline (i.e. follow a hedge or fencing) which this provides.

Following an instructor's training course in Australia, it was felt that the $\pm 10^\circ$ splay angle was too large and it was reduced to $\pm 6^\circ$. The effect was to accentuate the change of intensity of an echo as the head is turned and reduce the i.a.d. producing the direction cue. Subsequently, the splay angle was changed to between 8° and 10° to give an i.a.d. of 0.4 dB/deg.

During this critical period of the evaluation, we were in fact determining the key function of the aid.

11 Object Discrimination

A very important feature of spatial perception has not so far been discussed—that of object discrimination. We are visually able to see a parking meter beside a lamp post, say, because the two things look different. We can locate a step down because of the contrast in colour or shading between the path edge and the roadway. If, however, all things were the same colour and intensity, we would not be able to discriminate between them, and the environment would provide little stimulus to our eyes.

Similar discrimination should be possible with a sensory aid designed to help sense the environment. Much has been written on this in relation to the 'Sonic Torch' developed initially by the writer as one channel of the present two-channel system.⁴²⁻⁴⁴

The c.t.f.m. sonar system does in fact provide quite remarkable information about the environment, such that it is not difficult to recognize many different objects provided adequate *a-priori* information is available. For example, all poles sound the same although some will produce a louder sound than others. However, if a blind traveller reaches an intersection using a combination of the Sonic Glasses and his natural hearing, and then locates with the aid of the glasses a pole on the corner of the footpath, it is more likely that this is there to support traffic lights than a bus-stop sign. The latter would normally be encountered some distance from an intersection. A 'look' at the top of the pole with the glasses will *confirm* this assumption by the *character* of the sound caused by the group of lights. Many such examples can be given where *a-priori* information aids in the recognition of objects.

There are many categories of objects, however, where the character of the sound alone enables the user to classify an object as belonging to a certain group. This is made possible through the frequency spectrum of the

signals produced by the range coding.²² The following are some examples:

- (1) Smooth round pole—a single frequency.
- (2) Railings placed 20 cm apart—a sequence of single frequencies spaced approximately 170 Hz apart. This produces a very characteristic sound which cannot be mistaken.
- (3) Small leaf bush—approximates to a band-limited white noise due to a multiplicity of closely spaced scatterers. The bandwidth is determined by the depth (in range) from which scattered sound is received (0.5 metre produces band of 425 Hz) and the centre frequency is determined by the range of the bush.
- (4) Large leaf bush—band-limited noise produced by a limited number of larger scatterers and reflectors (smooth leaf surface). The character is harsh and somewhat rasping due to the large variation in amplitude of each individual signal component.

It is relatively simple to build up spectra corresponding to classes of objects but the sound they produce is unique and cannot readily be obtained in any other way.

Thus a third and very important cue in the sensory aid is object recognition or at worst discrimination by sound character.

The limit of discrimination is difficult to define. Rowell³⁸ has shown through simulation studies that in order to hear two tones as being *distinctly separate* their frequency spectra must be separated by approximately 1 octave, but subjects may well report there are separate notes when they differ only by a factor of 0.04. In fact, one's judgment of 'distinctly separate' in auditory perception varies greatly.

If, instead, the criterion were simply to detect the presence of two notes and then specify their separation, the variability in judgment may be less; this seems to be what happens in practice. For example, it is easy to recognize the presence of two poles and after practice not difficult to judge their range separation. The *perception* that results cannot be analysed except through verbal communication, and this is indeed variable. Controlled experiments to determine the limits of judgment are, unfortunately, lengthy and, for the most part, unrealistic. Thus one is forced to the conclusion that user evaluation will provide more useful information, even if specific questions cannot be answered except by a 'yes' or a 'no' from individuals.

Part 2. EVALUATION

12 Introduction

The evaluation of a sensory aid is of necessity many-faceted, even the meaning of the word is ambiguous between different social groups and in this project at least five had a strong interest.

- (a) The blind want to know the benefits the aid provides.
- (b) The agencies serving the blind are probably more concerned with the cost-benefit and must take into account other demands on their limited resources.

- (c) The professional teachers of the blind must, as a body, look at the long-term implications which may significantly affect their teaching methods—possibly involving them in extensive new teacher training courses. The benefits must be weighed against the possible benefits from alternative teaching techniques or devices.
- (d) The behavioural scientists want to know if the man-made system warrants a detailed study and, to this end, call for objective measurements.
- (e) The design engineers want to observe and measure performance in such a way that they can create better systems. This calls for special skills in combining both subjective judgments and objective measures to meet the needs of the end user in the best possible and most acceptable way.

Because of the many important non-technical social groups seen to be concerned an evaluation/development plan was drawn up in January 1968 mainly to meet their important point of view; and it was for the most part completed in June 1972. The cooperation and assistance of many individuals and organizations in New Zealand, Australia, the United Kingdom and the United States of America was vital. The project was in fact an experiment in teaching from which the man-machine performance could ultimately be determined in relation to the user population.

13 Risk Factor

There appeared to be one major risk involved in this programme following experience with the Sonic Torch and other similar devices. Rejection is fatal to a sensory aid—for whatever the reason. The concept of sensory aids involves a unique and specialist understanding and only the user market can be expected to be interested in development and evaluation; normal commercial practices for launching a new product are not viable. Hence, if one or more agencies serving the blind reject an aid after the expenditure of significant funds, no other agency is likely to provide further funds from the very limited resources available. Clearly at the commencement of the major programme the evidence in favour of the sensory aid was judged to be very high, based upon an extensive study of the problem of mobility. The key to success was to demonstrate beyond all reasonable doubt that a blind person could be taught to travel significantly better with the aid than without it—and this must be demonstrated to those believed to be most knowledgeable in the field of blind mobility—the teachers. Once adequately demonstrated, this fact becomes established; from there one can consider objective measures to substantiate the subjective judgments.

This may appear to be a most outrageous statement—it would be if, in fact, there were a theory of mobility on which to base a scientific study. No one yet has specified the task of the blind man in such a way that confidence in objective measures is high. So human judgment must remain predominant; unfortunately, it is subject to so many external influences and pressures that it can be unreliable. A process of gradual education was therefore adopted from the beginning.

(1) Through many hours of experience walking under blindfold using the Binaural Sensory Aid in various environments, we gained a unique insight into the use and general value of the aid. The performance of the device was adjusted and modified over a period of time until improvement in the performance was marginal to the basic issue—better mobility.

(2) The next step was to convince one experienced teacher of the blind, through his personal experience teaching three or four subjects, that the device had significant potential as an aid to mobility. Sighted subjects under blindfold were chosen to eliminate emotional factors as much as possible.)

(3) From the experience of one teacher, three teachers were trained in the use of the sensory aid—through personal experience in teaching some twenty blind people. These teachers were to form the nucleus of trained staff for training orientation and mobility specialists who were to carry out the evaluation.

(4) The final step in the educational programme was to train 20–30 orientation and mobility specialists for the major evaluation programme.

14 Sensory Perception

An important factor in the operation of the man-machine system which is probably not self-evident, is the mechanism of sensory perception. This remains inadequately understood even though it is being researched in many centres both in the visual and auditory fields. As with engineering systems where the transfer function of a 'black box' can be determined by applying a suitable stimulus and observing the response; so with the even more complex 'black box' of man's brain. There is no way, however, of applying the familiar impulse function from which the complete transfer function may be determined readily. The process is much more involved and only simple elements of an exceedingly complex system can be studied during any experiment with humans.

As an engineer, the writer felt he had the license to explore the possibilities of the binaural sensory aid through a process of self experimentation. In this way an appreciation was obtained of the perception of space, made possible through an echo-location system. Describing one's experience in such a way that useful information is made available was far from easy and not necessarily reliable.

An assumption was made, however, which formed the basis for most of the study. Whilst man is a complex machine of many variables, his basic design is universal and the response of one normal individual to a specified stimulus must indicate the response one would get from most people provided the tolerances placed upon the response are adequate.

In terms of applied psychology related to humans, this is a dangerous over-simplification but seemingly necessary. For example, it was observed that as the splay angle of the transducers was increased, the ability of a subject using the aid to recognize left or right stimulus signals increased. This experience must be

common to all people with normal hearing but the degree of sensitivity could be expected to vary widely, depending upon the neural characteristics of the individual. It was also observed that when *more* than two tones were present it was not always easy or even possible to distinguish them. If they were well spaced in frequency the problem was less, but the spacing required by individuals in order even to say two separate signals were present would vary considerably. If, however, one of the tones changed in pitch it would immediately dominate the attention. This must be a fundamental characteristic of human perception, but the degree of variation required to produce this effect probably depends upon the individual.

Thus a pattern of responses was built up and some of the tolerances were examined through carefully controlled experiments using well specified stimuli.⁴²

However, it was quickly found that as the stimulus is made more meaningful and greater freedom allowed the subject, the response is observed to be more well defined; yet more difficult to measure because of the additional complexity of the situation.

For example, a typical stimulus was a pulse of dichotic tone with a specific value of i.a.d. The expected response from the subject was an indication of the azimuth direction assigned to the lateral shift of the fused binaural signal in his head. This was not always repeatable within close tolerances ($\pm 5^\circ$). If, however, the dichotic signal changed with head movement in such a way that the lateral shift correlated with head rotation, the direction assigned to the lateral shift was more readily given—but the tendency of the subject was to centralize the signal in the head by looking in the direction to be assigned. This destroyed the initial information perceived by the subject and there is no way of recovering it without introducing a learning process at the same time through repetition.

A major change in the complexity of the stimulus is made when the device itself is used to provide this—even when the task remains simple. When the task is mobility, involving the locomotive system of the body, we are no longer in adequate control of the man-machine-environment complex. Entirely different techniques are required in such a unique unexplored relationship. The approach adopted is covered in the following sections.

15 Miniature Evaluation

15.1 Sighted subjects

It was shown by Cratty⁴⁵ that the acquisition of the skill required for mobility without vision was no different for sighted people working under blindfold than for blind people. There are of course fewer emotional problems encountered, and hence for the first trial of the binaural aid four sighted subjects were chosen. The devices which were used were the first models which could be considered to be portable (see Fig. 23). Cosmetics were of minor importance at this stage.

None of the subjects had prior experience under blindfold—except during occasional games. The aim was to teach all four subjects to travel from a laboratory on the University campus to a specific place in a local

shopping centre via a quiet suburban area, a moderately busy residential area, and a busy business intersection—a distance of approximately 1 km.

The period of training was approximately 40 hours over a span of 8 weeks. During this time each subject was separately taught to use the conventional long cane technique of travel and the Binaural Aid. The use of the cane was learned as an independent aid by two of the subjects, then the glasses were taught as a supplement to it. The other two subjects were first taught the glasses for a short period, and the cane as an aid was subsequently added in combination.

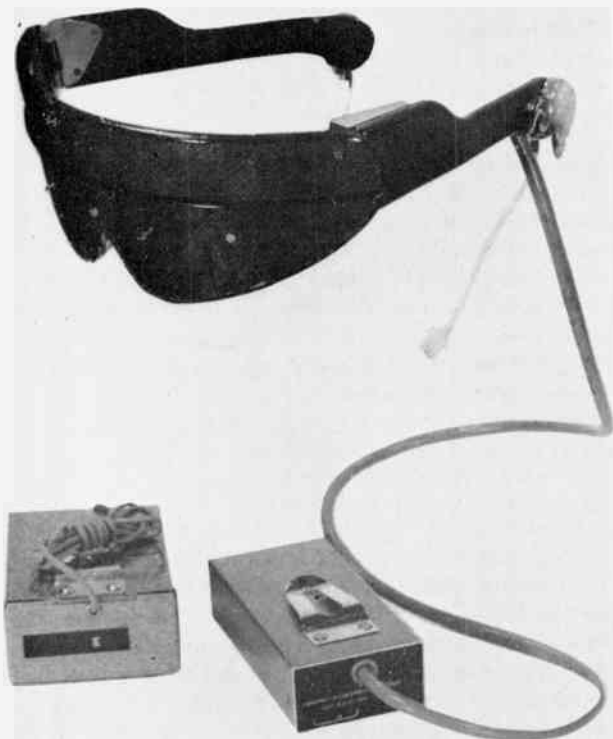


Fig. 23. Experimental Binaural Sensory Aid first used by sighted subjects under blindfold for preliminary evaluation.

It was quite evident from the results obtained, through frequent observations—that the teacher displayed greater skill in cane training than sensory aid training. Since the technique for teaching the glasses was self acquired, this difference was to be expected; but it had a profound effect on the results. Those who commenced training with the cane alone became more proficient and made more rapid progress. Even so, three of the subjects displayed an improved ability to travel with the sensory aid in combination with the cane. Various situations commonly encountered during travel on foot amply demonstrated the value of the glasses, and it was evident that with only 10–15 hours actual use of the sensory aid significant benefit was possible. The range of knowledge of the subject did of course remain limited.

A short length of film was produced showing one of the blindfolded subjects walking almost as though sighted and her comment was, that with the glasses she

felt so relaxed that she was tempted to ‘skip and jump’. The male ‘felt the challenge of travel under blindfold had gone’. Contact between the cane and objects in the travel path was almost eliminated.

It was then decided to put into operation the mini (exploratory) evaluation and a second orientation and mobility specialist was engaged from the U.S.A. It was also decided to introduce guide dog travellers to the programme because it was felt their need would be different.

From the experience with cane travellers it was evident that the primary use of the glasses would be in object avoidance and orientation. The guide dog traveller is not concerned about these problems since the dog is trained to handle them (not navigation). The sensory aid would then be of value in locating landmarks and recognizing the surroundings. Acceptance by guide dog travellers would then imply value as an environmental sensor in the form of object recognition and discrimination at a fast walking pace. More information would then be made available to the evaluators.

15.2 Blind Subjects

Several criteria were stipulated for the mini-evaluation.

- (a) Once a blind person had been trained to use the glasses and wanted to continue using them, he was to keep them on indefinite loan.
- (b) All subjects had to be physically fit.
- (c) All subjects had to be volunteers.
- (d) Only people between the ages of 18 and 55 were to be chosen.
- (e) All had to have normal hearing.
- (f) All had to be totally blind.

Two groups were involved. One group consisted of subjects trained to use the long cane and the glasses by the two O & M specialists in New Zealand. The other group was trained in Australia to use the glasses in conjunction with a guide dog.

Over a period of twelve months, 20 people were trained (8 guide dog users and 12 long cane users). The results were varied but, on the whole, very encouraging.

At the guide dog training centre in Australia, the blind people were given up to 70 hours of training whilst in residence over a period of 4 weeks. Their performance (in the use of the glasses) was judged to be superior to the other group. In New Zealand, no provision could be made for the trainees to have full-time training. The teaching was therefore on a part-time basis.

The blind subjects using the cane and glasses exhibited travel skills which on the whole were superior to what was possible with the cane alone, and all three teachers agreed that the glasses were of significant value (a purely subjective judgment). Ninety per cent of the blind who were trained felt they had benefited from the use of the glasses, but some more so than others.

No objective measures were taken because of the exploratory nature of the exercise. Teaching techniques were being acquired and mistakes were made which would have been reflected in the objective measures.

It was probably significant that those blind people who were trained by the guide dog user and the writer (both understanding the language of the aid) had a greater understanding of the environment through the glasses than did those trained by the O & M specialists. However, where known skills were being taught, the O & M teachers excelled in their own specialities. This posed a major problem which remains to this day. How are teachers to be effectively trained in the use of the 'glasses'?

16 Major Evaluation

A pre-production development period of 18 months was allowed for the devices to be used in the major evaluation, and experience during the mini-evaluation was successively fed into the engineering programme. Since the initial five devices gave little trouble, it was thought the basic design was at least adequate for an evaluation which would concentrate on the *concept* of the sensory aid. Tight performance specifications could not be drawn up because of the limited experience with the blind who seemed to be surprisingly tolerant. Any problems they had experienced could in fact have been due as much to their personality profiles or inadequate teaching as to inadequate performance, and it was not possible under the circumstances to isolate these causes.

16.1 The Evaluation Team

It is common to expect that the evaluation of a product will be carried out by an independent body. In principle this is a good policy, for in these circumstances the design group have normally determined the operation and performance of their product to their complete satisfaction. Those who are to evaluate the product normally understand its operation and are familiar with what is required. Evaluating the binaural aid was quite different; the exercise formed an integral part of the investigation into the engineering performance by the design group. In addition, no one outside the research and development team understood the device adequately, nor did anyone really appreciate what was expected of the man-machine performance. Those particularly interested in the evaluation as an aid to the blind were non-technical and inexperienced in handling technical problems. The evaluation of the Sonic Torch by non-technical groups had failed through a lack of basic understanding related to the torch. Thus it was decided by the writer to employ the R & D team from Canterbury as teachers of the O & M specialists and then monitor these teaching the aid to the blind.

The team in the USA comprised the writer, D. Rowell, an engineer who had specialized in the psycho-acoustic aspects of the device, W. Keith, a psychologist specialized in audiology and familiar with the device, and N. Bell, an orientation and mobility specialist.

16.2 International Participation

16.2.1 *Australia*

The mini-evaluation programme which had commenced early in 1970 was continued and expanded by the involvement of three more rehabilitation agencies, and six

more instructors were given training. The operation in Australia was intended to provide experience of problems which are likely to arise when the training of the blind is remote from the evaluation team and the manufacturer. If the subsequent performance of these blind was found to be inferior, for non-obvious reasons, compared with the results obtained under the guidance of the team, then the latter would have less significance. In effect, those in Australia formed a control group and played an important part in the overall programme.

16.2.1 *USA and UK*

Involvement of both the USA and the UK was considered vital by the writer so that two major and quite different groups should be involved, since their general approach to blindness is quite different.

In the USA there are many rehabilitation centres and mobility is taught by a body of approximately 400 'O and M specialists', who have a Master's degree. In the UK there is only one major rehabilitation centre and most people are dependent upon their local authority for special services. Some 50 mobility teachers of varied backgrounds operate through local authorities. The technique of teaching the blind is however the same in both areas.

The UK was to train up to 20 blind people through one teacher working over a period of 12 months full time. In the USA, approximately 140 blind people were to be trained using 18 teachers over a similar period.

16.3 Teacher Training

The ability of the teacher has a significant effect on a student's performance in a skill when this is of a complex nature. Blind mobility is probably one of the most complex skills we can expect a person to acquire, with the result that end performance is heavily dependent upon the trainer. Hence a variable—the teacher—which was built into the evaluation would be difficult to control and the assessment of its effect would almost certainly be highly opinionated.

Once again, the concept of an acceptable threshold was used in designing the programme. Three teachers had, without formal training, shown that blind people can be taught to use the binaural aid effectively and their mobility skill was observably superior to what it was without the aid.

A formal training course for teachers lasting four weeks should then have given each teacher a better chance of success well above a minimum threshold—even though four weeks training was thought to be quite inadequate and, inevitably, some of the teachers would be less responsive than the first three. Those who became more able, through directed experiences, would, however, be the means for demonstrating superior mobility skills in their students, provided of course, the device was capable of making this possible.

The aim of the training course was to get teachers to a level of attainment which allowed each one to travel in a city centre area under blindfold, using the binaural aid. Not all actually reached this stage and only a few

attained a high degree of travel skill. Almost all did, however, understand the basic principles of the training course and the operation of the device.

16.4 Training of the Blind

The pattern of training, which unfortunately varied in duration from 20 hours to 70 hours over periods of 2 weeks to 6 months, took the following 'general' form

(1) One week was spent on controlled exercises in a clear area, often in a hall, using poles which could be placed in a variety of patterns as shown for example in Fig. 24. These exercises were designed to teach the pitch-distance cue, the direction cue, and concepts such as parallel and perpendicular travel relative to guiding boundaries of the environment.

(2) One week travel with the long cane and glasses in a quiet residential area and a local shopping mall.

(3) One week travel to and within a local business area encountering increasing traffic and pedestrians.

(4) One week travel into a city centre using public transport.

The training took place under almost all possible climatic conditions from sweltering heat in excess of 30°C and 90% humidity to below -20°C in snow. Both teachers and their blind students seem to accept these hardships as inevitable in some parts of the world. Learning rates were not uniform under these conditions.

17 Evaluation Results

The data on the evaluation are almost exclusively in the form of answers to a professionally designed questionnaire. Out of the 96 blind people who were asked 169 questions each, 74 of them made returns. Bearing in mind that all had to seek assistance in having the questions read, and a sighted person completed the forms, this response indicates high motivation to make a return.

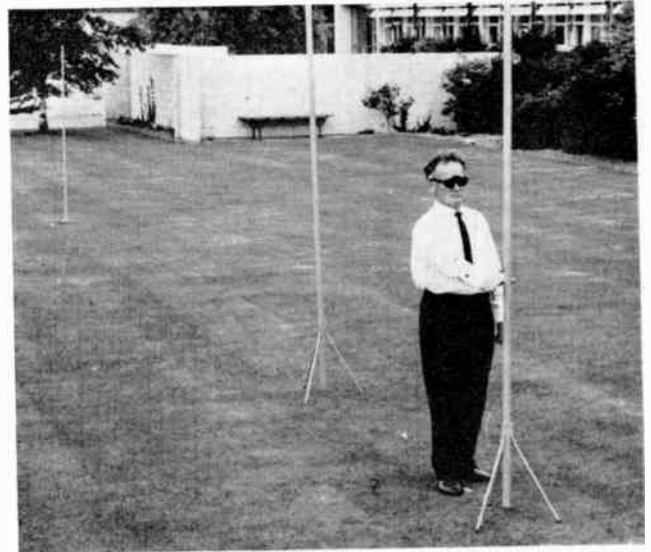
It is emphasized that not all participants had long experience with the device. Some had up to two years' experience, whilst others may have had only one or two months. When asked if they were keeping the glasses

- 10% replied 'No'
- 10% were undecided
- 80% replied 'Yes'

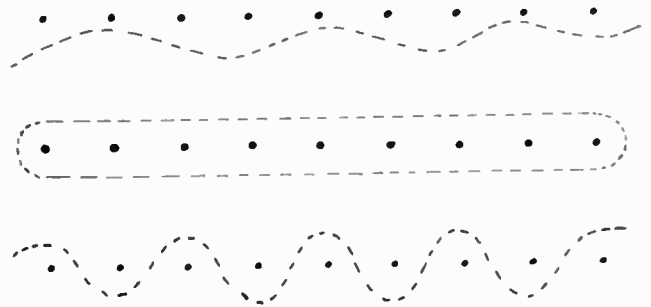
17.1 Learning Rates

The time taken to learn the distance cue, the direction cue and the combination of the two cues to locate objects was for approximately 50% of the students less than 2 days from commencing training. By the end of 7 days training, 90% of the subjects felt they had mastered the skills. However, the ability to use these in combination with the cane in real travel situations took longer to acquire: 60% of the students found it took between 1½ to 2½ weeks before adequate attention could be given to both the glasses and the cane. Even so, 40% felt an immediate benefit from the glasses whereas it was not until the third week that 80% could say this.

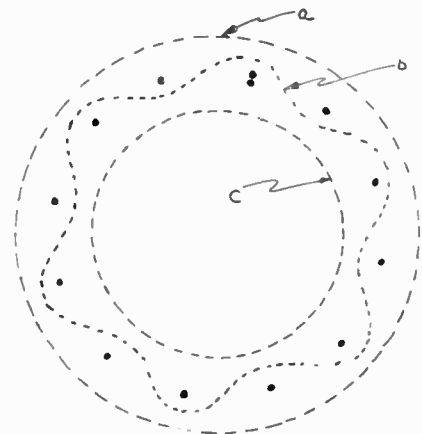
When asked if learning to use the glasses was simple, 53% said 'yes', which correlates well with the learning



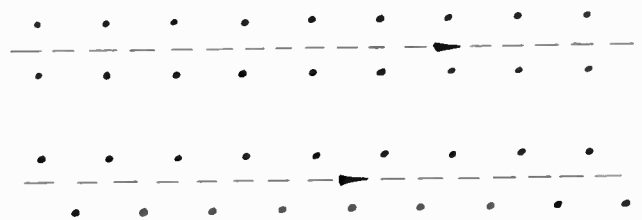
(a) Initial training exercise on distance and direction cues.



(b) Exercises in body control multiple object situation.



(c) Advanced exercises in body control.



(d) Body control in complex signal situations.

Fig. 24. Controlled exercises.

rate. 57% experienced little or no confusion from the sounds early in the training.

These data suggest that approximately 50% of the subjects had no problem in learning the use of the glasses within a period of 1–2 weeks. Most had grasped the concept and could use the aid within about 3–4 weeks. The actual training time varied between 20 and 70 hours.

17.2 Travel Skills

As the task becomes progressively more difficult rating of the binaural aid in its potential for improving certain mobility skills decreases and to some extent the teachers say the device has less effect in improving the skill compared with the cane alone.

Avoiding pedestrians is a skill which demands the use of all the features of the device display, and this produced better than a 70% positive response. There is clear evidence, however, that even greater skills are possible through improved device performance and better teaching methods. For example, 30% of the users responded that they could follow a sidewalk bordered by grass. The discrimination in sound required here is considerable, but if 23 people at the time of answering the questions have acquired the skill, the man-machine system must at least have this capability. The human auditory neural pathways appear to be capable of signal processing which it is difficult to conceive being done by a machine.

Since the devices in the field were known to be performing inadequately compared with what is now possible through improved engineering design, and since skills such as following sidewalk bordered by grass were not taught at all, it seems reasonable to assume that this skill could be acquired by more people if they were trained and used a more advanced device of this same type. It is unlikely, however, that such a skill could become a common need by the blind, and it is also unlikely that training at this level of sophistication would be supported financially. The additional cost would probably be best fed into activities which serve the many rather than the few. There are however other skills which should be improved.

Crossing a street was thought by 72% of the users to be easier with the binaural aid than with the cane alone. The teachers, on the other hand, felt the device would have small effect on mobility skills in this area. This is probably where there is greatest difference of opinion between teacher and user. A number of users were questioned on this matter and the reply was simple to understand.

Crossing a street in a town centre is a complex task and many skills are involved. The glasses provide much information which is confusing during training in this kind of setting and few teachers thought it would be of value. Some time after training, however, when the sounds had become more meaningful, the blind found the subtle signals from 'downtown' could be used more effectively and the specific task of crossing the street became easier. For example, groups of people could be followed at a pedestrian crossing; poles on the far side

of the road became navigation 'beacons' once they came into range; pedestrian islands in the roadway could either be located or avoided, and so on.

Information such as this is thought to convey meaning which highly objective measurements are unlikely to provide: this is because the latter reduce the use of *a-priori* information. The complex interplay of redundancy and wanted information, which aids in sorting out complicated situations, is not available.

17.3 An Objective Test

A study carried out by Armstrong, using five blind subjects trained in the United Kingdom (reported by Thornton),⁴⁶ indicated that the Sonic Glasses were being used by the blind to improve mobility performance. Particularly, physical contact with the environment was reduced and all users walked more smoothly with the binaural sensor than without. It was thought significant that the use of the binaural sensory aid helped the user to anticipate the down-kerb, even though the kerb itself could not be detected by the device. A knowledge of the environment acted as a main cue to situations involving danger, and in fact seemed to be better than the primary aid—the long cane—in certain circumstances.

A special test was carried out using the most experienced user, W.T. He was asked to walk a distance of 1300 metres over a route he had walked only twice before in a strange city—once was with the cane alone, and once with the cane and the glasses—and describe what he 'saw'. He was approximately 80% correct; and it was concluded that the binaural sensor can provide detailed environmental information.

It was also concluded that the binaural sensor becomes much more effective as an aid to mobility after a long period of use.

18 Display Effectiveness—Discussion of Results

In evaluating a sensory aid we are not evaluating a device, we are instead evaluating a new man. Initially, man is given a stimulus possessing objective characteristics and receives a sensation. When all the stimuli are learned, man should respond to the subjective characteristics and experience perception. At one time the two were thought by some to be the same; this and other experiments have demonstrated otherwise and it may be useful to keep them apart.

The sensory and motor systems cannot be considered in isolation, as various perceptual experiments have clearly indicated and therefore simple single-sense responses to the environment cannot be realistic. Any attempt to impose restriction on the learner was carefully avoided by involving only those people who would ensure freedom of experience for the blind user. (Where restriction was imposed inadvertently, learning rates were slowed down.) But we are left with only subjective results. The question which has to be answered before we can proceed beyond this point relates to the distribution of the answers. Can we say that the percentage of 'yes' or 'no' answers realistically indicates the degree to which the average trainee was using the information

from the device? For example, 98% of the users declared the glasses gave them a better ability to assess the distance of objects than was possible with the long cane system. This could mean almost anything from 'There is an object beyond the reach of the cane' to 'There is an object at 2.3 metres'. However, when the user was asked if the device gave more assistance in assessing the distance of moving objects, the response in favour of the aid dropped to 58%. Since 74 people were involved, this difference is highly significant. The task is certainly harder; but an important factor in the simpler question is now partly resolved. If the users were only interested in the presence of an object and not its distance, the answer to both questions would have been the same. But because stationary distance is easier to assess than moving distance, the latter gets a lower rating. Nevertheless, we cannot say that stationary distance is accurately assessed, nor can we say that the distance of moving objects can be assessed with reasonable accuracy.

Consider by comparison the effectiveness of normal vision in carrying out these tasks. Few people can assess distance accurately and it is impossible to assess the distance of a moving object in terms of a measured length. It would not be difficult to enter into a lengthy discussion on these simple features of our ability to perceive. In fact, we *perceive* the distance of objects but do not measure them. This is vital to our relationship with the world and forms part of what is known as *perceptual constancy*. The world must remain stationary as we move in it, and when a part of our environment moves we must perceive this as unchanging except in position—the *height* of a man remains the same irrespective of distance.

Can we gain insight to the blind man's perception of the world through the glasses from his answers? Consider the task of avoiding pedestrians in a crowded area. There will obviously be many pedestrians who will avoid the blind person and he would not know of them unless his perception were adequate. However, the user's response was that the glasses provided *additional* aid to 78% of them. Since 93% could avoid obstacles (i.e. stationary things) and 78% the moving things, the latter must have appeared to be the harder task. If, however, there were no constancy in their perception, both tasks would be equally difficult.

Both observation and film records amply verify the ability of the user to perceive his environment—at least crudely—and this is in fact quite an astounding finding which deserves greater study than has been possible so far. How was it possible for man to learn to react naturally to artificially generated sounds within the short training period of 40 hours? Could it be that the form of coding used was readily transformed to other sensory modalities and conveyed *meaning* rather than just information in the purely theoretical sense. It seems conceivable, in which case the concept of a *new sense* may not be so far-fetched, and non-visual perception for the blind is possible without directly stimulating the visual cortex. It is even conceivable that the *degree* of perception could compete with this more sophisticated concept in a mobility setting.

19 Cost Effectiveness

Probably the most important aspect of an evaluation is determining the cost effectiveness of a device or system being evaluated. This is also likely to be the most difficult to resolve for each group will view cost effectiveness differently.

In this field the universal reaction to a device which may well cost of the order of \$1000 to manufacture—in the relatively small numbers required—is one of scepticism about agency acceptance; and the blind do not see themselves being able to purchase such devices. The situation is not as bad as many visualize, however. Welfare schemes in many developed countries provide for devices which help to make handicapped people re-employable; some even make devices available once their effectiveness is established.

Whatever may be the special circumstances under which agencies for the blind operate, they all provide some form of rehabilitation and for this to be effective a blind person must undergo up to three months training. In some agencies this could be extended. The cost of training varies considerably, but in the USA probably lies between \$1000 per head for a relatively low standard of rehabilitation, to \$6000 for a high standard. Training in the use of a guide dog, for example, costs approximately \$3000. Clearly, costs will also vary between countries.

At the present time, mobility training using the long cane as the basic aid is not given independently of other forms of rehabilitation, but if it were, the cost would be unlikely to be less than \$1500 per head. This then is the vague base from which to work.

If we make some relatively simple yet realistic assumptions, we can arrive at an interesting conclusion.

Assume acceptance of the aid to the level where it is in *general* use by those who *need* it, and costs say, \$1000.

Training time for a blind person in the long cane system is on average 120 hours and the cost for this, as already stated, may be of the order of \$1500.

Training time for a blind person to be competent in the use of the sonic glasses has been found to be on average, 40 hours. The cost for this may be of the order of \$500 (pro rata with long cane). Hence the cost for training a blind person with both the long cane and the sonic glasses in combination serially is:

Long cane system	1500
Device (sonic glasses)	1000
Device training	500
	\$3000

This is comparable with the cost for a guide dog. However, if we now additionally take into account the added benefit of the aid, we can arrive at quite a different conclusion.

The glasses reduce travel stress and give the user a greater appreciation of the environment. It is evident from observation in the field that many skills with the long cane can best be taught whilst the trainee is using

the glasses, and the total duration of training could be reduced, since so many of these tasks are then made easier to learn.

There is reason to believe the long cane training time could be reduced by approximately one-third to 80 hours and include the glasses training. Then we have

Training cost with long cane and sonic glasses together	1000
Device cost	1000
	2000

This is only \$500 greater than the cane alone and of the order of \$1000 less than with a guide dog.

Hence, for relatively small extra cost, the long cane system of training may be significantly upgraded; or the overall mobility of blind people may be improved greatly for, may be, the same cost as a guide dog.

On this basis it would seem that cost-effectiveness is good. Clearly this deserves special investigation.

20 Conclusions

It is evident that a sensory aid using an auditory display can be used effectively by blind people and a high proportion are able to sense their environment sufficiently well to be able to locate landmarks. This confirms the ability to recognize at least some features of the environment.

In a dynamic situation such as when avoiding obstacles and pedestrians, the range and direction cues of pitch and interaural amplitude difference respectively can be used in combination without much difficulty. The level of conscious thought is not known but when two persons are passing each other, the time available for deliberation is negligible. *Natural* reaction is necessary if stress is to be reduced, and this seems to be the case.

All that can be said about the end result is that out of 74 people replying to a questionnaire, approximately 90% learned to use the device within the period allotted for training. None of the display features were difficult to understand, except by the rare person who found the aid to be of little value. The degree to which the aid will be used after the novelty has worn off remains to be determined, but some have used the aid over a period of two years and continue to be enthusiastic. Those who do not use the aid much at present usually lead the kind of life which does not make great demands upon them in terms of independent mobility.

Technical deficiencies, early errors in the display parameters, and the limitation of the cosmetic appearance of the glasses in their present form, detract from the overall value of the sensory aid to a blind person; and these factors should be considered when judging overall result.

Whilst some advance towards greater mobility for the blind has been made, many new questions have been posed which promise challenge comparable with the programme reported here. The greatest problem will be faced by the agencies serving the blind where decisions

on priorities have to be made. At one stage it was optimistically thought that improved mobility would greatly influence thinking in this field, but many complex factors have to be considered and it is only programmes such as this which bring them to the fore.⁴⁷

21 Acknowledgments

Many colleagues have over the years contributed to the development of the Binaural Sensory Aid through my years at the University of Birmingham, Lanchester College of Technology, and the University of Canterbury, and it is quite impossible to acknowledge them adequately. They were all key people at the point in time when they participated in the programme. Those who participated in the latter part of the programme are, however, mentioned by name in this paper, with the exception of Mr. Robert Pugh, who was the first O and M specialist to successfully train a blind person to use the Sonic Glasses in 1969.

Several organizations have contributed financially to the development and evaluation. The initial support by St. Dunstan's in the early years is especially acknowledged. The National Research Development Corporation, to whom all patents have been assigned, provided the major support at a time when agencies for the blind could not see the viability of the concept. Since then, several agencies for the blind have aided in the programme but the Seeing Eye Inc. must be given special mention.

The one agency in the USA which provided support for the concept from the beginning (1962) and which participated in the development over the years, was unable to participate in the final evaluation only because they could not provide qualified O and M specialists for training. Without their generous support in the past and the continuous enthusiasm of the blind administrators, T. V. Cranmer and F. Gissoni, this programme would never have progressed beyond the embryo stage.

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Manuscript first received by the Institution on 1st October 1973, in revised form on 19th February 1974 and in final form on 8th August 1974. (Paper No. 1613/MBE 14)

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IERE News and Commentary



The 49th Annual General Meeting of the IERE

*Held in the Institution, 9 Bedford Square, London WC1,
on Thursday 3rd October 1974.*

The meeting was opened by the President, Dr. Ieuan Maddock, at 6 p.m. when 46 corporate members had signed the Attendance Register.

The President first called upon the Secretary, Mr. G. D. Clifford, to confirm that all members had received due notice of the meeting. Mr. Clifford reported that notice of the thirteenth Annual General Meeting of the Institution since its Incorporation by Royal Charter, together with the Agenda, had been sent to corporate members in a communication dated 30th June 1974.

Minutes of previous Annual General Meeting

Dr. Maddock then referred to the Annual Report published on pages 431-448 of the August 1974 issue of *The Radio and Electronic Engineer*, copies of the report being available at the meeting for those members who had not yet received their Journal. Dr. Maddock said:

'Before I comment on the Annual Report, I do apologise for the fact that members have not had longer time to study it. It was not, perhaps, a good idea to have delayed the August Journal in order to give members the earliest possible opportunity to study the proposals put up by the Institutions of Civil, Mechanical and Electrical Engineers. We all know of the difficulties being experienced in the printing industry, but we did not anticipate that it would take quite so long to get the Journal out.

'In thanking everyone for attending this Annual General Meeting, however, I also hope that you have had a few minutes to run through the Report.

'The Introduction highlights one of the Council's immediate concerns as to what can best be done to improve the status of the engineer, and at the same time provide those facilities which are so necessary to maintain the status of the engineer in enabling him to keep up-to-date.

'Those sections of the Report dealing with our professional activities in meetings, conferences and publications, combine to show a constant growth in what might be termed services

to members. Much more can be done, although we are at the present time being inhibited by constantly rising costs. Even so, we are being helped, as you will have seen, by a steadily increasing membership, and perhaps it is in anticipation that economic affairs will soon right themselves that your Council and its Committees are sufficiently confident to plan ahead, as, for example, in the arrangements we are making to celebrate the Golden Jubilee of the Institution.

'I particularly make mention of the international character of the Institution, as shown by the circulation of our Journal and the meetings that are held by our members in various parts of the world. Nearer home we anticipated Lord Kilbrandon's Report by establishing active Sections in Northern Ireland, Scotland, Wales, and, of course, in England! We have 14 Sections throughout Great Britain and members of the Local Committees do a tremendous amount of work in fostering Institution activity and providing facilities for members to meet. I have especially noted in the past year the increased activity that has occurred in most of the Sections and we are very grateful to all the members who make this possible.

'As I have already said, this meeting is to some extent dominated by the public release of the proposals of the Civils, Mechanicals and Electricals. Whether or not there is any further development in this connection, it is obviously necessary for the Institution to keep very much alive its work and thoughts on education and training. It would be idle to pretend that there are still not some misgivings about the Institution giving up its examination work; it was, however, in an attempt to work federally in securing public recognition of the standards required of a professional engineer that we

(Photograph above) Evidently a remark on the lighter side has been made from the platform to judge by the smiles of several of the members present. Mr. Andrew St. Johnston, a Vice President, (*front left*) seems to be particularly amused, but Mr. J. Langham Thompson (*four rows behind*) is not quite so sure.

surrendered our examination work to the CEI. I must emphasize, however, that in the view of your Council, this does not gainsay the need for our continuing to use the very considerable knowledge which exists in our membership on the present and future problems involved in ensuring the adequate training of the professional radio and electronic engineer.

'We have this afternoon had a most useful meeting of the Council of the Institution, when we debated the future, not only of our own Institution but the profession of engineering in general.

'I am sure that you do not want me to enter into any great detail about our Annual Report. This, after all, is a record of what we have done in the year ended 31st March 1974. Before I formally move the adoption of the Annual Report, however, I welcome this opportunity to invite any member present to make comment on it, and on the additional information published in the August Journal.'

No questions were asked and the President moved from the Chair that the Annual Report of the Council be adopted. This was seconded by Professor W. Gosling (Fellow) and unanimously approved.

Auditors' Report, Accounts and Balance Sheet

The President then invited the Honorary Treasurer, Mr. S. R. Wilkins, to comment on the Auditors' Report, Accounts and Balance Sheet for the year ended 31st March 1974. Having just completed his first year as Honorary Treasurer, Mr. Wilkins said:

'I must confess that it is a great relief to me to refer to our published accounts and see that, although the margin is small, the Institution has nevertheless spent less than it has received!



The Honorary Treasurer, Mr. S. R. Wilkins, presents the accounts while the President, Dr. I. Maddock, and the Director, Mr. G. D. Clifford, listen thoughtfully.

'Previous Annual Reports have stressed the need for the Institution to build adequate reserves; our slight difference between income and expenditure is therefore a step in the right direction, but it needs to be much higher if we are to ensure the stability of our Institution.

'Around us in this building we can all see the maintenance work that has to be done; we all know how costs have escalated, especially during the last year, and I think we all recognize that although inflation might be held, there is no likelihood of our ever going back to the same costs in wages,

materials and services that prevailed only a few years ago. In other words, we must budget at today's costs. I was, in fact, one of the members of the Finance Committee that argued for a long time about the rate of increase in subscriptions. In the event, the decision that was taken a year ago has proved to be the right decision at the right time, and when I say the right time I am mindful of the fact that other Institutions have had to, or are about to, copy our example.

'I am happy to report, Mr. President, that since April 1st last, members have responded magnificently to these new charges. As we know from every Company report we read today, no Chairman or Finance Officer is willing to forecast the future, but I can say that we have been able to overcome this year's problems of mounting costs, and I am hopeful that this time next year I will be able to report an even sounder financial position.

'I think that the section of the Annual Report dealing with our finances, together with the accompanying accounts, is sufficiently explanatory, but if you wish me to, Mr. President, I shall be very pleased to answer any questions that members would like to ask, and then, if you will permit me, I would like, on behalf of the Finance Committee and the Council, to propose the adoption of the Accounts as published, together with the Auditors' Report.'

There were no questions and the motion having been seconded by Colonel G. A. Bartley-Denniss (Fellow), the adoption of the Accounts, Balance Sheet and Auditors' Report thereon for the year ended 31st March 1974 was approved unanimously.

Election of Council for 1974-75

The President then referred to the nominations made by Council for elections to its ranks for the year 1974-75, notice of which had been circulated to corporate members in the June 1974 (page 332) issue of *The Radio and Electronic Engineer*.

There had been no opposing nominations and a ballot had not therefore been necessary. Dr. Ieuan Maddock was re-elected as President and Dr. P. A. Allaway, Professor W. Gosling and Mr. A. St. Johnston as Vice-Presidents. In addition, two new Vice-Presidents were elected, namely His Royal Highness the Duke of Kent and Professor W. A. Gambling.

Professor D. E. N. Davies was elected to fill the vacancy for a Fellow created by the election of H.R.H. The Duke of Kent as a Vice-President. Professor Davies was already serving on Council as a Member and the vacancy created for that grade was to be filled by Mr. M. S. Birkin.

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

Dr. Maddock expressed his appreciation for the support he had received from his colleagues on the Council, and particularly thanked Professor G. B. B. Chaplin and Air Commodore S. M. Davidson, the retiring members.

Appointment of Auditors and Solicitors

The President said that he would like to take Items 5 and 6 of the Agenda together, namely the appointment of Auditors and of Solicitors. Dr. Maddock accordingly asked for approval to the re-appointment of Gladstone, Jenkins and Company as the Institution's Auditors, and that their remuneration should be at the discretion of Council, and that Braund and Hill be re-appointed as Solicitors to the Institution. The President's motion was carried unanimously.



The President congratulates Dr. K. J. Dean, first recipient of the Eric Zepler Premium.



Mr. James Elliot is presented with the newly established Sir Charles Wheatstone Premium.



Mr. G. A. Gerrard is handed his Rediffusion Television Premium which he received jointly with Dr. J. E. Thompson. The Institution's Editor, Mr. F. W. Sharp, stands by with the other prize.



The P. Perring Thoms Premium is presented to Dr. R. C. V. Macario for his paper which was judged to be the outstanding contribution on radio receiver practice.



Past President J. Langham Thompson with Dr. C. J. Paull and Mr. W. A. Evans to whom he has just presented the Premium he endowed in 1961 for an outstanding control engineering paper.



Mr. C. S. den Brinker is congratulated by Dr. Maddock on being awarded the first Admiral Sir Henry Jackson Premium for a historical paper.

Presentation of Premiums and Awards

With the conclusion of the formal business of the meeting, the President came to the presentation of premiums and awards to the authors of outstanding papers published in the



After the meeting Honorary Treasurer Sydney Wilkins discusses the Institution's financial position with Mr. Peter Elliott, a member of the Computer Group Committee and a past Chairman of the Scottish Section.

Institution's Journal during the year. The Secretary called upon the Institution's Editor, Mr. F. W. Sharp, to announce the names of the prize-winners and their papers.

Full details of these were published in an Appendix to the Annual Report, and Mr. Sharp referred to the fact that, commencing with the year under review, awards were to be made according to a new scheme. This now consisted of a total of 20 premiums which were grouped as main premiums, specialized technical premiums and general premiums.

The President then presented the prizes and congratulated the winners. The J. Langham Thompson Premium for the outstanding paper on the theory and practice of control engineering was presented by the donor, a Past President of the Institution, personally.

Any Other Business

The Secretary reported that he had not received notice of any further business, but he would like to take the opportunity of advising the members that Dr. Ieuan Maddock had that day been notified that he had been appointed a Foreign Member of the Royal Swedish Academy of Engineering Sciences. The conferring of this distinction on the President was noted with pleasure by the members present.

The President declared the meeting closed at 6.35 p.m.

After the conclusion of the Annual General Meeting, the President invited the prize-winners to join him and members of the Council at an informal reception in the Library.

ANNOUNCEMENTS

Ionospheric Radio Wave Propagation Special January/February 1975 Issue

A group of papers discussing the current position in Ionospheric Radio Wave Propagation is being brought together and will form a double issue of the Journal. The issues for January and February 1975 are being combined to accommodate these papers and the issue will be designated Volume 45, Number 1/2. It will be published towards the end of January.

The main contents of this special issue will be:

- 'Developments in ionospheric physics since 1957.'
By W. C. Bain and H. Rishbeth (*Appleton Laboratory*)
- 'Solar-terrestrial relations and short-term ionospheric forecasting.'
By F. E. Cook and C. G. McCue (*Ionospheric Prediction Service, Australia*)
- 'Long-term h.f. propagation predictions for radio-circuit planning.'
By P. A. Bradley (*Appleton Laboratory*)
- 'The propagation of l.f. and v.l.f. radio waves with reference to some systems applications.'
By B. Burgess (*Royal Aircraft Establishment*) and T. B. Jones (*University of Leicester*)
- 'Ionospheric perturbations and their effect on the accuracy of h.f. direction finders.'
By T. B. Jones (*University of Leicester*) and J. S. B. Reynolds (*Government Communications HQ*)
- 'The CCIR and the ionosphere.'
By G. Millington (*Consultant*)

Single copies of this combined issue may be purchased at a cost of £2.50.

The Graham Clark Lecture

The 20th Graham Clark Lecture is to be given by Sir Frederick Catherwood, at the Institution of Civil Engineers on Wednesday, 26th February 1975. Further details will be announced shortly.

CEI Examination Results

The May 1974 CEI Examination was conducted at 130 centres in the UK and overseas. The total entries for Part I—of whom the majority were overseas candidates—was 1410. The success rate was 35% in the case of UK candidates and 49% for those overseas. The total number of entries for Part 2 was 2101, the success rate being 43% for the UK and 42% for overseas candidates.

'The Engineering Specialists'

The Design Council has organized 'The Engineering Specialists' Exhibition to take place at The Design Centre, 28 Haymarket, London, from 8th January until 15th February 1975. This exhibition will describe the work of sponsored and private research organizations whose expertise is improving the design of British engineering products and equipment.

To run concurrently with this specialist design engineering exhibition the Design Council is arranging two afternoon seminars at The Royal Institution on 28th January and 4th February. These will consider the organization of design teams and design work to ensure the most beneficial use of specialists, and the selection of specialists for design projects and how their work should be controlled.

Further details of these seminars are available from Mr. W. H. Mayall, Design Council, 28 Haymarket, London SW1Y 4SU (telephone 01-839 8000).

International Broadcasting Convention 1974

Sponsors:

Electronic Engineering Association
Institution of Electrical Engineers
Institution of Electronic and Radio Engineers
Institute of Electrical and Electronics Engineers
Royal Television Society
Society of Motion Picture and Television Engineers

The fifth International Broadcasting Convention, held at Grosvenor House, London, during the week 23rd to 27th September was generally considered to be the most successful yet held. About 2,000 delegates were present, many from 33 countries overseas. Some 45 papers were presented (16 by overseas authors), and over 60 exhibitors took stand space.

The Convention was opened by H.R.H. The Duke of Kent, who said:

'Surely it would be difficult to think of a more dramatic example of growth in any industry than that which has taken place in broadcasting, and particularly in television, over the last few years—in fact since the first International Broadcasting Convention was held in London in 1967. Not only has the use of television been greatly extended, into industrial, commercial, and educational fields, but in purely broadcasting terms the advent of colour and communication satellites have produced between them something of a revolution.

'All these rapid advances now of course mean new hazards and responsibilities for the producers and managers of broadcasting. Indeed, it is certainly no exaggeration to say that the very capability of modern cameras and transmission systems to pick up and reproduce, instantaneously and faithfully, any image over any distance, has given television the power to influence by its presence the people and activities which not long ago it would merely have been recording as an interested onlooker. It is veritably a new force in the world scene.

'Although we at this exhibition are, I think, more concerned with the means than the end, I believe seasoned broadcasters would agree that it is important at a convention of this kind, chiefly preoccupied with technical matters, that people should not lose sight of what all the technical sophistication is actually trying to achieve. I think that there is a risk of becoming so rapt in the mysteries of digital pattern generation, or charge-coupled devices, that the fact that they are there merely to facilitate transmitting signals from one place to another gets submerged.'

His Royal Highness suggested that it would be a brave man who would forecast with any confidence what would happen in broadcasting in the years to come; but he had little reason to doubt that it would continue to expand rapidly both in television and sound radio.

The exhibition proved to be an excellent 'shop window', and most exhibitors reported useful and profitable contacts during the Convention. Very little that was novel or sensational was seen, but massive improvements to existing techniques were noted. The period since the 1972 Convention has been one of consolidation rather than innovation.

Stand representation by overseas exhibitors showed origins in Germany, USA, Hungary, Norway, Denmark, Finland and France, but this was not representative of the full overseas participation. Many UK exhibitors showed products of overseas origin, such as AKG, Ampex, Bauch, Bosch etc.

It would be invidious to single out for special mention any particular manufacturer's product. Digital techniques were much in evidence, and were highlighted by the BBC and IBA exhibits. Many products—particularly test equipment—now use digital rather than analogue processes. Vision mixers, for example, are now available with a wider range of facilities, compared with those of two years ago, due to digital design. Video tape recorders have become more sophisticated, with helical scan now claiming to achieve full professional standards. Portable hand-held cameras of studio quality were shown and demonstrated by both British and US manufacturers. Many of the developments shown on the exhibition floor were the subject of technical papers.

The technical sessions were extremely well attended, and the papers were of high quality. The first two sessions were chaired by J. Flaherty (USA), and were concerned with 'Studio Operation and Quadraphony'. A paper read by H. R. Palmer (New Zealand BC) dealt with the development of a studio complex for Wellington. On-site power generation, and advanced design of structure was described.

A new master control suite at Thames Television Studio Centre was described by G. W. Karn and T. Stoley. One-man operation for network switching and signal observation was obtained by the use of an 'ergonomically-designed' control desk and chair. A rapid change to two-man operation for basic presentation is possible.

A new special effects system was described by R. W. Fenton and C. R. Bradley (Marconi). Two units are used: an 'effects amplifier' unifies the former separate functions of mixing, fading, wiping and keying, with true colour addition in encoded PAL or NTSC, while the second unit is a digital pattern generator that achieves a wide range of geometrical shapes and various wipes.

E. M. Tingley, Secretary of the US National Quadraphonic Radio Committee (NQRC) described the study, made by the Committee, of seven quadraphony systems proposed by five organizations. The final report to the FCC is being prepared, and will be published early next year.

'Matrix quadraphony' was the subject of a paper by E. G. Trendell (EMI). An analysis of various methods for obtaining four-channel audio concluded that the SQ matrix was the best compromise system.

A paper by D. Stahl (RIAS, Germany) on 'Artificial head stereophony' was followed by a demonstration. Broadcasts from many stations now use this system, and it is claimed that a suitable loudspeaker 'field' (or, better, headphones) can provide an accurate sound field with full directional information, and the '... fidelity is superior to all other known methods'.

The 'Signal Origination' sessions were originally to be chaired by Dr. R. Theile but, due to his death, the chair was taken by Dr. G. B. Townsend (UK).

W. R. Hawkins and G. D. Roe (BBC) read a paper on 'Some recent developments in vision mixer technology'. It outlined the history and problems of mixing from many colour-programme sources, and described the BBC mixer-design philosophy.

'Telecine control by frame counting and memory unit' was read by D. A. Pay and J. H. Cox (Marconi). The number of frames passing the gate are counted. Any frame can be located, and auto-control functions operated by frame numbers. Two multi-level memories can retain required frame numbers in store for re-call.

J. P. Chambers (BBC) described the direct synthesis of television waveforms into p.c.m. coded form in his paper 'The use of digital techniques in television waveform generation'. The digital signals can be used to test digital processes and, of course, be converted to analogue. By way of example, a digital colour bar generator was described.

A companion paper by R. E. Fletcher (BBC) dealt with the practical problems involved in the manufacture and service of high-speed coders and decoders. Development of a video a.-d.c. with automatic error-correction was described.

'Domestic information display by television' was a joint paper given by P. Rainger (BBC) and W. N. Anderson (IBA) on the work that led to 'Ceefax' and 'Oracle' and, finally, to a unified system. (It is of note that the BBC commenced broadcasts on the opening day of the Convention.) A companion paper by B. S. Barnaby (GEC) and G. O. Crowther (Mullard) on 'Receiver design concepts for reception of digital data from the standard television signal' described the requirements of the receiver to select and interpret the data, store a complete page and read the memory for display. The implementation by I.s.i. was discussed.

The 'Signal Origination' sessions were chaired by D. H. Mills (S. Africa). A paper by R. H. McMann, C. Smith and B. VanBenthem of CBS Labs (USA) discussed the design philosophy and advantages of automatic colour balance.

'Level-dependent colorimetry of colour cameras' by H. Breimer and E. Tienkamp of Philips, Holland, discussed camera alignment errors, and showed that the error magnitude could be very large. It was suggested that further investigation into differential colorimetry is required.

A review of 'CCD image sensors for solid-state cameras' was given by Drs. K. H. Zaininger and J. E. Carnes of RCA Labs (USA). Various charge-coupled devices were considered, the conclusion being that such devices might be available in 3-4 years for medium-quality systems, but a significant advance in large-area silicon technology is required for full broadcast quality.

Outside broadcasting produced three interesting papers. 'A portable colour camera' was given by J. R. Crook (Marconi), in which the general design of a shoulder-mount camera was discussed. P. K. N. Ward (ITN) spoke about outside broadcast techniques in which an electronic camera plus v.t.r. is stated to offer advantages over a film camera. F. J. Atkinson and D. A. Rowland (Thames Television) described a portable control unit, capable of being air-freighted called the 'POD'. It included two hand-held camera channels and a video recorder, together with a four-channel sound mixer.

Sessions 7 and 8 were chaired by Dr. L. Golding (USA). Session 7 included three papers on the use of digital techniques. A paper on 'Digital transmission of colour television signals' by Dr. M. Hausdörfer (Robert Bosch, Germany) examined redundancy and irrelevance, showing that separating Y, U and V components, a d.p.c.m. system can offer a

bit-rate reduction. A paper by V. G. Devereux and Dr. G. J. Phillips (BBC) on 'Bit-rate reduction of digital video signals using differential p.c.m. techniques' provided a close examination of various d.p.c.m. systems, and concluded that sub-Nyquist sampling with 5-bit d.p.c.m. coding could provide a good-quality picture. 'Digital sound signals' was the subject of a paper by M. G. Croll, D. W. Osborne and C. R. Spicer (BBC) which described the 13-channel p.c.m. system now being used for distribution of stereo. Bit-rate reduction by companding was discussed, and a proposal made for a 6-channel system to operate on standard Post Office 2.048 Mb/s circuits.

Two papers on the use of satellites were given in Session 8. 'Computer simulation of f.m. television transmission by satellite' was presented by H. H. Fromm (ESRO), and 'Bandwidth optimization in a direct satellite television broadcast system' was read by A. N. Kent (Marconi). Both papers proved to be very interesting analyses of the problems involved.

'A harmonic carrier system for cable television' by I. Switzer (Canada) described the advantages of a system in which channel carriers are derived from harmonics of a master oscillator. 'Eurovision's technical facilities' were described by E. Griffiths (EBU).

Session 9, chaired by Dr. P. Zaccarian (Italy) was opened by 'Digital fields store television standards converter', described and demonstrated by five members of OKI Electric Industry (Japan). A paper by A. H. Jones and F. A. Bellis (BBC) on 'An approach to digital recording' described an experimental recorder to be used as a research tool, using magnetic recording. 'Digital time-base correction' by D. J. M. Kitson, R. E. Fletcher and R. H. Spencer (BBC) described a corrector for use with any v.t.r. on current recording standards.

Session 10 was chaired by G. Cook (UK), and was concerned with transmitter monitoring and maintenance. The opening paper on 'A detection system for discriminating against co-channel interference' by J. S. Lothian (IBA) showed how an improvement of two picture grades can be obtained for a single-source interference. A paper by Dr. M. D. Windram (IBA) described a u.h.f. receiver for monitoring use, transposer evaluation, service planning and maintenance. 'A portable u.h.f. test set' was described by G. G. Johnstone, C. R. Caine, M. T. Ellen and R. G. Seville (BBC). The receiver section uses digital synthesis for instant channel selection, and a wide range of test functions are provided.

Sessions 11 and 12 on 'Transmitters and Transposers' were chaired by E. Castelli (Italy) and H. Chemin (France). R. Agniel and M. Turteltaub (Thomson-CSF) discussed advances in v.h.f. and u.h.f. tetrode design using new techniques for increased grid dissipation. M. J. Culling (Pye TVT) described the use of heat pipes in 'A band II solid-state linear amplifier'. 'Directional m.f. aerial arrays' were the subject of a paper by E. T. Ford (IBA).

Three papers on transposers were given: J. J. Livy (IBA) described 'The design and construction of a pre-fabricated low-power transposer station', detailing current UK practice for u.h.f., which is a joint BBC-IBA venture. Swiss transposer practice was shown by E. Schwarz (Swiss PTT), and a 100W solid-state u.h.f. transposer was described by four members of OKI (Japan).

The 'Maintenance Philosophy' session was chaired by N. R. Grover (Canada) who gave the first paper, expressing the views of the Canadian BC. A paper by F. G. Parker, R. H. Belgrove and K. Howe (BBC) emphasized the need to 'Design for maintenance'. H. W. Boutall and R. P. Massingham (IBA) outlined the methods used in the IBA network,

and J. E. Packman (BBC) discussed 'Some aspects of unattended transmitting station maintenance'.

The session concluded with a paper by B. L. I. Berntsson (Sweden) on operational experience of a u.h.f. network since 1970.

An innovation for IBC 1974 was the provision of discussion sessions on subjects of special significance. Three of these were held, and each was well-attended with many valuable contributions from the floor. The first, on 'Ceefax/Oracle', was chaired by K. I. Jones (UK), and was stimulated by a panel representative of industry (Mullard and GEC), and the broadcasters (BBC and IBA).

The discussion session on 'Service Planning' was chaired by R. A. Dilworth (UK), and was preceded by three papers. The first, by J. H. Causebrook and Dr. R. W. King (BBC) was on 'U.h.f. field-strength prediction by computer'. The second, by D. M. Holden (GEC-Marconi Electronics) described 'A frequency planning method for Band II v.h.f./f.m. local radio'. The third was by F. H. Wise (IBA) on 'Planning of independent local radio'. This showed that

local radio coverage of the UK by v.h.f. and m.f. was already 30% with stations in four main centres.

A discussion session on 'Quadraphony' was chaired by R. S. Roberts (UK). Many valuable contributions were made, including those from the broadcasters (BBC and IBA) and industry representatives. It was clear that no immediate broadcast standard was likely. More knowledge of the fundamental hearing processes is required, and compatibility with existing mono and stereo broadcasting requires close attention.

R. S. ROBERTS

(*IERE Member of the Management and Papers Committees, IBC*)

Copies of the Convention Publication (IEE Conference Publication No. 119) containing all the papers presented may be obtained from Publication Sales Department, Institution of Electrical Engineers, Station House, Nightingale Road, Hitchin, Herts. SG5 1RJ, price £7.40 to members of the sponsoring organizations, £11.30 to the public.

Letters to the Editor (continued from opposite page)

It can be seen that high accuracy demands a high master oscillator frequency and more logic hardware.

Another solution to the problem of scale generation is found when one notices that both the frequencies of the equal tempered scale and the attenuation ratios of a uniform attenuator form geometric progressions. By modifying a Wien Bridge oscillator to incorporate an attenuator in the frequency determining network the oscillator will produce the 12 notes of the equal temperament scale, accurate to 1 or 2 parts in 10 (approx. 0.2 cents).†

JOHN LINCOLN

44a St. Thomas Road,
Brentwood,
Essex, CM14 4DF.

6th August, 1974

It is widely known that a high enough master oscillator frequency is required for the equal temperament ratios—this is comparable to and follows from lowest common multiple problems in arithmetic plus percentage accuracy considerations. The article by Gibbings is important as providing one of the very few electronic and non-digital means of producing the equal temperament scale (but it can perhaps

† Gibbings, D. H. L., 'R-C oscillator for generating the frequencies of an e.t. scale,' *J. Acoust. Soc. Am.*, 47, No. 6 (part 2), pp. 1563-8, June 1970.

be regarded as 'digital' since attenuator *steps* are used). It was written in 1969 and provides for 'octave-stretching' in pianos. This method is therefore the progenitor and perhaps 'inspiration' of Mr. Bedford's timing methods.‡

Coming back to the general problem—another obvious method of tuning to equal temperament scale (though more expensive) is by the use of a sufficiently accurate digital frequency meter (which once again uses dividers).§

The difficult truth for a musician to accept is the fact that only in the last 10 to 30 (at most) years has the world had an equal temperament scale of sufficient accuracy for errors to be absolutely undetectable by the human ear. Just think what was denied to all the great composers from Bach to Bartok!

ARTHUR TOWNING

9 Middlesex Drive,
Bletchley MK3 7JE,
Bucks.

24th September, 1974

‡ Bedford, L. H., 'Electronic aids for the tuning of musical instruments', *The Radio and Electronic Engineer*, 42, No. 9, pp. S.131-5, September 1972.

§ Cowie, G., 'Electronic piano design (part 3)', *Wireless World*, 80, No. 1461, pp. 143-5, May 1974.

Pike, W. S., 'Digital tuning aid', *Wireless World*, 80, No. 1463, pp. 224-7, July 1974.

Letters to the Editor

The Institution's Council does not necessarily agree with views expressed by correspondents.

Correspondence of a technical nature, or on any matter of interest to electronic and radio engineers, is welcomed.

From: F. P. Thomson, C.Eng., M.I.E.R.E., A.M.B.I.M.
S. J. MacSweeney, C.Eng., M.I.E.R.E.
J. Lincoln (Graduate)
A. Towing, B.A. (Graduate)

Qualifications of an Engineer

I strongly support A. M. Sandman's view* that '... the qualifications of an engineer is basically an intellectual problem which should be approached from the broadest viewpoint' and 'what is wanted in an engineer is creativity'.

Ever since *wireless* became *radio* and extended into what we now call *electronics*, and telecommunications broadened to undertake complex functions in measurement and control, and then broadened out again to embrace the multifarious applications of today, the radio and electronic engineer's ability to spearhead this worldwide development has depended very much on his natural inquisitiveness and broad experience. It is likely that no other branch of engineering has had such a profound influence on contemporary medicine, agriculture and horticulture, banking and finance, security and defence, economics, government, business administration, transport, research, etc. With instruments created by the engineer the frontiers of life itself have been penetrated, and man has explored the Moon and glimpsed other planets. And yet, despite this exhibition of foresight and ability, the engineer is regarded—and usually treated—as a person of far less status than an arts graduate, accountant, or non-technical business administrator!

In particular, electronic engineers have penetrated virtually every field in which other professionals have been regarded as the experts, and have exercised a profound effect on the world's fortunes. But there is one niggling feature of our initiative and enterprise. Whilst our inquisitiveness has for the most part been accepted by others and our ideas and inventions welcomed, our willing adaptability in seeking solutions to the other fellow's problems including the production of inventions and new hardware has seldom received reciprocal professional recognition; we are still regarded as the 'barber-surgeons' in a world of sophisticated medical professionalism. Take banking for example; electronic engineers introduced bankers to the efficiency of magnetic ink character recognition in 1960–61. During the years following, electronic engineers have shown bankers how to deal with a massive increase in paperwork, and the essentiality of more rapid and accurate accountancy, record-keeping and communications, by the introduction of a vast range of electronically-actuated equipment. One might think the Institute of Bankers would welcome electronic engineers who have devoted a substantial part of their working life to solving the problems of banking and financial data-processing, but an electronic engineer who seeks a grade of membership soon finds he is not welcome! And thereby he finds, also, that he is excluded from intelligent discussion among bankers.

* *The Radio and Electronic Engineer*, 44, No. 9, p. 516, September 1974.

Rather than attempt to restrict the horizons of engineers the CEI would be better employed in making an effective attack on the archaic prejudices which upgrade almost every profession except that of engineering. The CEI might also consider approaching other professional bodies with a view to persuading them that their corporate life would be enhanced by admitting to membership the engineers whose ingenuity and perseverance has upgraded the efficiency of that profession. Surely engineers' 'standards' can be raised only by making them socially and professionally the equal of non-engineering professionals?

F. P. THOMSON

39 Church Road,
Watford WD1 3PY, Herts.

1st November, 1974

'Start Again?'

With reference to the above editorial article in the August 1974 Journal and the proposals outlined on pages 390–391 entitled 'Future Organization of the Engineering Profession' which deal respectively with 'The Problem' and 'A Possible Solution' I should like to make the following comments to the IERE Council.

Firstly, may I suggest that since the proposals emanate at the behest of, and from three long established and powerful—by virtue of numbers—Institutions in the CEI, members of the other Institutions such as our own must to some degree be a little suspicious of the dangers inherent in the creation of the proposed Institution of Engineers (IE). Secondly, the powers and degree of autonomy being sought seem excessive relative to the deficiencies ascribed to the present CEI structure.

Surely it should be possible to arrive at some compromise between Institutions regarding the strengthening of the professional function at CEI level, the formation of a more effective liaison system for negotiations with the public and at Government level, and Committees drawn from membership of existing Institutions set up to deal with matters of a 'cross-disciplinary' nature. The proposed virtual abolition of the Institutions seems to be very drastic.

Perhaps the dangers of encroachment upon the domain of the engineer could be tackled by seeking to have appropriate trade-union legislation enacted to protect the engineers' position.

SEAMUS J. MACSWEENEY

17 Beech Lawn,
Meadowbrook, Dundrum, Dublin 14.

16th October, 1974

Electronic Tuning of Musical Instruments

With reference to the recent correspondence on tuning of musical instruments, I agree with Mr. Towing's suggested use of c.m.o.s. i.c.s. with a master oscillator.† With i.c.s. using the multiple derivative divider system the maximum error over any interval is as follows:

Series of divisors	Maximum error
116 to 219	5.34 cents
239 451	2.39
538 1016	1.06
989 1867	0.73
2067 3902	0.24
4175 7881	0.14

† *The Radio and Electronic Engineer*, 44, No. 2, p. 109, February 1974, and No. 5, p. 293, May 1974.

(continued opposite page)

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

Applicants for Election and Transfer

THE MEMBERSHIP COMMITTEE at its meetings on 28th December 1973, 24th October and 7th November 1974 recommended to the Council the election and transfer of 32 candidates to Corporate Membership of the Institution and the election and transfer of 10 candidates to Graduateship and Associateship. In accordance with Bye-law 23, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communication from Corporate Members concerning those proposed elections must be addressed by letter to the Secretary within twenty-eight days after the publication of these details.

Meeting: 28th December 1973 (Membership Approval List No. 198)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Associate Member to Member

SWIFT, James Walter. *Crawley, Sussex.*

Transfer from Graduate to Member

HAINES, Richard. *Chesterfield, Derbyshire.*
HILL, Malcolm Ronald. *Chesterfield, Derbyshire.*
KING, Michael Desmond. *Liphook, Hampshire.*
LINDSAY, David Keith. *Warrington, Lancashire.*
MUNRO, Robert Andrew. *Bognor Regis, Sussex.*

PEARCEY, Christopher James. *Rickmansworth, Hertfordshire.*

QURESHI, Rashid Ahmad. *Galley, Cheshire.*

SHARP, Peter Edward. *Walton-on-Thames, Surrey.*

TINNISWOOD, Richard Neil. *Marlow, Buckinghamshire.*

VEGA-LOZANO, Jose. *Hitchin, Hertfordshire.*

WAN KEE CHEUNG, Wan Sou Kwong. *Enfield, Middlesex.*

WILLIS, Alan Frank. *Bracknell, Berkshire.*

WOODWARD, Stanley Frederick Henry. *Esher, Surrey.*

YORK, Martin William. *Alton, Hampshire.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Graduate to Member

DINA, Steven. *Zaria, Nigeria.*
PATHANIA, Dharam Singh. *Chandigarh 20, India.*
SAVOOR, Krishna Rao. *Mysore State, India.*

Direct Election to Member

EMBEDOKLIS, Andreas Evangelou. *Nicosia 107 Cyprus.*

Meeting: 24th October 1974 (Membership Approval List No. 199)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Graduate to Member

HOLLIDAY, Roger William Dargue Chester. *Oxford.*
ROZIER, Paul Anthony. *Braintree, Essex.*

Direct Election to Member

COSHALL, Brian Archibald. *Titchfield, Hampshire.*
WOTTON, Edward Peter. *Tonbridge, Kent.*

NON-CORPORATE MEMBERS

Direct Election to Graduate

WILSON, David Russell. *Highgate, London N6.*

Transfer from Graduate to Associate Member

MASON, Colin. *Blaby, Leicester.*

Direct Election to Associate Member

BROWN, Roland John. *Bracknell, Berkshire.*

STUDENTS REGISTERED

BALLINGER, Timothy James. *Trowbridge, Wiltshire.*

SHAH, Rohitkumar. *Reading.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Member to Fellow

GAREWAL, Kehar Singh. *New Delhi-1, India.*

Transfer from Graduate to Member

LONGDEN, Denis Arthur. *B.F.P.O. 40 Germany.*

NON-CORPORATE MEMBERS

Direct Election to Associate Member

NARENDRANATH, Gopalakrishnarao. *Bangalore, India.*

STUDENTS REGISTERED

DALUGODE LIYANAGE, Rathnaweera. *Boralesgamuwa, Sri Lanka.*

LAU, Kam Hung. *Kowloon, Hong Kong.*

SAHABANDU, Gemunu-Nihal. *Kandy, Sri Lanka.*

SINGH, Tirath. *Kuala Lumpur, Malaysia.*

Meeting: 7th November 1974 (Membership Approval List No. 200)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Graduate to Member

CORDY, Alfred Richard. *Keynsham, Bristol.*
THOMAS, David Henry. *Leighton Buzzard, Bedfordshire.*

Transfer from Student to Member

BAILEY, Michael Anthony. *New Malden, Surrey.*

Direct Election to Member

GRAYSON, Paul Alfred Lucas. *Harlow, Essex.*
GREEN, Terry Scott. *Ryde, Isle of Wight.*
SMITH, Peter John. *Bordon, Hampshire.*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

JUBB, Alan. *Redland, Bristol.*

Transfer from Graduate to Associate Member

ARORA, Puran Chand. *Hanwell, London W7*
MEZU, Leo Aloy. *London SW16.*

Transfer from Student to Associate Member

ORIAN, Jean Serge Michawel. *Edgware, Middlesex.*

Direct Election to Associate

TREMAINE, Bernard John. *Huddersfield, Yorkshire.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Graduate to Member

FOO, Ho-Kin. *Wanchai, Hong Kong.*

Direct Election to Member

HO, Kam Bor. *North Point, Hong Kong.*

NON-CORPORATE MEMBERS

Transfer from Graduate to Associate Member

SAUNDERS, Roger Thomas. *Peak, Hong Kong.*

Addendum

Membership List No. 181 published May 1974

OVERSEAS

CORPORATE MEMBERS

Transfer from Graduate to Member

YOUNG, Stanley Junior Ronaldson. *Kingston, Jamaica.*

Addendum

Membership List No. 191 published August 1974

GREAT BRITAIN AND IRELAND

NON-CORPORATE MEMBERS

Election to Companion

READ, John Emms. *Manchester Sq., London W1.*

Members' Appointments

CORPORATE MEMBERS

Air Vice-Marshal S. M. Davidson, C.B.E. (Fellow 1971, Member 1951) has taken up the appointment of Assistant Chief of the Defence Staff (Signals). He succeeds **Rear Admiral Sir Peter Anson, Bt., C.B.** (Fellow 1972) who has retired from the Navy. Air Vice-Marshal Davidson, who was Station Commander RAF St. Athan and Air Officer Wales from January 1972 until October of this year, served as a Vice President of the Institution in 1972-73. He is currently Chairman of the Management Techniques Group Committee.

Mr. G. J. Stevens (Fellow 1966, Member 1965, Associate 1955) has been appointed Manager, Special Systems, with Standard Telephones and Cables Ltd., Footscray. He was previously concerned with electronic teleprinter design and development with the associated company of Creed and Company.

Mr. E. W. Burrell (Member 1970, Graduate 1966) has joined the Oxford Regional Health Authority as a Main Grade Engineer. Earlier this year he returned from Fiji where he had just completed a three-year tour of duty as a Radio Engineer with the Department of Posts and Telegraphs.

Mr. D. H. Clayton (Member 1974, Graduate 1971) who went to Pirelli General Cable Works Ltd in 1967 and was latterly a Technologist concerned with development of new types of coaxial cable, has joined Rediffusion Engineering Ltd as a Development Engineer.

Mr. J. T. Court (Member 1974, Graduate 1970) has moved from Instron Ltd., High Wycombe, where he was System Development Engineer concerned with materials testing machines and systems, to Sensors and Systems Ltd., Melbourne, Derby.

Mr. A. G. Cuthbert (Member 1972) has been appointed an Electrical Engineer with the Electrical Department of Dunedin City Corporation. Before going to New Zealand, Mr. Cuthbert was Project Engineer with Elliott Brothers, London Ltd. at Rochester.

Mr. A. H. Dale (Member 1970, Graduate 1967) who went to the Air Traffic Control Evaluation Unit at Hurn Airport in 1962, and moved to HQ National Air Traffic Control Service in 1971, is now a Signals Officer at the Civil Aviation Office for Scotland in Edinburgh.

Mr. A. Fong-Yan (Member 1958, Associate 1956) who was on the staff of the Telecommunications Department of the Hong Kong Technical College, has been appointed Vice Principal of Morrison Hill Technical Institute, Wanchai, Hong Kong.

Mr. N. O. Ilube (Member 1973, Graduate 1968), formerly a Senior Television Engineer with Uganda Television, has joined Midwest Broadcasting Corporation, Benin City, Nigeria, as a Senior Engineer.

Mr. H. S. Manku (Member 1974, Graduate 1969) who was with Business Computers Ltd. as a Post-Design Engineer, has joined the Link-Miles Division of the Singer Company (UK) Ltd., Lancing, Sussex, as a Senior Systems Analyst.

Mr. A. F. P. Newns (Member 1972, Graduate 1968) who joined the Pye Group in 1962 as a Student Apprentice and had been a Section Leader with Pye Telecommunications Ltd. since 1969, has been commissioned in the Engineering Branch of the RAF as Flight Lieutenant.

Mr. J. F. Pengelly (Member 1972) is now with the Submarine Systems Division of Standard Telephones and Cables Ltd at Southampton as Section Head, Control Engineering, in charge of electronics and soft ware development. He was previously with Marconi Space and Defence Systems as a Senior *Parmigan* Systems Engineer.

Mr. P. H. Redhead (Member 1973) has joined the Department of Posts and Telecommunications, Government of Fiji, as Senior Engineer (Mechanical and Electrical). For the past 9 years he was with H.M. Stationery Office and from 1968 was Senior Supervising Engineer, responsible for the maintenance of printing plant and auxiliary equipment including a computer typesetting system.

Mr. R. C. Theobald (Member 1972, Graduate 1968) is now a Development Engineer with Motorola GmbH. He was previously with the Amplaid Division of Amplifon in Milan working on research audiometry.

Mr. C. R. Wheeler (Member 1972, Graduate 1969) has taken up an engineering design appointment with NCR-Financial Systems Division in Dayton, Ohio. For the past 4 years he was an Electronics Project Engineer with Colt Industries Inc. working on weighing systems. Before emigrating to the United States in 1970, Mr. Wheeler was with Plessey Radar Ltd., Cowes.

Flt. Lt. R. L. Wilson, RAF (Member 1973, Graduate 1969) has been posted to the Electrical Engineering Communications Staff of HQ RAF Strike Command. He was previously Officer Commanding Air Electrical Engineering Flight at RAF Coltishall.

NON-CORPORATE MEMBERS

Mr. J. A. Akinwumi (Graduate 1971) is now Electronics Engineer with the Nigerian Post and Telecommunication Department. After returning from the UK in 1972

where he had been undertaking academic and technical training, he worked for Seismograph Services (Nigeria) Ltd. for two years as an Assistant Field Seismologist.

Mr. B. F. Barry, B.Sc. (Graduate 1968) has completed the CNAAC Course in Electrical Engineering at Liverpool Polytechnic and is now Electronics Engineer with Vernons Pools Ltd. primarily concerned with maintenance of computer equipment.

Mr. J. R. Carey, B.Sc. (Graduate 1970) has completed a degree course at the University of Birmingham and is now an Executive Engineer with the Post Office in Canterbury. From 1956 until 1971 Mr. Carey served with the Royal Signals, retiring in the rank of Warrant Officer.

Mr. L. Y. Cheung (Graduate 1971) who is with the Hong Kong Electric Company, has been appointed Senior Operations and Maintenance Engineer.

Mr. J. S. Dunn (Graduate 1969) is now with Burroughs Machines Ltd. as a Senior Product Assurance Engineer. He was previously with Rolls Royce Ltd. at Hamilton, Lanarkshire.

Mr. D. G. Fowler (Graduate 1961) has been appointed Sales Manager of the Northern Division of Advance Electronics Ltd. He was previously Export Sales Manager with Electrosil Ltd.

Mr. D. T. France (Graduate 1970) has joined Salford Electrical Instruments Ltd. as an Electronics Engineer: he was previously with the UK Atomic Energy Authority, Springfield Works.

Mr. E. G. Parker (Graduate 1972) who joined Northern Electric Wire and Cable Division, Kingston, Ontario, last year, has now been appointed Manager of the Research and Development Laboratory.

Mr. A. J. Shipton (Graduate 1966), formerly Sales Manager of the Consumer Division of Motorola Semiconductors Ltd., has joined Semicomps Ltd. as Marketing Manager.

Mr. D. W. Thompson (Graduate 1970) who was with Digital Equipment Corporation Ltd., has joined the Engineering Group of Plessey Microsystems, Towcester, as a Principal Engineer.

Lt. C. F. Mitchell, RN (Associate 1970) is now Radio Engineering Officer in H.M.S. *Intrepid*; he was previously in H.M.S. *Mauritius*.

Mr. J. L. Reyes (Associate 1974) is now a Lecturer 1 in Electronics at Crawley College of Technology. He was previously an Electronics Instructor at the Crawley Industrial Training Centre.

Members who have recently received new appointments are invited to send details to the Editor for inclusion in this section.

Obituary

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

Thomas Henry Pattinson (Fellow 1958, Member 1942, Associate 1938) died on 10th August 1974, aged 60 years. He leaves a widow and two children.

Thomas Pattinson entered the radio industry in 1929 and in the pre-war years worked for several companies concerned with design and development of receivers, test apparatus and components. At the beginning of the war he was with Murphy Radio, carrying out development and test work and in 1941 he joined the Radio Department of the Royal Aircraft establishment where he was mainly concerned with airborne radar equipment. From 1944-46 he was attached to Headquarters MAAF Italy to study the performance of RAF equipment in action. He returned to Farnborough for a further 18 months and then joined the Ministry of Civil Aviation Telecommunications Directorate where he was concerned with planning and installation of long-distance point-to-point radio links.

From 1950-56 Mr. Pattinson was with the Development Division of A.C. Cossor Ltd., working on 'Gee' equipment and in 1956 he joined Fleming Radio (Developments) Ltd., Stevenage, as Chief Development Engineer. In 1960 he took up an appointment as a Trials Engineer with the British Hovercraft Corporation Ltd. in East Cowes, Isle of Wight, and in 1967 became Design Engineer (Electrical), the post he held until his death.

Mr. Pattinson served on the Education and Examinations Committee of the Institution from 1948 until 1954.

Donald Charles Harrison (Member 1948) died whilst on holiday in France on 18th June 1974, aged 62. He leaves a widow.

Educated in Totnes, Devon, Mr. Harrison obtained his early technical training as an apprentice with Armstrong Siddeley Motors Ltd., Coventry. He remained in the motor

industry until the war when he joined Westland Aircraft where he worked as a charge hand in the tool room. In 1943 he joined the Ministry of Supply as a Technical Assistant and for the next 5 years he was concerned with research and development of equipment used in the production of radio and radar apparatus for the Services.

Mr. Harrison joined Imperial Chemical Industries in 1948 and worked for the fuel economy section of the Engineering Services Department for some years. He was then appointed an Assistant Advisor to the Engineering Director, a position which he held until his death which occurred just a fortnight before he was due to retire.

William John Alastair Lewis, B.Sc. (Eng.) (Member 1967) died on 1st August 1974 aged 38 years. He leaves a widow and two children.

After completing secondary school education at King's School, Rochester, Mr. Lewis studied at the Medway College of Technology for the B.Sc. (Eng.) degree in electronics of London University as an external student. After graduating in 1958 he joined Elliott Automation, Rochester, where he remained until 1966. During this period he progressed to the post of Senior Engineer responsible for installation and flight trials of airborne radar and control systems. He also worked on the development of a computer-controlled plotting equipment.

Mr. Lewis was then appointed Lecturer in charge of the Electrical Engineering Section of Corby Technical College where he was responsible for electronics courses for the Higher National Certificate, and was particularly involved in strengthening links with local industry. After working at Corby for five years, Mr. Lewis took up an appointment as Lecturer in Electronics at the Zambia Institute of Technology. Here he developed the Institute's work in the field of digital electronics and he took a leading part in commissioning a PDP/1140 computer at the Luanshya campus.

Lawrence Olusesan Olubajo (Member 1973, Graduate 1969) died on 22nd September, aged 34 years.

Born and educated in Nigeria, Mr. Olubajo came to the UK in 1964 to take the Diploma Course in Telecommunication Engineering at the Northern Polytechnic. On successfully completing this in 1968 he obtained a CBI Scholarship for Overseas Engineering Graduates and during the next two years undertook practical engineering training with Standard Telephones and Cables and the British Post Office, working respectively on radio receivers and transmitters and crossbar telephone exchanges. In 1971 Mr. Olubajo returned to Nigeria to take up the appointment of Communications Engineer with the Nigerian Ports Authority where he was responsible for the planning, installation and maintenance of the communications systems for the Lagos Port Complex.

David Malcolm Jaggat (Graduate 1964) died in December 1973 at the age of 32 years. He leaves a widow and two young children.

A native of East London, David Jaggat obtained his technical education at William Morris County Technical School, Walthamstow, and South West Essex Technical College. From 1957 to 1962 he was an Engineer Apprentice at the GEC Hirst Research Centre and after completing his training was appointed an Experimental Engineer. By that time he had completed endorsements to the Higher National Certificate to gain Graduateship of the Institution.

From 1963 to 1968 Mr. Jaggat was with Kelvin Hughes, initially as an Environmental Engineer and subsequently as a Development Engineer in the Radar Laboratories at Chadwell Heath. In 1968 he joined the Research and Development Laboratories of the Marconi Company at Great Baddow as a Research Engineer, with whom he remained until his death.

Forthcoming Institution Meetings

London Meetings

Wednesday, 8th January

AUTOMATION AND CONTROL SYSTEMS GROUP

Train Control Developments on British Rail

By J. W. Birkby (*British Railways Board*)
IERE, Lecture Room, 6 p.m. (Tea 5.30 p.m.)

Monday, 13th January

JOINT IEE/IERE MEDICAL AND BIOLOGICAL ELECTRONICS GROUP

A Review of Electron Microscopy

By Dr. V. E. Cosslett, F.R.S. (*University of Cambridge*)

IEE, Savoy Place, London WC2, 5.30 p.m. (Tea 5 p.m.)

Wednesday 15th January

JOINT MEETING OF AEROSPACE, MARITIME AND MILITARY SYSTEMS GROUP AND ROYAL INSTITUTE OF NAVIGATION

Colloquium on ADVANCES IN AIRBORNE EQUIPMENT FOR NAVIGATION AND FLIGHT CONTROL

Royal Aeronautical Society, 4 Hamilton Place, London W1, 10.30 a.m.

Advance registration necessary. For further details and registration forms apply to Royal Institute of Navigation, 1 Kensington Gore, London SW7.

Topics to be considered include trends in the design of flight control equipment, effects of miniaturization in airborne computers, the question of the boundary between hardware and software in such computers, and some aspects of the present state of the art of inertial and associated equipment.

Wednesday, 15th January

COMMUNICATIONS GROUP

Good Quality Reception from Medium-wave Broadcasting

By Dr. R. C. V. Macario (*University College of Swansea*)

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

Following an introductory background to the present and predicted state of the m.f. broadcast band, techniques for improving the quality of reception of the transmitted broadcasts will be described and demonstrated:

- (1) Synchronous detection of local broadcasts.
- (2) Synchronous detection of all broadcasts.
- (3) PICOR systems of bandwidth improvements.
- (4) Stereo possibilities.

Tuesday, 21st January

JOINT IEE/IERE COMPUTER GROUPS

Designing Machines for People

By Dr. C. R. Evans (*NPL*)

IEE, Savoy Place, London WC2, 5.30 p.m. (Tea 5 p.m.)

Wednesday, 22nd January

COMPONENTS AND CIRCUITS GROUP

Colloquium on THERMIONIC EMISSION DEVICES

POSTPONED

Wednesday, 29th January

JOINT IEE/IERE MEDICAL AND BIOLOGICAL ELECTRONICS GROUP

Sensing, Sizing and Sorting of Cells: the Laser Sorter

By D. F. Capellaro (*University College London*)

IEE, Savoy Place, London WC2, 5.30 p.m. (Tea 5 p.m.)

Wednesday, 29th January

COMMUNICATIONS GROUP

Speech Engineering

By Dr. A. J. Fourcin (*University College London*)

Haldane Theatre, Wolfson House, Stephenson's Way (off Euston Street), London NW1, 6 p.m. (Tea 5.30 p.m.)

Wednesday, 5th February

AUTOMATION AND CONTROL SYSTEMS GROUP

Hybrid Computers and Applications

By Dr. R. L. Davey (*Imperial College*)

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

Wednesday, 12th February

AEROSPACE, MARITIME AND MILITARY SYSTEMS GROUP

Channel Approach Aid for Milford Haven Conservancy Board

By A. P. Tuthill (*Decca Radar*)

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

Wednesday, 26th February

COMMUNICATIONS GROUP

Low Attenuation Corrugated Waveguides

By Professor P. J. B. Clarricoats and Dr. D. Olver (*Queen Mary College*)

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

Wednesday, 5th March

COMPONENTS AND CIRCUITS GROUP

Colloquium on EXPLOITING THE PROM

IERE Lecture Room, 2 p.m. Further details to be announced.

Thursday, 6th March

EDUCATION AND TRAINING GROUP

Colloquium on MODULAR COURSES

IERE Lecture Room, 10 a.m. Further details to be announced.

Kent Section

Tuesday, 21st January

Quadraphonics

By Dr. K. Barker (*University of Sheffield*)
Lecture Theatre 18, Medway and Maidstone College of Technology, Maidstone Road, Chatham, 7 p.m.

Thursday, 6th March

Flight Recording in Civil Aviation

By D. Waller (*British Airways European Division, Heathrow*)

Lecture Theatre 18, Medway and Maidstone College of Technology, Maidstone Road, Chatham, 7 p.m.

East Anglian Section

Wednesday, 5th February

Radar Approach to Weather Forecasting

By Professor E. Shearman (*Birmingham University*)

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

Thames Valley Section

Thursday, 23rd January

Optoelectronics Devices

By M. Miller (*Texas Instruments*)

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

Wednesday, 12th February

CAD of Type 2 Phase Lock Loops

By P. Atkinson and A. J. Allen (*University of Reading*)

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

The practical advantages of type 2 phase-locked loops compared with type 1, and digital as opposed to continuous are well known. Although such devices find great application in the instrumentation and telecommunications fields, little attention has been paid to their design methodology, because conventional forms of analysis are apparently of little value in this connection. The lecture will review the problem from a fundamental viewpoint taking a typical commercial digital phase-locked loop as an example. The study shows that stable operation of the loop over its operating range may be achieved using small-signal frequency response techniques which allow for both the effect of sampling and the expected changes in loop gain. A new universal chart will be described which allows the rapid determination of the optimum loop gain and filter characteristics required to meet a given specification. It will also be shown how the performance may be verified using a specialized time-domain computer simulation which allows large signal step responses and ultimate settling time to be determined. A numerical design example will be described in detail showing how the actual circuit component values are determined. The connexion between system bandwidth and ultimate settling time for the digital phase-locked loop will also be briefly discussed.

Southern Section

Tuesday, 14th January

JOINT MEETING WITH IEE

Optical Fibres

By Professor W. A. Gambling (*University of Southampton*)

Lanchester Theatre, Southampton University, 6.30 p.m.

Wednesday, 22nd January

Hybrid Integrated Microwave Amplifiers

By Dr. S. J. Hewitt (*Plessey, Roke Manor*)

Lecture Theatre 'F', University of Surrey, Guildford, 7 p.m.

Wednesday, 29th January

Underwater Imaging

By S. O. Harrold (*Portsmouth Polytechnic*)

Portsmouth Polytechnic (Park Road), Room AB 001, 7 p.m.

Thursday, 6th February

Bubble Memories

By Dr. J. R. Fairholme (*Plessey*)

Farnborough Technical College, 7 p.m.

Tuesday, 11th February

Autonull—The Suppression of Large Interfering Signals in Single and Multi-Equipment Installations

By M. M. Zepler (*Plessey, Roke Manor*)

School of Signals, Blandford Camp, Blandford, 6.30 p.m.

Wednesday, 12th February

Electronic Ignition—is it worth it?

By Dr. E. M. Stafford (*University of Southampton*)

Southampton College of Technology, East Park Terrace, 7.30 p.m.

Friday, 14th February

Electricity in the Entertainment Business

By J. H. Brooks (*BBC*)

Newport Technical College, 7 p.m.

Wednesday, 26th February

Time Series Feature Detection

By Dr. D. W. Thomas (*University of Southampton*)

Lanchester Theatre, Southampton University, 6.30 p.m.

South Western Section

Tuesday, 14th January

JOINT MEETING WITH IEE

Electronic Techniques in Archaeology

By Dr. E. T. Hall (*Department of Archaeology, Oxford University*)

The College, Regent Circus, Swindon, 6.15 p.m.

Wednesday, 22nd January

Mobile Radio in the Era of Spectrum Congestion

By Professor W. Gosling (*University of Bath*)

Room 4 E 3.10, University of Bath, 7 p.m.

Thursday, 6th February

JOINT MEETING WITH THE IEE

Television Engineering—A Look into the Future

By M. Cox (*Michael Cox Electronics*)

Main Lecture Theatre, Plymouth Polytechnic, 7 p.m. (Tea 6.30 p.m.)

Wednesday, 19th February

JOINT MEETING WITH RAES AND IEE

Engine Testing using Advanced Techniques

By P. A. E. Stewart (*Rolls Royce*)

No. 4 Lecture Theatre, School of Chemistry, University of Bristol, 7 p.m. (Tea 6.30 p.m.)

South Midland Section

Monday, 13th January

JOINT MEETING WITH IEE

Sound Control

By G. A. C. Watts (*Neve Electronic Laboratories*)

B.B.C. Club, Evesham, 7.30 p.m.

Wednesday, 5th February

Active Filters

By Dr. D. R. Wilson (*Polytechnic of Central London*)

The Foley Arms, Malvern, 7.30 p.m.

West Midland Section

Wednesday, 15th January

JOINT MEETING WITH ROYAL TELEVISION SOCIETY

Status of British Broadcasting

By C. B. Wood, (*BBC*)

ATV Centre, Birmingham, 7 p.m.

Thursday, 20th February

JOINT MEETING WITH IEE AND IPOEE

Communications—Bit by Bit

By H. B. Law (*PO Research Department*)

PO Training Centre, Duncan Hall, Stone, Staffs, 7.15 p.m.

East Midland Section

Thursday, 16th January

Digital and Computer Control of Industrial and Research Robots

By Dr. A. Pugh (*Nottingham University*)

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

Thursday, 13th February

An Evening Visit to the National Westminster Bank Computer Centre, Kegworth

Members who wish to take part in this visit must advise the Honorary Secretary not later than Thursday, 16th January 1975. Numbers will be limited.

North Western Section

Thursday, 16th January

Quadraphonics

By Dr. K. Barker (*University of Sheffield*)

Renold Building, UMIST, 6.15 p.m.

North Eastern Section

Wednesday, 15th January

Electronic Aids for Medical and Biological Studies

By Dr. E. T. Powner (*UMIST*)

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

Yorkshire Section

Wednesday, 22nd January

Video Cassette Recording

By K. R. Firth

Huddersfield Polytechnic, 6.30 p.m.

Thursday, 20th February

JOINT MEETING WITH IEE

Oracle—Information by Domestic TV

By G. A. McKenzie and P. R. Hutt (*IBA*)

Yorkshire Television Studios, Leeds, 6.30 p.m.

Merseyside Section

Wednesday, 12th February

Solar Energy

By W. R. Crooks (*North East Liverpool Technical College*)

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

South Wales Section

Wednesday, 15th January

Computers for Control in the Steel Industry

By M. Dean (*British Steel Corp.*)

Department of Applied Physics and Electronics, UWIST, Cardiff, 6.30 p.m. (Tea 5.30 p.m.)

Wednesday, 5th February

JOINT MEETING WITH IEE

Digital Techniques in Broadcasting

By Dr. C. J. Dalton (*BBC*)

Chemistry Lecture Theatre, Room 164, UWIST, Cardiff, 7 p.m.