Founded 1925

Incorporated
by Royal Charter 1961

"To promote the advancement of radio, electronics and kindred subjects by the exchange of information in these branches of engineering."

Volume 46 No. 6

June 1976

The Radio and Electronic Engineer

The Journal of the Institution of Electronic and Radio Engineers

Energy R & D Priorities

NOWADAYS the electronic and radio engineer may regard with some sense of achievement the almost trivial amount of energy required to activate many of the individual devices and systems for which he has been responsible; it is probably only when several million television receivers are switched on to view a programme in the middle of the night, for instance, that the Electricity Boards start to worry! A recent discussion document on energy research and development issued by the Advisory Council on Research and Development for Fuel and Power (ACORD) of the Department of Energy does, however, contain much that will be of interest and concern to the electronic engineer apart from any views he may have as a citizen.

The importance of the document is that it attempts to argue and set out priorities for the future. The chairman of ACORD and Chief Scientist of the Department of Energy, Dr. Walter Marshall, in his foreword, points out that there will be a widening gap in the UK, perhaps not until the turn of the century, between overall demand for energy and indigenous supplies of fossil fuels, i.e. coal, oil and gas. It is therefore important to identify the contribution that energy R & D can make to bridge the gap.

ACORD stresses that coal has the potential to supply all UK energy needs for several centuries. Without investment, however, the UK cannot be prepared for a future in which the demand for coal will be as large or larger than it is today. North Sea reserves of oil may rise as exploration continues, designated areas are expanded and recoverability improves. But eventually the supply of oil for chemical feedstocks will be a world-wide problem, as will the supply of motor fuels, unless other energy sources for transport are found. The need to use coal as a supplementary source of transport fuels, organic chemicals, etc. could eventually make it too valuable to burn for bulk heat-raising purposes. After the turn of the century, the gas industry will be seeking alternative supplies either by manufacturing substitute natural gas or by importing liquefied natural gas.

World reserves of reasonably priced uranium may be seriously restricted before 1990, but the demand could be met for centuries by the introduction of the fast reactor which liberates 60 times as much energy from uranium as thermal reactors. However, at the recent National Energy Conference in London, when the ACORD document was among those discussed, Sir Brian Flowers, as Chairman of the Royal Commission on Environmental Protection, questioned the long-term problems, both environmental and security, which the long radioactive life of plutonium, produced as a by-product in the fast breeder reactor, would certainly pose.

On other sources of energy ACORD says that the economic and environmental impacts of tapping the energy of the Sun and Moon—solar, wind, wave and tidal power—need to be investigated because they could make a useful contribution to energy supply as conventional energy prices rise; and while fusion power cannot contribute to the UK's energy resources over the next 50 years, its energy potential is so great that development of the technology must continue.

It is concluded that considerable attention needs to be paid to coal utilization and conversion technologies and the medium-term importance of North Sea oil and gas will justify high priority on the development of Continental Shelf technologies. On nuclear technology we must be prepared for an expansion but its extent will depend to a considerable degree on the social acceptability of nuclear power and on judgments about the effectiveness of safety measures. Any shortfall in fossil and nuclear primary sources of energy would greatly increase the need for alternative sources and this implies a wider R & D programme on primary energy than might be justified by economic evaluations at today's prices.

Finally it is stressed that the improvement of the efficiency with which primary energy is converted to electricity will be of continuing importance. Similarly, energy saving can contribute as much to the UK energy economy as a new source of primary energy, and R & D to achieve such savings deserves high priority.

If the recommendations made in the ACORD document and at the National Energy Conference are to be implemented they will undoubtedly call for ingenuity from engineers of all disciplines, not the least our own.

Contributors to this issue*

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Dr. P. Dassanayake is now a Lecturer in Electronics at the University of Sri Lanka, Katubedda Campus. He obtained the degree of B.Sc. (Eng.) in electrical engineering at the University of Sri Lanka and the degrees of M.Sc. and Ph.D. in electronics at the University of Wales Institute of Science and Technology, Cardiff. At Cardiff Dr. Dassanayake investigated digital phase-coded pulse compression techniques, including impatt diode phase shifters and sidelobe reduction filters.

Mr. G. Elliott graduated with honours in chemistry from London University in 1942, and was employed by the Admiralty until 1948 on a number of activities, including the formation and analysis of protective finishes, explosives and propellants. He then joined Standard Telephones & Cables Ltd., and worked for the next few years on the development of electronic materials, particularly on the purification of semiconductors and the growth of germanium and silicon single crystals for device production. From 1957 to 1967 he was a consultant specializing on the purification and analysis of high purity electronic materials. Mr. Elliott joined the Marconi Company in 1967 as a research chemist, where his work has included the development of electro-luminescent materials and more recently liquid crystal and electrophoretic materials for applications to display devices.

Mr. A. S. McLachlan joined the Post Office as a Youth-in-Training in 1939 and after the war moved to Post Office Training Branch, dealing with the preparation of educational literature, mainly on radio communication. Then followed a short spell in the Research Branch dealing with forward planning before joining the radio interference laboratory and working on the design and development of television detectors, interference tracing and measuring receivers, and methods of measurement of radio interference from a wide range of equipment.

Shortly after the Ministry of Posts and Telecommunications took over radio regulatory functions from the Post Office in 1969, Mr. McLachlan became Head of Radio Interference Branch of the Directorate of Radio Technology which has subsequently become part of the Home Office Radio Regulatory Department.

Dr. J. P. Newsome received his initial education and training as a student engineer with Siemens Brothers, Woolwich, London; during this period he studied part-time at Northampton Polytechnic, gaining the external B.Sc. degree of London University in 1947. From 1946 to 1948 he was a Development Engineer in the Marine Radio Department of Siemens and he then obtained an appointment as a Research and Development Engineer with the English Electric Company a Stafford.

In 1953 Dr. Newsome was appointed to the academic staff of the Department of Electrical and Electronic Engineering of the University of Nottingham and he has been Senior Lecturer since 1964. He obtained his M.Sc. in 1955 and the Ph.D. in 1962 with a doctoral thesis on the electrical characteristics of Hall generators. Dr. Newsome has held consultancies with the Radio Department of the Royal Aircraft Establishment, and he was a Visiting Research Scholar at the Case Western Reserve University, Cleveland, Ohio, for six months in 1968. His university appointments include that of a residential Hall tutor from 1964 to 1971. In addition to research in the field of the present paper his interests include speech communication and the response of rooms to speech and music.

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In 1972 he joined Pye-TMC Advanced Development Division as a member of the Digital Signal Processing Group, developing and implementing recursive digital filters using m.o.s., l.s.i. techniques.

*See also page 280.

UDC 621.365.5:621.391.823

Radio interference from r.f. heating equipment

A. S. McLACHLAN*

Based on a paper presented at the Components and Circuits Group Colloquium on H.F. Heating—Circuits and Techniques, held in London on 9th October 1974

SUMMARY

The incidence of complaints of r.f. interference from industrial, medical and scientific equipment is examined in the light of the acceptable limits set by international and national regulations. Some of the compromises which can be struck between the desirable and the practicable are illustrated by examples.

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1 Introduction

Industrial Scientific and Medical (ISM) apparatus is the term used internationally to describe equipment which intentionally uses radio-frequency energy for purposes other than telecommunications. Radio-frequency heating equipment belongs to this general class of equipment and itself may be subdivided into equipment for medical purposes and that for industrial and commercial purposes. Table 1 gives details of some r.f. heating devices and their uses.

R.f. heaters are, or should be, designed to make the r.f. energy do useful work rather than to be dissipated by conduction along mains wiring or radiated into space. It is impossible in practice, however, to prevent completely the escape of energy by radiation and conduction at the fundamental working frequency and at spurious frequencies including harmonics. Figures 1(a), (b) and (c) show the relationship between the harmonics of 27·12 MHz and the frequencies used for land mobile, v.h.f. sound radio and television purposes and u.h.f. television channels respectively.

Even though only a small proportion of the power available is dissipated in this way interference may be caused to radio services unless proper preventive measures are taken. Detailed treatment of these preventive measures are not within the scope of this paper but in general they involve attention to the following main points:

(i) Frequency stability of the oscillator.

(ii) Prevention of frequency pulling by the load variation which takes place during normal operation of the equipment.

(iii) Careful circuit design to minimize the production of harmonics.

(iv) Good engineering layout and construction to avoid unwanted resonances and spurious oscillations.

(v) Adequate screening of components and filtering of supply and control leads.

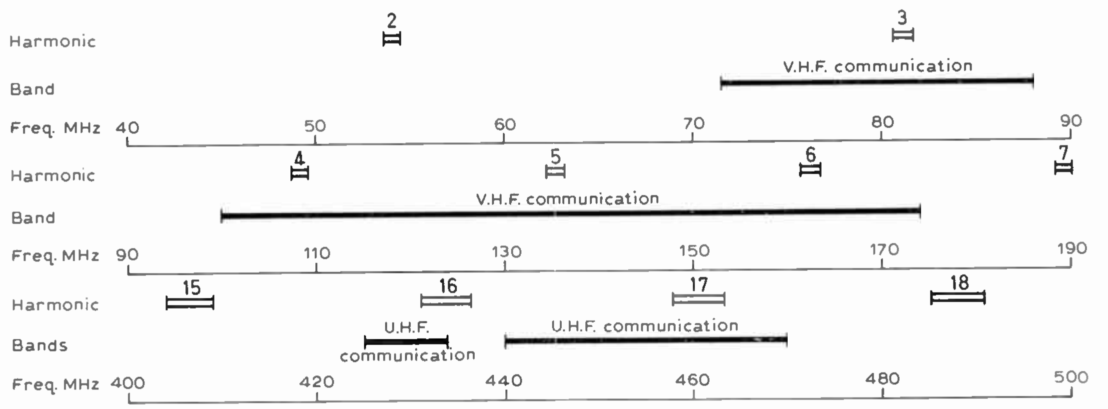
(vi) Maintenance and use of equipment by the user in accordance with manufacturer's instruction.

In the frequency range up to about 30 MHz interference may be conducted along mains and control leads or radiated directly from the equipment itself and the wiring which may be connected to it. In the case of low-frequency high-power machines it is possible for interference to be inductively or capacitively coupled from a machine or its associated wiring including the mains cables.

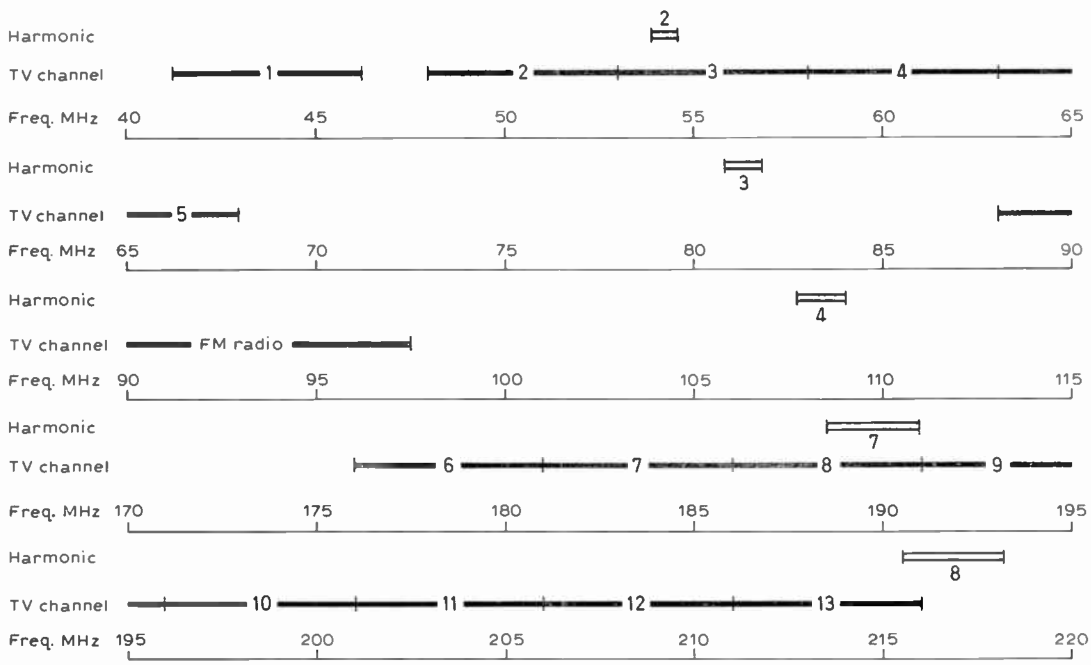
At frequencies above about 30 MHz the attenuation of mains wiring to r.f. currents increases rapidly and in most cases interference is caused by direct radiation from the machines and adjacent mains and control wiring.

2 Complaints of Interference from R.F. Heaters

In the United Kingdom the Home Office prepares an annual radio interference report which is based on Post

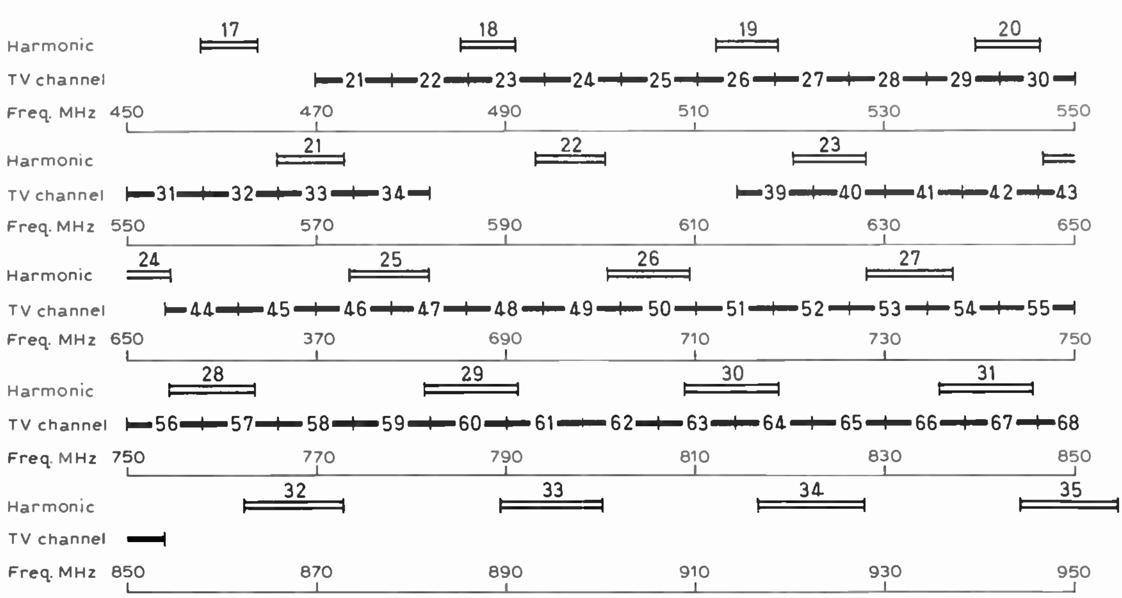


(a) Relationship between harmonics of 27·12 MHz ± 0·6% and land mobile and fixed radio communication services.



(b) Relationship between harmonics of 27·12 MHz ± 0·6% and v.h.f. broadcasting services.

Fig. 1.



(c) Relationship between harmonics of 27·12 MHz ± 0·6% and u.h.f. television channels.

Table 1
Radio frequency heating equipment

Type	Typical uses	Typical frequency of operation	R.f. power output
Medical diathermy	Deep heating of tissues	27·12 MHz ± 0·6%	200/300 W
R.f. excited arc welders	Radio frequency energy used to initiate the arc Non-ferrous metals especially aluminium are welded in an atmosphere of argon	R.f. exciter about 2 MHz	
Induction heaters	R.f. energy is inductively coupled to the work piece Heat treatment (case hardening), soldering, melting and zone refining	400 kHz, but may be from a few kHz to a few MHz	Up to 100 kW
Dielectric heaters	The work piece forms the dielectric of a capacitor Food processing, wood glueing, chipboard production, plywood moulding, plastics pre-heating for moulding	13·5 MHz 27–36 MHz	Up to 100 kW
Plastics welders	Welding of PVC and other plastics	27–82 MHz	Up to 50 kW but many 4–6 kW
Microwave ovens	Food production and processing	896 MHz ± 10 MHz	25 kW magnetron generators
	Cooking, domestic and catering trade Food and other industrial processing, newsprint drying, synthetic rubber pre-heating, polyurethane curing	2·45 GHz ± 50 MHz	Domestic 1–3 kW Industrial up to 30 kW

Office quarterly returns of complaints of interference to radio services. An extract from these reports giving details of complaints of interference caused by ISM apparatus in the years 1971 to 1974 is shown in Table 2.

The figures in Table 2 show that ISM complaints form only a small percentage of the total complaints each year and that the number of complaints for each category of ISM equipment is not very large.

It would not be right, however, to assume from these figures that there is no cause for concern and that all is well. On the contrary, although the total number of confirmed complaints arising from r.f. heaters is relatively small, the complaints which do arise are very difficult and usually costly to deal with and it often takes a very long time to abate the interference. Also it is likely that a number of complaints are due to r.f. heating equipment but because of the transitory nature of the interference, it has not been possible to trace the sources. An example of this occurred recently in the UK, on ground-to-air communication, near Manchester airport. Short bursts of a few seconds of fairly intense interference were occurring at long, irregular intervals, sometimes of a few days, others of a few weeks. The importance of the radio services suffering this interference made it imperative that the source be traced. This was eventually accomplished after the expenditure of a great deal of effort and the cause was found to be r.f. plastics welders, operating on non-designated frequencies and having poor frequency stability, installed in a factory approximately 30 miles away from the affected receivers. If interference had been caused to broadcast radio or television reception by this equipment it would not have been economic to expend the same number of man-hours and the case would have remained unresolved. The same factory therefore may have been the cause of very many unresolved cases of radio and television interference.

Complaints of interference in almost all cases arise because the r.f. heaters concerned:

(i) are not working on a designated frequency,

(ii) are not stable in frequency,

(iii) have levels of terminal voltage and radiation which are too high.

Table 2
Interference complaints in the United Kingdom

Year	Verified complaints all sources	Verified complaints ISM	%	Verified complaints					
				Medical diathermy	R.f. excited arc-welders	Induction heaters	Dielectric heaters	Plastics welders	Microwave ovens
1971	55 839	807	1·44	54	128	5	237	262	25
1972	58 060	740	1·27	42	55	—	244	282	10
1973	52 270	636	1·21	50	29	—	169	313	36
1974	42 001	453	1·51	40	64	5	109	185	14

The reason for these deficiencies is chiefly that in the past the frequency spectrum above 30 MHz was not used nearly so extensively for radio services as it is now. Consequently the choice of ISM operating frequency was not critical and there was less need to pay great attention to frequency stability or levels of radiation. As the occupancy of the higher frequency bands has gradually increased, however, the need for careful choice of operating frequency, good frequency stability and low levels of radiation has become more and more pressing. R.f. heaters are now being manufactured with these features in mind but the older heaters in use are likely to cause trouble for many years to come.

3 Rules for the Protection of Radio Services

The International Telecommunications Union (ITU) which designates frequency bands for the use of the various radio services makes provision also for radio frequency heating. Table 3(a) shows the ITU designated frequencies for ISM purposes. Unfortunately, however, 40·680 MHz because of its proximity to the sound carrier of television channel 1, Band I, on 41·5 MHz is not made available in the UK for ISM equipment and the alternative arrangements[1] shown in Table 3(b) have been made. Limits of r.f. terminal voltage and radiation are also laid down in Regulations.[2] The provisions of these Regulations are broadly in line with the International Special Committee on Radio Interference (CISPR) Recommendation 39[3] for ISM apparatus and apply to users of the equipment. The limits are shown

Table 3

(a) Frequencies designated by the ITU for ISM purposes

Frequency	
13·560 MHz ± 0·05%	no limits on radiation
27·120 MHz ± 0·06%	no limits on radiation
40·680 MHz ± 0·05%	no limits on radiation
2450 ± 50 MHz	no limits on radiation
5800 ± 75 MHz	no limits on radiation

(b) Provisions for industrial r.f. heater operation in the UK. BS 4809 : 1972

Frequency (MHz)	Radiation limit dB (μV/m)	Relaxed limit dB (μV/m)
13·560 ± 0·05%	unlimited	
13·560 ± 0·2%	110	
27·12 ± 0·6%	unlimited	
42 ± 0·2%	30	120†
49 ± 0·2%	30	120†
56 ± 0·2%	30	120†
84 ± 0·005%	130	
168 ± 0·005%	130	
896 ± 10 MHz	120	

† Relaxation applies in areas where the relevant television channel is not receivable.

in Table 4. In the frequency range 0·15 to 30 MHz the limits apply at 100 metres, and in the frequency range 30 to 1000 MHz at 30 m from the boundary of the user's premises.

4 Are the Limits the Right Ones?

In fixing limits of interference, care must be taken on the one hand to ensure adequate protection of radio services but on the other to avoid the imposition of unnecessarily stringent limits which might unjustifiably make the product to be suppressed uneconomic to produce or use.

The overriding requirement in this respect is the protection of radio services and it will be shown that the application of the established limit in conjunction with other accepted planning data in a typical practical situation leads to a no more than adequate protection of television reception and hence by implication that the limits chosen are realistic.

With the exception of Band I television, which in the UK suffers a much greater amount of interference from the high level fundamental frequencies of older ISM equipment operating in the lower v.h.f. band, the services in the various frequency bands are subject to complaints which vary from about 20 per annum for land mobile radio to about 80 per annum for each of the 625-line television Bands IV and V. The limits laid down for the protection of television reception are the most stringent of all existing limits.

A typical case of interference to u.h.f. 625-line monochrome and colour television reception in south-east England has therefore been chosen as an illustration of the application of limits for the protection of radio services in general from interference due to r.f. heating equipment.

Electromedical equipment and radio frequency plastics welding equipment is in many cases installed in premises which are close to dwelling houses and protection is thus required for these cases. The aim of Regulations is to protect radio installations in good condition in areas of adequate field strength. The International Radio Consultative Committee (CCIR) has recommended minimum field strengths to be protected for various services[4, 5] and it is usual in the UK to consider pro-

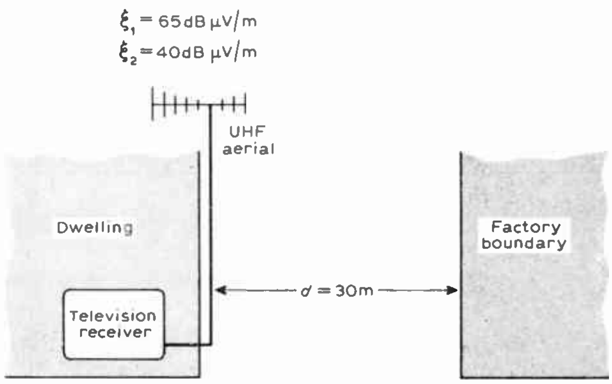


Fig. 2. Assumed worst conditions of interference from ISM equipment.

Table 4

Approximate equivalent limits of terminal voltage and field strengths for radio frequency heating equipment extracted from Statutory Instruments 1971 No. 1675

Frequency range in MHz		Maximum radiated field strength	Maximum terminal voltage	For protection of safety of life services	
exceeding	not exceeding	dB (μV/m)	dB (μV)	Maximum radiated field strength dB (μV/m)	Maximum terminal voltage dB (μV)
13·533	13·553	110	134		
13·553	13·567	unlimited	unlimited		
13·567	13·587	110	134		
26·957	27·283	unlimited	unlimited		
83·996	84·004	130			
167·992	168·008	130			
886	906	120			
For all other frequencies in the ranges specified below the limits of field strength and terminal voltage shall be as follows:					
0·15	0·2	34	70	24	60
0·2	0·285	34	66	24	56
0·285	0·49	48	66	38	56
0·49	0·5	34	66	24	56
0·5	1·605	34	60	24	51
1·605	3·95	48	60	38	51
3·95	30·00	34	60	24	51
30·00	470·00	30		20	
470·00	1000·00	40		31	

tection with reference to the CCIR Recommendations although this does not preclude efforts to improve matters when interference is experienced by listeners or viewers who are unfortunate enough to be outside the service areas defined by the minimum values of field strength. In the absence of overloading the extent of the degradation of the television picture and sound due to the interference depends upon the ratio of the wanted to unwanted signal at the input to the television receiver; this ratio is usually referred to as the protection ratio.

Assume for a moment that a dwelling is situated at a distance of 30 m from a factory boundary in the CCIR recommended minimum protected field strength of 65 dB (μV/m) for 625-line Band IV television and that the interference level is 40 dB (μV/m) at this distance. The situation is shown in Fig. 2.

Now where:

G_0 = aerial gain relative to an isotropic radiator [for a half-wavelength dipole $G_0 = 120/R$]

P = power received

ξ = received field strength

V = voltage on aerial terminals

R = impedance of half-wavelength dipole

It can be shown[6] that

$$P = \frac{1}{120} \cdot \frac{\lambda^2 \xi^2}{4\pi^2} G_0;$$

also

$$P = \frac{V^2}{R}$$

$$V^2 = \frac{R}{120} G_0 . \xi^2 \left[\frac{\lambda}{2\pi}\right]^2$$

$$20 \log_{10} V = 10 \log_{10} \left[\frac{R}{120} \cdot G_0\right] + 20 \log_{10} \xi + 20 \log_{10} \left(\frac{\lambda}{2\pi}\right)$$

Let:

ξ_1 = field strength of wanted television signal (μV/m)

ξ_2 = field strength of interference radiated from r.f. heater (μV/m)

V_1 = television signal voltage at receiver input (μV)

V_2 = ISM interference voltage at receiver input (μV)

G = television aerial gain relative to a half-wavelength dipole (aerial properly orientated) (dB)

G' = effective television aerial gain, relative to a half-wavelength dipole, for interference (dB)

Therefore

$$20 \log_{10} V_1 = 10 \log_{10} \left[\frac{R}{120} \cdot \frac{120}{R}\right] + 20 \log_{10} \xi_1 + 20 \log_{10} \left(\frac{\lambda}{2\pi}\right) + G$$

and

$$20 \log_{10} V_2 = 10 \log_{10} \left[\frac{R}{120} \cdot \frac{120}{R}\right] + 20 \log_{10} \xi_2 + 20 \log_{10} \left(\frac{\lambda}{2\pi}\right) + G'$$

The protection ratio is equal to:

$$20\log_{10} V_1 - 20\log_{10} V_2 = 20\log_{10}\xi_1 + G - 20\log_{10}\xi_2 - G'$$

But

$$20\log_{10}\xi = \text{field strength} \quad (\text{dB}(\mu\text{V/m}))$$

Therefore, assuming an aerial gain G of 12 dB, i.e. a good outdoor aerial, and an effective aerial gain G' to the interference which will depend upon the relative positions, in the horizontal and vertical planes, of the r.f. heaters and the television aerial, the protection ratios for the assumed situation may be calculated.

Three examples will be sufficient to make the position clear. These are:

1. The r.f. heater radiation enters the main beam of the television aerial: $G' = 12$ dB.

   Protection ratio $= 65+12-40-12 = 25$ dB.

2. The television aerial acts as a simple dipole as far as the r.f. heater radiation is concerned: $G' = 0$ dB.

   Protection ratio $= 65+12-40-0 = 37$ dB.

3. The r.f. heater radiation enters the back lobe of the television aerial which is assumed to have a front to back ratio of 20 dB: $G' = -8$ dB.

   Protection ratio $= 65+12-40-(-8) = 45$ dB.

It is of course possible to alter these protection ratios by choosing aerials with different gains and front-to-back ratios. The values used in this example, however, represent the optimum likely to be obtainable in most practical installations using commercially available aerials.

To judge the efficacy of the limit these values of protection ratio must be compared with the protection ratio required by the service which is to be protected. In this case it is u.h.f. 625-line colour reception and the protection ratio required by the UK 625-line PAL colour television system from a continuous wave or frequency modulated sound signal with no particular control of carrier frequency is given by the curve shown in Fig. 3.[7, 8] The dotted curve gives the protection required when the interference is present for between 1% and 10% of the time. The solid curve shows the protection necessary when the interfering carrier is amplitude modulated, as it is likely to be in r.f. heater radiation, and the interference is present for a longer period. The protection ratio shown by the solid curve in Fig. 3 is roughly equivalent to a subjective judgment of interference by viewers in which 50% find the interference just perceptible or better and 50% find it definitely perceptible or worse.

From Fig. 3 it can be seen that assuming the interference to be present for long periods:

for condition 1 there will be severe interference if the interfering signal is within the channel;

for condition 2 severe interference will occur if the interfering signal is within about −0·75 and +2·75 MHz of the vision carrier or is near the colour sub-carrier or the sound intercarrier frequency;

for condition 3 interference will occur if the interference is near the vision or colour sub-carrier or the sound intercarrier frequency.

From this example it is clear that, theoretically at any rate, the limit of permissible radiation is not nearly low enough to provide the protection required. It is clearly possible for there to be situations where even when the r.f. heater installation meets the CISPR limits there will still be severe radio interference.

5 The Practical Situation

It is not usual in practice, however, for all of the factors affecting the protection ratio to be maximized on the same site at the same time. To illustrate this point a detailed analysis has been made of a situation in south-east England where r.f. plastics welders in a small light-industry factory situated in a predominantly residential

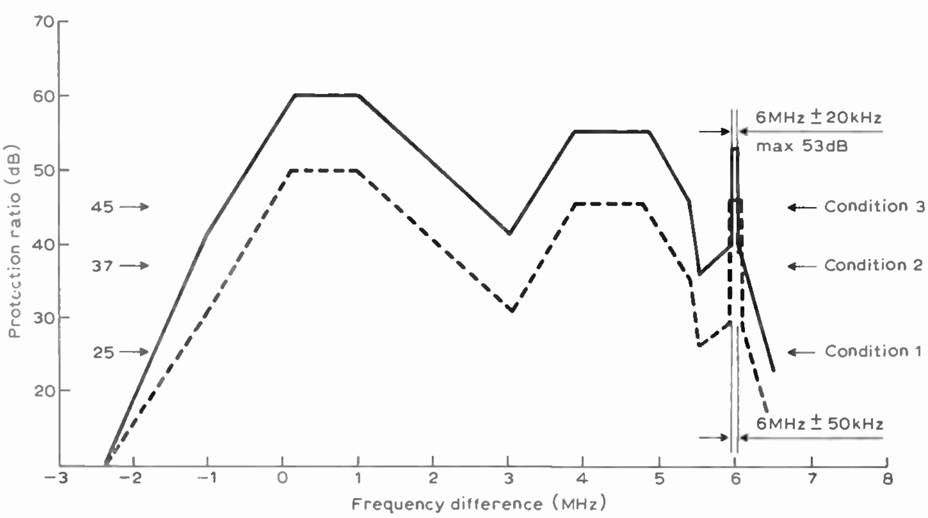


Fig. 3. Estimated protection ratios for the 625-line PAL colour television system (Standard I).
——— Interference from amplitude modulated signal present for long periods.
- - - - - Interference present for 10% or less of time.

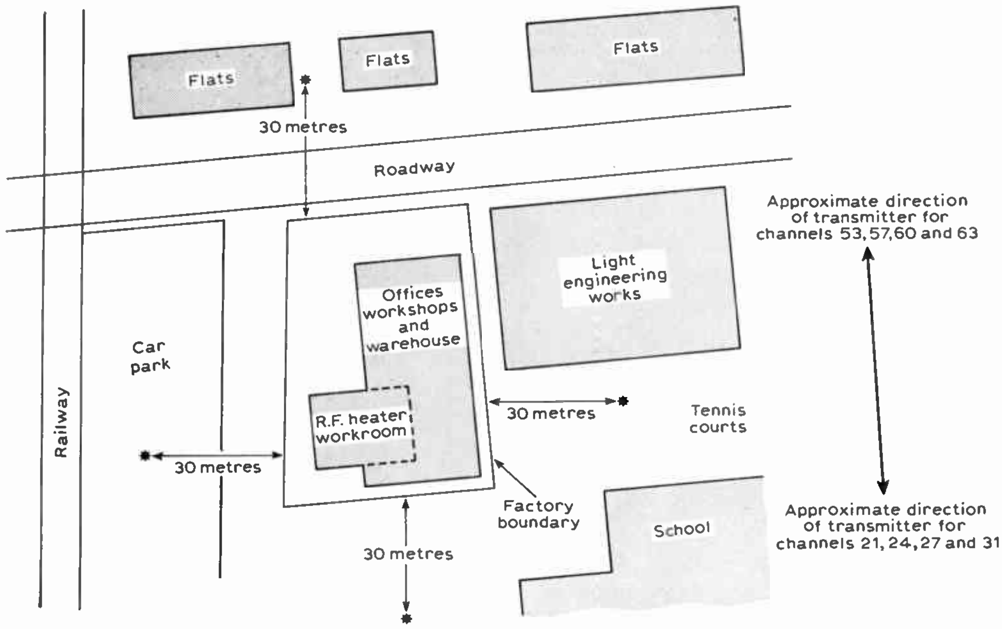


Fig. 4. Typical example of interference from radio frequency heating equipment.

area caused serious interference to nearby television reception. The immediate geographical situation is shown in Fig. 4. Although the flats (apartment houses) shown were the worst affected, other dwellings in the neighbourhood also experienced interference.

The cause of the interference was found on investigation to be due to 12 plastics seam welders used in the production of small plastics wallets, document cases and similar articles. None of the machines which were responsible for the interference were operating on the ITU or BSI designated frequencies. The frequency stability of the machines was very poor and all had levels of harmonic radiation in the u.h.f. bands exceeding the 40 dB (μV/m) limit. The highest level measured was 74 dB (μV/m), i.e. 34 dB above the limit. These were old machines which had been working in another location for a number of years without complaint but which immediately caused interference when the work was moved to this new location near dwellings and where the wanted television signal strength is of the order of 65–70 dB (μV/m), i.e. edge of service area conditions. Two newer machines operating on 27·12 MHz were found to cause no interference.

An immediate alleviation of the interference was brought about by the co-operation of the user in taking a number of temporary *ad hoc* measures such as avoiding the use of the worst offending machines during peak television viewing hours and using a monitor television receiver in the factory to indicate when the frequency of any of the machines had drifted to a degree where the harmonics could cause interference to the local television channels.

The long-term solution of the problem lies in replacing the old machines with new ones which meet the requirements of the Regulation in all respects. Table 5 shows the relationship between the frequencies of the television channels in use on the site and the radio frequency heating equipment harmonics which may be present when new equipment is installed. It may be seen from Table 5 that if equipment tuned to 42 MHz ± 0·2% were to be used the problem would be completely solved as none of the harmonics of 42 MHz ± 0·2% fall within any of the television channels. At present, however, there is no suitable r.f. equipment available using 42 MHz, and 27 MHz equipment is to be installed.

Equipment tuned to 27·12 MHz ± 0·6% does not, unfortunately, provide such a satisfactory solution because the 19th harmonic just overlaps the edge of channel 27 and the 28th, 29th and 30th harmonics overlap channels 57, 60 and 63 respectively.

The UK television service does not provide for six channels to be receivable in one location. The planned distribution is for four channels only, in this case ultimately channels 21, 24, 27 and 31, but channel 21 is not yet allocated to a service. The location is, however, on the edge of two service areas and the other group of channels 57, 60, 63 and, ultimately also 53 are receivable although the direction of the transmitter is opposite to that for the first group. Channel 21, when it is provided, will be clear of interference. Channel 53 will be affected.

To examine the effect of removing the old non-complying machines and replacing them with new machines which do comply, the results of the measurements at the locations shown in Fig. 4 may be used to find the protection ratio which is achieved. This can then be compared with the protection ratio required as shown in Fig. 5. In this location, however, the field strength of the harmonics of the two 27·12 MHz machines in service were found to be lower than could be measured using the standard measuring receiver (about 20 dB (μV/m) in this frequency range) and therefore calculation of actual protection ratio from measured values was not possible.

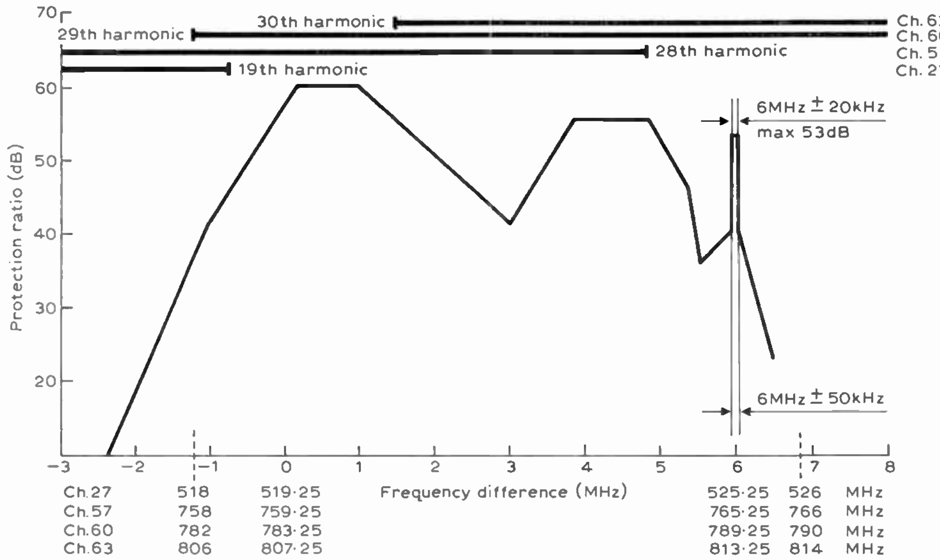


Fig. 5. Relationship between frequency range of harmonics of r.f. heating equipment on 27·12 MHz and the protection ratio required for television channels.

To ascertain what might happen in other similar situations a level of interference field strength, in the direction of the nearest television aerial, about 10 dB below the limit may be assumed. This is justified on the basis that the equipment is judged on the highest level measured over the frequency range in the direction of maximum radiation. In practice, of course, it is possible that the television receiver aerials will be in the direction of maximum radiation and that the harmonic causing the interference will be on the limit but the probability is small.

Making this assumption for the service using channels 24, 27, 31 and ultimately 21, it can be seen that the change to 27·12 MHz with the required frequency tolerance brings about an immediate improvement by ensuring that 3 of the 4 channels are clear of interference. For the fourth channel, i.e. channel 27, the 19th harmonic is capable of causing interference.

The distance from the r.f. heater room to the television aerial is about twice that to the nearest 30 m point from the factory boundary, i.e. the point in the car park. The field strength at the television aerial will therefore be of the order of 24 dB (μV/m), i.e. $40-(10+6)$, and the protection ratio in this case is given by the ratio of the two field strengths since there is no difference in the aerial gain for the two figures as the r.f. heater room is in the same direction as the television transmitter.

Therefore

$$\text{protection ratio} = 69\text{ dB }(\mu\text{V/m}) - 24\text{ dB }(\mu\text{V/m}) = 45\text{ dB}$$

For reasonably interference-free reception, a protection ratio of 45 dB is required if the interference is present for more than 10% of the time. In this case because channel 27 is on the very edge of the harmonic spread the interference is unlikely to be present for more than a few percent of the total time and a protection ratio of about 30–35 dB would be sufficient.

For channels 57, 60 and 63, and ultimately 53 also, the protection ratio required is 60 dB if the interference is present for more than 10% of the time, which will certainly be the case for channels 57 and 60. Since the television transmitter lies in the opposite direction to the r.f. heater room, interference will enter via the back of the aerial.

Therefore

$$\text{protection ratio} = 67\text{ dB }(\mu\text{V/m}) - 24\text{ dB }(\mu\text{V/m}) + 8\text{ dB} = 51\text{ dB}$$

If the CCIR minimum protected field strength of 70 dB (μV/m) had been available the protection ratio would have been 54 dB. For these channels in this situation the CISPR limits may not always be adequate to protect reception to the standard required by CCIR Recommendation 418–2 or Report 306–1 and the presence of 14 machines on the same frequency instead of only two as at present may worsen the situation. Thus the occupants of dwellings, near to an r.f. heater room in edge of service area conditions, may experience interference from time to time even though the r.f. heater installation meets the CISPR limits of radiation. Other nearby viewers should be clear of interference in the same circumstances because of the screening effect of buildings and the greater separation distances.

The usefulness of the CISPR limits for the protection of radio services thus depends to a great extent upon some diversity of the many parameters involved. Normally it is unlikely that all the adverse factors will coincide in the same place at the same time and thus reasonable protection is afforded without too great a hardship to the manufacturers and users of r.f. heating equipment. In areas of higher wanted field strength equipment complying with the CISPR limits should give no cause for complaint.

As far as the practical example given in this paper is concerned it is virtually certain that the installation of

Table 5

Relationships of television channels and interfering frequencies

Television channels in use on site		Radio frequency heating equipment		
Channel no.	Frequency range (MHz)	Harmonic number for 27·12 MHz ± 0·6%	Harmonic number for 42 MHz ± 0·2%	Frequency range (MHz)
			11	461·076–462·924
		18		485·226–491·094
24	494 to 502	Clear	Clear	
			12	502·992–505·008
27	518 to 526	19	Clear	512·183–518·377
			13	544·908–547·092
		20		539·14 –545·66
31	550 to 558	Clear	Clear	
			14	586·824–589·176
		21		566·097–572·943
			18	754·488–757·512
		27		728·325–736·641
57	758 to		Clear	
	766	28		754·795–763·924
60	782 to		Clear	
	790	29		781·953–791·207
			19	796·404–799·596
63	806 to		Clear	
	814	30		808·71 –818·490
			20	823·92 –841·68

new machines meeting the CISPR limits will eliminate complaints of interference to u.h.f. reception on the television channels in the primary service area, and it is unlikely, if the new machines have the same characteristics as the existing 27 MHz machines, that there will be any very serious interference to the other receivable channels.

6 Conclusions

It has been shown that the CISPR limits of interference for ISM equipment are not stringent enough to protect television reception in Bands IV and V in all conditions but that in a practical situation, because of the number of factors affecting the results, reasonable protection is given.

The example given is a very limited one applying only to two television bands and it would have been useful to extend the examination to other services in other Bands. This has been impossible, however, because the measurement work was done in the course of an investigation of complaints and as there is always great pressure to clear the interference and report to the relevant authority no time was available for a more analytical approach.

Nevertheless, it is instructive to compare the theoretical calculation of the protection ratio to be expected from the CISPR limit and that achieved, in a typical edge of television service area situation, by the application of these limits in conjunction with the use of an ITU designated operating frequency, to machines in a light industrial estate close to dwelling houses. Experience with other cases of interference leads to the conclusion that similar analyses applied to other services would yield similar results.

7 Acknowledgments

Acknowledgment is made to the Home Office Director of Radio Technology for permission to publish this paper and to the staff of Radio Interference Branch for their part in carrying out the measurements and preparation of the reports.

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Manuscript first received by the Institution on 26th June 1975 and in final form on 5th September 1975. (Paper No. 1719/Com. 128).

UDC 621-7

A review of fault detection methods for large systems

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Based on a paper presented at the IERE Conference on Advances in Automatic Testing Technology held at Birmingham from 15th to 17th April 1975

SUMMARY

A critique is made of current research into practical fault finding procedures for the maintenance of complex engineering systems. The half split and other methods currently in practice are analysed and their main weakness shown to be that no account is taken of the various costs involved. Also analysed are cost conscious methods which are useful in diagnosis training or in designing fault detection guides. A brief look is taken at advanced diagnostic techniques which are aided by an on-line computer in selecting the next test to be made.

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1 Introduction

With the ever increasing complexity of engineering equipment of all types and disciplines the engineer and technician are faced with acute maintenance problems. One of the most incomprehensible aspects is that of diagnosing a fault in an inoperable system. The problem is compounded by the increasing obsolescence rate of equipment which allows less time for familiarization. The cost of downtime is often very high, especially in integrated production plants.

There is a real need therefore to develop methods which will enable faults to be found and rectified in the shortest possible time and at the minimum total cost. In addition to direct savings in lost production and consumed maintenance facilities, capital cost savings may be expected since fewer standby systems will be needed.

The problems of fault detection are considered against a maintenance background but the techniques discussed are also applicable in the quality control and assurance field. Similarly, the logical techniques are appropriate in any complex engineering system be it mechanical, electronic, electrical, hydraulic, etc. In fact the author has used some of the techniques in the successful diagnosis of human systems, e.g. in the diagnosis of patients suffering from thyroid disorders[1].

2 Approaches to the Problem

Basically three distinct approaches have been made to improve the efficiency of fault detection.

Approach 1: Personnel training in functional analysis/fault finding guides. This method has the advantage of producing instantly experienced technicians for a very low (or zero) capital outlay. The only cost involved is that of training. This approach is very useful when the frequency of fault occurrence is low and/or the cost of downtime is not particularly high.

Approach 2: The introduction of fully automated testing and switching devices similar to those used on computer, missile and aircraft checkouts and for some makes of motor cars (e.g., Volkswagen). These are really checking procedures in that a complete battery of tests is usually run independent of early indication of a fault. This approach is useful and justifiable when the downtime cost is very high (or the consequences of fault development are serious) and/or the frequency of fault development is high.

Approach 3: This is the middle ground between the two previous approaches and is appropriate when fully automated checking procedures cannot be justified but some automation is necessary to assist in diagnosis. Here the purpose is to locate the fault by using the minimum number of tests or at the least cost (which is often not the same as minimizing the number of tests). This approach is also suitable when automatic testing devices are included but because the elapsed time for a test is significant then the order of testing and the number of tests to be made are important.

This paper concentrates on techniques which are consistent with Approach 3.

3 Formalizing the Approach

The previous casual statement of purpose: '. . . to locate the fault by using the minimum number of tests or at the least cost . . .', requires analysis and enlargement.

3.1 Objective

The objective of the approach is to determine the best sequence of applying tests so that the diagnosis is made in the optimal manner as specified by the criterion or criteria.

3.2 Criteria

The criterion depends on the physical situation. Often it is stated as the minimum number of tests to reach the correct diagnosis or when the tests have unequal durations then it is often stated as the minimum time to reach the correct diagnosis. Although in a few situations one of these criteria may indeed be correct, in most cases the criteria are inadequate since no account is taken of the cost of the various testing actions or the financial and other consequences of incorrect diagnosis. In yet other situations there is danger of incurring further faults by applying particular tests to the system and this danger must be accounted for.

The most widely applicable criterion is to minimize the *total* cost of fault finding and rectification. This is particularly suitable in production and other commercial environments where the downtime results in actual or potential loss of profit or income. This is generally a more appropriate criterion than minimizing time since the consequences of time and the cost of testing/diagnosis/rectification are included.

The most notable exception to the adoption of this criterion is in cases where the *cost* of downtime is not directly applicable, e.g., military operations or where human safety is involved. Other useful criteria are:

maximize the probability of correct diagnosis subject to a fixed testing cost (time) and

minimize testing cost for a given probability level of acceptance.

Decision theorists will be familiar with the methods and the appropriateness of the methods of Wald, Savage, and others, in this area.

3.3 Depth and Extent of Diagnosis

It has been shown in Refs. 2 and 3 that the three cases:

(i) search (detection) for a fault when it is known that the system has failed,

(ii) checking operability and searching for a fault,

(iii) checking operability,

are all equivalent to diagnosis in different depths. Similarly whether the system has definitely only one fault or many faults, or indeed if it is faulty at all, may be considered to be problems of inspection rather than diagnosis. Finally, whether diagnosis is made when the faulty unit (component) or module is identified depends solely on the definition of a 'unit'.

In subsequent analysis of various methods the 'system' may be a radar-missile system where the 'units' are the surveillance radar, tracking radar, communications system, computer, missile launcher and missile, or modules of these. Alternatively the 'system' may be a domestic hi-fi set and the modules or components represent the 'units'. The terms 'system' and 'units' are thus general.

4 Logical Fault Finding Techniques

To detect a fault in a system one normally carries out various tests and the physical tests used in any situation depends on the nature of the system under investigation. Depending on the physical situation then responsive tests, elemental probe tests, signal tracing and substitution, stress methods, replacements, etc. may be used. The choice of suitable tests is very much a physical engineering matter; sometimes a straightforward and obvious choice, in other cases the subject of much analysis.

Independent of the physical tests possible, one is faced with a logical decision problem. That is, in what sequence should the tests be applied to identify the fault. An intuitive approach does not guarantee an optimal solution. It will be found convenient to consider the system as falling into one of three categories. Strictly these categories are non-overlapping, mutually exclusive and exhaustive. In practice, however, the boundaries are not quite so rigid.

A number of the techniques which will be considered require involved calculations to be made so that the best sequence of testing may be identified. These calculations can be made via a Post Office modem to a general-purpose digital computer which may be some distance from the system under investigation, or by a small special-purpose computer on site. To enable these techniques to be used in conjunction with diagnostic training methods or in preparing fault finding guides, it is possible for the calculations (in categories 1 and 2 only) to be made during the preparation of the guides. This overcomes the need to make calculations during actual fault finding.

4.1 Category 1: System composed of N identical elements—perfect information

Although systems composed of identical items are unusual in practice this category may be broadened to include systems where the *a priori* probabilities of failure of the units are approximately equal and the testing costs are also approximately equal. Hence it will be seen that the system may be composed of many physically different elements so long as the testing costs and failure characteristics of the various elements are approximately the same. Perfect information implies that testing errors do not occur.

A simple procedure which does not immediately identify the faulty element but does rectify the fault is to replace the units of the system with spare units which are known to be in good condition. These replacements may be made sequentially and the system operability checked after each replacement. Alternatively the units may be replaced en bloc. Depending on the relative costs of downtime and unit replacement, this strategy may be desirable. The replacement methods are attractive when

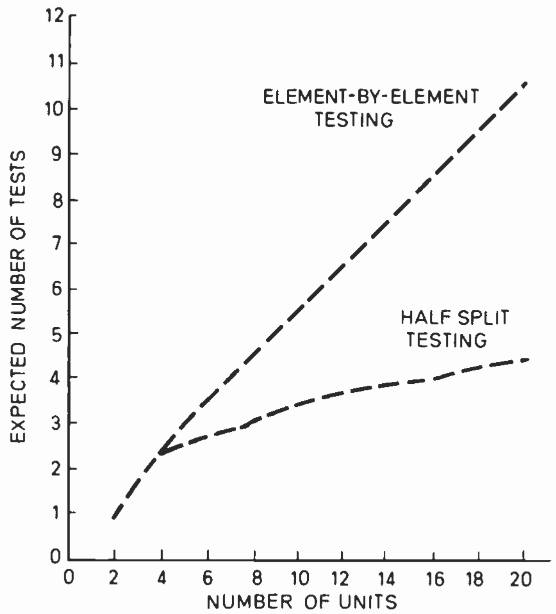

Fig. 1. Comparison of element-by-element and half split testing methods.

the cost of downtime is high and/or the cost of unit replacement is low and/or faults in units may be rectified without system downtime. Obviously this strategy is not limited to systems in this first category but is applicable (often with greater benefit) to more complex systems. The value of this approach is easily determined for any system.

Element-by-element testing is often possible. Since the various elements have the same probability of failure and all testing costs are the same then the order of testing is quite unimportant and a random (non-overlapping) strategy may be chosen.

The half split method is a frequently employed and very efficient testing strategy. The method starts by making a group testing of any $N/2$ units (where the system consists of N units.) If the system fault is found to lie in these $N/2$ units then these are further sub-divided into two groups of $N/4$ units and the process continues. If at any point the fault is not found to lie in the tested group then it is assumed to lie in the corresponding untested group and it is this untested group that is subsequently divided. The method continues until a single unit is isolated as the defective item. The method requires modification in some series/parallel circuits. It will be observed in Fig. 1 that for systems in this category the half split method is vastly superior to element-by-element testing.

4.2 Category 2: System composed of N non-identical items—perfect information

This is the general case where the system comprises N items with probabilities of failure p_i ($i = 1 \ldots N$) and testing costs t_j ($j = 1 \ldots M$) where M is the total number of possible tests. (Usually $M \geqslant N$ but this need not be so.) Again no testing errors can occur.

In this case the half split method is generally unsuitable since it requires all the probabilities to be equal for it to pinpoint the fault in the minimum time. Moreover, since it does not consider the costs of the various tests, it is unable consciously to minimize these or any other costs. Nevertheless, because of the great power of this method reasonable results can often be obtained in practice.

Kozlov[4] considers a special case where the test costs are equal (though the probabilities need not be the same). He proposes a method which involves calculating the conditional probability of failure for each unit by the formula:

$$p_i^* = \frac{p_i}{1-p_i}\left[\sum_{i=1}^{N}\frac{p_i}{1-p_i}\right]^{-1}$$

Thereafter the method is similar to the half split method except that the groupings are made such that the sum of the conditional probabilities is equal in each split and *not* necessarily the number of units.

To cover the general case of unequal probabilities and unequal testing costs the entropy concept is frequently used. The entropy concept has been used in thermodynamics and physics for a number of years but it was Shannon[5] who first suggested its use as an information measuring technique. Good[6] considered its use in diagnosis. Basically, entropy is a measure of uncertainty and in test selection is defined as:

$$E = -p_i \log p_i$$

where p_i is the probability of item failure. Kozlov[4] proposes the use of entropy concept in engineering system diagnosis. The technique is similar to that used in Ref. 1. Although proposed under this category of system, entropy-based models are also suitable for more complex systems where testing errors can occur.

The methods of dynamic programming[7] have also been used for fault finding in systems of this category and it has been shown[8] that the optimal policy for element-by-element testing—the present extent of this technique in diagnosis—is to select the tests which minimize the ratio p_i/t_i. (p_i and t_i are as previously defined.) Some of the specialized models based on the dynamic programming concept which have been described are:

The case where the system fails when K out of N items fail, i.e., the system has spare or standby facilities.[9]

A special case where dynamic programming is applied to a half split approach. The model, however, is not generally suitable for engineering systems.[10]

The updating of item failure probabilities based on previous testing experience. It is worth noting that the title of this paper may be misleading since the technique itself is not adaptive—only the updating of item failure probabilities is adaptive.[11]

4.3 Category 3: System composed of N non-identical units—imperfect information

This is the ultimate in system complexity. It is a general system as in the previous category but it is further complicated by the possibility of testing errors. This means in effect that a unit which is not faulty may be indicated as faulty, while a unit which is faulty will be occasionally indicated as not faulty. Since testing errors can occur the system is then similar in test outcomes to one where the fault is intermittent. Hence the techniques

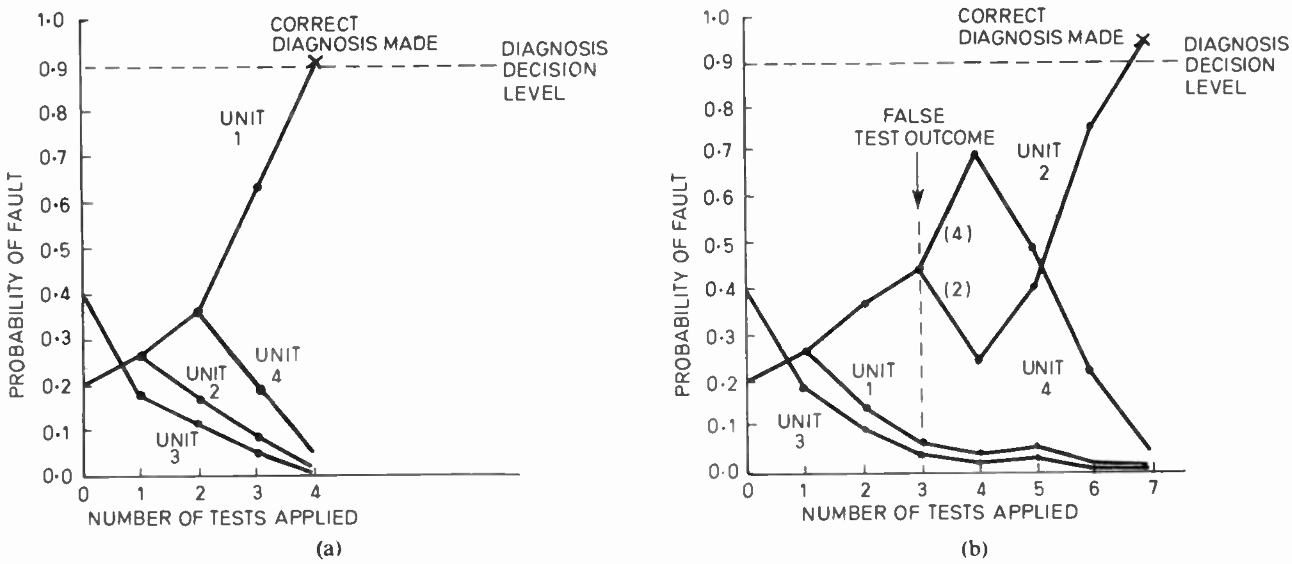

Fig. 2. Examples of changes in probability level when using the entropy method. (Reproduced from Ref. 15 by permission of the Institution of Mechanical Engineers).

developed for systems with testing errors may also be used to diagnose systems with intermittent faults. In systems in this category it is often necessary to apply a test a number of times and the ' balance of evidence ' is accepted rather than the results of any particular tests.

Because of the possibility of testing errors the half split method is generally quite unsuitable since this method places absolute confidence in every test outcome. Consequently if even one error is made in testing then an incorrect diagnosis is guaranteed. Hence frequent incorrect diagnoses may be expected if this method is used for systems in this category.

Methods based on the entropy concept would appear to be of significant value in diagnosing this type of complex system since one or more false test readings may occur and still the correct result obtained, that is, provided sufficient correct test readings are also received. After a test is made the *a priori* probabilities of failure are updated (e.g. Bayesian statistics) and the new *a posteriori* probabilities indicate the extent of present knowledge concerning the relative probabilities of failure. Figure 2(a) shows the case where no false responses are received with consequential swift diagnosis. Figure 2(b) shows the case where a false response is obtained but subsequent correct responses sway the balance in favour of the true fault and the correct system diagnosis is eventually made. In both these cases it will be seen that diagnosis is made when one of the probabilities is greater than or equal to 0·9. But why should diagnosis be made when the probability is 0·9? Why not (say) 0·8 or 0·99 or any other convenient level? This indicates the main problem in using the entropy method, namely selection of the best probability level at which diagnosis should be made. The selection of the probability level is closely related to the number of tests which should be made. The answer lies in analysing the consequences of an incorrect diagnosis. If the 'cost' associated with an incorrect diagnosis is high then in general a large number of tests will be necessary to give a high probability of correct diagnosis and a corresponding low probability (and expected cost) of incorrect diagnosis. If the cost of incorrect diagnosis is low then errors in diagnosis are more tolerable and few tests will be necessary to satisfy the lower diagnosis decision level. In lowering the diagnosis decision level the incidence of incorrect diagnosis must be expected to increase. The selection of the correct probability level is thus a balance between the cost incurred in further testing and the potential cost of an incorrect diagnosis due to insufficient information. The selection of this level is regretfully an arbitrary decision and thus detracts from the usefulness of the method.

An extension of the dynamic programming method[12] attempts to overcome some of the weakness of the entropy method by including in the computational procedure the cost of replacing a good item when it has been incorrectly diagnosed as the faulty item. Also the probability of testing errors occurring is included. These inclusions help to remove some of the subjective element in deciding the diagnosis decision level. It was stated earlier that the method of dynamic programming has only been proved for element-by-element testing and this constraint is immensely restrictive. Were this barrier to be removed then this method is likely to be very useful in the majority of fault finding situations.

Adaptive dynamic programming is a special version of the general technique. Its potential value as a diagnostic technique is enormous and the method is currently the objective of much research. A modification of the general technique of dynamic programming has been applied to the sequential testing of marine boiler tubes.[13] In this particular use of the general technique the very desirable attribute of adaptive dynamic programming was experienced, namely the technique included its own stopping rule (equivalent to the specification of a diagnosis decision level). Hence a totally quantitative approach to fault finding was achieved.

A final technique worth mentioning is that of pattern recognition.[14] Again the potential is significant but until the results of current research become more freely available a critical appraisal is not possible.

5 Conclusion

Depending on the complexity of the system under investigation so different groups of testing strategies are possible. Some techniques are universally superior to others but equally a large grey area exists where no one technique has absolute supremacy. For any given system the relative merits of the techniques change as the parameters of the system change, e.g., changes in probability of unit failure with time, changes in probability of testing errors, changes in test costs, etc. Current research is attempting to improve existing methods and develop new methods of fault finding. Additionally it is concerned with the selection of the most appropriate technique in any particular circumstance.

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Manuscript first received by the Institution on 30th January 1975 and in final form on 12th November 1975. (Paper No. 1720/ACS12).

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UDC 548-15+537.363+537.37

Recent developments in liquid crystals and other new display techniques

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Based on a paper presented at a meeting of the South Western Section in Bristol on 5th December 1974.

SUMMARY

The current state of the art in liquid crystal displays and the characteristics of other newly-developed displays, particularly electrophoretic and electrochromic devices, are discussed. The advantages and disadvantages of the different types of displays for particular applications are examined. The new liquid-crystal phase-change, guest-host system and the electrophoretic display appear to have a wide range of applications. For certain specialized devices, such as the digital watch, however, where very low voltage, low power operation is essential, the twisted-nematic liquid crystal display appears to be uniquely suitable. The electrophoretic and solid-state electrochromic systems are capable of satisfactory operation at much lower temperatures than the other types. All the systems discussed are capable of providing large area displays with a very low power consumption and give a good contrast ratio in high ambient lighting, so might be expected to fulfil some applications not accessible to the l.e.d. or plasma panel. The thermally-addressed liquid crystal panel appears to be a promising development for flat-screen data displays carrying large numbers of digits.

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1 Introduction

Many engineers have now become familiar with liquid crystal display devices, which have been under development for the past few years, and are now coming into limited manufacture. After some initial difficulties in determining the best addressing techniques, construction and optical presentation of these displays, they are becoming acceptable for many specialized applications, particularly where very low power operation, or large display areas are required. Some improved display modes have now been developed in liquid crystals, and the choice of the best types of display for commercial applications is now becoming more clear.

At the same time, other types of display have been under development, which are similar in so far as they also consist of thin films of organic materials enclosed within glass cells, and also operate at low potentials and very low power levels, although different functional principles are involved. These are the electrophoretic and the so-called electrochromic displays; there is also a more genuine electrochromic system, which is truly solid-state, consisting of thin films of inorganic compounds sandwiched between conducting electrodes. The latter is, however, in a very early state of development.

2 Display Requirements

It is the purpose of this paper to discuss recent developments in the liquid crystal field and the newer display techniques, to compare their performance, and to estimate their commercial applications. New display techniques have to compete with existing devices, particularly the l.e.d. display, which has proven reliability and an exceptionally long life. To obtain a share of the market, in competition with l.e.d.s, plasma panels and fluorescent displays, these new display systems must offer any of the following advantages:

- Lower voltage, lower power operation
- Large area capability with minimal power requirements
- Good readability in very high ambient lighting conditions

The display applications we have to consider when comparing the various techniques are:

- Simple on/off indicators
- Annunciator (fixed message) panels
- Single or multi-digit numeric or alpha-numeric strip displays for calculators, digital instruments, clocks and watches
- Analogue (tape scale) displays
- Large area clock and tote-board displays for public places
- Large area mimic diagrams for process control
- Radar displays
- Matrix displays capable of several rows of alpha-numeric data
- Data terminals, for computer read-out, where a large amount of alpha-numeric data is displayed
- Fast operating shutters.

3 Liquid Crystal Displays

There have been many expositions on liquid crystals and their applications in the technical press in the past few years, and it is only proposed to give a brief outline of their basic physical properties in this paper. For more detailed background information it is recommended that some of the better reviews should be consulted.[1–4] A detailed discussion of the chemistry and structure of liquid crystals can be found in Gray's book.[5]

Liquid crystals are organic compounds which, because of their polar nature and the elongated shape of their molecules, are able to preserve a form of long-range molecular order within a mobile liquid. This liquid-crystalline or mesomorphic phase exists between two well-defined temperature limits, the melting point of the solid at the lower end, and the isotropic transition point at the upper end of the temperature scale. These temperature limits define the operating range of a display device. One or more of three fundamental structures may be exhibited in the liquid mesophase, the nematic, smectic or cholesteric (chiral-nematic) configurations. Figure 1 shows the three possible structures in diagrammatic form, together with typical compounds which exhibit these structures. The question of whether a material will take up a nematic or smectic arrangement is dependent on subtle differences in the polar nature and polarizability of the molecule, together with the lengths of the terminal chains of carbon atoms. For a cholesteric (chiral-nematic) structure, the molecule must contain an asymmetric carbon atom (marked with a * in the formula) and therefore does not necessarily have to be a derivative of cholesterol, as the name might suggest; the term 'chiral-nematic' is now considered to be more appropriate.

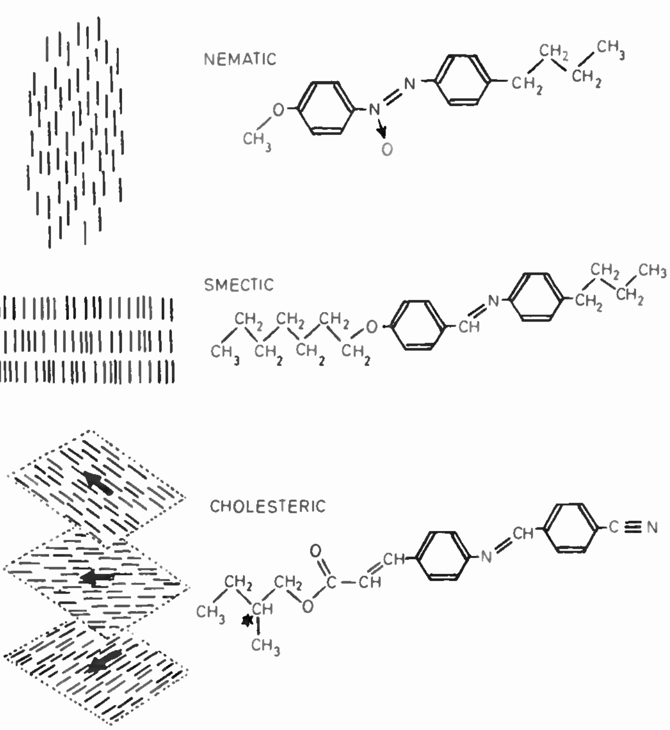


Fig. 1. Liquid crystal structures and chemical composition.

Because of their ordered structure, and polarizable nature, liquid crystals are anisotropic with respect to their dielectric constant, refractive index, electrical conductivity, magnetic susceptibility and viscosity. Thin films of liquid crystals may be held in uniform alignment by suitable treatment of the confining surfaces, in which case they behave similarly to a single birefringent crystal. The anisotropy of the dielectric constant allows the molecules to realign themselves in an electric field. Two types of molecules are possible, one in which the dielectric constant parallel to the molecules axis, $\varepsilon_{\parallel}$, is greater than that perpendicular to the axis $\varepsilon_{\perp}$, i.e. the dielectric anisotropy $\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp} > 0$, and the converse, with $\Delta\varepsilon < 0$. The realignment in electric fields and the anisotropic optical properties give rise to some striking effects which can be utilized in display devices.

While liquid crystals have been recognized since 1888, the first practical application was not suggested until 1936 in a Marconi patent[6] which described the use of nematic organic compounds as a light shutter to replace the Kerr cell. Because of various practical difficulties, this application was apparently not followed up, and further exploitation was not revealed until the work of RCA (dating from about 1963) was disclosed in Heilmeier's paper[7] in 1968. Since then, there has been considerable research and development activity directed towards constructing reliable display panels, determining the best addressing techniques, synthesizing organic molecules with the correct properties and evaluating new display techniques.

3.1 Dynamic Scattering

The earliest display technique, described by Heilmeier[7] is dynamic scattering, which requires a nematic liquid crystal material with a negative dielectric anisotropy. The application of an electric field to a thin film (10 to 20 μm) of the liquid crystal causes the molecules to align with their axes perpendicular to the field. In the presence of conducting ions, there is considerable interaction with the aligned molecules which oscillate in the disturbed field, and if sufficient current flows (a matter of a few microamperes per square centimetre), an electro-hydrodynamic turbulence is set up. Because of the anisotropic nature of the medium, the turbulent layer contains large numbers of refracting boundaries in violent motion, and this creates the appearance of frosted glass.

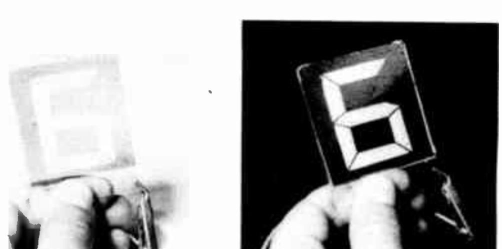


Fig. 2. Dynamic scattering display with dielectric mirror.

The liquid crystal layer scatters most of the incident light in the forward direction, so that for maximum brilliance, a mirror is required behind the device to return the scattered light to the observer. Alternatively, the display can be viewed by oblique back illumination. The threshold voltage V_T for dynamic scattering has been derived:

$$V_T = 2\pi \left(\frac{K_{33}\pi}{(K_1\varepsilon_{\parallel}/\eta_1)\left(\frac{\varepsilon_\perp}{\varepsilon_\parallel} - \frac{\sigma_\perp}{\sigma_\parallel}\right) + (\varepsilon_\parallel - \varepsilon_\perp)\frac{\sigma_\perp}{\sigma_\parallel}} \right)^{\frac{1}{2}} \quad (1)$$

where K_{33} = elastic constant for bend
K_1, η_1 = viscosity coefficients
$\varepsilon_\parallel$ = dielectric constant parallel to molecular axis
$\varepsilon_\perp$ = dielectric constant perpendicular to molecular axis
$\sigma_\parallel$ = conductance parallel to molecular axis
$\sigma_\perp$ = conductance perpendicular to molecular axis.

Experimental data confirm this relationship.[8] Ionic relaxation time must also be considered, when computing the threshold, and there is a frequency dependence given by:

$$V(t)^2 = \frac{V_T^2(1+f^2\tau^2)}{A^2-(1+f^2\tau^2)} \quad (2)$$

where f = frequency
τ = dielectric relaxation time = $\varepsilon/4\pi\sigma$
A^2 = dimensionless coefficient $\simeq$ 3 for some materials.

The cut-off frequency

$$f_c = (A^2-1)^{\frac{1}{2}}/\tau$$
$$\simeq \sqrt{2}.\frac{4\pi\sigma}{\varepsilon}$$

Most dynamic-scattering displays operate at 15 to 30 V r.m.s., 25–200 Hz, with a current density of about 3 μA/cm². Reflective displays use a metal or dielectric mirror, which usually forms part of the back electrode, while transmissive displays with a very good contrast ratio are obtainable using a back plate of black louvred plastic, to obtain optimum lighting conditions.

A typical reflective display using a dielectric mirror is shown in Fig. 2, which illustrates the good contrast obtainable against light and dark backgrounds. The large area clock display in Fig. 3 has an active area of 18 × 7 cm backed by a louvred plastic film and illuminated by a 4 W fluorescent tube.

While good contrast is usually obtainable from reflective dynamic scattering displays, difficulties may be sometimes encountered from specular reflections of bright light sources, unless special reflectors or masking arrangements are used (as in the Sharp pocket calculator). This effect is illustrated in Figs. 4 and 5. Figure 4 shows fixed message panels, the left-hand one with a dielectric mirror, and the right-hand with a non-specular reflector; under these conditions of illumination, the message is clearly visible on both devices. However, by rearranging the lighting with some strong directional illumination (Fig. 5), the contrast on the left-hand device is completely lost but still maintained in the other display.

Fig. 3. Large area digital clock display.

Dynamic scattering displays depend on conduction for their operation, and conductivity doping agents have to be added for this purpose. A number of studies of chemical and electrochemical reactions in liquid crystal mixtures have been made.[9–12] In practice, laboratory tests have indicated a life in excess of 30 000 hours, with a very low failure rate, and some suppliers are now claiming an expectation of life of at least 20 000 hours for their devices.

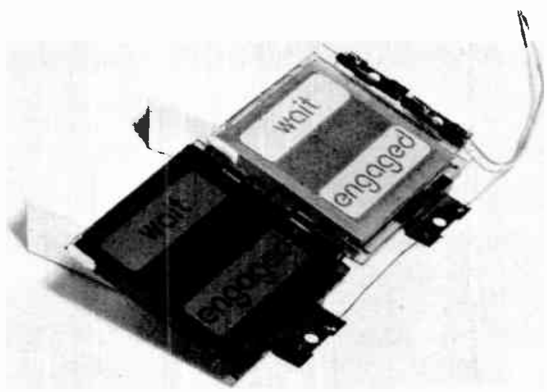


Fig. 4. Dynamic scattering message panels with dielectric mirror (left) and non-specular reflector (right).

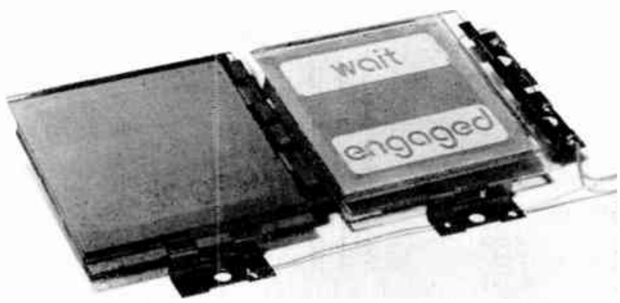


Fig. 5. Dynamic scattering message panels, under strong directional illumination.

3.2 Twisted-nematic Field-effect System

Liquid crystals with a positive dielectric anisotropy are required for the 'twisted-nematic' display, suggested by Schadt and Helfrich,[13] as the molecules are required to align their major axes in the direction of an applied electric field. The transparent conductive electrodes of the device are previously prepared so that the liquid crystal molecules align themselves unidirectionally in the plane of the electrodes. This is the uniform or unidirectional homogeneous orientation, and can be achieved by rubbing the surfaces vigorously in one direction with cotton wool or lens tissue before assembling the device; a more reliable technique has recently been described by Janning,[14–16] in which the surface is evaporated at an oblique angle with a thin layer of SiO. The display is assembled with the rubbed directions in orthogonal relationship, then filled with the positive nematic liquid crystal mixture. The device is viewed between polarizing filters. The arrangement is shown diagrammatically in Fig. 6(a), which illustrates the 90° molecular twist between the opposing electrodes. The twisted polar structure has the effect of rotating a plane polarized light wave through 90°, so that if crossed polarizers are used, the device transmits light, while with parallel polarizers, the transmission is blocked. When an electric field is applied, as in Fig. 6(b), the molecules take up the homeotropic orientation in the field, perpendicular to the electrodes (except for very thin layers immediately adjacent to the surfaces) and the 90° twist is thereby eliminated, so that the cell switches to the opposite state. Figure 7 shows a 4-numeric display of this type.

The twisted-nematic display has the following advantages:

(a) It operates at very low voltage and low power, i.e. down to 2 V and a fraction of a microwatt per digit. This is particularly useful in portable equipment, and for interfacing with integrated circuits.

(b) Because the device is basically field effect, with very small leakage currents and electrode potentials, the probability of electrochemical degradation is small and the life expectancy is high.

(c) The display does not suffer from specular reflections under unfavourable lighting conditions, as diffuse reflectors are always employed.

There are some disadvantages, mainly the restricted viewing angle (due to birefringence), which, however,

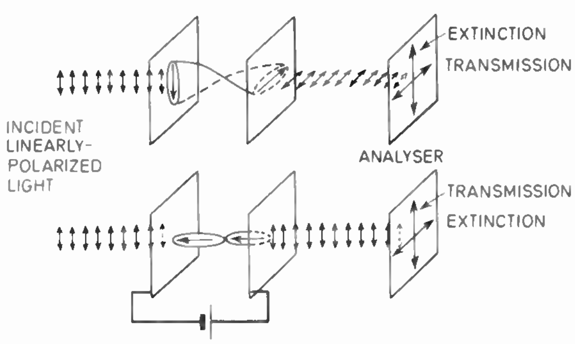


Fig. 6. Twisted-nematic display system.

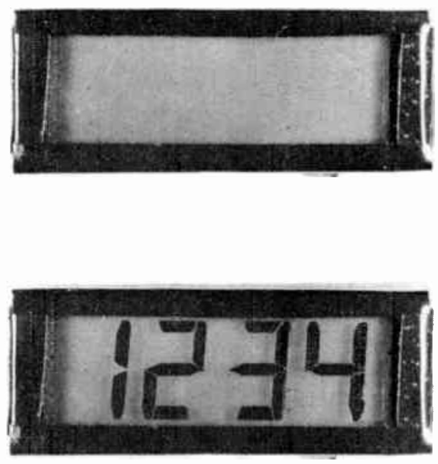


Fig. 7. Twisted-nematic 4-numeric display.

can be increased to about ±50° by raising the drive voltage to say, 5 or 6 V. In addition, the display is not quite so bright as a reflective dynamic scattering type, because of the transmission losses in the polarizers; new types of polarizing film and better reflectors are now improving the performance in this respect.

The synthesis of new organic compounds has greatly improved the low voltage performance of twisted nematic displays. Materials originally available, e.g. as used by Schadt and Helfrich,[13] tended to crystallize near to room temperature. Workers at Hoffmann–LaRoche have now produced room temperature mixtures[17] containing positive nematic compounds which have values of $\Delta\varepsilon$ in the range 18 to 25 and thresholds in the region of 1 V. Commercially available products of this type are listed in Table 1.

Table 1

Hoffmann-LaRoche No.	Mixture type	Nematic range, degC	$\Delta\varepsilon$	Threshold voltage	Resistivity ohm–cm
RO-TN-200	Schiff's base	−15° to 64°	18·3	1·1	$>10^{10}$
RO-TN-100	ester	6·5° to 47°	24·9	0·9	$>10^{10}$
RO-TN-101	ester	0° to 71°	17·7	1·05	$>10^{10}$

Of these, the ester mixtures have a high chemical stability, while the Schiff's bases require more careful handling to exclude moisture and oxygen.

A series of highly stable positive nematic compounds has been developed at Hull University,[18, 19] based on the biphenyls and terphenyls. Mixtures of this type are now available commercially from British Drug Houses, as listed in Table 2.

We can see that there is a good selection of positive nematic compounds, which will allow the realization of display devices with operating potentials down to about 1·5 V (for 90% switching). To minimize any electrolytic action, it is normal to operate with a.c. drive, as recommended also for dynamic scattering. For twisted nematic

Table 2

B.D.H. No.	Nematic range, degC	$\Delta\varepsilon$	Threshold voltage	Resistivity ohm–cm
E1	−2° to 38°			
E2	(−5°)to 45°			
E3	−2° to 54°	10 to 12	1·0	> 10^{10}
E4	4° to 60°			
E7	−10° to 59°			

displays, frequencies up to 2 kHz may be used. By applying a drive of 5 to 6 V, faster switching and a wider viewing angle are obtainable.

The low voltage and very low power requirement of the twisted-nematic display are essential for the operation of very compact devices such as the digital wrist-watch. The battery space available is very restricted and generally limited to one cell of about 1·5 V, which should supply the instrument for at least one year. The Sharp Corporation, which also markets liquid-crystal pocket calculators, has recently developed a special i.c. chip for the Orient Watch Co. to drive a twisted nematic display.[20] The single c.m.o.s. l.s.i. chip operates from two separate supply voltages; the battery voltage of 1·55 V is used to power the oscillator and divider portion, and a stepped-up voltage of 5·5 V is used to power the portion of the chip used for the display driver function. The square wave output of 512 Hz is used to drive a voltage multiplier composed by Schottky-barrier diodes to provide the voltage for the liquid crystal display. The power drain of the circuits operated at battery voltage is 4 μW, and the power drain of the circuits at the stepped-up voltage is 1 μW while the display itself takes 1 to 2 μW; one battery is expected to last for two years. This example illustrates the unique application of twisted nematic displays in digital watches, and it is probable that at the present time no other display mode offers such an effective saving of power consumption.

The threshold voltage for a twisted-nematic system to begin reorientation is given by:[13]

$$V^2 = \frac{4\pi}{\Delta\varepsilon}\left[K_{11}\left(\frac{\pi}{2}\right)^2 + (K_{33}-2K_{22})\varphi^2\right] \quad (3)$$

where K_{11} = elastic constant for splay
K_{22} = elastic constant for twist
K_{33} = elastic constant for bend
$\Delta\varepsilon$ = dielectric anisotropy
φ = twist angle (usually $\pi/2$).

The rise time τ_R and fall time τ_D are defined as:[21]

$$\tau_R = \eta\left[\varepsilon_0 \Delta\varepsilon E^2 - \frac{K\pi^2}{d^2}\right]^{-1} \quad (4)$$

$$\tau_D = \frac{\eta d^2}{K\pi^2} \quad (5)$$

where η = average viscosity
E = electric field strength
d = electrode spacing
$\Delta\varepsilon$ = dielectric anisotropy
$K = K_{11} + 1/4(K_{33}-2K_{22})$.

The response times of twisted-nematic displays (and also dynamic scattering displays, to which similar formulae apply) are relatively slow, i.e. about 30 ms turn-on and 200–500 ms turn-off, depending to some extent on the particular materials used. The response can be varied by selecting materials with a high anisotropy and low viscosity. The response speeds are adequate for many applications in watches, clocks and calculators, but faster response can now be obtained at the expense of greater complexity in the addressing circuits by the use of new positive nematic compounds, recently described.

The new materials exhibit dielectric constants which are frequency dependent,[22–24] i.e. as the frequency of the addressing voltage is increased, reversal of the dielectric anisotropy from positive to negative occurs at a cross-over frequency, which may be between 500 Hz and 50 kHz, depending on the temperature. This property enables a rapid switch-off to be attained, using a two-frequency addressing system, or by applying a high frequency turn-off signal immediately following the low-frequency addressing signal. Rise and fall times of the order of 5 ms are claimed.

In their experiments, Bücher *et al.*[23] used a mixture of 3-ring chloro-substituted benzoyl esters which provided a mixture with a room-temperature nematic range.

The decay time is given by

$$\tau_D = \eta\left[\frac{V_1^2}{4\pi d^2}(\varepsilon_\parallel-\varepsilon_\perp)_1 - \frac{V_2^2}{4\pi d^2}(\varepsilon_\perp-\varepsilon_\parallel)_2 - \frac{\pi^2 K}{d^2}\right]^{-1} \quad (6)$$

where V_1 and V_2 = voltages at frequencies f_1 and f_2
d = cell thickness
$(\varepsilon_\parallel-\varepsilon_\perp)_1$ and $(\varepsilon_\perp-\varepsilon_\parallel)_2$ = dielectric anisotropies at frequencies f_1 and f_2
K = effective elastic constant
η = effective viscosity.

An interesting variation on the twisted-nematic system enables a colour contrast display to be obtained. Greubel[25] and Scheffer[26] both suggested the use of pleochroic polarizing films to act as an optical retarding film and polarizer combined. The twisted nematic cell is sandwiched between a normal plane polarizer and pleochroic polarizing film, when highly coloured reflection or transmission is obtainable. When the cell is switched, the complementary colour is displayed. Kobayashi and Takeuchi[27] have recently demonstrated devices of this type. The arrangement can be adapted to give reflection displays using only a single pleochroic polarizer.

The characteristics of a typical display are shown in Table 3.

3.3 Colour Displays

A number of variations on the Fréedericksz effect[28] have been examined for producing tunable birefringent colours, e.g. the D.A.P. effect of Schiekel and Fahrenschon,[29] but these are generally difficult to con-

Table 3
Characteristics of liquid crystal twisted-nematic display

Typical operating voltage	2 to 6 V a.c.
Threshold	1 V
Rise time	30 to 100 ms
Decay time	200 to 500 ms
Power dissipation	0·1 to 0·5 μW/cm²
Life	over 25 000 hours
Typical temperature range (operating)	0° to 60°C

struct and control and have a very narrow viewing angle, so will not be discussed in any detail. Much easier control is obtainable by introducing a birefringent film into the twisted-nematic display, as described by Greubel[25] and Scheffer.[26] The birefringent layer is introduced between the twist cell and the analyser. In a birefringent medium, plane polarized light may travel at different velocities, depending on the orientation of the polarization plane with reference to the optical axis of the layer. The wave can be resolved into two components, one with its E vector along the optic axis and the other with its E vector orthogonal to it. Since these two waves have different velocities, they become out of phase by an amount which is dependent on the wavelength of the light. The phase difference or optical retardation δ is given by

$$\delta = \frac{2\pi}{\lambda}\Delta nt \qquad (7)$$

The birefringence

$$\Delta n = n_e - n_o$$

where $n_e = c/V_e$, $n_o = c/V_o$ = refractive indices of the extraordinary and ordinary rays respectively

c = velocity of light

t = thickness of the sheet.

The retardation causes the light emerging from the sheet to be elliptically polarized, to a degree depending on the wavelength, and when the light is analysed, using a linear polarizer, colours are observed. The transmission of unpolarized light in an assembly consisting of a birefringent sheet between two linear polarizers is given by

$$T = \tfrac{1}{2}\cos^2(\alpha-\beta) - \tfrac{1}{2}\sin 2\alpha . \sin 2\beta \sin^2 \delta/2 \qquad (8)$$

the angles α and β being defined in Fig. 8.

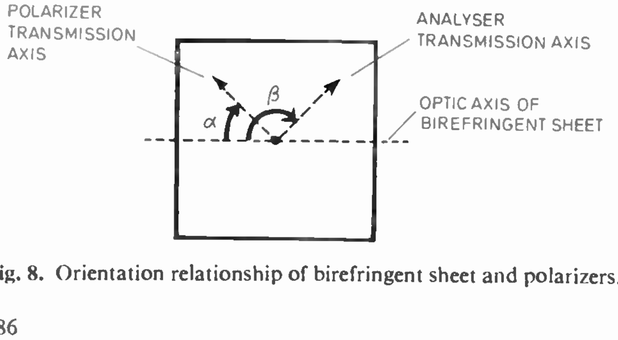


Fig. 8. Orientation relationship of birefringent sheet and polarizers.

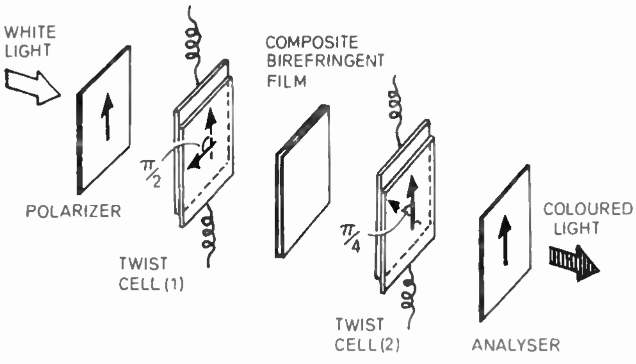


Fig. 9. Multi-colour system using composite birefringent sheet.

The colours are strongest when the plane of polarization of the incident light and the transmission axis of the analyser are both at $\pi/4$ radians to the optic axis of the birefringent sheet. Complementary colours are obtained in the orthogonal positions of the analyser, and the use of a switchable twisted-nematic cell enables the polarization of light entering or leaving the film to be rotated electrically. More than two colours can be switched by stacking cells and using films with different retardations,[26] or as demonstrated by Shanks,[30] cells of different twist angles (e.g. $\pi/2$ and $\pi/4$) can be used, together with a composite birefringent layer containing two or more birefringent sheets with non-parallel optic axes. The diagram of Fig. 9 shows the arrangement of the latter system.

A more complex colour light valve has been described by Sato and Wado[31] in which three narrow-band filters are cascaded, each composed of a suitable mixture of cholesteric and nematic liquid crystals to give blue, red and green transmission. The value of this system is that it is not very directionally sensitive, as circularly polarized light is used. A positive nematic cell is employed as an electrically controlled optical wave plate. As each colour filter requires its own voltage-controlled cell, the construction is complicated, and may not be commercially attractive.

3.4 Phase-change Guest-host System

The cholesteric liquid crystal structure can readily be converted by an electric field into a quasi-nematic homeotropic (perpendicular) structure.[32, 33] The structural change is complex, involving rotation of the helical structure, followed by distortion and unwinding of the helix. It is customary to use a mixture of about 5 to 10% of a cholesteric compound dissolved in a positive nematic for this application. The application of a small a.c. field produces a strongly scattering focal-conic structure, with a frosted appearance similar to that produced by dynamic scattering; the fundamental difference is that the scattering state is semi-permanent, and persists when the electric field is removed. When the field is increased to a suitable value, of the order of 2×10^4 V/cm, the liquid crystal is transformed to a clear homeotropic structure; the scattering state returns immediately the field is removed, or reduced below the threshold value. The merit of the phase-change mode is the switching speed, which can be of the order of a few milliseconds for voltages appreciably in excess of the threshold.

The critical field for the cholesteric-nematic phase transition is[34]

$$E_T = \frac{\pi^2}{2P_0}\left(\frac{K_{22}}{\Delta\varepsilon}\right)^{\frac{1}{2}} \quad (9)$$

where K_{22} = twist elastic constant

P_0 = zero field pitch

$\Delta\varepsilon$ = dielectric anisotropy.

A plot of the normalized helix pitch P/P_0 against a normalized applied voltage V/S_T shows a very well defined threshold level.

The original guest-host colour-contrast display, described by Heilmeier[35] used a pleochroic dye dissolved in a positive nematic liquid crystal. The dyestuff, which should have a strongly anisotropic optical absorption, was orientated by interaction with the liquid crystal molecules and so assumed a perpendicular alignment with the positive liquid crystal molecules when an electric field was applied. The absorbance of the dye is at a maximum when the electric field vector is parallel to the axis of the molecule. Polarizers were employed to determine the orientation of the electric vector. Thus, by arranging the initial molecular orientation to be parallel to the electrodes, changing to perpendicular on applying a field, the optical absorption was switched between maximum and minimum. The original technique and materials used did not give adequate contrast for most commercial applications and a new variation, based on the phase-change effect has recently been described by White and Taylor.[36] The new system utilizes unpolarized light, and the cholesteric structure (produced by the addition of 5 to 15% of cholesteric material to a positive nematic liquid), enables the dye molecules to absorb all polarizations of light in the relaxed state.

Dyes with a very high optical order parameter are required; the parallelism of the dye molecules to the optic axis of the system is conveniently described by an order parameter S, defined by

$$S = \tfrac{1}{2}(3\cos^2\theta - 1) \quad (10)$$

where θ is the angular deviation from the optic axis.

The light transmissions $T_{\parallel}$ polarized parallel, and $T_{\perp}$ polarized perpendicular to the optic axis are given by

$$T_{\parallel} = \exp\left[-(2S+1)\alpha_0 d\right] \quad \text{or} \quad \alpha_{\parallel} = (2S+1)\alpha_0 \quad (11)$$

$$T_{\perp} = \exp\left[-(1-S)\alpha_0 d\right] \quad \text{or} \quad \alpha_{\perp} = (1-S)\alpha_0 \quad (12)$$

where α_0 = attenuation constant in an isotropic host

d = thickness of layer.

Thus, when

$$S = 1, \quad T_{\perp} = 1 \quad \text{and} \quad T_{\parallel} = \exp(-3\alpha_0 d)$$

and when

$$S = 0, \quad T_{\perp} = T_{\parallel} = \exp(-\alpha_0 d)$$

By measuring $T_{\perp}$ and $T_{\parallel}$ for a specific liquid-crystal-dye system, the order parameter S can be calculated as follows:

$$S = \frac{\log T_{\parallel} - \log T_{\perp}}{2\log T_{\perp} + \log T_{\parallel}} \quad (13)$$

A number of special dyestuffs with values of S in the region of 0·71 to 0·73 were investigated and those with transmission bands in the blue region were found to provide the best contrast.

For working with unpolarized light, both the normal modes of propagation of light should have a component of the electric field parallel to the director of the liquid crystal. This is attainable in the cholesteric structure, in which the normal modes of propagation parallel to the helical axis are elliptically polarized. If the cell thickness is d, the transmission of unpolarized light is

$$T = \tfrac{1}{2}[\exp(-\alpha_1 d) + \exp(-\alpha_2 d)] \quad (14)$$

where α_1 and α_2 = attenuation constants for the two normal modes.

In a reflective cell, in which the mirror reflects all the light and does not depolarize it, the reflectivity is calculated by replacing d by $2d$ in equation (14). The highest contrast ratio is obtainable with circularly polarized light, although this is not readily attainable because of the high birefringence of the liquid crystal materials.

The cholesteric phase-change mixture relaxes to a scattering state when the switching voltage is removed and under these conditions the transmission of the system approximates to that of an isotropic medium:

$$T_{iso} = \exp(-\alpha_0 d) \quad (15)$$

and the contrast ratio is given by

$$R = \exp(2S\alpha_0 d) \quad (17)$$

Although conditions in practical displays are not ideal, it is found that displays which are somewhat brighter than the twisted-nematic type are obtainable, because there are no transmission losses in polarizers. By utilizing positive nematics with low threshold voltages (as previously described) and adjusting the cholesteric pitch to about 3 µm, it has been found possible in a 12 µm cell to operate in the region of 12 to 18 V, making the system competitive with twisted-nematic displays.

The advantages of the guest-host-phase-change system are therefore:

(a) Bright display and good colour contrast.

(b) Low operating potential and power consumption, compatible with c.m.o.s. driving circuits.

(c) Fast switching speed.

(d) Low cost, by elimination of polarizers, i.e. comparable with dynamic scattering displays.

3.5 Large-screen Multi-digit Displays

Recently, developments in thermally-addressed liquid panels have offered the possibility of constructing data terminals carrying large amounts of alpha-numeric data. In the past, considerable difficulties have been encountered in addressing multi-digit liquid crystal displays. For addressing a display containing more than four digits, with each segment individually connected, the arrangement is cumbersome with respect to the number of connecting leads and wasteful with respect to the number of addressing circuits. Because liquid crystal displays themselves consume very little energy, considerable power economy is possible by reducing the addressing circuits by using multiplexing or matrix addressing. While many addressing techniques have been explored, the inherent slow response of the liquid crystal system has made it difficult to scan more than about 30 to 40 lines. Complex solutions to this problem have been investigated, for example that of Brody *et al.*[37] who used a matrix of thin film transistors, about 14 000 in all, in a thin film circuit, in direct contact with a twisted-nematic liquid crystal structure. Devices of this type can no doubt be produced on a production basis, but there must inevitably be low yield problems, leading to high unit cost.

The solution adopted by the Bell Laboratories was to use external scanning of a simple liquid crystal panel by means of a laser beam.[38, 39] Thus, a high density of recorded data is possible, without the complexity of direct electronic addressing and the prohibitive number of access leads, or a complex substructure of switching elements. The thin film of liquid crystal is enclosed between two plates, provided with a transparent conducting surface, in the usual way. The liquid crystal cell is addressed by means of a scanned laser beam. Systems using both cholesteric mixtures[38] and smectic mixtures[39] have been investigated. The electrode surfaces are treated with surface active agents, so that the film is initially transparent, but when scanned by a laser beam at about 1 μm wavelength with a power of a few milliwatts, an opaque, light-scattering state is created by the localized heating, followed by rapid cooling. The rapid thermal cycling of both cholesteric and smectic liquid crystals produces an optically scattering focal-conic texture. The cholesteric scattering pattern can be bulk erased by applying an audio frequency field across the electrodes. The smectic pattern can be erased selectively by scanning slowly with the laser beam, and at the same time applying an electric field of about 35 V at 1·5 kHz across the electrodes.

The display itself can be relatively small, with a large screen presentation obtainable using a simple projection system. The arrangement is shown in Fig. 10, and the system has been described in detail in *Bell Laboratories Record*.[40] High resolution of 50 line-pairs per millimetre and 4000 lines per field can be achieved. The present experimental system is somewhat bulky with respect to the laser, deflection and modulation assemblies. The beam is deflected by a galvanometer mirror, with writing carried out by an acousto-optic deflector and intensity controlled by an acousto-optic modulator. It is likely that the modulation and deflection elements will eventually be reduced in size with the development of new electro-optic devices, and gallium arsenide injection lasers now under development could be used for the infra-red source, so that the system should in due course become much more compact.

4 Electrophoretic Displays

The electrophoretic display is in some respects similar to liquid crystal displays in that it is filled with a thin film of an organic liquid, although the principles of operation are quite different. The display is thus another member of a class of 'liquid-state' devices.

The process of electrophoresis has been employed for a long time in the vacuum tube industry for the deposition of insulating coatings on heaters, emissive coatings on cathodes and phosphor coatings on glass screens. It was generally considered that such a process would be too slow for application to the display field. However, I. Ota has now described electrophoretic display devices of reasonable speed, using various coloured pigments.[41]

Basically, the device consists of a coloured pigment, suspended in a film of liquid containing a contrasting, coloured dyestuff. When a potential is applied to a transparent conducting electrode, forming one face of the display, the pigment is attracted by the electric charge and produces a coloured pattern determined by the electrode shape. The portions of the display which are not operative, together with the background area, are given an opposite potential which repels the coloured pigment, so that only the contrasting colour of the dyestuff is visible. When the potentials are removed, the pigment remains on the electrodes by electrostatic attraction, so providing a memory.

A schematic illustration of the electrophoretic cell in cross-section is given in Fig. 11. The origin of the charge on the particles has not been conclusively established. In aqueous systems, a potential, the zeta potential, is formed between a dispersed solid phase and the dispersion liquid, and there appears to be no method as yet for predicting the magnitude and polarity of the charge which may be developed in a specific system. In the case of non-aqueous systems, with which we are dealing here, the mechanism of potential generation is even more uncertain and speculative.[42] The zeta potential is involved in the migration of dispersed colloidal particles in an electric field, and even if similar conditions were applicable to organic dispersions, these are not necessarily appropriate to the present case where the

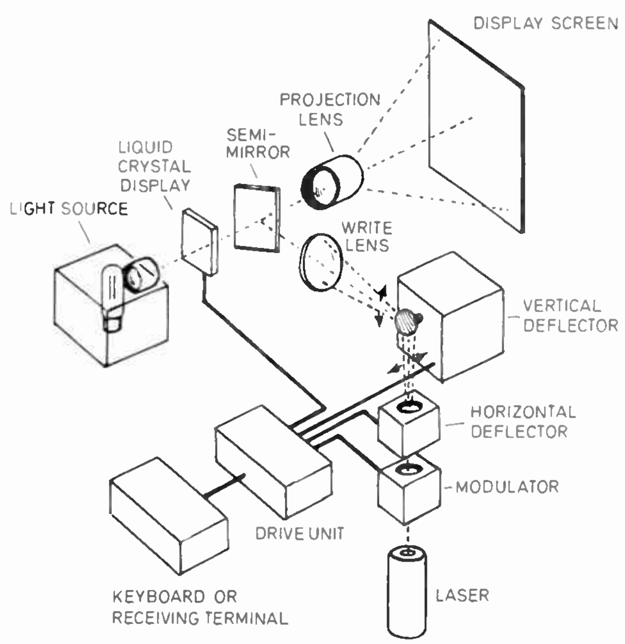


Fig. 10. Thermally addressed data display system.

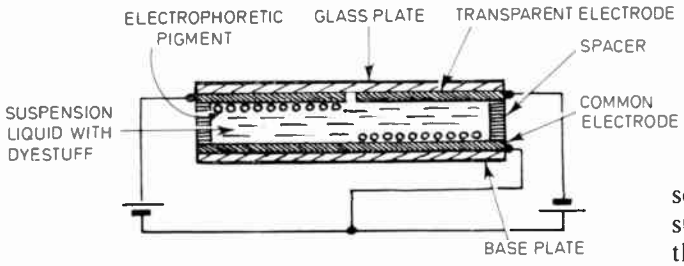


Fig. 11. Cross-section of electrophoretic display cell.

particle size is much larger (values of 0·5 to 3 μm have been quoted by Ota[41]). It has been found that some organic pigments exhibit electrophoretic migration while others of the same particle size appear to have little or no charge, and it is probable that the structure of the organic pigment molecule determines its ability to take on a charge of a specific polarity, rather than the generation of a classical zeta potential.

The components of an electrophoretic system are: the pigment, the suspension medium (liquid), the dyestuff, and surface active agents.

The pigment should be optically dense and highly coloured, or white, and its density should match that of the suspending liquid, so that no settling takes place. The pigment particles must be appreciably smaller than the gap between the electrodes and should have a relatively high mobility in the medium when charged.

The suspension medium must be a good insulator, chemically inert and of suitable density to match the pigment.

The dyestuff should be highly soluble in the medium and provide an intensely coloured contrast to the pigment.

Surface active agents are useful in improving the dispersion and controlling the charging of the pigment particles.

The switching speed of this type of display is dependent on the electrophoretic mobility μ, which is given to the first approximation by

$$\mu = \frac{\varepsilon\zeta}{K\pi\eta} \qquad (18)$$

where ε = dielectric constant of the liquid

ζ = zeta potential

K = numeric constant

η = viscosity.

Thus for a fast switching speed at low voltage, the ratio ε/η should be as large as possible. In practical systems, at operating voltages of 15–20 V d.c., the switching speeds are in the region of 50 to 500 ms. Ota has recorded response times down to about 15 ms but at an applied potential of 100 V. In general there is no defined threshold, and operation down to a few volts is feasible, at a slower switching rate.

Two preparations have been quoted for electrophoretic devices:[41] (i) containing the pigment TiO_2, coated with polyethylene, suspended in mixture of solvents, mainly tetrafluorodibromoethane with a dissolved black dyestuff, and (ii) the pigment Hansa yellow, suspended in a similar mixture. The object of coating the titanium dioxide particles with polythene is to reduce the effective density of the suspended particles and improve the electrophoretic properties. The particle volume concentration in each case is given as 2·5% with a dye concentration of 1·5%. The current density quoted is 2 μA/cm² for the TiO_2 suspension and 0·16 μA/cm² for the Hansa yellow, both with 100 V applied across a 100 μm layer. These current densities are appreciably lower than for dynamic scattering liquid crystal displays, and similar to those for the field-effect devices.

The response curve of a typical panel is shown in Fig. 12, and the contrast ratios for different layer thicknesses at different operating voltages are given in Fig. 13. Experimental digital clocks have been made showing a contrast ratio of 40 : 1 with 75 V pulse operation. The memory function of the display simplifies the driving circuits and reduces the power consumption, as addressing voltages need only be applied for short periods, as required, and refresh scanning need only take place every few minutes. The short addressing periods reduce the rate of any possible electrochemical decomposition reactions within the cell.

No conclusive information is yet available on the origin of the memory effect, and it is not clear whether this is simply due to Van der Waals attractions or whether semi-permanent space-charge layers are involved. No figures are yet available for long-term life-tests, the life of experimental panels being quoted as about 3000 hours so far, the failure process involving a non-uniform appearance in reflection and colour (granulation). When these stability problems have been further studied, there appears to be no reason why the life expectation should not exceed 20 000 hours.

An experimental Marconi 7-segment display, approximately 75 mm × 50 mm is shown in Fig. 14. This

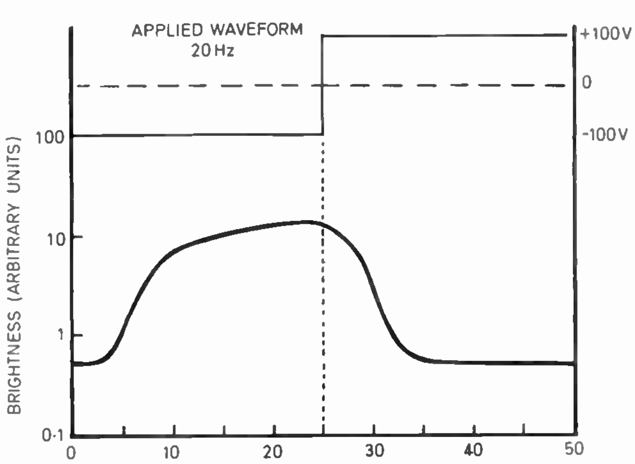


Fig. 12. Response speed of electrophoretic display.

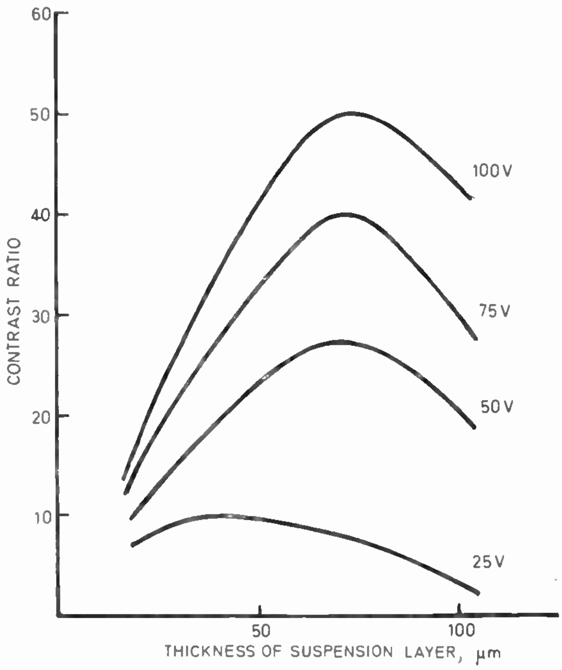


Fig. 13. Contrast ratio of electrophoretic device as a function of thickness.

device is operating at 20 V d.c., and shows yellow characters against a dark green background. Another interesting display is a simple 3-terminal analogue or tape-scale device, illustrated in Fig. 15; here the colour is orange against a black background. The electrophoretic display, because of its polarity sensitivity and its lack of threshold, is one of the few systems capable of producing a 3-terminal tape scale, driven from a simple potentiometer circuit; there are many applications of this system to fuel gauges, pressure gauges and temperature indicators. Table 4 shows some typical display characteristics, which may vary considerably with the voltages and materials used.

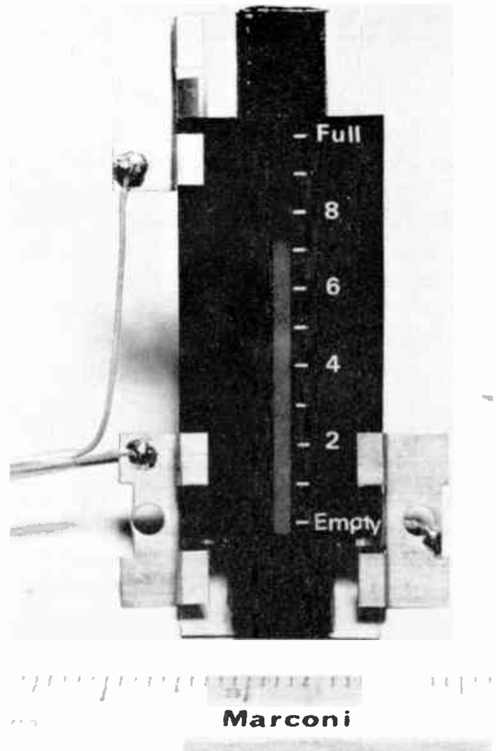


Fig. 15. Electrophoretic analogue display (tape scale).

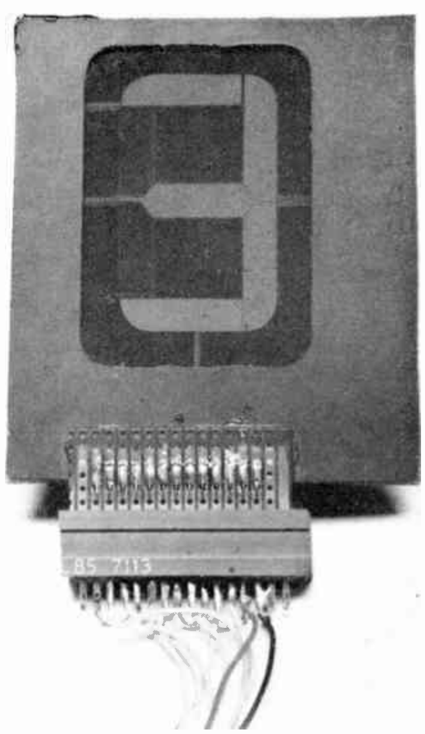


Fig. 14. Electrophoretic 7-segment display.

Table 4

Characteristics of electrophoretic display

Typical operating voltage	±30 V (down to 2 V at reduced speed)
Threshold	<1 V
Rise time	50 to 500 ms
Decay time	50 to 500 ms
Power dissipation	5 to 50 μW/cm²
Storage time	several days
Life	3000 hr/1 Hz
Temperature range (operating)	−20° to +60°C or wider

As reported by Dalisa and Delano[43] the electrophoretic display maintains a high contrast ratio over a very wide viewing angle, similar to that of the printed page.

The advantages of the electrophoretic display can be summarized as follows:

(1) High contrast in very bright ambient lighting, without difficulties due to mirror reflections, or directional effects due to polarizers.

(2) Tape-scale (analogue) capability.

(3) Wide temperature range. Depending on the characteristics of the suspension medium, oper-

ating ranges, without degradation of switching speed, of about $-20°$ to $+100°C$ are quite feasible.

Points against the electrophoretic display are the somewhat slower switching speeds at room temperature, the requirement for higher drive voltages (although no higher than for dynamic scattering displays) and the lack of long-term life-test data.

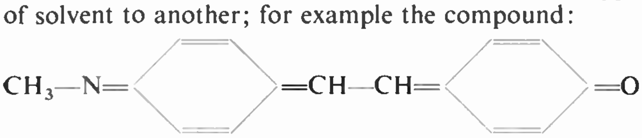
5 Electrochromic Displays

Electrochromism, in organic materials at least, seems to have first been suggested by Platt in 1961[44] for certain types of dyestuff prepared by Brooker and co-workers. He concluded that it should be possible to obtain electrochromic shifts in the merocyanine dyes, which can exist in two resonance forms of general structure

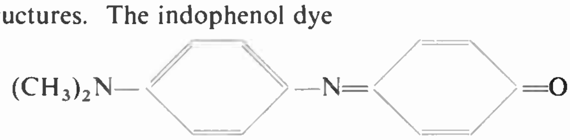
(i) O=CH—CH=CH— - - - - - —CH—CH—NH_2

(ii) $^{\ominus}$O—CH=CH—CH= - - - - - =CH—CH=$NH_2^{\oplus}$

Colour shifts were observed in changing from one type of solvent to another; for example the compound:



had an absorption peak of 600 nm in pyridine, but 445 nm when dissolved in water. This corresponded to an energy change of about 1·5 eV between the two structures. The indophenol dye



also showed large colour shifts.

Platt suggested that an electrochromic effect should be observed by changing the relative energies of the two resonance structures by means of an applied electric field to achieve the same result as obtained in different solvents. The field required would be about 1·5 V per molecular length, or about 10^7 V/cm for an aligned molecular system, to achieve a complete colour shift. Some colour change would be expected at much lower fields, but even so, the potential on a 10 μm thick cell would be of the order of several thousand volts. The expected switching speeds were better than 10^{-9} s.

Since Platt's paper, little has been heard of electrochromism in organic dyes, probably because of the impractically high potentials required, but electrochromism in solid materials has been studied by Deb,[45] based on his previous work on the optical and photoelectric properties of metal oxides and the formation of colour centres.[46, 47] Thin films of the oxides of molybdenum and tungsten, MoO_3 and WO_3 form colour centres when exposed to ultra-violet radiation in the region of the fundamental absorption edge. The same type of colour centres can be produced by applying a d.c. electric field of about 10^4 V/cm across the film at room temperature. By observing the effect in transverse structures with evaporated gold electrodes, the coloration could be seen to form first at the cathode and spread across to the anode. On reversing the potential, the colour centre cloud was observed to migrate back to the new anode, being bleached at the same time; continued application of the potential generated more colour centres, commencing at the new cathode. The formation of colour centres appears to be a function of many parameters, including electrode materials, impurities and ambient conditions.

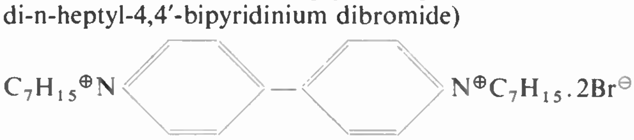
Deb prepared sandwich structures by evaporation of about 1 μm of WO_3 onto tin-oxide coated glass, followed by evaporation of a thin transparent gold film. Using gold as the cathode and applying 2 V across the film, the oxide layer developed a deep blue coloration in a few seconds. Measurements suggest that the development of colour in this system is accompanied by the formation of a non-linear I–V characteristic, similar to that of a diode, with coloration occurring in the reversed bias condition.

Later work by Faughnan *et al.*[48] has confirmed these observations.

At present, devices of this type are somewhat slow in operation and there are some difficulties involved in the erase operation. However, further research is likely to improve the performance, as many other variations of metal oxides and electrode materials are possible. If the process involved is indeed purely electronic, the possibility exists for very fast switching.

The attractive feature of the metal-oxide electrochromic system is that it is truly solid-state, and therefore could be made very robust; it might also offer the possibility of operation to military specifications in the temperature range $-40°$ to $+70°C$, without difficulties arising from viscosity, freezing or leakage.

Recently, another so-called 'electrochromic' display has been described by Schoot *et al.*,[49] which is in fact an electrochemical redox system, and has little similarity to the electrochromism discussed by Platt.[44] The basis of the display is a reduction/oxidation reaction, in which a product is formed which has a strong light absorption. The organic compounds used are the viologens, 4-4′-dipyridinium derivatives. The specific compound used for the display was the diheptyl viologen bromide (N-N′-di-n-heptyl-4,4′-bipyridinium dibromide)



The compound is reduced at the cathode of an electrolytic cell in a one-electron step to a stable purple-blue radical ion. The redox potential $E_0 = -0{\cdot}66$ V vs SCE (saturated calomel electrode). The complete reduction is a two-stage process, the cation (A^{2+}) undergoing the following reaction:

$$A^{2+} \underset{-0\cdot45\ \mathrm{V}}{\overset{e}{\rightleftharpoons}} \dot{A}^{+} \underset{-0\cdot66\ \mathrm{V}}{\rightleftharpoons} A$$

A radical $\dot{A}^{+}$ is deep blue, while the final product A is brown. The later compound reacts immediately with the original ions, $A^{2+}+A \rightarrow 2\dot{A}^{+}$, so that the reduction product is normally only the blue compound $\dot{A}^{+}$. The blue compound with the anion Br^- gives an insoluble purple compound $\dot{A}^{+}Br^{-}$, which adheres to the cathode surface, providing a memory effect. The coloured layer

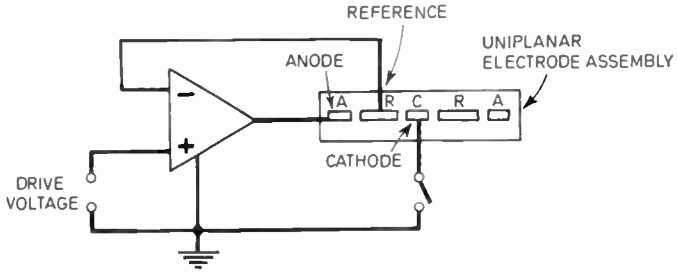


Fig. 16. Drive circuit for electrochromic cell.

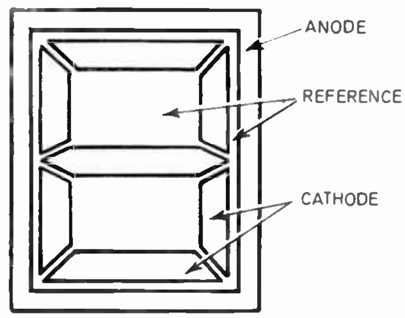


Fig. 17. Planar electrode configuration in electrochromic 7-segment display.

is a poor conductor and builds up uniformly, due to self-healing. The display can be readily erased, as the reaction is reversible, and electron transfer is easy because of the intimate contact between the coloured layer and the cathode.

The absorption band of the diheptylviologen bromide $\dot{A}^{+}Br^{-}$ is broad with a maximum at 545 nm, and the absorption coefficient of the dye is high.

Seven-segment displays have been constructed, the segments forming the cathode, with a common anode and a reference electrode. The reference electrode is used to detect the presence of the coloured layer by measuring the potential difference between the reference electrode and the cathode. The basic drive circuit is shown in Fig. 16, and the arrangement of electrodes, all in one plane, for the 7-segment indicator is illustrated in Fig. 17. The cell is constructed of two glass plates in a similar manner to liquid crystal cells, but the spacing between the plates is normally much wider, at about 2 mm. The liquid filling is an aqueous solution of 0·1 M diheptylviologen bromide with 0·3 M KBr to increase the conductivity. The cell must be hermetically sealed to exclude oxygen, which destroys the memory effect. Operating potentials are very low, as indicated in Fig. 18 in which writing voltage is plotted against writing time for different values of reflectance. There is a sharp threshold at about 0·2 V, which can be useful for matrix addressing.

A reflectance of about 20% can be obtained with a charge density of 2 mC/cm², implying an efficiency of about 100%; the contrast is then about 5 : 1. By transferring more charge a contrast ratio of up to 20 : 1 can be obtained. The erase speed is 10–50 ms, depending on the electrode material and the ohmic resistance of the cell. For the one write–erase cycle the energy consumption is about 4 mJ/cm² or 1 mJ for a digit of size 10 × 5 mm with 7 segments, each of 1 mm width. During the memory period, no power is consumed and if a storage time of 1 min is assumed, the average power consumption works out at about 70 μW/cm². Table 5 gives some typical characteristics.

The advantages of this type of display are the high contrast, without use of mirrors or polarizers, low voltage operation and memory capability. Disadvantages are the possible electrochemical decomposition reactions in d.c. driven electrolyte and variations in storage and switching speed with temperature. So far, over 10^5 write–erase cycles have been recorded without failure.

Table 5

Characteristics of 'electrochromic' redox display

Typical operating voltage	±1·5 V
Threshold	0·2 V
Write time	10 to 100 ms (reflectance 20%)
Erase time	10 to 50 ms
Power dissipation	70 μW/cm²
Storage time	over 1 month
Life	over 10^5 write–erase cycles

Some difficulties have been observed in the simple system during the erase cycle, as due to the high impedance of the coloured layer, current may be increasingly concentrated in regions from which the plating is first removed and a layer starts to build up on the opposite electrode before the original cathode layer is removed. Special additives can be used to release an oxidizing ion to assist in clearing the deposit on the cathode; unfortunately, this also reduces the duration of the memory effect.

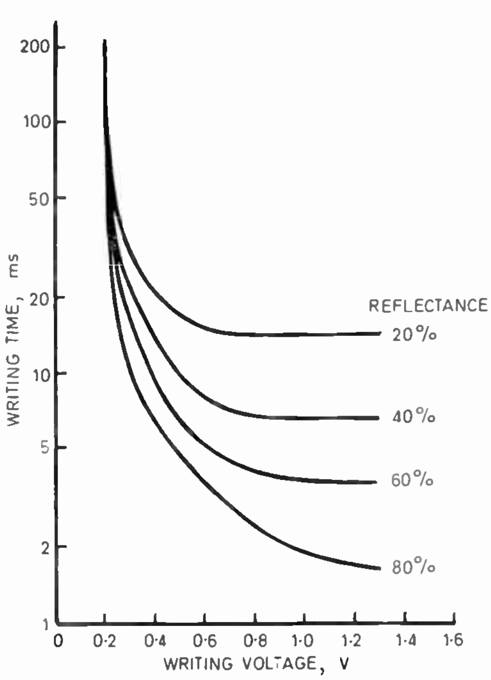


Fig. 18. Writing time of electrochromic device as a function of drive voltage.

6 Other Display Systems

Two other new display systems deserve mention, but are probably not sufficiently developed to offer practical competition with the displays previously discussed. These are the electrochemiluminescent[50–52] and the electro-fluorescent systems.[53] The electrochemiluminescent system uses the light emission of excited organic molecules in an electrolyte medium; it is theoretically capable of a high efficiency of up to 26%. The electro-fluorescent system uses the fluorescence of rare-earth organic complexes in ultra-violet light, which can be quenched by the application of low d.c. potentials; the rare-earth compounds are dissolved in a solvent/electrolyte medium, and the response allows the fast scanning of a 1100 × 1100 matrix to be attempted. For further information on these systems, the references given should be consulted. These devices are still in the research stage and it is known that the electrochemiluminescent devices are being studied by Battelle Research Centre in Geneva and by Bell-Northern Research in Ottawa; the electro-fluorescent system is being studied by Eastman Kodak Research Laboratories. Thus, we might expect practical developments of these devices in the near future. Both are low voltage, but relative high current systems, as they depend on supporting electrolyte solutions for their operation. They might therefore suffer from lifetime problems at this stage.

7 Discussion

It is still difficult to predict at this stage, from the mass of data available, which display modes are likely to be of major commercial importance. However, there are a number of characteristics which stand out and point to specific applications in the areas indicated at the beginning of this paper.

For simple on/off indicators, annunciator panels and mimic diagrams, the coloured electrophoretic display gives a striking indication over a very wide viewing angle and requires no mirrors or polarizers. Because of the memory capability, only intermittent addressing or refreshing is required. Fast switching (less than 500 ms) is not usually necessary in these applications. For outdoor applications the ultimate operating temperature range, probably wider than −20° to +70°C, is a great advantage.

For small digital displays, many users are now leaning towards the twisted-nematic liquid crystal mode, because of its very low voltage–low power capabilities, particularly for portable equipment. Improvements in polarizers and reflectors are now contributing towards a brighter display, although some viewing angle restriction remains. For digital watches, with very restricted battery space, this is possibly the only type of display at present suitable. The guest-host phase-change system would offer a better viewing angle if the operating voltage could be reduced further.

Where larger area displays are required, as in clocks, tote boards, or mimic diagrams, and higher voltage supplies can be provided, the choice is less clear. Back-illuminated dynamic scattering, guest-host phase-change, or electrophoretic displays will all give a good performance. One would tend to avoid the twisted-nematic display because of difficulties in maintaining the optical uniformity over very large areas, and the cost of polarizing sheet.

Only one system discussed here is capable of providing a satisfactory 3-terminal analogue or tape-scale display, and that is the electrophoretic device.

Radar and matrix displays present considerable scanning problems with all the systems, and while such displays have been constructed using the dynamic scattering, twisted nematic and simple phase change modes, these usually have a low brightness and contrast because of the low duty cycle. To facilitate a faster scanning rate, it is likely that the guest-host phase-change mode may prove more effective, as the response speed is of the order of a few milliseconds, and there is a sharply defined threshold voltage.

Fast operating shutters are also served best by the guest-host phase-change mode; twisted-nematic devices, even using switched anisotropy for rapid turn-off, do not achieve quite the same speed.

For data terminals presenting large numbers of alphanumeric characters, matrix addressing, even with individual thin-film transistor switches, appears too cumbersome, and the laser-scanned panel is probably the only system having commercial possibilities.

Most displays incorporating variable colour appear to be too complex or require further development before becoming commercially acceptable. However, the simple colour-contrast display based on dichroic polarizers is simple to construct and can be used in all applications where the twisted-nematic display is acceptable.

Table 6 summarizes the conclusions on new display applications. Where a double star is shown, the display mode is considered very suitable for the application; a single star indicates that the display mode could prove satisfactory with some further development. In general, the tendency has been to avoid displays containing electrolytes or passing appreciable currents, because of life considerations, and to avoid if possible high voltages (30 V or over).

8 Acknowledgment

The author wishes to thank the Technical Director, GEC-Marconi Electronics Ltd. for permission to publish this paper.

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Table 6
Display applications

Application ↓ / Display mode →	L.C. dynamic scattering	L.C. twisted-nematic	L.C. twisted-nematic (dichroic polarizer)	L.C. phase-change guest-host	L.C. laser addressed	Electrophoretic	Electrochromic (solid state)	Electrochromic (liquid) (redox)
On–off indicators						★★	★	★
Annunciator panels				★★		★★		
Single/multi-digit strip displays for multimeters and calculators	★★	★★		★			★	★
Digital watch displays		★★		★		★	★	★
Analogue (tape-scale) displays						★★		
Large area clocks and tote boards	★★			★★		★★		
Large area mimic diagrams	★★					★★		
Radar displays				★				
Matrix displays				★				
Colour contrast displays			★★	★		★		
Data terminals					★			
Fast shutters				★★				
Special military applications						★	★	

★★ : already very suitable ★ : further development needed

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Manuscript first received by the Institution on 1st July 1975 and in final form on 13th October 1975. (Paper No. 1721/CC259.)

UDC 621.382.23:621.375.4.029.64:621.3.018.12

Microwave amplification and phase shifting with impatt diodes

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SUMMARY

The gain-phase responses of X band amplifying impatt diode phase shifters have been experimentally investigated. The design procedure is described for a gallium arsenide diode for which 180° phase shifts were obtained with gains of 7·5 dB. The power handling capability of the phase shifter is limited by the incidence of parametric oscillation due to the non-linear inductance associated with the avalanching mechanism. Signalling speeds of 20 Mb/s were shown to have no deleterious effects and speeds of 4 or 5 Gb/s are theoretically possible.

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1 Introduction

Solid-state microwave systems operating at frequencies above 5 GHz commonly use impatt diodes, either as oscillators, or amplifiers. In phase-coded communication and radar systems, and in phased array radars, the phase shifters that are at present used have a loss and these losses increase with increasing frequencies. Impatt diodes, which can be used at frequencies into the millimetre wave band, can be used as phase shifters that provide gain instead of loss[1] and if, as in portable, miniature equipments, the power supply requirements are important, the use of impatt diodes enables a common power supply to be used for the oscillator, phase shifter and amplifiers. The design and characteristics of impatt diode phase shifters are considered in this paper.

2 Impatt Diode Phase Shifters

There are now a considerable number of analyses of the small and large signal admittances of the impatt type of diodes. These analyses[2] show that near the avalanche frequency the admittance changes rapidly with d.c. bias current, and at a constant frequency and r.f. input power the bias current can be switched between two values such that the diode's negative conductance has the same value but the susceptance values change. Figure 1 shows the calculated small signal admittance of a p^+nn^+ gallium arsenide impatt diode chip which has a punch-through factor of 1 and a breakdown voltage of 40 V. The parameters are frequency and bias current, and the avalanche frequency was 7·98 GHz. The admittance was calculated using the simple theory of Gilden and Hines.[3] It can be seen that, if, for example, the input signal frequency is 11 GHz, switching the diode bias current from 15 to 67 mA changes the susceptance from 210 to 40 S/cm^2, but does not change the value of the conductance. This property of the diode is exploited in the design of phase shifters which, because of the negative resistance, also amplify the input signal. Phase shifting is best done with a reflection amplifier configuration, so that if a transmission line of characteristic impedance Z_0 is terminated in an impedance $R+jX$ a signal experiences a phase shift

$$\phi = \tan^{-1}[X/(R-Z_0)]-\tan^{-1}[X/(R+Z_0)]$$

and the power gain is

$$[(R-Z_0)^2+X^2]/[(R+Z_0)^2+X^2]$$

where R is a negative quantity.

3 Design of Reflection Phase Shifters

The design of an impatt diode reflection phase shifter involves the selection of two suitable diode impedance points (corresponding to two bias points) to which the diode could be switched, and a suitable matching network to give the required power gain and phase shift. The choice of diode impedance values and matching network are inter-related so that there is no unique criterion for design. A linear programming approach was thus used, in which the centre frequency, gain and phase shift were specified, a typical matching network with nominal parameter values was assumed and, by an impedance transformation, the two required diode

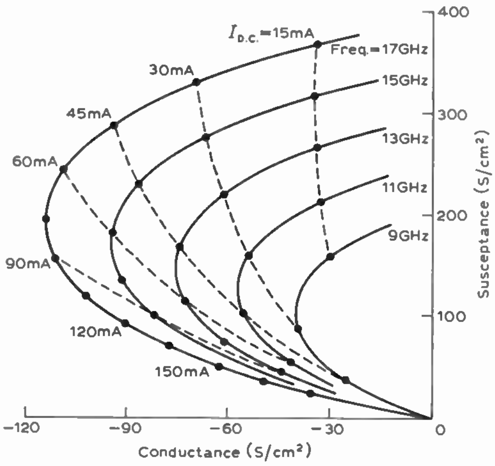

Fig. 1. The admittance of a p^+nn^+ gallium arsenide impatt diode chip as evaluated from the simplified small signal theory of Gilden and Hines[3]. Breakdown voltage = 40 V. Punch-through factor = 1.

impedance values were computed. A search of the values of the parameters of the matching circuit was then made to locate the two points on the measured diode impedance versus current curve which gave the best fit to the required specification.

The reflection phase shifter consisted of a circulator coupled coaxial cavity with the diode mounted at the end of a 7 mm, 50 ohm, coaxial line.[4] The diode impedance was first determined[5] as a function of frequency, bias current and r.f. input power and then a coaxial transformer was designed to give the required phase shift and gain for a specified centre frequency. The gain and phase response of the phase shifter was determined using a Hewlett Packard 8410 network analyser.

The impatt diodes used in the experimental work were Raytheon type MS 856 A, which were packaged 200 mW, J-band gallium arsenide diodes with breakdown voltage typically 30 to 50 V. The equivalent circuit of the 16 A package was taken to be a L-section with a series inductance of 0·4 nH and a shunt capacitance of 0·3 pF. The small signal admittance of the chip of the diodes used in the experiments is given in Fig. 2, where data are presented for frequencies of 9·0 to 10·0 GHz for a range of bias currents. The data are seen to agree qualitatively with the calculated and theoretical results given in Fig. 1.

The response of an experimental phase shifter using double slugs is shown in Fig. 3, where the gain and phase shift responses are plotted versus d.c. bias currents for frequencies of 9·1, 9·2, and 9·3 GHz and for a r.f. input power of 1 mW. It can be seen that the phase shifter performance had a maximum gain at 9·2 GHz, and for a 180° phase shift gave a gain of 7·5 dB when the bias current was switched from 40·5 mA to 47·0 mA.

The dynamic response of the phase shifter was also investigated using phase reversal keying. The diode was biased to 43·7 mA and a 'plus minus' code of 3·2 mA was superimposed. A balanced mixer microwave receiver was used and bit rates of up to 20 Mb/s, the limit of the

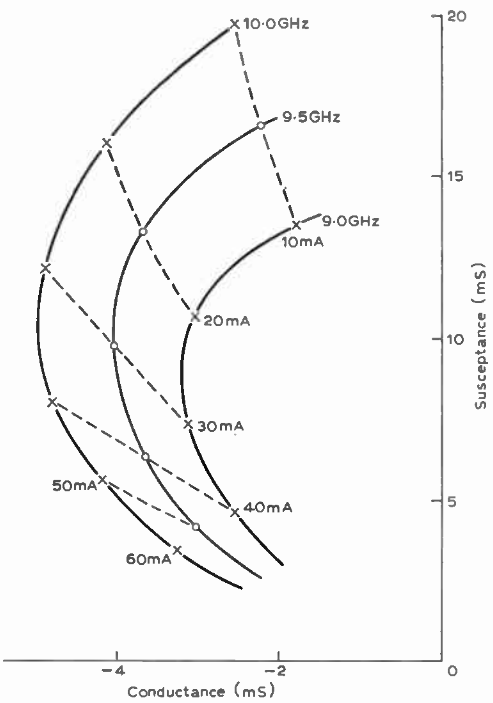

Fig. 2. Experimentally determined small signal admittance of a Raytheon gallium arsenide impatt diode chip type number MS 856A. The admittance is plotted versus d.c. bias current for frequencies of 9·0, 9·5 and 10·0 GHz.

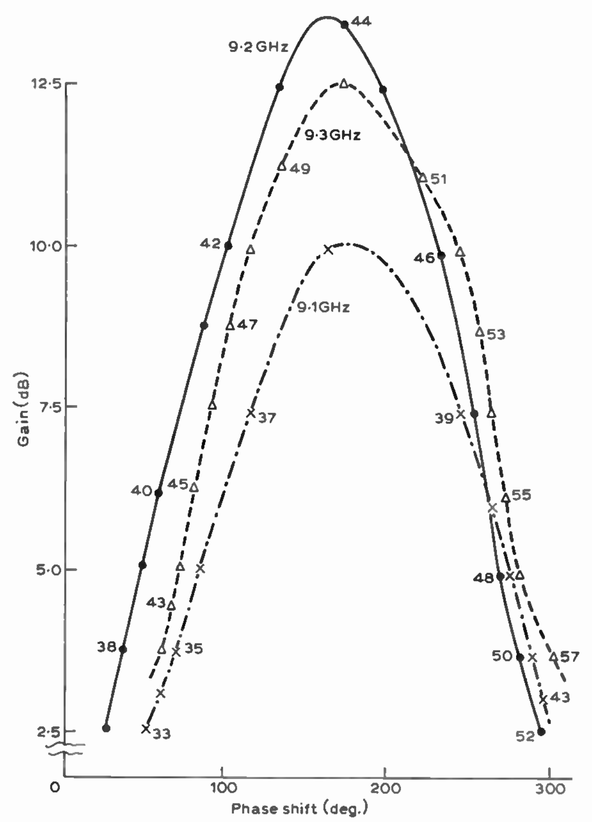

Fig. 3. The gain–phase response of an experimental phase shifter using Raytheon MS 856A impatt diodes and a matching network of two moveable slugs. Data are given for frequencies of 9·1, 9·2 and 9·3 GHz and a r.f. input power of 1 mW. For clarity only selected values of d.c. bias current are presented in the Figure.

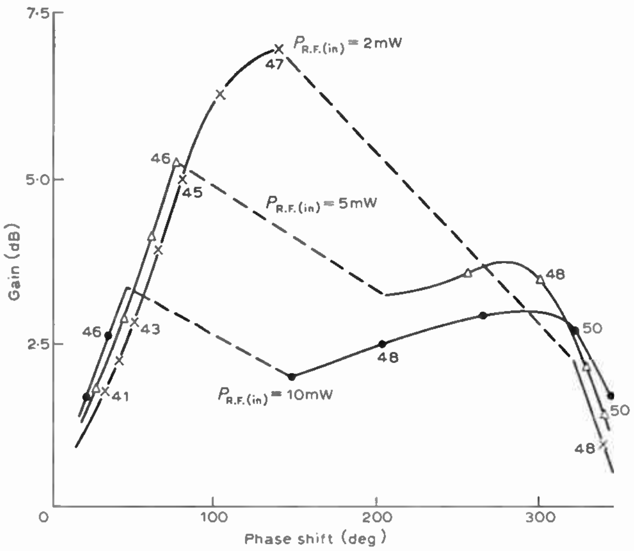

Fig. 4. Gain–phase response of the experimental phase shifter at 'large' signal inputs of 2, 5 and 10 mW at a frequency of 9·2 GHz. The dashed lines correspond to unstable regions, whilst the solid lines correspond to stable amplification. Again only selected current values are given, although measurements were made at intermediate values of current.

word generator, could be accommodated with no noticeable deterioration in the performance of the phase shifter.

The upper limit on the switching speed in a 50 ohm line may be calculated from a knowledge of the depletion capacitance of the diode. The depletion capacitance depends on the diode area and the thickness of the active region but typical capacitance values are about 1 pF so that bit rates of about 4 to 5 Gb/s should be achievable at X band.

4 Large-signal Non-linearities of Impatt Diode Phase Shifters

It is known[2] that the impedance of an impatt type diode depends on the signal level and since the power handling capability of phase shifters is of interest to systems designers, measurements of the gain-phase response were made on the above phase shifter for various r.f. input powers. Typical results for the phase shifter operating at a frequency of 9·2 GHz are shown in Fig. 4 where the values of phase shift and gain are plotted versus d.c. bias current for various r.f. input powers. As the r.f. input signal level was increased a discontinuity (shown as a dotted line) was observed in the gain phase response. An examination of the spectral output of the phase shifter showed that parametric oscillations were occurring in the impatt diode at increased r.f. drive level, e.g. at an input frequency of 9·3 GHz the parametric frequencies were 7·1 and 2·2 GHz. These parametric interactions have been studied analytically by Hines[6], and very recently by Schroeder[7], who studied stability criteria, and it was shown that the non-linear inductance of the avalanching region gave rise to several non-linear effects. The non-linearity of the inductance depends, among other parameters, on the r.f. voltage, and the d.c. bias current, and on the frequency of operation, and is extremely non-linear at frequencies around the avalanche frequency, which unfortunately is the region where impatt diode phase shifters are operated.

5 Conclusions

The impatt diode phase shifter can be biased to provide gain and rapid phase switching with low current drive requirements, and is worth considering for radio systems that have impatt diode oscillators or amplifiers. The present experimental work at X band using p^+nn^+ gallium arsenide diodes investigated the gain phase response of phase shifters and showed that phase shifts of 180° could be obtained with gains of 7·5 dB or so. However, a fundamental limitation exists on the power handling capability of the phase shifter, since the diode has to be operated at frequencies close to the avalanche frequency, where non-linear effects produce parametric oscillations at power levels well below the thermal capability of the diode.

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Manuscript first received by the Institution on 29th August 1975 and in final form on 1st December 1975. (Short Contribution No. 177/CC255.)

UDC 621.372.54:621.376.3

An experimental delta-modulation transversal filter for compression of chirp data-signals

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SUMMARY

The paper examines the application of the delta-modulation transversal (d.m.t.) pulse-compression filter for chirp signal generation and processing in chirp-signal data communication systems. The d.m.t. filter is compared in this respect with the lumped-component dispersive network. Details are given of the design, construction and operation of an experimental pulse-compression d.m.t. filter. The flexibility of the design procedure for the d.m.t. filter, relative to that for the dispersive network, allows modifications to be considered to the signal processing and the signal parameters with the aim of reducing error rate and filter complexity.

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List of Principal Symbols

$f(t)$	chirp signal
$f_c(t_1)$	compressed chirp signal
$f_d'(t)$, $f_d''(t)$	dispersed chirp signal at output of normal matched filter with zero amplitude over time interval t_0, at output of weighted matched filter
f_0, F	chirp signal centre frequency, frequency sweep
G_c	compression gain
$H(\omega)$, $h(t)$	matched filter transfer function, impulse response
t_d, t_g	signal delay, group delay
t_0	time interval over which $f'_d(t)$ has zero amplitude
T	chirp signal-element period
ω_0, ω_i	chirp signal centre, instantaneous angular frequency
$u = 2\pi F/T$	chirp signal parameter
v_x	delay line voltage at a distance x from the input (passive transversal filter); also shift register flip-flop output voltage level (delta-modulation transversal filter)
g_x, r_x	transversal filter scaling resistor conductance, resistance

1 Introduction

The use of chirp signals in future data communication links to aircraft via satellite relay has been proposed and is being investigated.[1] Such communication systems would have to be significantly tolerant of multipath interference and Doppler shift whilst exhibiting a low error rate. The chirp signal form is one suited to this task.

Chirp signals, which are frequency swept in character, are generated from the baseband signal at the transmitter; at the receiver, the signals are time-compressed by means of a matched filter, usually in the form of a lumped-component dispersive network.

This paper examines, with emphasis on design instrumentation and operation, the application of a delta-modulation transversal pulse-compression filter (d.m.t. pulse-compression filter) for chirp signal generation and compression. The d.m.t. pulse-compression filter may have significant advantages over the lumped-component dispersive network.

2 Chirp Signal Data Communication System

Chirp signals, which are modulated data signals, have waveforms of fixed amplitude with positive or negative linear rate of change of frequency with time representing respectively data 1 and 0 baseband signals. These two waveforms occupy the same frequency band and are represented by the expressions

$$\left.\begin{aligned} f(t) &= \cos(\omega_0 t \pm \tfrac{1}{2}ut^2) = \cos\psi(t), \quad &(1)\\ \omega_i &= \frac{d\psi(t)}{dt} = \omega_0 \pm ut \quad &(2)\end{aligned}\right\} -\tfrac{1}{2}T < t < \tfrac{1}{2}T$$

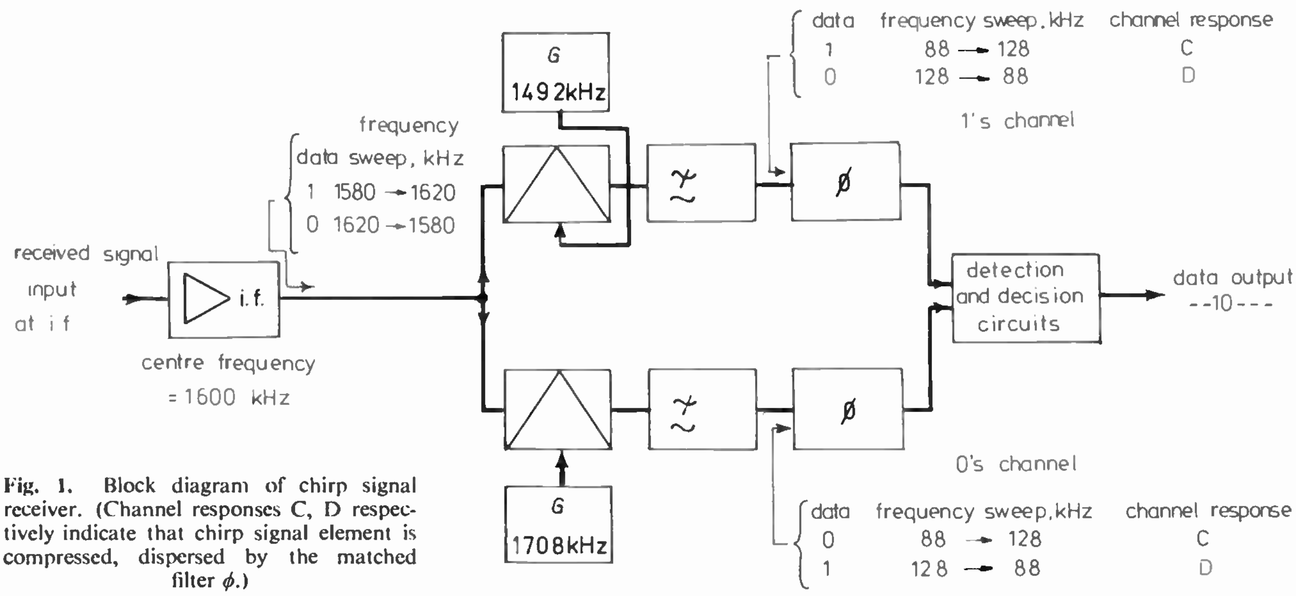


Fig. 1. Block diagram of chirp signal receiver. (Channel responses C, D respectively indicate that chirp signal element is compressed, dispersed by the matched filter ϕ.)

$\omega_0/2\pi$ is the signal centre frequency and $\omega_i/2\pi$ the instantaneous frequency; u is a constant equal to $2\pi F/T$, where F is the frequency sweep, T the signal element period.

Figure 1 shows in block diagram form a chirp signal receiver for a chirp signal having the parameters given in Table 1. Numerical data and instrumentation referred to in this paper are with reference to this chirp signal.

Table 1

Chirp signal parameters

Parameter	Value
Data rate	1200 bauds
$\omega_0/2\pi$	108 kHz
F	40 kHz
Data 1 signal format	88 → 108 kHz
Data 0 signal format	108 → 88 kHz

This signal is designed for use in a ground/aircraft satellite relay system using an L band carrier. The received signal is processed to have an intermediate (centre) frequency of 1600 kHz; it then enters two channels, the 1's channel and the 0's channel. In the 1's channel a mixer reduces the signal frequencies to the values quoted in Table 1 and the matched filter compresses the 1's signal and disperses the 0's signal as shown diagrammatically in Fig. 2 (note that, in practice, chirp signals are usually transmitted contiguously). In the 0's channel, the mixer alters the direction of frequency sweep so that the compression of the data 0 signal can be achieved using an identical design of matched filter to that used in the 1's channel. The outputs from the matched filters are full-wave rectified. The decision whether a data 1 or 0 has been received is made by comparing the amplitudes of the outputs from the two matched filters using peak read and store detectors, which may have a gating facility.

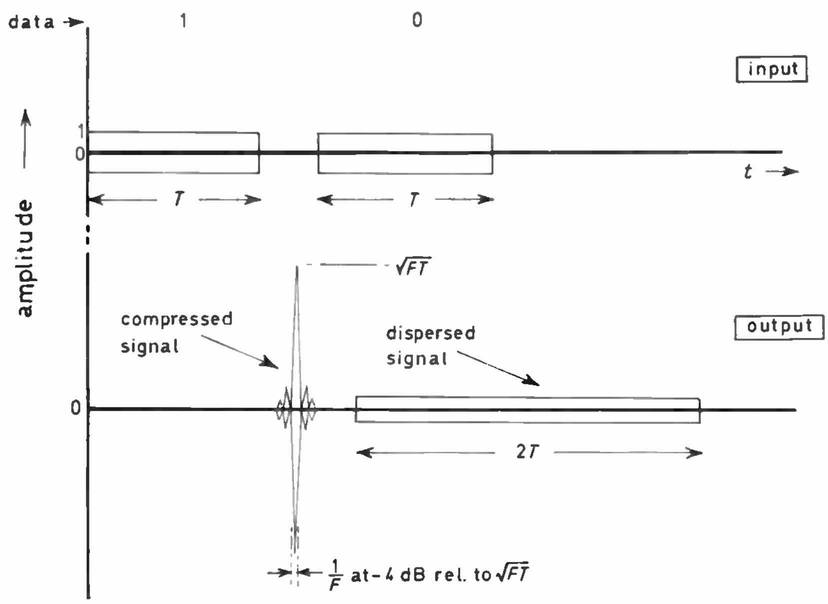


Fig. 2. Signal element envelopes at input and output of a matched filter (matched to a data 1 chirp signal).

Additional information on chirp signal processing in data communications can be found in previous papers.[2, 3]

The compressed output signal $f_c(t_1)$ from a matched filter when an isolated chirp signal $f(t)$ is applied to the input is given by (ref. 7, p. 133).

$$f_c(t_1) = A \sin \frac{\pi F t_1(1-|t_1|/T)}{\pi F t_1} \cos(\omega_0 t_1 + \theta) \qquad -T \leqslant t_1 \leqslant T.$$

$f_c(t_1)$ has a maximum possible value when the sine and cosine terms separately achieve a maximum value for the same value of t_1. The phase angle θ varies in a random manner due to the fact that the system signal processing is not phase-locked; consequently the peak amplitude of successive compressed chirp signals shows a random variation or jitter. When a dispersive network is used as the matched filter, the compressed and dispersed signal elements occupy a period $>2T$ and there is thus additional jitter due to interference between overlapping signal elements; the jitter is most acute for a ---1010--- data stream, when the peak amplitude of the compressed chirp signal may fall 15·5% below the theoretical maximum value.

The ratio

$$\frac{\text{peak amplitude, compressed chirp signal}}{\text{peak amplitude, dispersed chirp signal}}$$

is termed the compression gain G_c. Any maladjustment of the communication system, which reduces G_c significantly below its theoretical maximum value can result in a significant increase in the data error rate. G_c is dependent on the composition of the data stream due to overlapping of signal elements at the matched filter output. For an isolated chirp signal element (having the parameters quoted in Table 1), $G_c = 8{\cdot}2$; for an all 1's (or all 0's) data stream G_c has its lowest value of about 3·4.

For the chirp signal with which this paper is concerned, the matched filter is usually realized by means of a lumped-component dispersive network using cascaded bridged-T sections.[3] A typical dispersive network required 48 bridged-T sections, and a compact design had a volume of 3000 cm^3 and weight 2 kg.

3 The Delta-Modulation Transversal Filter

The matched filter used in the chirp signal receiver can be specified in two ways,

(a) in terms of the transfer function $H(\omega)$, which is the complex conjugate of the frequency spectrum of the signal to which it is matched, and

(b) the impulse response $h(t)$, which is the time inverse (suitably delayed) of the signal to which it is matched.

For a chirp data 1 signal, $H(\omega)$ is given by (with some approximation[2])

$$H(\omega) = k \exp \mathrm{j}\left(\frac{(\omega_0-\omega)^2 T}{4\pi F} - \omega t_d\right) = k \exp \mathrm{j}\phi, \qquad (f_0 - \tfrac{1}{2}F) \leqslant f \leqslant (f_0 + \tfrac{1}{2}F) \quad (3)$$

and the group delay t_g is then

$$t_g = \frac{-\mathrm{d}\phi}{\mathrm{d}\omega} = \frac{(\omega_0-\omega)T}{2\pi F} - t_d \quad (4)$$

t_g decreases linearly with increase in frequency at the rate (T/F) over the frequency band $(f_0 \pm \frac{1}{2}F)$. In these expressions k is a real constant and t_d is the mean value of t_g.

For a chirp data 1 signal, $h(t)$ is given by

$$h(t) = \cos\{\omega_0(t-t_d) - \tfrac{1}{2}\mu(t-t_d)^2\}, \qquad (t_d - \tfrac{1}{2}T) < t < (t_d + \tfrac{1}{2}T) \quad (5)$$

where $t_d \geqslant \frac{1}{2}T$.

The transversal filter, shown in Fig. 3(a), is an alternative form of matched filter to the dispersive network described in the previous Section. In this filter, the signal is fed into a terminated delay line sufficiently long to accommodate a complete signal element. Scaling resistors of conductance g_x are connected to taps along the delay line and the currents through these resistors are summed to yield at the output at a particular instant in time a current $i_s = \sum v_x g_x$, where v_x is the delay line voltage at a tap distant x from the line input. The scaling resistor conductance values are proportional to sampled values of the time inverse of the chirp signal $f(t)$ to which the filter is matched. For a large number of tapping points, the filter output at a time t is essentially of the form

$$\int g(x)\, v(x-x')\, \mathrm{d}x$$

where x' is a linear function of t; with $f(t)$ as input, this expression may be shown to be effectively of the form

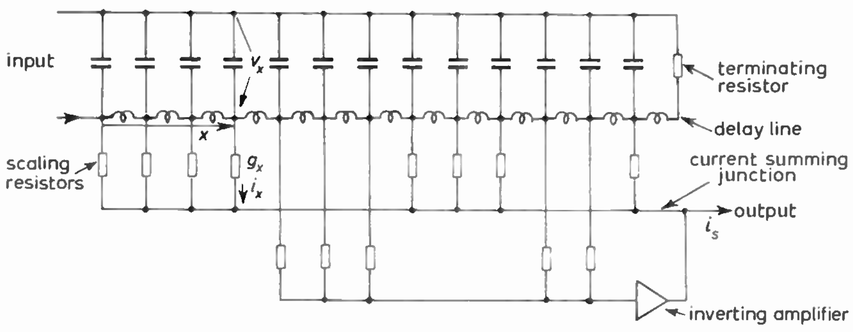
$$\int f(t) f(t+\tau)\, \mathrm{d}t$$

where τ is a linear function of t. This expression represents the process of correlation, which is equivalent to the process of matched filtering.

The transversal filter[4] is used for equalization in data and video transmission systems,[5, 6] for signal weighting and (in sometimes a modified form) pulse compression in radar systems.[7, 8] Winkler, in a paper concerned with the use of chirp signals for communications, presents the transversal filter as the matched filter for compressing chirp data signals.[9]

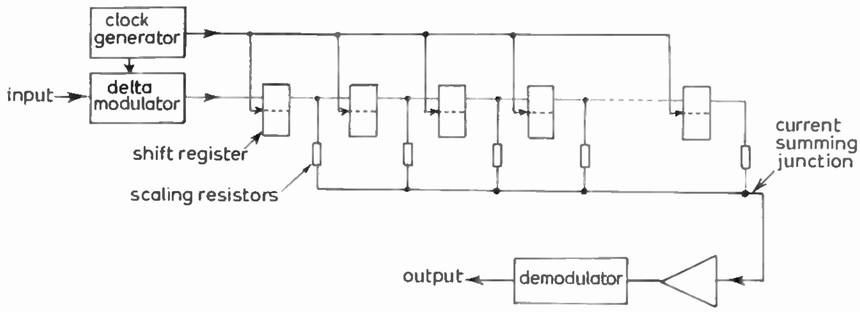
Figure 3(b) shows the delta modulation transversal filter (d.m.t. filter), which differs from the passive form of Fig. 3(a) in that the analogue signal at the input is converted to digital form using a delta modulator and the passive delay line is replaced by a shift register; the analogue form is recovered at the output using a demodulator consisting of an integrator and a low-pass filter. Lockhart[10] has observed that the d.m.t. filter is effectively a non-recursive binary transversal filter with quantization noise filtered by the binary transversal filter.

Scott-Scott and Bognor[11] have proposed a transversal filter for the compression and generation of chirp signals in which the scaling resistors are replaced by resonators as shown in Fig. 4. Each resonator is fed with two signal components, one being delayed and inverted



(a) The transversal filter

Fig. 3.



(b) The delta modulation transversal filter.

relative to the other. As an impulse is passed down the previously cleared shift-register, each resonator is activated for a discrete period of time so generating a quantized chirp signal.

4 A Comparison of the Delta-Modulation Transversal Pulse-Compression Filter with the Lumped-Component Dispersive Network

4.1 The Lumped-component Dispersive Network

When used with a hybrid circuit,[3] which effectively causes the signal to pass through the network twice, the network size is halved.

The design procedure is complicated and inflexible and the network requires special components (the inductors have preferably to be 'set-up' after assembly). The transfer-function is 'all-pass' and has matched filter characteristics over the signal bandwidth only.

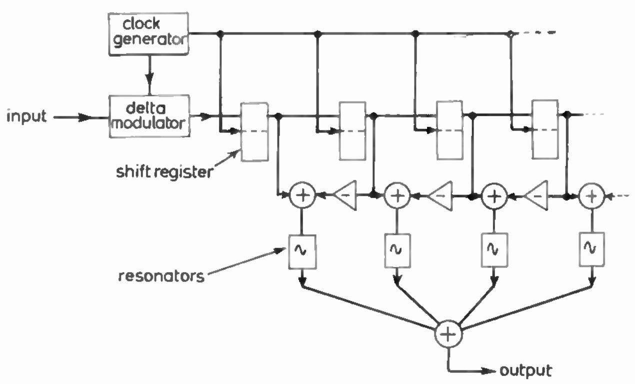


Fig. 4. Delta modulation transversal filter using transversely connected resonators for compressing and generating chirp signals.

4.2 The D.M.T. Pulse Compression Filter

This uses standard, inexpensive, stable components. A single shift register can be used with different clock rates and with several sets of scaling resistors to provide matched filters for chirp signals with different parameters. When constructed from discrete components, faulty components can be readily located and replaced.

The filter can be used for chirp signal generation and compression, the transfer function being basically that of a true matched filter. The design procedure is flexible and the transfer function can be readily modified or shaped.

The performance is less than ideal due to the quantization of the signal (in the delta modulator) and of the correlation process (through the use of a finite number of scaling resistors). The filter performance may vary with the input signal level and it will be necessary to control this level in a chirp signal receiver using a form of a.g.c.

The filter requires a power supply and is heat producing, which could be a disadvantage. When constructed from discrete components there are a large number of circuit connexions, which could be a source of unreliability.

5 Computer Simulation of the D.M.T. Pulse-Compression Filter

By simulating the operation of the d.m.t. filter using the digital computer, several design studies were carried out and these are summarized below. The information derived from this work was used to guide the design of an experimental d.m.t. filter matched to the chirp signal whose parameters are given in Table 1. Interference-free operation was assumed in this work.

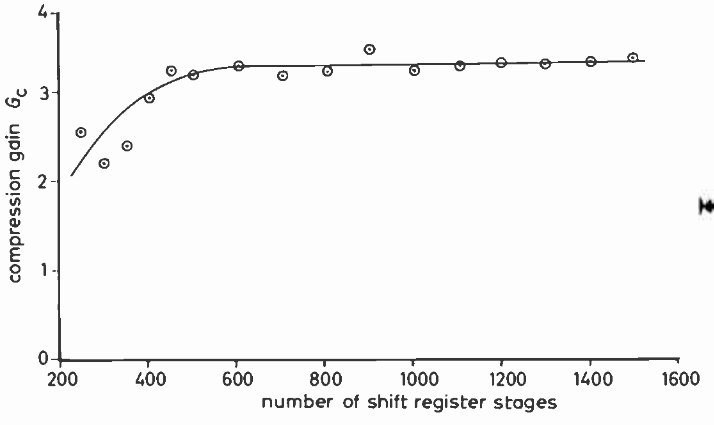


Fig. 5. Variation of compression gain G_c with number of shift register stages for an all 1's (or 0's) data pattern. (Results obtained by computer simulation.)

Fig. 6. Output of simulated d.m.t. pulse-compression filter using a 600-stage shift register for a --110011-- data pattern.

5.1 Number of Stages in the Shift Register

The d.m.t. filter design was based on optimization of the compression gain G_c. To make optimum use of the information stored in the shift register, a scaling resistor was assumed to be connected to the output of each stage of the shift register. Figure 5 shows the variation of G_c with the number of stages in the shift register. Figure 6 shows the output (taken directly from the current summing junction) from the simulated 1's channel d.m.t. filter with a 600-stage shift register for a --110011-- data pattern; the output is virtually identical with the output from an ideal matched filter.

5.2 Optimum Delta-modulator and Shift-register Clock Rates

The shift register clock rate must be such that the input from the delta modulator over the duration of one chirp signal element just fills the shift register. Assuming a 600-stage shift register, the required shift-register and delta modulator clock rate is 0·72 MHz. An improvement in G_c is obtained by using a delta modulator clock rate which is an integer multiple of the shift register clock rate; thus using a delta modulator clock rate of 2·88 MHz, every fourth delta modulator output pulse would be fed to the shift register input. Note that the delta modulator effective clock rate is significantly greater (about 3 times) than the minimum sampling rate required by the sampling rate theorem to define the highest chirp signal frequency component.

For a delta modulator running at the basic clock rate, a $\pm 2\%$ deviation in clock rate from the ideal value resulted in a 1% reduction in the peak amplitude of the compressed signal.

5.3 Effect on G_c of Chirp Signal Phase Angle θ

The d.m.t. filter can represent more closely the characteristic of a true matched filter than the dispersive network. Accordingly, it was found that the jitter on the peak amplitude of the compressed chirp signal due to random variations in θ was significantly less for the d.m.t. filter than for the dispersive network. Analysis showed that for the d.m.t. filter with a 600-stage register, G_c varied between 3·0 and 3·6 for different values of θ and for an all 1's (or 0's) data pattern.

5.4 Effect of Component Tolerances

The summing junction current i_s is at any instant given by $\sum v_x g_x$ and is influenced by the tolerances on v_x, the shift register flip-flop output voltage levels, and on g_x. The shift register output circuits should ideally provide accurate, low-impedance sources of e.m.f.; in practice, this requirement is not too easily satisfied. It is necessary to limit the highest value of g_x so that loading of the flip-flop output circuits is negligible. Analysis showed that the d.m.t. pulse-compression filter was tolerant of variation of $(v_x g_x)$ values from the ideal. For random variations in $(v_x g_x)$ up to a maximum of $\pm 25\%$, the effect on the compressed and dispersed output signals was negligible. A worst case analysis for the same maximum tolerance showed a reduction in compression gain of 30%; such an extreme condition is unlikely, but possible.

6 Details of an Experimental D.M.T. Pulse-Compression Filter

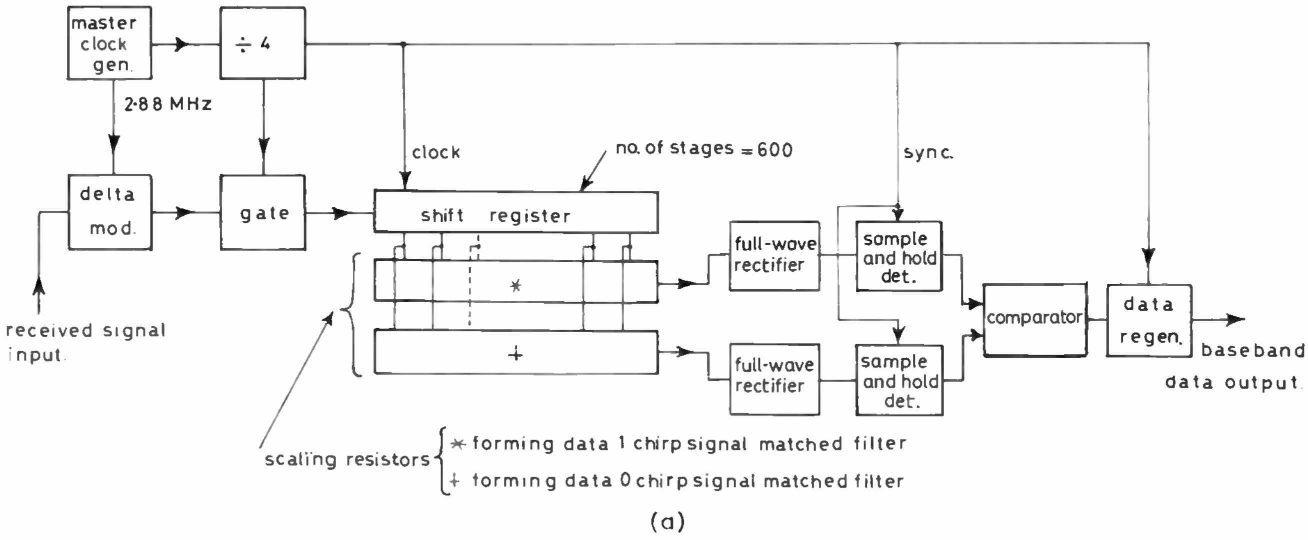
An experimental d.m.t. filter was constructed to examine instrumentation problems and operating behaviour.

The equipment was constructed to provide the following facilities:

(a) Signal processing of received data 1 and 0 chirp signals; the outputs from the data 1's and 0's pulse compression filters to be full-wave rectified and fed to sample-and-hold detectors (with variable gating); detector outputs to be fed to a comparator followed by a baseband data regeneration circuit.

(b) Generation of data 1 and 0 chirp signals; signal elements to be either (i) cyclic and contiguous or (ii) isolated or overlapping (using an external trigger).

Block diagrams for these systems are shown in Figs. 7(a) and (b).



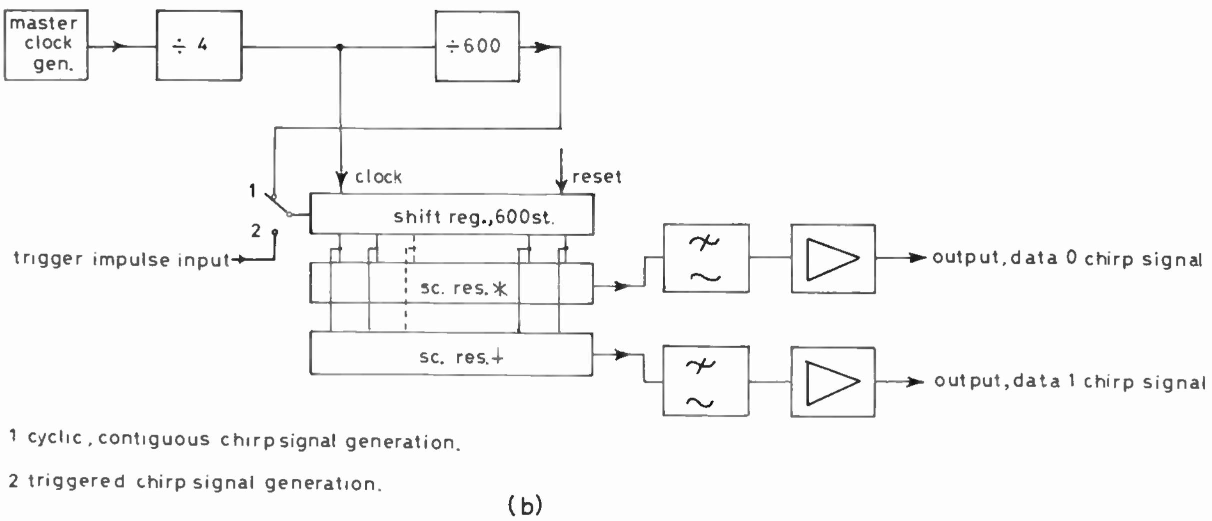


Fig. 7. Block diagram of an experimental d.m.t. pulse-compression filter and ancillary circuits, (a) for processing received data 1 and 0 chirp signals, (b) for generating data 1 and 0 chirp signals.

The 600-stage register was constructed from 120 Texas Instruments' integrated circuits type SN 7496N; these devices are 5-stage shift registers with the Q output of each stage brought out to a pin. The scaling resistors used were $\frac{1}{8}$-watt, 5%-tolerance preferred values (E12 series), used in some cases in parallel-connected pairs to reduce the resistance quantization error; the maximum and minimum scaling resistance values used were respectively 110 kΩ and 10 kΩ, the latter value avoiding any significant loading of the shift register flip-flop outputs. The 600 scaling resistors of each of the two sets varied between these limits and their resistance values were calculated on the principle that the conductance g_x varies with x as f(t) varies with t (equation (1)).

The layout of the experimental d.m.t. filter resulted in long leads for the power supply, clock pulse and summing junction lines. To minimize switching transients on the power supply line, capacitors were connected directly to the power-supply pins of each shift-register integrated circuit.

The master clock generator was run at 2·88 MHz. The output was fed directly to the delta modulator clock input and divided by four before feeding to the shift-register clock line. When receiving chirp signals a gate allowed every fourth delta modulator output pulse to pass to the shift register input.

No inverting amplifier was used in the filter (to effectively represent negative values of g_x—see Fig. 3(a)); consequently the summing junction output contained a d.c. level which was eliminated by biasing. The summing junction output was fed to a high value resistance (and not a low value as normally used); the summing principle is maintained with this arrangement and a relatively high output voltage is achieved.

The average shift register flip-flop output logic voltage levels were +3·4 V (binary 1) and +0·4 V (binary 0). The filter output when receiving chirp signals was about 1·3 V peak to peak. The tolerance on these logic levels is typically ±20%, but can exceed this value. For the integrated circuits used in the shift register, the logic levels were measured to be within ±10% of the average.

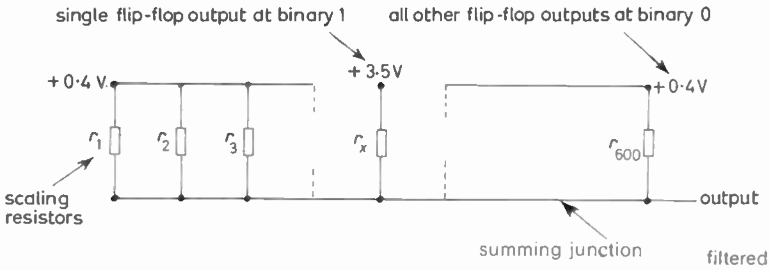
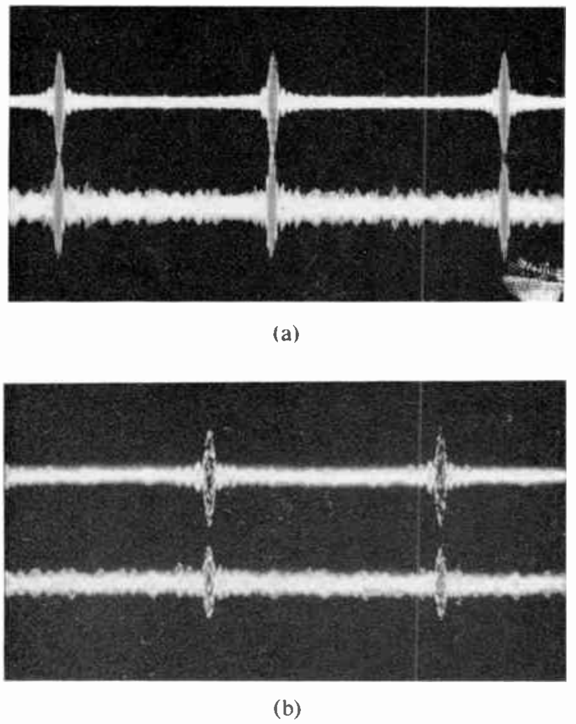


Fig. 8. D.m.t. filter shift register voltage levels when generating a chirp signal.

For the generation of contiguous chirp signals, the shift register must initially be cleared; a binary 1 pulse is then fed into the shift register followed by 599 binary 0 pulses (i.e., no input for 599 shift register clock periods); this pulse sequence is derived by dividing the shift register clock rate by 600. The shift register voltage levels at any instant are as shown in Fig. 8. In this Figure, the single impulse passing down the shift register is at the scaling resistor r_x. The resistance of all the scaling resistors connected in parallel is 29 Ω. Since r_x varies between 10 kΩ and 110 kΩ, it can readily be calculated that the output voltage is approximately 9 mV p–p.

No separate demodulator (i.e. integrator and low-pass filter) was employed immediately after the summing junction (see Fig. 3(b)). This simplification was adopted since the full-wave rectifier circuit was an envelope detector with low-pass filtering characteristics.



(a)

(b)

Fig. 10. Output from 1's channel chirp signal receiver using (a) a dispersive network, (b) the experimental d.m.t. filter with all 1's data pattern chirp signal input. In each case upper trace is noise-free at input, lower trace is with Gaussian noise interference (0dB signal/noise ratio).

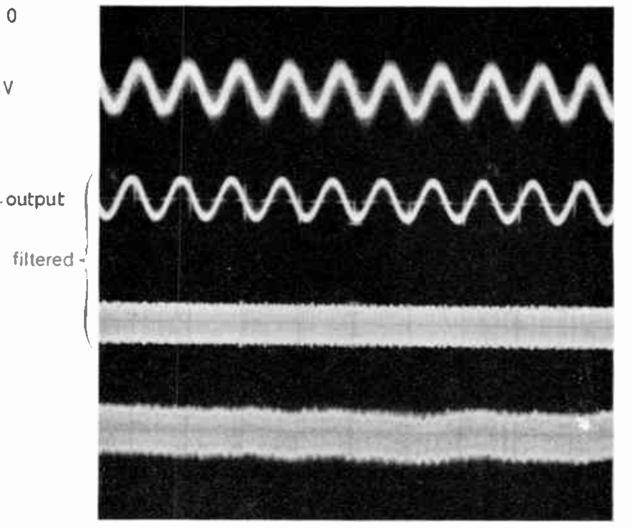


Fig. 9. Output from the experimental d.m.t. filter with 108 kHz sinusoidal input signal; output shown filtered/unfiltered and using fast/slow time base to display high/low frequency noise components.

7 Operation of the Experimental D.M.T. Pulse-Compression Filter

7.1 Noise Generated by the D.M.T. Filter

Noise generated by the d.m.t. filter falls into three categories:

(a) above chirp-signal frequency-band switching noise,

(b) in-band noise,

(c) below chirp-signal frequency-band noise.

Noise in category (a) had a strong component at 1·44 MHz, which may be readily removed with an elementary low-pass filter. Noise in category (c) was significant but present only when the d.m.t. filter was processing received signals and evidently originated in the delta modulator. Figure 9 shows the output from the d.m.t. filter with a 108 kHz sinusoidal signal at input. Noise in categories (a), (c) is evident, but noise in category (b) appears to be significantly small. Figure 10 shows separately the output from the d.m.t. 1's channel filter and a dispersive network for a data 1 chirp signal at input under noise-free conditions and with added Gaussian noise (0 dB signal/noise ratio). The dispersive network is a linear system and consequently with a matched chirp signal at input an interfering noise component may at any instant add to or subtract from the peak amplitude of the compressed signal component. The d.m.t. filter is quasi-linear; with a matched chirp signal at input it may be argued that the delta modulator output sequence is ideal and gives the compressed chirp signal at output; an added noise component at the input will produce a delta-modulator output sequence which is non-ideal and will result in a compressed signal at output with reduced peak amplitude. This argument appears to be borne out in practice and it will be further noted that the noise component at times other than at the compression time is less with the d.m.t. filter than with the dispersive network.

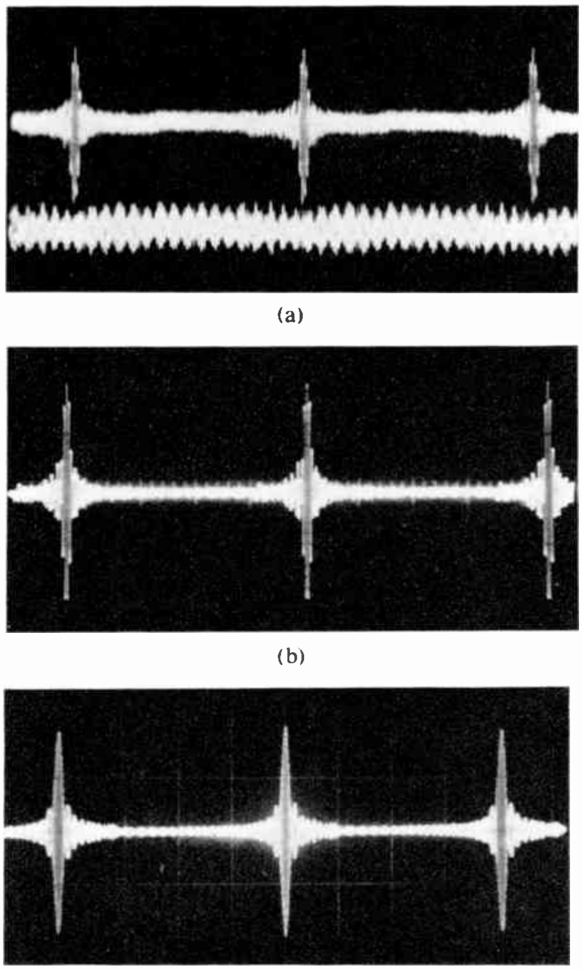


Fig. 11. Chirp signals generated (with an all 1's data pattern) by (a) d.m.t. filter, (b) d.m.t. filter with simple band-pass filter at output, (c) swept-frequency generator. Compressed in each case using a dispersive network. Lower trace in (a) shows dispersed chirp signal.

7.2 Chirp Signal Generation

Figure 11(a) shows a chirp signal generated by the d.m.t. filter compressed and dispersed by a dispersive network. Figure 11(b) shows the improvement in this compressed signal obtained by adding elementary high and low-pass filters to the d.m.t. filter output. For comparison, Fig. 11(c) shows a chirp signal generated by a swept-frequency function generator and compressed by a dispersive network. The d.m.t. filter generated chirp-signal results in values of G_c which are very close to the ideal.

7.3 Error Rate Measurements

Figure 12 shows the variation of error rate with signal/noise ratio for chirp signals processed at the receiver using the d.m.t. filter; results are given for two data patterns and gating periods. In taking these measurements, the delta modulator was initially fed with a chirp signal alone at optimum level; the signal/noise ratio was varied by introducing noise whilst maintaining the chirp signal level constant; this mode of operation would exist in practice in a receiving system with coherent a.g.c. The error rate curves show the advantages to be gained from using a gating period significantly less than T and also the effect of the data pattern on error rate; this latter point arises through the dependence of the amplitude of the dispersed signal on the data pattern as described in Section 2.

The error rate performance of the chirp signal communication system is below that of the *ideal* p.s.k. system when compared on the rational basis of (signal energy/signal element)/noise power spectral density.

This result arises because the data 1 and 0 chirp signals are not truly orthogonal and can be regarded as a price to be paid for a system, which is resistant to multipath interference and Doppler shift; the basis of this resistance is explained in reference 1.

8 The Use of Signal Weighting Techniques to Obtain Improved Error-rate Performance

It is anticipated that the chirp signal receiver when synchronized will operate with a detector gate time equal to 10% of the data period ($833\frac{1}{3}$ μs). The error-rate

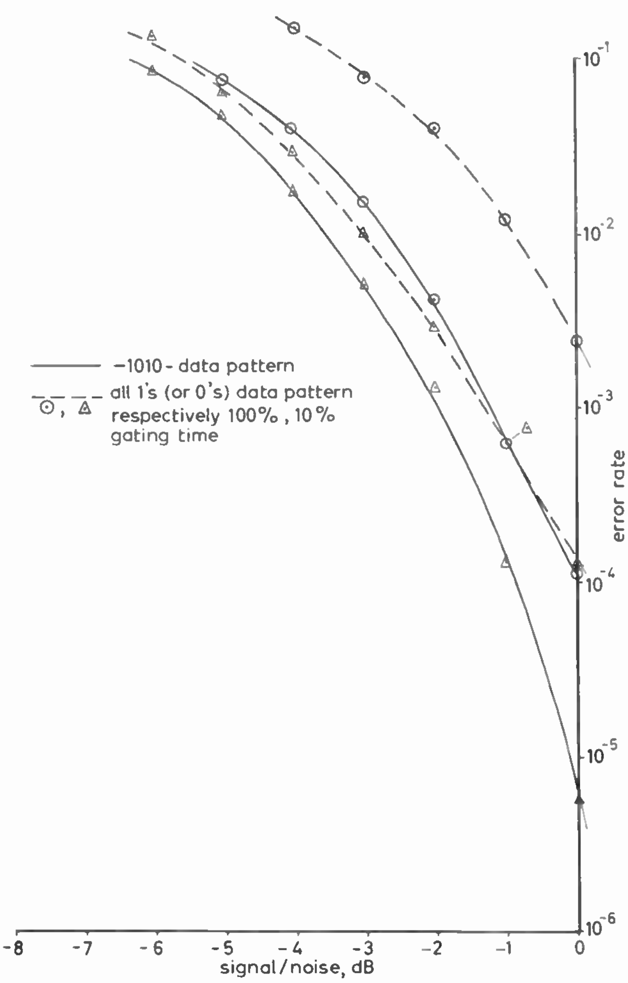


Fig. 12. Graph showing the variation of error rate with signal/noise ratio for chirp signals with Gaussian noise interference and processed using the experimental d.m.t. filter.

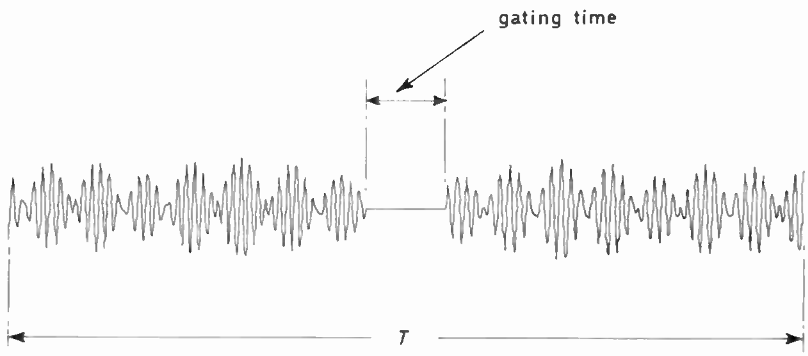


Fig. 13. Dispersed chirp signal $f_d'(t)$ with signal level reduced to zero over a time interval t_d equal to and centred on the gating time.

performance would clearly be improved if the amplitude of the dispersed signal at the output of one of the two data channels could be reduced without at the same time significantly reducing the peak amplitude of the compressed signal present at the output of the other data channel at mid-gating time. This modification to or weighting of the dispersed signal is readily effected because the response of the d.m.t. filter is so readily capable of modification.

The analysis is based on the use of the fast Fourier transform and has been carried out for an all 1's (or 0's) data pattern. The procedure is as follows. Figure 13 shows a weighted dispersed chirp signal $f_d'(t)$ over one data period derived from a normal (or unweighted) dispersed chirp signal by reducing the signal level to zero over a time interval t_0 equal to and centred on the gating time; the signal $f_d'(t)$ will contain spectral components outside the chirp signal receiver bandwidth $f_0 \pm \frac{1}{2}F = 108 \pm 20$ kHz and is thereby not allowable. An allowable weighted dispersed chirp signal $f_d''(t)$ is now derived by limiting the spectral components to $f_0 \pm \frac{1}{2}F$ of $f_d'(t)$ having t_0 slightly greater than $0{\cdot}1T$. This calculation is repeated using different values of t_0 to obtain an acceptable form of $f_d''(t)$ with near-zero amplitude over the gating time. The weighted matched filter transfer function and impulse response are then derived from $f_d''(t)$ and the chirp input signal.

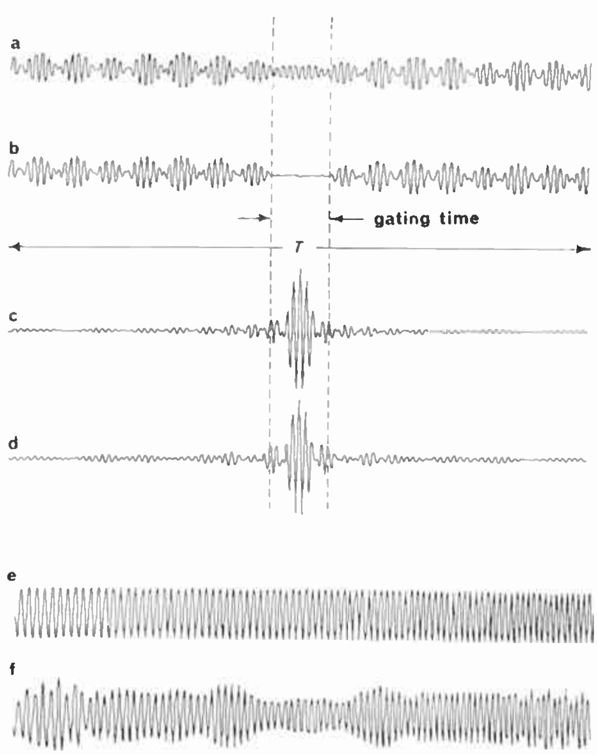


Fig. 14. Signal waveforms at the output of a data 1 chirp signal unweighted (normal) and weighted matched filters.

Dispersed chirp signal (data 0 chirp signal at input): (a) normal matched filter, (b) $f''_d(t)$, weighted matched filter.

Compressed chirp signal (data 1 chirp signal at input): (c) normal matched filter, (d) weighted matched filter.

Impulse response: (e) normal matched filter, (f) weighted matched filter.

Figure 14 shows the results obtained using this technique. Waveforms a, b and c, d are respectively the dispersed and compressed chirp signals at the output of the unweighted (normal) and weighted matched filter; the two compressed chirp signal waveforms are seen to be very similar. Waveforms e, f are the impulse responses of the unweighted and weighted matched filter (used to define the values of the d.m.t. filter scaling resistors—see Section 3).

9 Effect of Chirp Signal Centre-frequency on Filter Design

The d.m.t. filter is equivalent in operation to a sampled-data matched filter (see Sect. 3). The output $f_c(t_1)$ with a matched chirp signal at input is a sampled sinewave of frequency f_0 with a $(\sin x)/x$ envelope (equation (3)).

As f_0 is reduced, the number of samples/cycle N in $f_c(t_1)$ will increase and the quantization loss is reduced; however, under these circumstances the envelope of $f_c(t_1)$ will be less well-defined and the jitter referred to in Sect. 2 will become enhanced. The compression gain G_c is primarily a function of $D = FT$ (see Fig. 2), so that in a system where the chirp signal parameters F, T (i.e. D) are specified, f_0 might be regarded as a variable.

If M is the number of shift register stages and τ is the sampling interval, then (from Sect. 5, para. 3).

$$M = T/\tau$$

Now

$$\tau = 1/f_0 N$$

so that

$$M = Tf_0 N = D\frac{f_0}{F}N$$

Thus as f_0 is reduced M may be reduced, but the jitter referred to above will become more severe, so that clearly a balance between these two factors must be established.

10 Conclusions

This work has shown that the d.m.t. filter has the ability to process chirp signals with a significant degree of flexibility.

Whilst the experimental circuit used employed discrete components, any further development would necessitate the introduction of a higher degree of circuit integration.

It should be noted that the experimental d.m.t. filter was of necessity matched to a chirp signal whose parameters were selected in part to facilitate the design of a dispersive network; if the chirp signal was free of this restraint, this filter could have been reduced in size.

11 Acknowledgments

This work is part of a research project carried out in the Department of Electrical and Electronic Engineering, University of Nottingham with the support of Procurement Executive, Ministry of Defence. The authors wish to thank Mr. D. Hirst for his advice and help throughout this project.

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Manuscript first received by the Institution on 3rd February 1975 and in final form on 7th May 1975. (Paper No. 1722/CC256.)

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Correction

In the short article 'Digital television trials with compact transmission equipment', received from the Independent Broadcasting Authority, and published on page 182 of the April Journal, a misprint occurred in line 4 of the last paragraph but one. This should have read '. . .modified for operation at 140 Mbit/s'. The Post Office, in drawing attention to this error, has pointed out that while it is indeed hoped that 140 Mbit/s will be adopted as an international standard for digital data transmission, it is already accepted as standard by the CCITT. The British Post Office's use of 120 Mbit/s was an interim system rather than experimental and in the course of the next three or four years will be superseded by the 140 Mbit/s system.

There is also a minor printing error in the sixth line of the second paragraph of the article where the figure '200' has been repeated: the route length was 200km.

The following correction should be made in the paper 'Crystal band-pass lattice filters with equal ripple pass bands and arbitrary stop bands' published in the April 1976 issue of *The Radio and Electronic Engineer:*

Page 190, Table 3. The second term in the title of the Table should read:

$$\omega = \omega_0 + \tfrac{1}{2}\Delta\omega . x_D,$$

Recognizing Good Design

The Design Council, in its endeavour to find and promote the best in British design, runs several annual Award schemes. Companies are invited to submit their products for assessment by panels of expert judges who also ask for comments from users of the products and, where relevant, independent authorities and institutions. In this way the Council hopes to find, and subsequently promote, the best that British industry has to offer. The promotional opportunities available to winning companies all carry the full backing of the Design Council's promotional services.

There are four Award programmes:
- Engineering Products
- Engineering Components
- Medical Equipment
- Motor Vehicles and Accessories

Engineering products include all types of industrial machinery, mechanical, electrical and electronic equipment, scientific instruments, mechanical handling and construction plant. Air and sea transport, private road vehicles and civil engineering constructions are specifically excluded.

Engineering components include all types of commercially available engineering component irrespective of size or complexity.

Products must have been designed and made by British companies and should have been in production and service for long enough to enable reliable user reports to be obtained. Products embodying foreign components will not be excluded, but products made to a foreign design will be excluded unless it can be shown that significant improvements of British origin have been made.

Companies may make more than one submission. Completed submission forms and all enquiries should be addressed to: Anthony H. L. Key, Engineering Awards Manager, Design Council, 28 Haymarket, London SW1Y 4SU (Tel. 01-839 8000). The closing date for entries for the 1977 Award is 31st August 1976.

EITB Training Levy Order

Proposals submitted to the Secretary of State for Employment by the Engineering Industry Training Board for a levy on employers within the scope of the Board equal to 1% of their payroll in the year ended 5th April 1976 have been approved.

Employers in the engineering construction sector with emoluments of less than £50 000 will be exempt from levy and all other employers, employing less than 60 people, will also be exempt from levy.

Employers who satisfy the Board that they adequately meet their own training needs may seek exemption from the levy. The levy will be used to make grants for a wide variety of training in the industry including the training of managers and supervisors. Grants will also be available for group training schemes.

It will be recalled that the Industrial Training Act 1964 empowers the Secretary of State to set up industrial training boards to improve standards of training throughout industry. The Act covers any activity of industry or commerce including those of nationalized as well as private industries. Boards are given powers to levy employers in their industries and to pay grants to employers providing approved training. One of the largest of the 23 Training Boards, the EITB, was constituted in July 1964 and covers approximately 26 600 establishments and 3 300 000 employees.

Inaugural Meeting of Fellowship of Engineering

The newly created Fellowship of Engineering set up earlier this year by the Council of Engineering Institutions (CEI) held its inaugural meeting at Buckingham Palace on 11th June, when some one hundred Founder Fellows were welcomed by the Duke of Edinburgh, the Senior Fellow, who presided.

Following an initiative from Prince Philip some years ago, the Fellowship was created by CEI to provide a means for the exchange of opinion and specialist knowledge and to give advice on national issues of the day which involve engineering considerations. This nucleus of influential and eminent chartered engineers will thus be available to give guidance to the Government and others on matters involving engineering and experience. It is intended that the Fellowship will be accepted nationally and internationally as a body with sufficient authority to present the views of engineers free of sectional interests and to cooperate with similar bodies at home and overseas.

The creation of the Fellowship was announced last February by Prince Philip when he was President of CEI. He said that in fulfilling its objects the Fellowship would do much to raise the standing and prestige of our engineers. Immediately following Prince Philip's announcement, 137 distinguished chartered engineers were invited to become Founder Fellows. These were made up from those who were currently Fellows of the Royal Society together with a number of other eminent engineers selected after consultation with the Presidents of CEI's fifteen member institutions.

Of those invited to become Founder Fellows, 129 have now accepted. The Founder Fellows include five Fellows of the IERE: Professor H. E. M. Barlow, Sir Arnold Lindley, Sir Ieuan Maddock, Admiral of the Fleet The Earl Mountbatten of Burma and Mr. H. F. Schwarz. Additional Fellows will be elected by the Fellowship itself, eventually to a number not exceeding 1000 but not more than 60 in any one year.

After signing the Roll and hearing an introductory statement from Prince Philip, the Founder Fellows at the meeting discussed the work and the future role of the Fellowship. An Executive Committee was formed under the chairmanship of Lord Hinton of Bankside who, as CEI President, will provide a coordinating link between the Fellowship and CEI.

The Fellows will be expected to participate fully in the work of the Fellowship, and by giving it the benefit of their knowledge and experience help to promote the status of engineering.

Student Design Award for 1976

The Design Council 'Molins' Design Prize, sponsored by Molins Ltd., is an annual competition intended to encourage the art, science and practice of engineering design in mechanical and electronic engineering in universities, colleges and polytechnics. Cash prizes of £500, £250 and £100 are given each year to the first, second and third place winners who also receive a 'trophy' in the form of an aluminium cube into which diminishing concentric circles are machined. It is appropriate that this cube is a standard test piece designed to test the machining skills of the final year Molins' engineering apprentices.

Mr. R. J. Bush, a B.Sc. Honours graduate in communications engineering from Plymouth Polytechnic, received the first prize for his visual method of monitoring sound levels during 'live' group sessions and mixing sessions in recording studios. The system replaces up to 24 moving-coil signal-level meters by a coloured bar-graph display on a television screen and it is stated to increase the efficiency of the information flow to the engineer, allow him to make more objective decisions during the process of sound mixing, and lead to greater ease and accuracy of operation. Another electronic device, an audio delay system which can enhance sound reproduction, gained second prize for Mr. W. J. Harmsworth, a graduate in electrical and electronic engineering from Brighton Polytechnic. The system first converts an audio signal into a sequence of digital words, stores them in a memory element for a desired delay time and then reconstitutes them into an output signal. This method of reproducing sound can be used to good effect in auditoria where the resonance of sound is a particular problem and may affect the quality of music, in particular, or speech.

The judges took account of the realism of the projects submitted—altogether there were 23 entries—and by awarding two major prizes to electronic engineering projects reversed the mechanical engineering bias established in 1975, the first year of the competition.

Mechanical engineering design has not been totally eclipsed this year. For the second year in succession an HNC graduate in Production Engineering (Industrial Design) from Salford College of Technology was among the three prizewinners. Mr. P. A. Smith devised a machine for placing the cover on the nozzle of detergent bottle caps. It uses hydraulic, electrical and mechanical devices to place the nozzle re-sealing cover on detergent bottle caps at a rate which matches the moulding times and detergent filling rates. This enables the machine to be incorporated in the final production stage of the plastics cap mouldings or as part of the detergent production line.

The judges were generally appreciative of the standard of submissions taking into account the fact that none of the authors was a practising engineer. However, they were critical of a number of entries which were no more than reports on research or experimental work and completely ignored the feasibility of the design for production. Because the competition is for practical design projects, the judges took account of the realism of the project objectives and did not highly rate projects which met only trivial needs, ignored costs, or were already covered in textbooks.

The Design Council 'Molins' Design Prize competition is open to students (excluding post gradutess) following diploma or degree courses in engineering or engineering science at a university, college or polytechnic in Great Britain. Students taking courses in other disciplines may also be eligible at the discretion of the organizers.

Notice to all Corporate Members of the Institution of Electronic and Radio Engineers

Nominations for Election to the 1976-77 Council of the Institution

In accordance with Bye-Law 49, the Council has nominated the following members for election at the Annual General Meeting to be held in London on Wednesday, 6th October 1976.

The President

For Election: P. A. Allaway, C.B.E., D.TECH.

The Vice-Presidents

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

For Re-election:

Professor D. E. N. Davies, D.SC., PH.D.; Professor W. A. Gambling, D.SC., PH.D.: D. W. Heightman; J. R. James, PH.D.; J. Powell, B.SC., M.SC.

For Election:

Professor W. Gosling, A.R.C.S., B.SC.; R. C. Hills, B.SC.

Honorary Treasurer

For Re-election: S. R. Wilkins

Ordinary Members of Council

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

FELLOWS

The following must retire:

R. C. Hills, B.SC.; P. L. Mothersole; Professor K. G. Nichols, B.SC., M.SC.

For Election:

L. A. Bonvini; Sir Raymond Brown, KT., O.B.E.; L. F. Mathews, O.B.E.

MEMBERS

The following must retire:

H. Blackburn; Professor D. W. Lewin, M.SC.; M. M. Zepler, M.A.

For Election:

N. G. V. Anslow; K. Copeland; Group Captain J. M. Walker, R.A.F.

ASSOCIATE MEMBER

The following must retire:

C. R. Fox

For Election:

Lieutenant-Commander J. Domican, R.N.

ASSOCIATE

The following must retire:

G. Phillips

For Election:

T. D. Ibbotson

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

Bye-Law 50 provides that:

Within twenty-eight days after the publication of the names of the persons nominated by the Council for the vacancies about to occur any ten or more Corporate Members may nominate any one other duly qualified person to fill any of these vacancies by causing to be delivered to the Secretary a nomination in writing signed by them together with the written consent of the person nominated undertaking to accept office if elected, but each nominator shall be debarred from nominating any other person for the same vacancy.

By Order of the Council

GRAHAM D. CLIFFORD,
Secretary.

26th June 1976.

Fighting for the Professional Engineer

LINDA DICKENS*

Reprinted from *Personnel Management*, May 1976

At the end of 1975 the Council of Engineering Institutions (CEI) did something which, for it, was remarkable. It published a report urging professional engineers to join trade unions.

The report followed the setting up of a working party in September 1975 to look into the relations between the institutions, professional engineers and trade unions, and to recommend action. The CEI became aware of considerable discontent among engineers concerning their status in the community, their levels of remuneration and concern about how recent and pending legislation in the employment field, such as that on 'industrial democracy', would affect them. The CEI was also being criticized for not doing more to provide the professional engineers with a powerful voice when dealing with government and not performing a more effective public relations function. Many professional engineers felt the CEI had not performed the function intended for it, which was to unify and enhance the profession and to present a common front to the public and government.

All this led to plans to restructure the CEI, threats from certain member institutions to withdraw from it, and to attempts by the CEI to do something to meet the expectations which professional engineers had of it. This is the background from which the report on professional engineers and trade unions emerged. The CEI obviously thought that this was one area where it could try to give a lead. But in so doing it stirred up a hornet's nest.

The question of professional unionism is one which gives rise to much heated debate among professionals themselves and even more heated claims and counter-claims by organizations seeking to represent them. The CEI report[1] is a good starting point from which to seek to examine the arguments about the unionization of professional employees and 'professional unions'.

UKAPE and APST versus the TUC Unions

The two professional unions which the CEI recommended as suitable for professional engineers working in the private sector are the United Kingdom Association of Professional Engineers (UKAPE) and the Association of Professional Scientists and Technologists (APST). UKAPE was formed in 1969 and APST in 1972 to meet a perceived need for collective representation on the part of professionally qualified employees—a need highlighted by narrowing differentials.

The two organizations differ in their concept of what a professional union is, or should be, but both have a specific field of recruitment which centres on members of chartered institutions. These are members of the CEI bodies for UKAPE, and members of the Council of Scientific and Technical Institutions (CSTI) for APST. The engineering and scientific institutions are primarily learned bodies concentrating on education and qualification. What they cannot do is negotiate over their members' pay and conditions of employment. This was the role UKAPE and APST hoped to perform.

But the professional unions are not alone in hoping to organize professional employees in industry. The professional employee in the private sector for example is also being wooed by such unions as the Technical Administrative and Supervisory Section of the Engineers Union (AUEW TASS) and the Association of Scientific Technical and Managerial Staffs (ASTMS). How is the professional employee to decide which to accept?

If we take professional engineers as our focus, we find the major arguments which are put forward by UKAPE centre on the very concept of 'professional'. Qualified engineers, UKAPE argues, do not want to have their views swamped by those of non-professionals and lower-level technicians in their dealings with the employer. They do not want to be part of a 'political' TUC union. They want a union which, like UKAPE, respects a professional's allegiance to a code of ethics. They do not want to be drawn into militant confrontation with the employer, to whom they feel a special loyalty. Perhaps most importantly they want their superiority over staff who are not professionally qualified recognized and their status as professional engineers asserted. Status is of course partly a question of financial reward but it is also bound up with image. Nothing annoys a chartered engineer more than the public's image of an engineer as someone in greasy overalls.

But if professional engineers do feel like this one is justified in wondering why so few of them (only 5500) have actually joined the professional union which was set up to cater specially for them. One explanation might be that these views are not shared wholeheartedly by the remaining 200 000 or so chartered engineers in Britain or as far as the private sector is concerned by the 120 000 professional engineers employed there. Another explanation might be that they do not see membership of the professional union as the way to achieve these things.

There is some evidence to support both hypotheses. As far as the anti-TUC argument is concerned this certainly does not appear to be accepted by all professional engineers. According to the CEI report almost 90% of the professional engineers in unions are in TUC-affiliated or TUC-recognized unions. It is becoming increasingly common for white-collar unions, including those organizing at the 'professional' level, to affiliate to the TUC. The members of the Association of University Teachers have recently been voting on this very issue. Affiliation is not generally seen by such unions in political terms but as a way of obtaining a say in government decision making and of increasing their negotiating power. The CEI report itself stated that 'it would be wrong to suggest that a union affiliated to the TUC would, for that reason alone, be an unsuitable one'.

Views on Industrial Action

TUC affiliation can increase an organization's effectiveness, and proved effectiveness is perhaps the main thing which UKAPE lacks and which other unions can offer the professional employee. UKAPE's lack of effectiveness owes something to its small membership and consequently limited finances and also to its failure to obtain recognition from employers, which we shall discuss later. But UKAPE is also caught up in the conflict between professionalism and

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effectiveness. UKAPE feels that it is unprofessional to take industrial action against an employer. However if a union is to be effective it has to 'deliver the goods' to its membership. If professional engineers are worried (as they are) about decreasing differentials between them and their subordinates and about their unfavourable salary position when compared to professional engineers abroad, then a union which is to attract and retain them has to show itself able to do something about such things.

UKAPE rejects what it terms the 'left-wing TUC leaderships' philosophy of confrontation' with the employer. Instead it argues that professional engineers can exert pressure by mounting press campaigns, by raising issues at company annual general meetings and by lobbying in the corridors of power. Ironically, this last tactic is one which non-TUC unions find so hard to employ; people in power will not deal with them. But even if these tactics could be used they seem somewhat removed from the real world of industrial relations. Although a union does not have to strike to be effective, one can question the likely effectiveness of a union which on principle shuns industrial sanctions. Admittedly professional employees do not resort to industrial action very often (partly because is is not always the most effective weapon) but in Britain, as abroad, professionals like teachers and doctors have been willing to take such action when they felt it to be in their interests. Can the professional engineer afford to be different from his fellow professionals?

Perhaps, not surprisingly, UKAPE's stance on industrial action is not shared by APST which takes a more realistic view of industrial life. Although it shares with UKAPE the belief that the professional employee can get what he wants through logical and reasoned argument, APST does recognize that an organization's credibility is open to question unless it at least countenances industrial action when the employer appears impervious to logic and reason. Even so, APST belives it 'blotted its copybook' recently when its members struck for the first time. The strike at BDH Chemicals at Poole was over recognition.

The 'Recognition' Problem and Bargaining Units

Recognition by the employer for negotiation is perhaps the *sine qua non* of an organization's effectiveness. It also provides a springboard for growth. UKAPE'S membership has declined over the past five years, largely because of its failure to obtain recognition from any major employers. The Engineering Employer's Federation refused to recognize it and individual engineering companies took the same line. In the early days of the Industrial Relations Act 1971, however, hopes ran high among UKAPE officials. The Act, it was thought, would be used to force employers to recognize the professional union and it would go from strength to strength. These hopes were dashed when rational bargaining structures were given preference over professional exclusiveness.

Unfortunately for UKAPE, chartered engineers in industry work alongside non-professional engineers and when it comes to deciding bargaining units little attention is paid by employers to the possession of a professional qualification. They concentrate more on the nature of work being carried out. UKAPE'S professional exclusiveness (its very *raison d'être*) was one of the main reasons why it was refused recognition at C. A. Parsons and associated companies. Following an application under the Industrial Relations Act, the Commission on Industrial Relations (CIR) investigated the issue and found that 'looking at the companies as a whole there is no distinguishable group of posts for which a professional qualification is or will become a requirement in the foreseeable future'.[2] To have drawn the bargaining unit around those people whom UKAPE was able to accept into membership (that is the members of chartered institutions) would have made nonsense of firms' bargaining structures as well as cutting into areas where TASS was recognized.

Unions such as TASS which have been recognized for a long time by the engineering employers do not take kindly to possible encroachment by new unions into what they regard as their area of recruitment and they can mount effective opposition which would no doubt deter employers from recognizing UKAPE even if the bargaining unit problem could be overcome.

The professional unions have tried to meet the problem of bargaining units, realizing that employers do not place the same emphasis on professional qualifications as they do. The basis of APST membership came from a merger with the British Association of Chemists. People who were in membership of the BAC as at July 1972 were eligible for APST membership regardless of any lack of professional qualification. From the beginning, therefore, APST had a wider outlook than UKAPE. The main initiators in the formation of APST were the institutions which form the CSTI, particularly the Royal Institute of Chemistry, and members of those institutions provide the professional recruitment area for APST. But APST membership has also always been open to people who possess a degree or equivalent qualification in science or technology and to people who are 'working at a comparable professional or managerial level alongside or in association with Full Members of the Association'. The nature of APST membership therefore is now quite varied, as recruitment on sites is producing a three to one bias against the chartered institute members.

The biggest influx of members in APST has been the ICI 'Blue Book' staff who voted in a ballot held at the company in favour of APST. They account for some 2500 of APST total membership of just under 10 000. The ICI recruits include such people as marketing men who form part of the middle management grades covered by the 'Blue Book'. These developments seem to indicate that APST is on the way to becoming a managerial rather than a professional union. Although it claims that it does not want to move too far from its origins by recruiting too many non-professional and non-scientific staff, this may be the only way for the organization to survive.

UKAPE faced with the same bargaining unit problem formed an alliance with the Association of Supervisory and Executive Engineers (ASEE). This is a non-TUC body which was also deemed suitable by the CEI report. The idea was that ASEE could take into membership all those people in a bargaining unit who were not eligible to join UKAPE and the two organizations would then act together as a joint negotiating panel. But employers have been no more willing to recognize the two bodies acting together than they were to recognize either separately. The realities of operating in private sector industry seem to call for a merger between the two bodies if they are to get anywhere, but this of course would dilute UKAPE's professional image. Although such a merger might make sense in terms of the realities of industry, UKAPE members outside manufacturing are likely to resist any such move. It is among such members that professional idealism appears to flourish most strongly.

UKAPE has also followed APST's example and has widened its recruitment scope. But while it will now take into membership non-institute engineers or professional staff who are not engineers but do work of the same level as professional engineers, such people are recruited into a separate grade—site associates—and cannot sit on UKAPE's Executive Council or be sent to the Delegate Conference.

Although UKAPE was recommended by the CEI report it nevertheless felt let down by it. One reason for this was the fact that the CEI recognized that 'an industrial employer does not make distinctions based simply on a professional qualification' and so included the following among the criteria by which it thought a union's suitability should be judged: 'membership is primarily professional and its qualifications for membership are related more to industrial levels of responsibility than to academic qualifications'. To UKAPE this amounted to a rejection of the professional idea by the very bodies responsible for awarding the professional qualifications.

Minority Groups in Large Unions

UKAPE was also disappointed by the report's finding that in the public sector the unions representing professional engineers 'have long provided good service' and could be recommended to professionals in the public sector. Unlike APST, UKAPE had aspirations to recruit in the public sector despite the fact that unions like the National and Local Government Officers' Association (NALGO) and the Institution of Professional Civil Servants are recognized and well established collective bargaining arrangements exist.

But the CEI did reinforce the argument that it 'would be quite inappropriate . . . for a professional man to be in common union membership with an overwhelming proportion of unqualified people whose work he had to direct and whose interests could be quite at variance with his'. The likelihood of a closed shop coercing them into joining their subordinates' union is something which apparently worries many senior staff, professional and non-professional alike. Yet the wish on the part of employers to avoid fragmented bargaining arrangements and multi-unionism and the desire on the part of all employees to be represented by experienced and effective organizations argues against setting up a management staff association or bringing in a professional union with a limited recruitment area.

The problem of minorities within a large union is of course a real one but it is often exaggerated. As the CEI report implicitly recognized, unions such as NALGO manage to represent successfully a wide range of staff in the public sector. (Indeed if there are complaints from within such vertically organized unions they are more likely to come from subordinate employees than senior staff.) A union can negotiate separate procedural and structural arrangements for the various distinct sections of its membership. There is no reason why senior staff within a large union should not have their own more-or-less autonomous committee or even belong to a separate branch, which will decide policy and represent their particular interests. At least by forming a section within a large union professional and managerial staff have access to resources and backup facilities which professional unions with only a few thousand members cannot hope to provide.

TASS Activities

It is on such arguments as the provision of expertise and backup facilities that the established TUC unions base their appeal to professional employees. They know, and stress, that relatively newcomers such as the professional unions cannot possibly compete in this area. TASS and ASTMS each have a number of successes in representing various types of employees to which they can point. They also stress that TUC affiliation brings with it affiliation to recognized international trade union bodies as well as a say in industrial decisions made by government and the EEC.

One area where TASS is trying to recruit professional and other managerial staff is aerospace and its recruitment literature for that industry highlights the ways in which this union attempts to attract such employees into membership. The catalyst to collective representation in aerospace has been the planned transfer to public ownership. TASS emphasizes that 'Engineers, Scientists, Managers and Technicians' must be heard during this transfer and that if rationaliztion follows nationalization then such employees will need 'a powerful voice to defend their interests'. The recruitment literature includes details of TASS activity in the field of aerospace and stresses that officials know the industry. Aware that the kind of staff it is trying to recruit are sometimes reluctant to join unions, TASS recruitment literature points out that senior staff in every nationalized industry are organized by established trade unions and that separate structures can be created for the conduct of negotiations for senior and management staff.

This 'positive' approach to wooing the professional employee is, however, only one aspect of the way TUC unions go about winning their membership. It is accompanied by propaganda aimed at showing that organizations like UKAPE are a waste of time. In a booklet put out by TASS entitled 'Which way forward for professional engineers?' much space was devoted to arguments against the need for 'professional' unions and against UKAPE in particular. ASTMS has also collected 'evidence' against such bodies which it will present to the Certification Officer in an attempt to prevent them being declared independent.

But the real battles for membership are not fought in the letter pages of the financial and technical press or by the circulation of recruitment literature. Although both these tactics can have an important influence on employees' perceptions of unions and their willingness to join, what really matters is what happens at the place of work. It is now a generally accepted truth that one of the major factors affecting an employee's willingness to join a union is whether that union is recognized by the employer in respect of his grade of employee. Here the established TUC unions win over the professional unions hands down. As we have seen, employers prefer the established TUC unions and from their established bases within private industry such unions are in a position to extend into professional and managerial areas.

The EPEA Position

TASS claims that professional engineers and senior managers are now its fastest growing occupations while ASTMS has also successfully organized managers, including professionally qualified employees, in private industry.

However, it is still true to say that for many staff employees the jump from professional union or staff association on the one hand to AUEW TASS or ASTMS on the other seems to be too great, even though such unions appear to offer the greatest chance of effective representation. It was a jump at which the CEI itself baulked. Although it did not rule out TUC trade unions the CEI report only recommended one as potentially suitable for professional engineers in the private sector. This was the Electrical Power Engineers Association (EPEA). It was found suitable while other TUC unions were not because its rules contain 'desirable restraints on strike action' and it 'recognizes the value of a code of conduct'. To date, however, as its name suggests, the EPEA has operated within the electrical power generating industry and for it to take advantage of the CEI recommendation it will have to extend its field of recruitment. The EPEA national executive is seeking to do this but it faces opposition. Opposition from within the EPEA comes from members

* *Editorial note.*—The recent ASEE Annual Delegate Conference unanimously approved a ballot of members on a 'transfer of engagements' to the EPEA and recommended this amalgamation.

who feel such a move will dilute the Association's concentration on their own interests. More telling, however, is the opposition from other TUC unions. Although the EPEA argues that it would not recruit at the expense of fellow TUC affiliates, TASS has already cried 'Bridlington'.

Employer hostility

The TUC principles governing relations between unions,[3] which have developed out of the original Bridlington Principles of 1939, provide that no union shall try to recruit workers of a certain grade where another union has organized the majority of them. This might at first appear not to apply to the EPEA's planned recruitment of professional engineers and middle managers in private sector industries since existing unions in these industries will often not have a majority of such people in membership. But the TUC principles recognize that there may be circumstances where a union might not have organized a majority of the workers in question because of 'exceptional difficulties', for example employer hostility to such organization. In such a case no union can begin to recruit without consultation and agreement with the existing union. Where there is disagreement between the two unions the TUC can set up a Disputes Committee.

The CEI report may have fired the debate about professional engineers and unions but clearly does little if anything to resolve the issue. What then is likely to happen to the professionally qualified employee in private industry? The Employment Protection Act 1975 provides for the Advisory Conciliation and Arbitration Service (ACAS) to investigate a recognition problem and make recommendations as to which union should be recognized, in respect of which employees and in respect of which issues. To use this procedure a union must be 'independent' as judged by the Certification Officer. UKAPE has already applied for a certificate of independence and APST is likely to do so soon. Although ASTMS is ready to raise numerous objections to such bodies being granted a certificate of independence it seems unlikely that the Certification Officer will find them 'under the domination or control of an employer or a group of employers' or 'liable to interference by an employer . . . (arising out of the provision of financial or material support or by any other means whatsoever) tending towards such control'.* Once certified as independent, UKAPE and APST can use the Employment Protection Act's procedure in attempts to gain recognition from employers. But the procedure is also open to unions such as ASTMS who are likely to seek to use it to oust APST from footholds it has so far obtained. A challenge by ASTMS on APST's position within ICI, for example, looks imminent.

The ACAS view

The way in which ACAS will handle recognition problems has yet to be seen. Although the Act states that the opinions of the employees concerned should be ascertained, it does not lay down the kind of guidelines as to the scope of bargaining units and the nature of bargaining agents which were provided for the CIR in the Industrial Relations Act. Nevertheless it is difficult to see how ACAS faced with a C. A. Parsons situation would reach a conclusion which differed from that reached by the CIR. ACAS may not specifically be told by the Employment Protection Act that the union recommended as the bargaining agent must be an effective organization with sufficient resources to represent the employees but clearly this is something which it will take into account in making its recommendations. Similarly, when determining the extent of a bargaining unit ACAS is likely to consider the nature of work done and the existence of common interest among employees as much as professional or other qualifications they may or may not hold. It is also likely to balance the possible need for separate bargaining arrangements for certain types of employees against the need for any new bargaining unit to fit into the existing pattern of management and union organization and the need not to disrupt arrangements which appear to be working well.

If the professional unions can win the support and potential membership of a substantial number of employees in a realistically-defined bargaining unit then they may be able to win ACAS recommendations in their favour. But to stand any chance of doing this, UKAPE especially will have to change its outlook and widen its scope. In moving away from professional unionism, however, the professional union loses its very reason for existence and becomes just one more union in the highly competitive white collar field.

* This is the definition the Certification Officer will use. See Trade Union and Labour Relations Act 1974 (ch. 52) Section 30. *Editorial note.*—On June 7th UKAPE was granted a Certificate of Independence.

References

1. CEI, 'Professional Engineers and Trade Unions', London 1975. (See *The Radio and Electronic Engineer*, February 1976, p. 53).
2. Commission on Industrial Relations, 'C. A. Parsons & Co. Limited and Associated Companies', Report No. 32 (London, HMSO 1972.)
3. TUC, 'Relations between Unions,' London 1970.

Standard Frequency Transmissions—April 1976

(Communication from the National Physical Laboratory)

April 1976	Deviation from nominal frequency in parts in 10^{10} (24-hour mean centred on 0300 UT)	Relative phase readings in microseconds NPL—Station (Readings at 1500 UT)	
	Droitwich 200 kHz	*GBR 16 kHz	†MSF 60 kHz
1	0	698·3	612·2
2	0	697·9	612·3
3	0	698·1	612·3
4	0	698·6	612·1
5	0	698·3	612·1
6	0	700·1	612·3
7	0	698·7	612·3
8	0	698·7	612·5
9	0	698·7	612·4
10	0	698·6	612·2
11	0	698·4	612·2
12	0	698·6	612·3
13	0	698·4	612·3
14	0	698·3	612·2
15	0	698·4	612·2
16	0	698·4	612·3
17	0	698·0	612·3
18	0	698·2	612·4
19	0	698·4	612·4
20	0	698·4	612·5
21	0	698·3	612·5
22	—	698·2	612·4
23	0	698·3	612·4
24	0	698·2	612·5
25	0	698·4	612·5
26	0	698·7	612·4
27	0	698·3	612·5
28	0	698·5	612·5
29	0	698·5	612·5
30	0	698·4	612·7

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

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

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

New BSI Publications

Performance of Stabilized Power Supply Apparatus

The British Standards Institution has just published BS 5148 'Method for specifying the performance of stabilized power supply apparatus'. This new Standard describes the method to be used by manufacturers in describing the performance of stabilized power supplies designed to provide calibrated values of voltage and/or current in connection with electrical measurements, and of their accessories. It is identical in content with IEC Publication 443. Contents include definitions, determination of errors, and tests as well as general requirements concerning statements and tests.

Copies of BS 5148 are available from BSI Sales Department, 101 Pentonville Road, London N1 9ND. Price £3.50 including postage.

Guidance on Double Insulation

The British Standards Institution explained the principles of the method of construction of electrical equipment known as 'double insulation' fourteen years ago in BS 2754. With the increase in the variety of equipment the method of classification of different forms of construction has become more difficult to use, and BSI has published a simplified classification in the new BS 2754, 'Memorandum on Construction of Electrical Equipment for Protection against Electric Shock'. This classifies equipment according to the method of connection to the electrical supply. Guidance on the forms of construction to be used for each class of equipment under different environmental conditions is also included.

This memorandum is not itself a specification but is intended to be used as a guide by specifiers such as other BSI committees concerned with preparation of standards. The revision includes definitions of a number of terms and recommends their use where applicable in other British Standards.

Copies of BS 2754 are available from BSI Sales Department, 101 Pentonville Road, London N1 9ND. Price £3.10 including postage.

New Reference for Electricity Supplies

After the success of its World Electricity Supplies wallchart, Technical Help to Exporters (THE), the department of the British Standards Institution which advises exporters on overseas technical requirements, has now published an updated version in handy booklet form. The new 'World Electricity Supplies' booklet has an introduction and notes in French and German as well as English and gives details of the supply sources, household, commercial and industrial voltages, voltage tolerances and frequencies of 148 countries throughout the world. It costs £1.50 to THE members and £1.75 to non-members (postage included) from Sales Office, Technical Help to Exporters, British Standards Institution, Maylands Avenue, Hemel Hempstead, Herts. HP2 4SQ.

BS 9000 Scheme: Guide to Approved Components

The 1976 edition of PD 9002: BS 9000 'Component Selection Guide' has just been published by BSI, updating information on all approvals and specifications for electronic components in the BS 9000 scheme. This is the only comprehensive document for speedy technical reference on BS 9000 and is an essential guide for those involved with this rapidly expanding scheme. There are now approximately 100 manufacturers approved under the scheme, as well as 30 distributors and 10 independent test laboratories, with many more to come. Over 500 qualification approvals exist for individual component types, and this total is increasing steadily by approximately 15 approvals per month. Large users of electronic components such as the Ministry of Defence and the Post Office are placing considerable emphasis on the BS 9000 scheme.

With the aid of the new guidance document, PD 9002, users wishing to select from components approved under the BS 9000 scheme can narrow their choice from hundreds of possibles to two or three probables in just a few seconds. The document is now published in a loose-leaf binder for ease of amendment and will be regularly updated every four months for a five-year period. It is available on an annual subscription basis, and currently covers information up to 1st February 1976.

Parts 1, 2 and 3 form between them a complete list of approvals of products and firms, together with an index which provides a method of easy cross-reference between components and specifications. Parts 4 to 8 contain abstracts of technical data about all published BS 9000 series detail specifications, together with the type codes and manufacturers of approved products. Details of products from UK manufacturers which conform to a parallel European approval scheme for electronic components (CECC) is also included. The BS 9000 scheme is currently being extended by the publication of BS E9000 specifications corresponding with CECC documents.

Copies of PD 9002 are available for a yearly subscription of £11.00 from Sales Office, British Standards Institution, Hemel Hempstead, Herts. HP2 4SQ.

Letter Symbols for Quantities and Units used in Electrical Engineering

BS 1991 'Letter Symbols Signs and Abbreviations' is published by BSI in six parts, and a revised edition of BS 1991, Part 6 'Electrical science and engineering', has recently been issued. Since its first publication in 1963, Part 6 has been a well-used source of reference for good practice in the use of the symbols for quantities and units in electrical technology. Its recommendations are urged upon authors of papers in the Institution's Journal and most other professional technical publications.

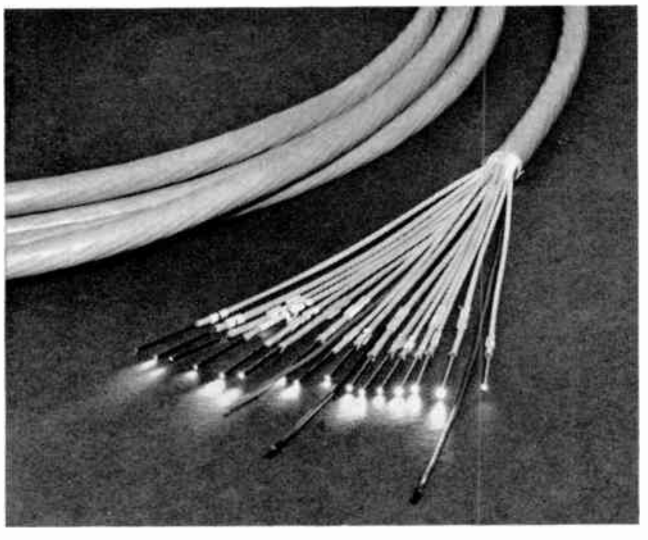
The revision was made to maintain the broad correspondence with relevant recommendations of the International Bureau of Weights and Measures, of the IEC, and ISO. Part 6 had in the course of the last decade gradually fallen out of line or had become out of date in a number of respects, a few of which were important. The changes mostly relate to SI units and the latest practice with unit symbols; although the alignment on symbols for quantities with corresponding IEC and ISO publications had remained good, the opportunity has been taken to improve the alignment in this respect with IEC 27–1 (1971).

Copies of BS 1991 Part 6 are available from BSI Sales Department, 101 Pentonville Road, London N1 9ND. Price £3.50 including postage.

Industrial News

New Multi-core Fibre Optic Cable

A new multi-core fibre optic communications cable has been developed by Rank Optics of Leeds. The example in the accompanying photograph contains sixteen fibre optic channels plus three conventional wire links and was produced for the linking of a computer main frame to peripheral devices operating in noisy electrical environments. Alternative numbers and configurations of optical and electrical channels can be produced to meet specific requirements. The fibre optic channels and wire links are grouped on a conventional electrical cable arrangement and jacketed in PVC to form a compact and flexible multi-channel link.



Plessey Capacitors Factory in Germany

Plessey Capacitors has established a new 2000 sq. metres factory in Germany as part of a major programme to advance its business operations in that country. The new factory is at Landsberg am Lech, near Munich. Initial plans are for the manufacture of high volume products for which a local source of supply is considered necessary to meet customer requirements. Already, installation of automated production lines for metallized polyester capacitors is nearing completion.

UK Television Manufacturers' Appraisal of Teletext Market

The British Radio Equipment Manufacturers' Association (in conjunction with Research Bureau Limited) have completed a comprehensive market research project into the possible future demand for television sets incorporating a Teletext facility.

Teletext is the service that can be provided by television to allow written summaries of news and information, transmitted by the BBC (CEEFAX) and IBA (ORACLE), to be received in the home. The necessary coded signals are included in the blanking vertical period; the system is at present experimental until September 1976. Teletext is complementary to the Post Office's Viewdata system which uses the telephone network for supplying signals to Teletext receivers.

The results of the research are regarded as encouraging and tend to confirm earlier optimism of the ultimate success of Teletext. Among Research Bureau Limited's conclusions are that special attention will need to be paid to the informational needs of women; and that the need for immediate news was significant. The effect of the additional receiver cost on demand is dealt with in the research report.

The research was conducted in three stages. The first (23 pages) explored the information possibilities and concepts of Teletext. This led to an appraisal in the second stage (56 pages) of these topics in terms of their degree of interest, current source of information, frequency of use, etc. The final stage (50 pages) attempted to assess the market potential of Teletext, using the data generated from the first two stages.

Colour Television Exports from Hong Kong

Hong Kong exported eight times as many colour television sets between January and July 1975 as she did in 1974, according to the Hong Kong Trade Development Council. Export figures for colour sets during this period show a value of £899,000 as compared with exports of £112,000 in 1974.

The largest customer for the sets is Australia who have suddenly discovered Hong Kong as a source of supply: in 1974 they bought no sets at all, but up to July 1975 they had bought nearly 3,000 sets worth some £314,000. West Germany in the first seven months of 1975 placed orders worth £246,000—almost three times as much as last year. Other significant markets are Nigeria who bought sets worth £156,000, Singapore (£60,000), Saudi Arabia (£44,000), United Arab Emirates (£41,000), and Kuwait (£25,000).

Exports of black and white television sets have also increased substantially with exports for the half year totalling £75,000 as against £545 last year.

British Equipment for Jamaican Government Television Project

A complete new broadcasting station in Kingston, Jamaica, is to be equipped by Link Electronics of Andover. The contract has been won in the face of stiff competition on a world-wide tender for the project which is being funded by the World Bank. The Educational Radio and Television Production Centre will be part of the World Bank's second major educational project in Jamaica. When the studios become operational, educational programmes will be recorded for broadcasting many hours during each day over the Jamaican national radio and television networks.

Link's contract covers the design, equipment supply, and system installation for the Production Centre. It will include two complete television studios, master control and presentation areas, two multiplex telecine machines, a station monitoring system, microwave links to the transmitter site and the installation of three video tape machines. Additionally, there will be a sound broadcasting/recording studio with a tape editing suite, and a film editing and dubbing facility with two review theatres. A wide range of equipment—mostly British—is included in the Link contract, including: eleven Link Electronics cameras (two of which are for the Link telecine machines), Vinten camera pedestals, Neve and Audix sound consoles, Prowest picture monitors and vision mixers, lighting by Electrosonic and Berkey, Leevers-Rich tape recorders, Electronic Visuals waveform monitors, and a Rediffusion distribution system.

Due to be commissioned in June 1976, the new station in Kingston is expected to go on the air in the Autumn, following a period of training and preparation.

Members' Appointments

BIRTHDAY HONOURS

The following members' names appear in Her Majesty's 1976 Birthday Honours List:

KNIGHT BACHELOR

John Emms Read (Companion 1974) Chairman EMI Group; Sir John has represented the classes of Honorary Fellows and Companions on the Council of the Institution since 1975.

MOST HONOURABLE ORDER OF THE BATH

To be an Ordinary Member of the Military Division of the Third Class, or Companion (C.B.)

Major-General Henry Ernest Roper (Member 1953) late Royal Corps of Signals, Colonel Commandant Royal Corps of Signals.

MOST EXCELLENT ORDER OF THE BRITISH EMPIRE

To be Ordinary Knight Commander of the Military Division (K.B.E.)

Vice-Admiral Philip Alexander Watson, M.V.O. (Fellow 1967) Chief Naval Engineer Officer and Senior Naval Representative, Bath.

To be an Ordinary Officer of the Civil Division (O.B.E.)

Arthur Charles William Haddy (Fellow 1960, Member 1942) Chief Recording Engineer and Director, The Decca Record Company Ltd.

To be Ordinary Member of the Military Division (M.B.E.)

Major Stanley Rycroft, REME (Member 1971) British Embassy, Teheran.

To be Ordinary Member of the Civil Division (M.B.E.)

William Michael John Parfrey (Member 1962) Quality Manager, Cossor Electronics Ltd.

CORPORATE MEMBERS

Mr. R. A. H. Gooday (Fellow 1965, Member 1957, Associate 1951) has retired from his post as Senior Lecturer in Management Studies at the City of Birmingham Polytechnic, and is now working as an independent Management Consultant. Mr. Gooday joined the Polytechnic as a Lecturer in 1970, becoming Senior Lecturer in 1972.

Group Captain J. H. Jenkins, RAF (Retd.) (Fellow 1968) is now Senior Training Adviser (Technician and Technologist) with the Construction Industry Training Board. He joined the CITB in 1971 on retirement from the RAF his last appointment being Deputy Director Electrical Engineering 2 in the Air Force Department of the Ministry of Defence.

Mr. G. A. McKenzie, B.Sc. (Fellow 1968) was the representative of the Independent Broadcasting Authority to receive the Royal Television Society's Geoffrey Parr Award for 1976. This Award was made jointly to the design teams from the BBC, IBA, and BREMA who were responsible for 'pioneering work which led to the specification of a data broadcasting system, Teletext'. Mr. McKenzie is head of the Automation and Control Section of the IBA's Experimental and Development Department, and in the eight years he has held that position he has been responsible for extensive studies in the use of computer, automation and digital techniques for the control of large networks of unattended television transmitters.

Mr. J. M. Peters, M.Sc., B.Sc.(Eng.) (Fellow 1964, Member 1955, Graduate 1951), after completing three years as Deputy Director in the Directorate of Standardization, Ministry of Defence, has returned to Portsmouth as Assistant Director Production in the Weapons Production Directorate. From 1967 to 1973 he was Head of Radar Production Group at the Admiralty Surface Weapons Establishment. Mr. Peters served as a member of the Institution's Professional Activities Committee, and previously on the Technical Committee, for some twelve years, retiring earlier this year.

Mr. C. J. Cadzow (Member 1971, Graduate 1969) has been appointed Sales and Marketing Manager following organizational changes in the broadcasting systems group, Mercury Electronics, where he has been since 1971. He was previously with the BBC as a Planning and Installation Engineer.

Mr. R. K. Duley (Member 1973, Graduate 1968) who was formerly Technical Sales Manager with Sarasota Engineering Co. Ltd., Eastleigh, Hampshire, has now been promoted to Chief Engineer. From 1969 to 1971 he was Project Leader on the design and development of electronic traffic signal controllers with GEC/Elliott Traffic Automation.

Flt. Lt. P. M. Eckert, B.Sc., RAF (Member 1976, Graduate 1972) has been transferred from No. 1020 Signals Unit, Royal Radar Establishment, where he was serving as a signals analyst, to be Officer Commanding Engineering Information Centre at the Maintenance Data Centre, RAF Swanton Morley, Norfolk.

Mr. P. J. Gallagher, M.Sc., Ph.D. (Member 1969, Graduate 1966) who was previously a Principal Lecturer at Bradford College, has been appointed Head of the School of Technology and Design at the College. Dr. Gallagher is Chairman of the Yorkshire Section of the Institution and has recently joined the Education and Training Committee. He has also just been nominated to succeed Sir Leonard Atkinson as the Institution's representative on the Court of the University of Bradford.

Mr. J. Hanscott (Member 1969) who joined British Airways (then BOAC) in 1966 as Senior Ground Communication Officer, is now Project Manager at Heathrow Airport.

Mr. S. Helm (Member 1976, Graduate 1971) who has been with Davy Ashmore International Ltd., Stockton-on-Tees, since 1969, has been promoted from Electrical Engineer to Senior Electrical Engineer.

Lieutenant F. J. Jeffries, RN (Member 1973, Graduate 1969) has been promoted to Training Quality Control Officer in HMS *Collingwood*. From 1973 he was Radio Section Officer, Weapons and Electrical Engineering Department, HMS *Blake*. While serving as Watch System Controller at the Mauritius Transmitter Station in 1971, Lieutenant Jeffries was awarded the Institution's President's Prize and Mountbatten Medal for his performance in the 1969 Graduateship examination.

Mr. P. N. Kirwan (Member 1972, Graduate 1967) is now Senior Consulting Engineer with the USM Corporation, Beverly, Mass., USA. After experience with the Marconi Company and in the RAF, Mr. Kirwan took up a post in the United States as Project Engineer with Fairbanks Morse Inc., before joining USM in 1973 as Consulting Engineer.

Mr. C. H. Langton, M.Sc. (Member 1963, Graduate 1952) has been awarded the degree of M.Sc. for research in the field of control engineering at the University of Bradford. Mr. Langton is a Senior Lecturer in Electronic Engineering at the York College of Arts and Technology.

Mr. A. H. Lord (Member 1973, Graduate 1969) is now Technical Liaison Engineer, Service and Installation Division, with EMI Medical Ltd. He joined the Company in 1967 as Junior Development Engineer.

Sqn. Ldr. D. W. Molesworth, RAF (Member 1967) has returned from the United States where since 1974 he has been on exchange duties serving with the US Air Force. He is now on the Electrical Engineering staff at Headquarters RAF Strike Command, High Wycombe.

Mr. A. A. Munro (Member 1973, Graduate 1970) has taken up the appointment of Electronic Engineer (Automatic Test Equipment) with Marconi Space and Defence Systems Ltd., Hillend, Fifeshire. Since 1973 he has been with BAC as a Design and Development Engineer.

Mr. J. E. Ojei (Member 1973) has taken up the appointment of Director of Studies of the Nigeria Technical Correspondence College, Lagos. From 1971 he was Commandant of the School of Electrical and Mechanical Engineering of the Nigerian Army with the rank of Major.

Mr. J. R. Prince (Member 1968, Graduate 1963), formerly with the Research Division of the Fighting Vehicle Research and Development Establishment, is now a Principal Professional Technology Officer with the Ministry of Defence Procurement Executive.

Mr. R. Sansom, B.A. (Member 1972, Graduate 1968), who is with the ML Aviation Company at White Waltham, Berkshire, has been promoted from Senior Design Engineer to Project Engineer.

Mr. A. P. P. Scorer, B.Sc. (Member 1974), for the past seven years an Engineer with Rank Radio International, has been appointed to a Research Fellowship at Leeds Polytechnic.

Mr. K. Soundararajan, B.E. (Member 1973, Graduate 1969) has been appointed a Senior Scientific Officer Grade I in the Avionics and Flight Simulation Division of the Aeronautical Development Establishment, Bangalore. He was previously a Lecturer and Scientific Officer with the Department of Electrical Engineering of the Indian Institute of Science in Bangalore.

Mr. J. W. Southgate (Member 1968, Associate 1962) has taken up the post of Marketing Manager with Crow of Reading Limited. He was previously with the Rank Organization.

Mr. R. R. Thorogood (Member 1971) who since 1973 has been Manager of the Space Communications Department of the Société des Télécommunications Internationales du Cameroun, and was responsible for the building of the West African monitoring station for the *INTELSAT IS-IVA* series of satellites at Zamengoe, Cameroon, has received the award of 'Chevalier de l'Ordre du Mérite du Cameroun'. Before his present appointment Mr. Thorogood held posts with Cable & Wireless Ltd. in various parts of world the including the West Indies, Kenya, the Falkland Islands and Hong Kong.

Mr. P. J. Watson (Member 1971) who has been Senior Project Engineer in the Meter Department at GEC Measurements Ltd., Stafford, since 1966, has joined Ferranti Ltd., as Deputy Chief Engineer (Chief Engineer Designate) in the Instrument Department of the Instrumentation Division.

Mr. L. G. Wood (Member 1959, Graduate 1957) has been promoted to Senior Lecturer at Southampton College of Technology. Mr. Wood retired from REME in 1961 with the rank of Captain and took up a teaching appointment with Tidworth Down County Secondary Modern School, before joining the staff of Southampton College of Technology in 1971 as a Lecturer II.

Mr. A. D. Woode (Member 1967, Graduate 1962) has taken up the post of Senior Engineer with the European Space Agency at Noordwijk, Holland. Since 1972 he has been a Senior Engineer with Microwave & Electronic Systems Ltd., Newbridge, Midlothian.

NON-CORPORATE MEMBERS

Mr. R. Atkinson (Graduate 1968) has taken up the post of Customer Engineering Support Manager in the Advanced Switching Division of the Plessey Company at Poole, Dorset. Since 1974 he has been a computer systems engineering instructor with the Computer Machinery Company, Hemel Hempstead, following a period as a Lecturer in the Department of Computing and Mathematics at Norwich City College.

Mr. R. B. Dissanayake (Graduate 1975) has been appointed Engineer Grade III in the Radio Laboratory of the Sri Lanka Engineering Service. He was previously Telecommunication Inspector with the Sri Lanka Telecommunication Department, Colombo.

Mr. C. T. Seow (Graduate 1969) has been promoted to Technical Assistant (Special Grade) with the Telecommunications Department of Malaysia in the Perak Region at Ipoh, Malaysia. He previously held the grade of Technical Assistant (HF-VHF Radio) in the Department at Kota Bhara, Kelantan.

Mr. R. B. Smith, B.Sc. (Graduate 1969) has taken up the post of Engineer at the local radio station, BBC Highlands, Inverness. He was formerly Assistant Station Engineer with BBC Radio Merseyside in Liverpool.

Mr. R. C. Eaton (Associate Member 1974) was promoted to Chief Wireless Technician last August, and is now at the Headquarters of the Home Office Directorate of Communications after three years as Senior Wireless Technician at the Fire Service Technical College, Moreton-in-Marsh.

Flt. Lt. D. M. Potter, B.A., RAF (Associate Member 1974, Graduate 1971) has left the RAF where he was Flight Lieutenant (Education at) RAF Cosford, and has been appointed a Lecturer in Electronics with BAC Ltd. at the King Faisal Air Academy of the Royal Saudi Air Force, Riyadh, Saudi Arabia.

Mr. T. D. Ibbotson (Associate 1966) has been appointed Technical Director of S. G. Brown Communications Ltd. He joined the Company more than 20 years ago and since 1963 has been Chief Engineer of the Communications Division.

Obituary

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

Colonel George Arthur Bartley-Denniss (Fellow 1962, Member 1956) died on 3rd April 1976, aged 59 years; he leaves a widow.

Born at Barnstaple, Devon, and educated at Cheltenham College and the Royal Military Academy, Woolwich, George Bartley-Denniss was commissioned in the Royal Artillery in 1936. Soon after the War started he was posted to the Far East but was captured in 1942, spending the remainder of the war in a P.O.W. camp. After repatriation he completed the Long Gunnery Staff Course, qualifying as an Instructor in 1949 and following two years as a Technical Staff Officer with the rank of Major, he took the Technical Staff Course (Fire Direction Division) at the Royal Military College of Science, Shrivenham. After two years commanding a Heavy Anti-Aircraft Battery he went back to the RMCS in 1954 as a Lecturer, and then, from 1955 to 1957, he was a TSO1 in the Directorate of Electronics Research and Development, Ministry of Supply, with the rank of Lieutenant-Colonel. Colonel Bartley-Denniss's next appointment was as Commanding Officer of Regiment at Paphos, Cyprus, and from 1958 to 1961 he was TSO1 Radar and Electronics in the Royal Artillery Directorate at the War Office. He returned to RMCS once again as a full Colonel in 1961 to take up the appointment of Military Director of Studies (Electronics and Guided Weapons) which he held until his retirement in 1963. He then joined Decca Radar Ltd., Hersham, and for the next eight years was responsible, as Applications Manager, for the introduction of new electronic devices into industrial and medical applications. During the five years prior to his death he took charge of the external relations of the Research and Development Division.

Ernest Edgar Clark, B.E.M. (Member 1963, Graduate 1958) died on 28th February 1976, aged 56 years. He leaves a widow and two sons and a daughter.

'Nobby' Clark served for 26 years in the Army, entering the Army Apprentices School and, after passing courses as Electrical Fitter at the Royal Military College of Science, served in the Royal Tank Corps and Royal Armoured Corps from 1938 to 1945. He then transferred to REME, eventually reaching the rank of Warrant Officer Class I, and specializing on electronic aspects of guided missiles. Following retirement from the Army, Mr. Clark was for some few years with EMI, subsequently International Computers and Tabulators, concerned with commissioning and maintenance of EMIDEC computers. From 1964 to 1974 he worked for the Naval Division of Elliott Brothers, later the Naval and Ocean Engineering Division of Marconi Space and Defence Systems, initially as Chief Trials Engineer, concerned principally with underwater acoustics, and later as Project Group Manager in the Digital Systems Group, where he was responsible for building and selling computer-based systems for survey and research, including satellite navigation. From 1971 he was Marketing Manager for a wide range of the Division's products in these and associated fields. Four years ago Mr. Clark moved to Underwater and Marine Equipment Ltd. of Farnborough as General Manager; in this post he was particularly interested in quality assurance and he was a Council member of the Association of British Oceanographic Industries.

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

Applicants for Election and Transfer

THE MEMBERSHIP COMMITTEE at its meeting on 6th May 1976 recommended to the Council the election and transfer of the following candidates. In accordance with Bye-law 23, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communication from Corporate Members concerning the proposed elections must be addressed by letter to the Secretary within twenty-eight days after publication of these details.

Meeting: 6th May 1976 (Membership Approval List No. 221)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Graduate to Member

CHATWELL, Paul Steven. *Abingdon, Oxfordshire.*

Direct Election to Member

LUDLOW, Victor John. *Weston-super-Mare, Avon.*
RHODES, John George Laycock. *Malmesbury, Wiltshire.*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

COATES, Erice Normay. *Wantage, Oxfordshire.*

Direct Election to Graduate

BURLEIGH, Peter John. *Coxheath, Kent.*
BUTLER, Gerard Hugh. *Dublin.*

Direct Election to Associate Member

BRINKLOW, Paul Henry. *Camberley, Surrey.*
McMILLAN, Norman. *Acomb, Yorkshire.*
TIMMS, Peter Anthony. *Irby, Wirral, Merseyside.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Graduate to Member

ADELEYE, Isaac Ola Adekunle. *Lagos, Nigeria.*
GBEMINIYI, Olasebika Olasupo. *Auchi, Nigeria.*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

NG, Kai Ming. *Hong Kong.*

Direct Election to Graduate

OROGE, Clement Olusegun. *Ibadan, Nigeria.*

Transfer from Student to Associate Member

SITSABESAN, Sellappah. *Velanai, Sri Lanka.*
UPADHYAY, Narbdeshwar. *Faizabad, Uttar Pradesh, India.*

Direct Election to Associate Member

ALLUM, Christopher George. *Dubai. U.A.E.*
CHAN, Han Tiong. *Singapore.*
LING, David F. C. *Hong Kong.*
OGOLLA, John Joseph. *Nairobi, Kenya.*

STUDENTS REGISTERED

LIONG, Chang Kuan. *Singapore.*
THEODOSSIOU, Socratous Theodosios. *Limassol, Cyprus.*

A New Record Turntable

An electronically-controlled single-play record deck known as the ADC Accutronic 4000 and claimed to be the first major leap forward in the development and application of record playback systems for three decades (i.e. since the introduction of the l.p.), is being manufactured by BSR Ltd.

The pick-up arm is moved into the playing position by a separate servo-controlled motor with a clutch system so that the arm is completely disengaged from any mechanism while actually playing. The arm has the usual side-thrust and counterbalance adjustments associated with high quality equipment. A d.c. motor direct-drive turntable is used which ensures that rumble, hum, wow and flutter are at a minimum.

The novel feature of the deck, however, is that the pick-up motor is controlled by logic circuitry incorporating l.s.i. m.o.s. chips and this is programmable so that the stylus may be set down at the beginning of any track (or band) on the disk. It can play a selection of any or all of the bands in any pre-selected order. The cartridge, based on ADC XLM Mk. II, includes an infra-red l.e.d. generator and detector which can 'see' the relatively reflective areas on the records between the bands; the logic circuit can then count the bands and accurately set the stylus down. There are also opto-electronic sensors in the base of the arm to detect the beginning and end of 12 in. and 7 in. disks.

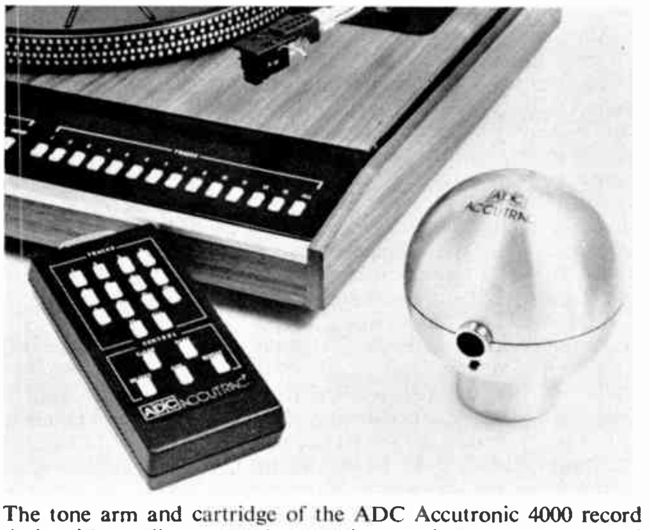
All this is programmed through an impressive array of buttons on the front of the unit which are all repeated on an ultrasonic remote control transmitter resembling a hand-held calculator. The ultrasonic control signals are directed at a separate receiver connected by cable to the unit, which therefore can itself be in a remote position.

After placing the disk on the turntable everything is done by push-button and, apart from the band selection facility, a great benefit is that this eliminates the risk of damage to the record by handling the pick-up.

The turntable will retail at 'just under £300—inclusive', which seems reasonable for the degree of sophistication involved. BSR Ltd. are planning to produce two further models; the Accutrac 3000 and 2000 which will have all the same controls but with belt drive turntables and lower prices.

Although one might think that there is too much 'sophistication', the basis for the unit is an excellent direct-drive turntable and a pick-up which is free from all mechanisms while in action and free from the human hand during band selection. Add to this all the control facilities and you have an exciting advance in audio equipment.

D.S.



The tone arm and cartridge of the ADC Accutronic 4000 record deck with cordless control transmitter and the remote control receiver.