Volume 52 Number 4 April 1982

The Radio and Electronic Engineer

Journal of the Institution of Electronic and Radio Engineers

IERE NEWS AND COMMENTARY

PAPERS

Company Profile

The history of Elliott Brothers (London) Ltd is told from its foundation in the early years of the nineteenth century up to the late nineteen sixties which saw the establishment of the first automation company—Elliott Automation. This company subsequently divided, part remaining with the General Electric Company and the other part linking with Fisher Controls. A number of the more outstanding products of this long existence are briefly described.

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The Radio and Electronic Engineer

The Journal of the Institution of Electronic and Radio Engineers

NEWS AND COMMENTARY

The Lessons of a Satellite Failure

Meteosat-1, which was launched on 23rd November 1977, failed on 24th November 1979 after two years duty, although its theoretical lifetime was three years with 50% success. This failure, caused by a protective device in the electrical power supply, prevented the spacecraft from carrying out its main missions—image taking and dissemination. The data-collection mission was the only one that could be maintained.

At the first sign of malfunction of the satellite in November 1979, a team of experts met at ESOC to analyse the failure—identifying the origin and evaluating the consequences in an attempt to overcome it. On the recommendation of this team many investigations, tests and simulations were performed on a breadboard of the suspected device to explain the source of the phenomena.

It appeared that a digital circuit, which was designed to be triggered only in the case of overcurrent, was able to oscillate depending on the value of a resistor. Technological studies showed in fact that a degradation mode specific to this resistor caused its resistance value to be equal to this critical value.

The studies, whose goal was to resume operation of the satellite, could not indicate a successful recovery procedure, and it was thus decided to abandon the imagery and dissemination mission.

However, an objective was still to be reached: find a way to avoid the repetition of such damage on *Meteosat-2*. The reliability procedures were thus looked into and resistors in all the protection devices of the electrical power supply were replaced. Moreover, a relay was added to each of these protection devices either to keep them on circuit or to by-pass them.

The satellite is now also fitted with two batteries, thus enabling the available peak electrical power to supply all missions simultaneously during a period of more than three years.

The grounding of the thermal shields will significantly reduce the electrostatic discharges which were experienced on *Meteosat-1* and the induced sporadic changes of the satellite configuration. In addition, the triggering level of the logic circuits was reinforced to reduce even further the sporadic changes of the satellite configuration due to electrostatic phenomena. Furthermore, two on-board experiments, one for radiation measurements and the other for electrostatic event monitoring, will allow a better knowledge of the electrostatic charge/discharge phenomena.

During the commissioning of the satellite, the radiometer was submitted to an exhaustive decontamination. This will reduce the duration of decontamination periods in the future.

In addition, as the vibration level expected from *Ariane LO3* was higher than that of the American launcher *Thor Delta*, the structure of the satellite was reinforced.

On 19th June 1981 the second flight model of *Meteosat* was successfully launched by the third qualification launch of the European launcher *Ariane*. After a one-month drift, *Meteosat-2* reached its final position over the Gulf of Guinea. Following evaluation of its performance and after exhaustive decontamination of the radiometer, the satellite was declared operational and started its routine phase on 11th August 1981.

New Technique for Checking V.L.S.I. Circuits

Since the 'soft error' was diagnosed in 1978, Very-Large-Scale Integrated (v.l.s.i.) circuit memory manufacturers have sought a method of detecting the minute amount of naturally occurring radioactive impurities which, if present in v.l.s.i. circuit materials, can disrupt circuit performances.

Now however, Harwell has developed an extremely sensitive technique known as fission track autoradiography (FTA) which can detect the presence of uranium in concentrations as small as 2 parts in 10^9. This provides manufacturers with a quality control enabling them to assess raw materials and components, thereby reducing the risk of component failure.

The 'soft error' effect is produced by alpha-particle emissions from radioactive impurities present in any part of the v.l.s.i. circuit assembly. The energy possessed by an alpha-particle can produce an electric charge which may change the content of a single memory location, giving rise to computational errors. Because of this, semiconductor manufacturers are now specifying alpha-particle emission rates of less than 0·001 particles/cm^2/hour for their memory device materials.

It is not possible to detect such emission levels directly. The Harwell FTA technique exploits uranium-235, the fissile isotope present as 0·72% of natural uranium; prepared specimens of semiconductor material are coated with a polyimide film solid state nuclear track detector (s.s.n.t.d.) and irradiated with thermal neutrons in Harwell's Materials Testing Reactor, DIDO. On irradiation, the U-235 undergoes fission and the resulting fission particles are registered as tracks on the s.s.n.t.d. Afterwards the polyimide film is chemically etched to develop the fission tracks which can then be examined by optical microscopy. From the information gained it is possible to determine precisely the amount of uranium present, down to 2 parts in 10^9 (or a surface distribution of 3×10^{-6} μg/cm^2) and thus to calculate alpha-emission rates of a little as 0·0002 particles/cm^2/hour.

FTA has been used successfully to evaluate many of the materials used in semiconductor manufacture, including silicon, silicide, gold and other metallic foils and resins and ceramics, and Harwell is providing commercial services to leading semiconductor companies in the UK, the USA and Japan.

Recording the 78 rpm era and earlier: an attenuating heritage

Edison, despite the assertion which the popular song makes for reasons of prosody rather than history, did not invent sound, or even sound recording. Sound had been already around for a few million years by 1857 when Leon Scott recorded audio waveforms. Edison was however the first to reproduce sound from a recording, and that event, so beloved of Hollywood biographers of the great 'scientist', is now one hundred and five years in our past. Edison-Bell cylinder recordings were on their way by 1887, and the rival Berliner disks followed in 1894. The same year saw the establishment of the Pathé company, followed in 1898 by the Gramophone Co. which was using the 'His Master's Voice' trademark by the turn of the century. The Victor Talking Machine Co. (taken over by the Radio Corporation of America in 1929) dates from 1901, shortly after which a patent-sharing agreement was concluded with Columbia.

Thus commercial recordings may be dated from about 1890. Major artists were on record by 1900, and by 1910 the industry was coming of age with many famous singers and instrumentalists represented in the catalogues, and orchestral recordings just beginning to appear. The early 1920s saw a lull caused by competition from broadcasting, but the industry took off again later in the decade aided by the switch to electrical recording, which had been foreshadowed by developments at Western Electric as early as 1915.

Sound recording has thus existed for more than a human lifespan and the early recordings represent an invaluable and irreplaceable heritage depicting the music and performers of an age that is now as far in the past as that of Vittoria was to the youthful Bach. Unfortunately 78 rpm records are bulky to store, and over ten times as heavy as a modern microgroove l.p. for equal playing time, so the tendency to 'get rid of those old records' is strong. They are also notoriously brittle and so are easily broken. 'Wax' cylinders are also, for reasons of their own, delicate and bulky to store. It thus becomes important that we should conserve this diminishing heritage before it is too late.

Preserving the material is however not enough; it is also necessary to be able to read it accurately, correcting (so far as we can) for technical characteristics and limitations of the recording equipment, and making due allowance for the modifications of performing practice made necessary (or thought to be so) by these technical limitations. For this purpose, we need measurements made on recording-studio equipment that may have survived (and remained available for experiment). Equally, we need every scrap of evidence about studio practice still remaining unpublished in the memories of those who knew the 'old days'. For example, comparatively little has been published about the microphone techniques used in the 1920s and 1930s. For the earliest period of the industry, direct memory is of course already lost, and those who worked in the 1920s, or even the 1930s, are likely to be as old as the 20th century; so the matter is of some urgency.

Nothing of the above is new, either in itself or in recognition of the problems. The National Sound Archive, the archives of the BBC, *The Gramophone* magazine and EMI, as well as corresponding archives in other countries, and the private collections of amateurs already preserve many thousands of early records. What is comparatively recent is the attitude to the actual signals stored in these records.

It has gradually become apparent that if one can listen through some rather obvious faults, old recordings (and not least those made acoustically) have qualities which *in some ways* have not been surpassed to this day except in some of the latest special-quality records, such as the Nimbus SAM issues. The main limitation in the heyday of seventy-eights was that there was then *no domestic equipment adequate for playing them*. Today, by modifying stylus radius and tracking force, we are able to exploit the very refined pick-up technology developed for microgroove disks, and thus to hear for the first time what is really on the records. Moreover the worst fault of seventy-eights was the surface noise, caused principally by the filler incorporated (amazing though it may seem to modern ideas) in order to 'grind down the needle' and make it fit the groove. Fortunately much of this noise is of an impulsive nature that can be greatly attenuated by modern signal-processing electronics (but with the reservation that an ideal way of doing this without harming the signal has yet to be developed), especially since the use of a stereo pick-up enables both groove-walls to be examined separately. Microelectronics and computer analysis also make possible much more refined correction of frequency-equalization than in the past.

These methods have revealed a previously largely unrecognized sense of depth and spaciousness in the best early recordings, and a corresponding subjective tendency for the music to capture the listener's attention in a way that modern multi-microphone multi-track noise-reduced recordings may fail to do. Thus the performances acquire new musical value quite apart from their historic interest. These qualities may be associated physically with a superior ability to track fast transients, conferred by the higher surface speed and the hardness of the shellac composition of seventy-eights in comparison with the modern 33⅓ rpm vinyl disk. Cylinder recordings also possess advantages of their own, including a very smooth recording medium free from filler.

The practical consequence is that the more pressings of a given record are available, the better chance there is of reconstructing the original signal by finding, for each moment in the performance, at least one groove-wall that is free from major asperities or damage caused by earlier playings with old heavy pick-ups. Thus even when good examples of a recording have been secured for posterity, more are welcome.

It would accord with the specialization of its name and Charter towards information engineering if our Institution were to give special encouragement to efforts to conserve both the heritage of early records and, just as importantly, surviving information about the details of how they were made. There are two principal cut-off dates. The first is when electrical recording was introduced, usually in the latter half of the 1920s depending on the particular studio, and often accompanied by a marked initial *worsening* of audio quality. The second may be set arbitrarily at around 1940. With a few notable exceptions, artists working after this date afterwards re-recorded the same works on more modern (if not necessarily better) media. Recordings made respectively prior to each of these dates are of greater interest, although those made later are by no means to be despised (they too will one day be a century old).

P.B. FELLGETT

Note:

Any reader having personal memories of pre-war recording techniques is invited to write to the author, Professor P.B. Fellgett, The University of Reading, Department of Cybernetics, 3 Earley Gate, Whiteknights, Reading RG6 2AL. The author will also consider purchase, at agreed price or valuation, of pre-war records (disk or cylinder) that any member may be willing to donate in aid of the IERE General Fund Appeal. (*Please do* not *send records in the first place, but give* full *label details including catalogue no., maker, identity of music and performers etc.*)

British Telecom's 100km Monomode Fibre Transmission Experiment

The recent demonstration by British Telecom Research Laboratories of transmission of 140 Mbit/s signals over a continuous 102 km length of monomode optical fibre has been made possible by a number of technical advances in fibre, lasers and detectors. The experiment illustrates the advanced state of the component technology now existing in the UK and has major implications for future system development.

The optical fibre systems currently in production operate with regenerators, i.e. digital amplifiers, spaced at 7 to 10 km intervals. These are necessary because light pulses become both attenuated and distorted over such distances so that to go further would lead to severe degradation of the signal.

All the present systems use graded-index fibre which allows the light to travel in more than 200 different ray paths or modes. Because these travel at slightly different speeds, a pulse of light travelling in such a fibre becomes spread out in time and eventually would overlap.

At the wavelength of the light used (850–900 nm, just outside the visible range) fibre attenuation ranges from 2 to 5 dB/km. This means that over a 10 km fibre, the received signal is 100,000 times less than the power launched into the fibre.

Monomode Fibre

The present experiments have used monomode fibre. This has a much smaller core diameter, so that the light carrying region can only support one 'ray path' or guided mode. This enormously reduces the pulse spreading in the fibre, from around 1 ns/km in graded-index fibre to as little as 10 to 100 ps over 30 km of monomode fibre.

Further benefit was gained by moving to a longer wavelength (deeper into the infra-red) which reduced power loss. At 1300 nm wavelength, monomode fibres have an attenuation of about 0·4 to 0·5 dB/km; this falls to 0·25 to 0·35 dB/km at the 1500 nm wavelength used in the experiment. Thus loss over the full 100 km link (including 11 joints) measured only 33 dB—an exceptionally low value. All fibre was made at Martlesham.

Although monomode operation virtually eliminates pulse spreading due to mode dispersion, it has much less influence on that due to another factor – material dispersion. This arises because radiation of different wavelengths travels at different speeds in glass.

Although pulse spreading from material dispersion falls to near zero at 1300 nm, at 1500 nm it is about 18 ps/nm for every km of fibre. This means that fast pulses from a laser source of 4 nm linewidth would be broadened by about 7 ns over 100 km, which is unacceptable for 140 Mbit/s transmission.

Transmitters and receivers

Pulse spreading due to material dispersion is kept within acceptable limits by using transmitters of greatly reduced spectral linewidth output. This is achieved by injection locking, using two lasers.

The first laser is run continuously under carefully controlled conditions so that it produces a stable single-wavelength output. Some of the power of this first laser is focused into the second laser which is pulsed on and off to generate the signal. When the second laser starts to oscillate, it automatically locks to the injected wavelength, so that power pulses are generated of light which is essentially of single wavelength.

In some versions of this transmitter, linewidths as narrow as 10^{-3} nm have been observed. In systems terms, this means that pulse spreading is negligible over distances of 100 km. The design has been pioneered by Martlesham and is crucial in achieving the necessary performance.

At the receiver end of the fibre, the world's most sensitive receivers for the 1500 nm wavelength are being used, also designed and built at Martlesham. They use p.i.n. detectors fabricated from GaInAs material with GaAs f.e.t. amplifiers in a hybrid integrated package. Similar devices are now being sold world-wide by Plessey.

Land System Prototype

While the 100 km experiment demonstrates the remarkable potential of today's optical technology, plans to use monomode fibre systems in the Telecom's trunk network call for 30 km repeater spacing. With that in mind, a prototype repeater section has been cabled at Martlesham.

It contains 31·6 km of monomode fibre, has joints at 2 km intervals, and has an insertion loss of 17 dB at 1300 nm and 16 dB at 1500 nm. The joint losses average 0·17 dB at 1300 nm and 0·11 dB at 1500 nm.

These figures are important for two reasons. First, they were obtained using a fully automated splicing jig designed at Martlesham for application in the field, greatly reducing the effect of operator skills on system performance. Second, they are much lower than had been expected; it had been thought that the tiny core diameter of monomode fibre (5 μm) would give rise to virtually insuperable problems in field jointing.

The low figures result from the good dimensional control achieved in the fibre, the precision of the fibre-end preparation tool and the detailed design of the automated fusion splicing jig. Field tests on similar cables are planned for Spring 1982.

This 31·6 km prototype repeater section has been used for studies of transmission at rates higher than 140 Mbit/s (1980 telephone channels). Operation at 565 Mbit/s (7680 telephone channels per fibre) has been successfully demonstrated.

In other experiments, the 100 km fibre link has been used to carry broadcast quality television pictures in pulse frequency modulation format. The equipment used for this was developed from an earlier Martlesham design similar to that being used in some CATV applications.

In summary, the 30 km repeater spacing objective for production systems for the land network in the mid-eighties is seen to be readily achievable given good production control. Such systems should also be readily upgradeable to the next higher capacity level (7680 channels). In the undersea systems market, there is great scope for exploiting even longer repeater spacings, promising more cost-effective equipment and the possibility of unrepeatered links between islands or the UK and Europe.

Much of the background to this project is covered in papers in the Special Issue of *The Radio and Electronic Engineer* on Optical Fibre Communications (July/August 1981) and at the IERE Conference on Fibre Optics in March 1982 (Conference Proceedings no. 53).

Members' Appointments

CORPORATE MEMBERS

Major General P. Girling, C.B., O.B.E. (Fellow 1969) has recently been awarded an Honorary M.A. degree by The Open University. From 1972 until his retirement last year, General Girling was the OU's Director of Operations, coordinating the management of the University's audio-visual aids, publishing, correspondence services and warehousing departments. His final Service appointment was Director of Electrical and Mechanical Engineering (Army).

A. J. McMillan (Fellow 1980, Member) has been appointed Managing Director of SIRA Safety Services, Chester. Mr McMillan was previously with ICI, latterly as Manager and Certifying Officer, Approvals Service for Intrinsically Safe Electrical Systems (ASISES).

Lt Col B. Reavill, REME (Fellow 1981, Member 1965) has relinquished his post as Commanding Officer at 33 Central Workshop REME at Newark and taken up a new appointment as Head of Software Division, Telecommunications & Radar Branch REME in Malvern.

W. B. Bishop-Miller, B.A. (Member 1973, Graduate 1968) who was Head of the Department of Engineering at Salisbury College of Technology, has taken up the post of Vice Principal at Barrow-in-Furness College of Further Education.

D. K. Craig (Member 1971) who has been with British Airways since 1953, has recently been appointed Overhaul Manager with responsibility for the repair and overhaul workshops for all aircraft mechanical and avionic components.

Wg Cdr W. A. Gossage, B.A., RAF (Member 1971, Graduate 1969) is now Officer Commanding Engineering Wing at RAF West Drayton. He was previously at the Ministry of Defence as Air Eng 13d (RAF).

Lt Col N. Lyons, R. Signals (Retd) (Member 1968, Graduate 1962) who retired from the Army in 1977 and became Assistant Director of the Electronic Components Industry Federation, is now also Secretary-General of the European Electronic Component Manufacturers' Association (EECA) in Brussels.

K. Mondal, B.Sc., M.Tech., Ph.D. (Member 1979, Graduate 1973) is now on the staff of Bell Laboratories at Allentown, Pennsylvania. Dr Mondal previously held a Chair in the Department of Electrical Engineering at Lehigh University, Bethlehem, Pennsylvania.

P. Mainwaring (Member 1960, Graduate 1953) has been appointed Director of Engineering of the Broadcasting Corporation of New Zealand. Mr Mainwaring began his engineering career with the British Broadcasting Corporation in 1947 and joined the New Zealand Broadcasting Corporation as a Technical Officer ten years later.

S. C. Sood, B.E., M.Tech. (Member 1980, Graduate 1978) has taken up an appointment as Project Engineer with Peerless Control Systems in Milton Keynes. He was previously a Design and Development Engineer with Thorn Automation in Nottingham.

NON-CORPORATE MEMBERS

Wg Cdr D. M. McKeown, M.B.E., RAF (Associate Member 1975) has been appointed Head of Branch, Signals 66 (Air), at the Ministry of Defence following his promotion. His previous posting was as Staff Officer on the MOD (Air) Training Staff at RAF Abingdon.

SECAM TO PAL DIGITAL TRANSCODER

The BBC has produced its first digital SECAM to PAL transcoder, using the CCIR recommended digital sampling standard of 13·5, 6·75, 6·75 (CCIR Recommendation AA11). This implies a sampling frequency of 13·5 MHz for luminance and 6·75 MHz for each of the two colour-difference signals. signals (U and V). These are converted to digital signals and allow inputs and outputs of luminance and colour-difference signals on the new standard.

With the new transcoder the incoming SECAM signal is decoded into the luminance (Y) and two colour-difference signals U and V). These are converted to digital signals and placed in a two-field store with a clocking signal rate of 864 clock pulses per line. This operation is locked to the input line frequency. The contents of the store are then read out at the same number of clock pulses per line, but with the clocking signal locked to the System I output line frequency. This has the effect of widening or narrowing the time interval between samples in order to produce a correct output line frequency. The signal components are reconverted to analogue signals and coded into a System I PAL signal.

If the SECAM decoder is replaced by a high-quality PAL decoder, the transcoder becomes a synchronizer. As such it has none of the imperfections of the typical composite signal synchronizer. Also, because the input clock has been designed to follow the rapid changes in line length associated with some helical scan video recorders, the transcoder can operate as a time-base corrector.

ENAMELLED STEEL SUBSTRATES

The report on a nine-month investigation by ERA Technology into the use of porcelain enamelled steel substrates in thick film circuitry has recently been circulated to its sponsors.

Enamelled steel substrates for thick film circuits is a new technology which is attracting widespread interest. It has been particularly well received by the telecommunications industry, for example, where the assembly of circuitry on an enamelled steel base is seen to offer important advantages in terms of thermal dissipation compared with conventional printed circuit board assemblies. Automotive and military electronics are other areas where the mechanical robustness of enamelled steel is important.

The ERA laboratory-based study which has attracted sponsors from Britain, France, Germany, Italy, Canada, Australia and the United States has been designed to produce essential data on the properties and performance of enamelled substrates and thick film metallizations from both European and American sources.

ERA has obtained some very promising results with particular paste substrate combinations but the report draws attention to limitations posed by the temperature sensitivity of some of the substrate glazes during processing. Significant differences in the physical properties of enamelled steel substrates obtained from several sources have been identified as well as differences in the processing characteristics and electrical performance of a number of proprietary pastes.

The project report is accessible to additional sponsors at a fee of £1050. Interested organizations should contact Keith Browne, Electronics Technology Department, ERA Technology, Cleeve Road, Leatherhead, Surrey KT22 7SA.

Letters to the Editor

From: **Professor Emeritus P. Beckmann**
Professor R. A. Waldron, M.A., Sc.D., C.Eng., FIERE

Electric Forces

It is not widely known that in 1912, Leigh Page of Yale University derived the Maxwell equations from no more than Coulomb's Law and the Lorentz transformation.[1] The import of this discovery is that if Coulomb's Law is inaccurate for high velocities (of one charge with respect to another), then the Lorentz transformation is merely a mathematical device with which to force Maxwell's electromagnetics (but not anything independent of electromagnetic measurements) to agree with experiment. Therefore, if presently accepted electromagnetics is in need of correction, then Prof. Waldron is perfectly right in making Coulomb's Law the starting point.[2]

However, it seems that his modification goes in the wrong direction, for the attraction between two opposite charges would *increase* with velocity, whereas it is known to decrease (cf. deflection of the electron beam in a c.r.t.).

In an attempt to discover what might possibly be wrong with Coulomb's Law at high velocities, I turned to its Newtonian version in gravity, noting that the equivalence of inertial and gravitational mass (the latter being the analogue of charge) has been established only for masses at rest with respect to each other. If one postulates that inertial mass is invariant, but that the gravitational attraction between masses is given by the Newton–Coulomb Law modified to

$$F = \Gamma \frac{m_1 m_2}{r^2}(1-\beta^2)^{3/2} \qquad (1)$$

where Γ is the gravitational constant, and $\beta = v/c$, with v the velocity of one mass (charge) with respect to the other, the result, to second-order terms in β, is an additional term in the gravitational potential, proportional to r^{-3}, which leads to an effect well known in theoretical mechanics:[3] the rotation of the elliptical orbit that, by the unmodified Newton–Coulomb Law, should be stationary (as in the orbits of the planets). What one obtains, in fact,[4] is Einstein's celebrated formula for the rotation per orbit, or advance of the perihelion of the planets,

$$\Delta\psi = \frac{24\pi^3 a^2}{c^2 T^2 (1-e^2)} \qquad (2)$$

(a, major axis; e, eccentricity; T, period of orbit), which has been experimentally verified where measurable (Mercury, Venus, Earth).

Equation (2), usually derived by General Relativity Theory, follows from (1) by Newtonian mechanics (not to be confused with Newtonian gravitational theory).

The modified Newton–Coulomb Law (1) may or may not yield workable electrodynamics at high velocities; but it does go in the direction of a *weakened* attraction of two charges at high velocities.

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1 Page, L. 'A derivation of the fundamental relations of electrodynamics from those of electrostatics', *Amer. J. Science*, **34**, pp. 57–68, 1912.
2 Waldron, R. A., 'Electric forces', *The Radio and Electronic Engineer*, **51**, pp. 553–60, November/December 1981.
3 Landau, L. D. and Lifshits, E. M., 'Theoretical Physics', vol. 1, 'Mechanics', Sec. 15, Problem no. 3; English translation (Addison-Wesley, Reading, Mass., 1965).
4 Beckmann, P., 'Electromagnetism, Gravitation and Relativity', Essay submitted to the 1970 contest of the Gravity Research Foundation; unpublished.

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18th January 1982

I agree with Prof. Beckmann that my force formula indicates a force which increases with v. While this may appear surprising at first sight, it does not contradict any observations, for the force is not observed. What is observed is the track of the electron or other charged particle, and this is correctly predicted by my force formula.

Prof. Beckmann's comments about gravity are interesting. I, too, attempted to apply this approach to gravity, and have discussed my results on pages 184–190 of my book (reference 1 of 'Electric forces'). I think there is too little observational evidence at present to permit the drawing of definite conclusions—the anomalous precession of Mercury, for example, may be attributable to various causes, so it is impossible to say to what extent it should be ascribed to a velocity-dependent law of gravitation. Perhaps experiments with artificial satellites would help.

R. A. Waldron

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9th February 1982

Standard Frequency and Time Service

(Communication from the National Physical Laboratory)

Relative Phase Readings in microseconds
NPL—Station
(Readings at 1500 UT)

JANUARY 1982	MSF 60 kHz	GBR 16 kHz	Droitwich 200 kHz
1	−8·6	37·0	75·7
2	−8·9	37·5	75·5
3	−8·9	36·2	75·4
4	−8·7	36·8	75·3
5	−8·8	35·7	75·2
6	−8·7	36·8	75·1
7	−8·5	35·5	74·9
8	−8·8	36·2	74·9
9	−8·9	35·9	74·9
10	−9·0	37·1	74·9
11	−9·0	36·8	74·9
12	−9·5	37.0	74.8
13	−9·3	35·7	74·6
14	−9·6	35·7	74·5
15	−9·4	34·3	74·5
16	−9·6	33·3	74·5
17	−9·6	33·0	74·3
18	−9·8	33·0	74·2
19	−9·6	33·7	74·0
20	−9·8	33·7	73·9
21	−10·0	34·1	73·7
22	−10·0	34·2	73·6
23	−9·8	33·5	73·4
24	−10·0	33·8	73·2
25	−10.0	34·5	73·1
26	−10·0	35·2	72·9
27	−9·8	36·5	72·7
28	−10·0	36·5	72·5
29	−10·0	35·8	72·4
30	−10·0	37·0	72·2
31	−10·0	37·0	–

Notes: (a) Relative to UTC scale (UTC_{NPL}–Station = +10 at 1500 UT, 1st January 1977.
(b) The convention followed is that a decrease in phase reading represents an increase in frequency.
(c) 1 µs represents a frequency change of 1 part in 10^{11} per day.
(d) It may be assumed that the satellite stations on 200 kHz at Westerglen and Burghead will follow the day to day changes in these phase values.

New Books Received

The following books which have been received recently have been placed in the Institution's Library and may be borrowed by members resident in the British Isles.

Digital Control using Microprocessors
PAUL KATZ (*Technion—Israel Institute of Technology*). Prentice-Hall, Englewood Cliffs NJ, 1981. 15.5 × 23.5 cm. 292 pages. £16.95 (Hardback).

CONTENTS: Analytical background. Digital control design via continuous design. Discrete design of digital control. Multivariable digital control, state space approach. Mechanization of control algorithms on microcontrollers. Analysis of the implementation of the numerical algorithm. Selection of sampling rate.

This book provides a thorough guide using up-to-date theory and recent developments to designing systems based on microprocessors and gives a systematic introduction to the principles and methods of digital control. It is suitable for both students who require a modern approach to digital control design and for experienced engineers who wish to change from analogue compensators to microcontrollers. The design methods are demonstrated on actual working microcontrollers with emphasis given to real design problems and effective methods to overcome them.

Foundations for Microstrip Circuit Design
T. C. EDWARDS (*Royal Military College of Science, Shrivenham*). John Wiley, Chichester, 1981. 15.5 × 23.5 cm. 264 pages. £12.75 (Hardback).

CONTENTS: A basic review of TEM-mode transmission line theory. Transmission lines for microwave integrated circuits. Static-TEM parameters and design at lower frequencies. Behaviour and design at microwave frequencies. Discontinuities in microstrip. Parallel-coupled microstrip lines and directional couplers. Power capabilities, transitions, and measurement techniques. Some representative microstrip circuits. Computer-aided design.

The book provides foundations for the accurate design of microstrip components and circuits applicable to microwave or high-speed digital sub-systems. The text is primarily intended for design engineers and research and development specialists but it will also be of value to lecturers and students on graduate electronics and communications engineering courses.

Introducing Microprocessors
IAN R. SINCLAIR. Keith Dickson, London, 1981. 14 × 21.5 cm. 121 pages. £4.50.

Understanding Microprocessors
LLOYD RICH. Reston Publishing Company, Reston, Virginia, 1981. 15.5 × 23.5 cm. 296 pages. £14.20

CONTENTS: The anatomy of digital logic. Binary addition and subtraction. BCD subtraction, division and fractions. Digital memories. System fundamentals. System subsections. Basic microprocessor organization. Digital logic analysis.

A carefully developed introduction to microprocessor systems.

Experimentation with Microprocessor Applications
THOMAS W. DAVIS (*Milwaukee School of Engineering*) Reston Publishing Co., Reston, Virginia, 1981. 17.5 × 23.5 cm. 236 pages £8.20

CONTENTS: History of computers and microprocessors. Instruction familiarization. Instruction timing. Binary addition and subtraction. Input/output: logic simulations. BCD arithmetic and conversions. Push button interface—BCD counting. Logic design. Serial ASCII to BCD code conversion. Keyboard input. Hexadecimal addition/subtraction program. Microprocessor software. Binary multiplication. Algorithmic development—finding the square root. Arrays and tables. Decision making process. Stack operations. Decimal to binary and binary to decimal conversions. Seven segment displays and multiplexing. Hardware diagnostic techniques. 7490 decade counter test fixture. Interrupt driven real time clock. The design process. D/A conversions principles. Analog to digital conversion techniques. An auto-ranging digital voltmeter. Data terminal interfaces. Random number generation. Security systems. Automotive applications, the digital tachometer. Traffic control. Real time data acquisition. Stepper motor control. Computer to computer communications. BCD to Morse code conversion. Timing and control—the elevator simulation. A calendar routine.

For use in conjunction with microprocessor textbooks in a laboratory course.

Solid State Devices 1980
J. E. CARROLL (Editor) Institute of Physics, Bristol, 1981. 16 × 24.5 cm. 225 pages. £25. $62.50

CONTENTS: Recent progress on solid state displays (C. Hilsum). Process induced crystal defects in silicon (B. O. Kolbesen and H. Strunk). Devices and circuits for bipolar (V)LSI (J. Lohstroh). MOS power devices-trends and results (J. Tihanyi). New CMOS technologies (B. Hoefflinger). Modelling of device technology (E. Constant). Electron beam lithography and its effect on semiconductor device technology (P. J. Daniel). Vapour phase epitaxial growth of III-V compounds (R. W. Brander and M. M. Faktor). Corrosion problems of metal conductor lines in integrated circuits (J. M. Eldridge).

This volume contains nine invited review papers presented at the 10th European Solid State Device Research Conference and the 5th Symposium on Solid State Device Technology. The development of semiconductor devices has always been a joint venture between technology, physics and invention and this collaboration is reflected in these reviews by acknowledged experts.

Fun with Silicon Chips in Modern Radio
GILBERT DAVEY. Kaye & Ward, London, 1981. 15.5 × 21.5 cm. 64 pages. £4.25

Modern Filter Design: Active RC and Switched Capacitor
M. S. GHAUSI (*Oakland University*) and K. R. LAKER (*Bell Laboratories*) Prentice-Hall, Englewood Cliffs NJ, 1981. 16 × 23.5 cm. 541 pages. £27 (Hardback)

CONTENTS: Filter transmission and related topics. Operational amplifiers. Sensitivity. Continuous-time active filters biquadratic realizations. High-order filter realization. Active switched capacitor sampled-data networks.

This book is intended as a text for senior undergraduates and the first year graduate and can serve for self-teaching and reference by practising engineers. It claims to be the first book giving detailed analysis and design procedures for switched capacitor filters. Among the advances discussed are computer-aided design methods for coupled or multiple-loop feedback topologies used to realize low-sensitivity high-order active filters and switched capacitor networks to realize precision monolithic filters.

Electronics TEC Level IV
D. C. GREEN (*Willesden College of Technology*). Pitman, London, 1981. 18.5 × 24.5 cm. 278 pages. £6.95

CONTENTS: Transistors. Integrated circuits. Small-signal audio-frequency amplifiers. Negative feedback. Operational amplifiers. Audio-frequency large-signal amplifiers. Sinusoidal oscillators. Non-sinusoidal waveform generators. Noise. Controlled rectification.

This book provides a comprehensive coverage of the techniques used in modern analogue equipment. It has been written on the assumption that the reader already possesses a knowledge of electronics, electrical principles and mathematics to TEC Level III.

Wind Solar Energy for Radiocommunications and Low-power Electrical Systems (2nd Edition)

EDWARD M. NOLL. Howard W. Sams & Co., Indianapolis, 1981. 13.5 × 21.5 cm. 264 pages. £9.05

CONTENTS: Solar energy and photovoltaic converters. Wind energy conversion. Batteries and inverters. Practical solar power supplies and applications. Practical applications.

An introduction to the techniques used in converting light energy and wind energy to electrical power with examples of practical installations.

Electronic Test Equipment—Operation and Applications

A. M. RUDKIN (Editor). Granada Publishing, St Albans, 1981. 16 × 24 cm. 316 pages. £20 (Hardback)

CONTENTS: Low frequency oscillators. Signal generators. Sweep generators. Voltmeters. A.f. and r.f. power meters. Distortion meters. Frequency meters and counter-timers. Modulation timers. Oscilloscopes. Spectrum analysers. Component bridges. Microprocessors and programmable instruments.

Written by a team of specialist contributors, the purpose of the book is to provide engineers, scientists and technicians with guidance into the use of electronic test equipment in their everyday work. The complete absence of any references to the extensive literature on these subjects is unusual in a work at this level.

First Class Radiotelephone License Handbook

EDWARD M. NOLL. Howard W. Sams & Co., Indianapolis, 1981. 13.5 × 21.5 cm. 486 pages. £8.80

CONTENTS: Station frequency assignments and power-output rating. Broadcast duties and facilities. Broadcast microphones. Record and tape machines. Studio and control-room facilities. Remote facilities. AM broadcast transmitter. AM broadcast antennas and lines. FM transmitters. Stereo broadcasting. Transmitter monitor and test equipment. Television broadcasting. Fundamentals and audio circuits. Transmitters and AM broadcasting. FM broadcasting. Television broadcasting. Rules and regulations. Experience tests.

Intended for those who have to pass FCC examinations to operate and maintain commercial radio and television broadcasting stations in the USA. Provided this aim is borne in mind, it may well be use to those carrying out similar work elsewhere.

Dictionary of Audio, Radio and Video

R. S. ROBERTS. Butterworths, Sevenoaks, Kent, 1981. 14.5 × 22 cm. 248 pages. £15.00

These dictionaries belong to a series covering electrical and electronic engineering. They provide not only clear definitions of all the terms now currently in use in the UK and USA but also explain many terms in depth; illustrations and extensive cross-references are included.

Dictionary of Telecommunications

S. J. ARIES. Butterworths, Sevenoaks, Kent, 1981. 14.5 × 22.5 cm. 329 pages. £15.00 (Hardback)

Oscilloscopes

STAN PRENTISS. Reston Publishing Company, Reston, Virginia, 1981. 15 × 22.5 cm. 161 pages. £6.95 (Paperback) £12.55 (Cloth)

CONTENTS: Oscilloscopes and their uses. Spectrum analysers. Logic analysers. Storage/sampling oscilloscopes and time domain reflectometry. Investigating video terminals and cassettes, including the art of using vectorscopes. Waveform analysis.

As the contents indicates, the treatment of this book embraces the more sophisticated oscilloscopes and it should be a useful introduction for the professional engineer.

Effectively using the Oscilloscope

ROBERT G. MIDDLETON. Howard W. Sams & Co., Indianapolis, 1981. 13.5 × 21.5 cm. 168 pages. £6.95

CONTENTS: Audio tests and measurements, Impedance measurements. Television tests and measurements. Digital logic tests. Semiconductor tests and measurements. Miscellaneous applications. Oscilloscope performance checks.

The text is very generously illustrated to show how the individual tests are made. Servicemen and technicians will find this book a useful aid in using the oscilloscope to its fullest potential.

Digital Circuits and Systems

RICHARD L. CASTELLUCIS. Reston Publishing Company, Reston, Virginia, 1981. 16 × 23 cm. 332 pages. £14.95

CONTENTS: Number systems. Logic gates. Flip flops. Shift registers. Counters. Integrated circuit counters. Encoding and decoding. Counting systems. Memory and memory devices. Computer arithmetic circuits. The operational amplifier. Digital-analog, analog-digital conversion circuits. Microcomputers.

This text is intended for use at the postsecondary instruction level. The text contains worked problems as well as self-testing questions.

Linear Integrated Circuits—Practice and Applications

SOL D. PRENSKY (*Fairleigh Dickinson University*) and ARTHUR H. SIEDMAN (*Pratt Institute*). Reston Publishing Company, Reston, Virginia, 1981. 15.5 × 23.5 cm. 354 pages

CONTENTS: Introduction to linear integrated circuits. General conditions governing linear integrated circuit design. Differential amplifier stage in integrated circuit design. Operational amplifier characteristics. General operational amplifier applications. Testing and breadboarding operational amplifiers. Power amplifiers: direct current and audio. Consumer communication circuits. Regulators and control circuits. Digital-interface circuits. Precision and instrumentation operational amplifiers. Specialized linear-integrated circuit applications.

Intended as a practical reference for engineers, technicians and students, it contains much information on current devices.

Cable Television (2nd Edition)

JOHN E. CUNNINGHAM. Howard W. Sams & Co., Indianapolis, 1981. 21.5 × 31.5 cm. 392 pages. £8.40

CONTENTS: The television signal. System requirements. Coaxial cable transmission lines. Cable tv amplifiers. The headend—antennas and propagation. The headend—signal processing. Powering the cable tv system. Program origination. The complete system. Two-way transmission and special services. Long-distance transmission. Cable tv instrumentation and test equipment. Proof of performance and system measurements. Troubleshooting and component testing. Advanced testing of amplifiers and passive components. System integrity, radiation, and signal ingress. Protection against lightning and power-line surges. Fiber optics. Communication satellites.

A useful introduction for the technician concerned with cable television systems.

Operational Amplifiers

I. E. SHEPHERD. (*Hydraulics Research Station*). Longman, Harlow, Essex, 1981. 14 × 21.5 cm. 318 pages. £25.00

CONTENTS: Operational amplifiers—the broader view. Ideal operational amplifiers and practical limitations. Frequency-dependent parameters. Effects of external components. Noise and drift. Feedback—some advantages and limitations. Miscellaneous applications. Active filters. Recent advances.

Written in an easily readable style, the book first deals with operational amplifier circuits from a theoretical approach and then investigates their advantages and limitations in practice. It is suitable as a reference for undergraduate and post-graduate students of electronic engineering, HNC/D, TEC Higher level and CEI examinations as well as the practising engineer.

Beginner's CB and Two-Way Radio Repairing

NEWT SMELSER. Nelson-Hall Publishers, Chicago. June, 1981. 20.5 × 26 cm. 232 pages $29.95 (Hardback); $14.95 (Paperback)

Op-Amp Handbook

FREDRICK W. HUGHES (*Lindsey Hopkins Technical Education Centre*) Prentice-Hall, Englewood Cliffs NJ, 1981. 18 × 24 cm. 294 pages. £14.25

CONTENTS: Operational amplifier functions and characteristics. Basic op-amp circuits. Signal processing with op-amps. Op-amp oscillators. Op-amp applications to audio circuits. Op-amp protection, stability and testing. Experiments to determine op-amp characteristics and parameters. Basic op-amp circuit design. Collection of practical op-amp circuits.

This book aims to provide a basic understanding on op-amps and their applications for those at various levels whether an electronics student, engineer or technician.

New and Revised British Standards

Copies of British Standards may be obtained from BSI Sales Department, 101 Pentonville Road, London N1 9ND. Non-members should send remittances with orders. Subscribing members will be invoiced and receive 50% discount.

BASIC ENVIRONMENTAL TESTING PROCEDURES

BSI has published a new Part 2.1XA and revisions of parts 2.1T and 2.2T in the series of British Standards designated BS 2011 **Basic environmental testing procedures.** This well-established series is mainly intended to ensure that manufacturers, test houses and users have a common procedure for environmental tests to assess the durability of electrotechnical products under various conditions of storage, transport and use.

The new Part 2.1XA, **Test XA and guidance: Immersion in cleaning solvents** (£6.00) is identical with IEC 68–2–45, published by the International Electrotechnical Commission and will be of particular interest to the electronics and other industries which manufacture components suitable for mounting on printed circuit boards. The standard will help designers to predict the effects of immersion in two commonly-used cleaning solvents, on superficial markings, encapsulation, coating etc on the characteristics of electrotechnical products.

The first of the two revisions, Part 2.1T, **Test T: Soldering** (£12.00) is identical with IEC Publication 68–2–20. It sets more stringent requirements for the three individual tests than did the 1977 edition, the complete group of tests now being laid out in a more logical and comprehensible format. This Part is closely related to the second of the two revisions, namely Part 2.2T **Guidance on Test T: Soldering** (£5.00) which is identical with IEC Publication 68–2–44 and will be of particular benefit to writers of specifications that make reference to the tests dealt with in Part 2.1T.

PROGRAMME LEVEL METERS

The latest Part of BS 5428 **Methods for specifying and measuring the characteristics of sound system equipment,** is Part 9 **Programme level meters,** (£13.00) which incorporates current UK requirements for peak programme meters and therefore replaces BS 4297 **Characteristics and performance of a peak programme meter.** The new Part is technically aligned with international standards IEC 268–10 and IEC 268–10A.

Part 9 gives recommendations concerning characteristics to be specified and relevant methods of measurement for programme level meters in general and for peak programme meters in particular. The latter are dealt with in a separate section which also specifies performance requirements for peak programme meters Types 11A and 11B. Type 11A meters are used by all UK broadcasting authorities as well as in a variety of other sound control applications where the best possible use of the dynamic range is to be obtained by precise control of the microphone output.

The Part also sets out the conditions for specification and measurement, together with a classification for the characteristics to be specified. The appendices detail the preferred indicating equipment and slow mode of operation. An extra section dealing with volume indicators (vu-meters) is currently under consideration.

CUSUM METHODS FOR PROCESS/QUALITY CONTROL

A further Part of BS 5703 **Guide to data analysis and quality control using cusum techniques.** Part 3 **Cusum methods for process/quality control by measurement** (£21.00), extends the range of cusum techniques presented in the first two Parts of the standard. The situations to which these methods apply are the same as those for which control charts for variables might be used.

Following a brief reminder covering the basic principles of cusum charting, Part 3 considers the need for decision rules and introduces the concept of run length as a basis for comparison of control procedures. This is followed by an explanation of the various processes for which the methods are appropriate and the types of process parameters (sample means, ranges and standard deviations) by which control can be effected. Procedures for control of the process average by the use of sample means are described in detail.

In dealing with control of variation, the impact made by inexpensive calculators is noted so that schemes are provided for monitoring small sample standard deviations, as well as the traditional method of using sample ranges.

Methods suitable for use with tabulations (instead of charts) are also included, together with a selection of computer algorithms covering procedures both for one-sided and two-sided control. Finally, suggestions are given for the analysis of process capability data, dealing with the identification and measurement of possible contributions to overall variations, the use of retrospective cusum analysis for assessing the validity of the capability data, and procedures for identifying anomalous process features.

Part 3 incorporates much new material, some of which was specially developed for this standard and has not previously been published. It is expected that reference to this guide will be made in future related British Standards and other relevant publications, including the Packers' Code and Inspectors' Manual which gives guidance on the new Average Quantity system for prepackaged goods, now being introduced within the EEC.

ASSESSMENT OF RELIABILITY

An important addition to BS 5760 **Reliability of systems, equipments and components,** namely Part 2 **Guide to the assessment of reliability** (£21.00) recommends general assessment procedures and provides guidance on quantitative and statistical aspects such as reliability modelling, the provision of data and the concepts of redundancy and simulation.

Section One of the new standard gives references to basic statistical terms and lists the symbols used in reliability studies. Recommendations are also made concerning the procedures to be used in estimating failure and repair time distributions.

Section Two explains basic reliability modelling, the provision of reliability data and system reliability which, in turn, introduces the concepts of redundancy and simulation. This section concludes with reliability testing and Bayesian analysis. There is also an appendix which presents, in tabular form, properties of various statistical distributions used in the assessment of reliability.

OFFICE MACHINE SAFETY

An important new safety standard for many types of electrical machines used in offices and similar business premises has recently been published. Entitled BS 5850 **Safety of electrically energized office machines** (£24.00) it covers a wide range of equipment including typewriters, cash registers, paper tape readers and punches, staplers, duplicators, erasers, pencil sharpeners, magnetic tape handlers, motor-operated files, tabulators, overhead projectors and micrographic equipment as well as machines for adding, calculating, accounting, book-keeping, photocopying, electrostatic copying, dictation and mail processing.

The purpose of the new standard is to eliminate, as far as possible, hazards that could otherwise arise during the use of such devices to the risk of the operator and those who might come into contact with the equipment; also service personnel in certain specified cases. The standard does not, however, deal with data processing equipment and associated electronic systems, teleprinters, or duplicating machines and offset lithographic facilities intended primarily for paper sizes larger than A3.

BS 5850 implements the aggreement contained within CENELEC Harmonization Document HD 372 and thus is largely the result of international consensus. Nevertheless, some differences from this international agreement have been incorporated to comply with UK law, namely the Factories Act 1961 and the Offices, Shops and Railway Premises Act 1963. In addition, the requirements have been drafted to avoid conflict with the Low Voltage Directive and the Health & Safety at Work Act 1974.

The new standard comes into effect immediately, but the existing BS 3861 Parts 1, 2 and 3 will not be withdrawn until 30 June 1983, in order to allow industry a transitional period in which to adjust to the latest requirements.

HEARING AIDS

BSI has published two further specifications relating to hearing aid equipment.

The first of these is a revision of BS 2813 **Dimensions of plugs for hearing aids** (£5.50) which has now been aligned with IEC Publication 90 and CENELEC HD 304. BS 2813 gives appropriate dimensions and tolerances to ensure interchangeability of plugs used for hearing aids. It covers both two-pin polarized plugs and three-pin plugs.

The second specification is BS 6111 **Reference coupler for the measurement of hearing aids using earphones coupled to the ear by means of inserts** (£5.00). This is a new British Standard which describes a coupler for loading the earphone with a specified acoustic impedance when determining the physical performance characteristics, in the frequency range 200 Hz to 5000 Hz, of air conduction hearing aids coupled to the ear by means of ear inserts (eg ear moulds or similar devices). Although the coupler described in the standard does not allow the actual performance of a hearing aid on a person to be obtained, it is recommended by the IEC for use as a simple means for the exchange of specifications and physical data on hearing aids. The new standard is identical with IEC Publication 126 and CENELEC HD 305.

The first three Parts of BS 6083 **Hearing aids,** a new standard based on IEC Publication 118, have been published: the existing document, BS 3171, published in 1968, will be withdrawn when sufficient Parts of the replacement standard are available to provide adequate coverage of the subject. The following aspects are dealt with in the current issue:

Part 1 **Method of measurement of characteristics of hearing aids with induction pick-up coil input** (£5.50). This describes a method of ensuring satisfactory physical performance of hearing aids using an induction pick-up coil within an audio-frequency magnetic field, in terms of frequency response and sensitivity.

Part 2 **Methods of measurement of electro-acoustical characteristics of hearing aids with automatic gain control circuits** (£8.00). This is intended to facilitate measurements of certain characteristics of hearing aids with a.g.c. circuits, which are considered necessary for a physical description of the automatic gain control function.

Part 3 **Methods of measurement of electro-acoustical characteristics of hearing aid equipment not entirely worn on the listener** (£5.50). This Part is intended to facilitate methods of determining the overall electro-acoustic performance for this type of hearing aid by providing information concerning the measurement of such parameters as frequency response, air-to-air gain, acoustic output gain and output controls, internal noise of the equipment etc.

A STANDARD FOR INTERFACE SYSTEMS

A new standard of great interest to manufacturers, designers and users of electronic measuring instruments is BS 6146 **An interface system for programmable measuring instruments (byte serial, bit parallel)**. The standard is in two Parts, published simultaneously, and is identical with IEC 625–1 and IEC 625–2.

BS 6146 provides a common scheme which will enable various combinations of measuring instruments and associated devices from different manufacturers to be connected into an automated instrumentation system. The standard applies generally to laboratory and production test environments which are both electrically quiet and restricted as to physical dimensions (distances between the system components).

Part 1 is entitled **Specification for functional, electrical and mechanical requirements, system applications and requirements for designer and user** (£31.00). It is primarily applicable to the interface of instrumentation systems, or portions of them, in which the data exchanged among the interconnected apparatus is digital (as distinct from analogue); the number of devices that may be interconnected by one contiguous 'bus' does not exceed 15; the total transmission path length over the interconnecting cables does not exceed 20 m and the data rate across the interface on any signal line does not exceed 1 megabit per second.

Part 2 **Code and format conventions** (£18.00) defines a number of codes and formats which are applicable to the device functions of apparatus interconnected via the interface system specified in Part 1. To support the overall objective of permitting a wide range of products and product capabilities to be interfaced, it has not proved feasible to specify a single code set and message format. It has been possible, however, to define a limited set of guidelines and alternatives setting forth a number of different codes and formats generally applicable to products implemented with Part 1 capability. Part 2 applies both to devices with limited ability to generate, process or interpret a variety of codes and formats and to devices with extensive ability to generate, process and interpret unique and very specialized codes and formats.

One hundred and eighty years of instrument making

Some historical aspects of Elliott Brothers (London) Ltd. and Fisher Controls Ltd.

TREVOR WOODMAN* and JOHN KINNEAR, M.A., C.Eng., F.I.E.R.E.†

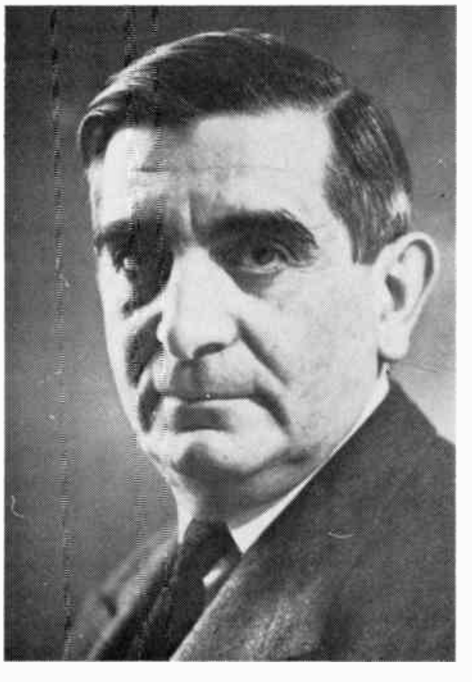
This story starts in 1795 when a young man, William Elliott, was apprenticed to William Backwell of Sash Street, Gray's Inn, London, a compass and drawing instrument maker. However Elliott was unable to complete his apprenticeship owing to the death of his master but subsequent events proved that he had learned sufficient in this trade to found, in 1800, what was to become a successful business. This he did in a small room in Sash Court, Gray's Inn, London, working as a maker of drawing instruments and trading under his own name. Soon he moved to the upper floor of a house in Holborn and by 1807 had acquired sufficient goodwill and reputation to enable him to extend his facilities by leasing a shop and workshop in High Holborn. At the same time he extended the scope of the business by adding surveying and mathematical instruments to the list of products all bearing the name 'W. Elliott'.

By 1816, the business had increased, and from the order book of that period the entry for 28th August 1816 indicates the work being undertaken for 'Her Grace, the Duchess of Wellington, to have a large Magic Lantern 34/–'. There are similar order entries that show the main products were telescopes, reading glasses, barometers, microscopes and drawing instruments; the repair of opera glasses and similar items also seemed to play an important part of the daily trade.

The expansion of the Ordnance Survey and the formation of the early railway companies created a large increase in the demand for theodolites and surveying instruments of all kinds and in 1830 Elliott found it necessary to move to larger premises at 56, Strand, London, taking into partnership two of his sons, Frederick Henry and Charles Alfred. The Company began to exploit the field opened up by the growth of the railways and the widespread use of steam power in industry, and the 'steam engine indicator' which was a new and important instrument and used to provide a graphical presentation of cylinder pressure against piston stroke. This small instrument was developed over the years by Darke, Richards and others and remained in production well into the 1930s.

At this time, there was great activity in all branches of physical science, which resulted in the manufacture of a

Frederick Henry Elliott.
Joint proprietor and subsequently sole proprietor from 1853 to 1873.



Sir Leon Bagrit.
Managing director of Elliott Brothers (subsequently Elliott Automation) from 1948 to 1967.

** Fisher Controls Ltd., Brenchley House, West Street, Maidstone, Kent ME14 1UQ*
† Marconi Avionics Ltd., Elstree Way, Borehamwood, Hertfordshire WD6 1RX

The Radio and Electronic Engineer, Vol. 52, No. 4, pp. 164–170, April 1982

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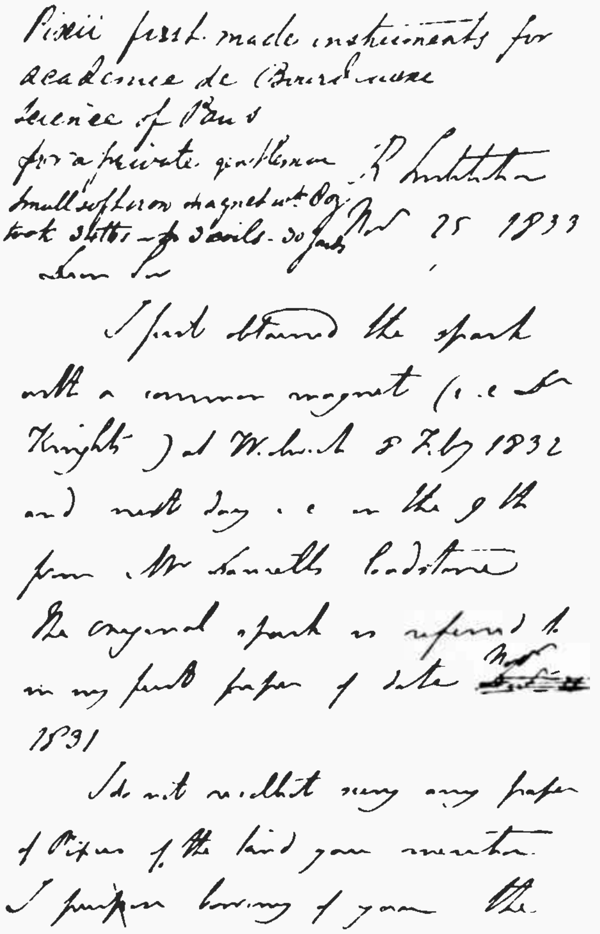
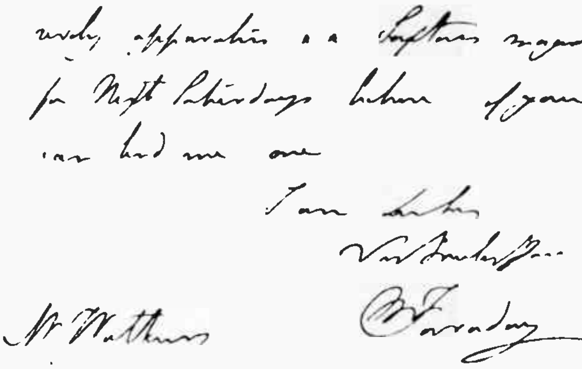


Pixii first made instruments for Academie de [illegible] Science of Paris for a private gentleman [illegible] Nov 25 1833 [illegible]

I first obtained the spark with a common magnet (i.e. Dr Knight's) at Woolwich 8 Feb 1832 and next day i.e. on the 9th from Mr Daniell's loadstone. The original spark is referred to in my first paper of date Nov 1831

I do not recollect seeing any paper of Pixii of the kind you mention. I propose borrowing of you the



[illegible] apparatus [illegible] magnet for Next Saturday [illegible] if you can lend me one

I am Dear Sir Very truly Yours

Mr Watkins M Faraday

Letter from Michael Faraday to Mr Watkins, General Manager of Elliott Brothers, in which electromagnetic induction is discussed.

wide range of scientific instruments such as spectroscopes, induction coils, electrometers, chemical balances and other apparatus for the great experimental scientists such as Michael Faraday and Sir Humphrey Davy. In 1840 orders were frequent for electrical machines of varying applications, galvanometers and batteries. And for this work Elliott was awarded a Bronze Medal at the Great Exhibition of 1851 and the catalogue, in the British Museum library, shows a list of instruments displayed, which included a 'very comprehensive set of drawing instruments complete with water colours, a 30 inch transit telescope and wheel and pediment barometers'.

In 1853 the founder died, leaving the flourishing business to be managed by his sons, Charles and Frederick, under the style of Elliott Brothers. It was not long before the business of Watkins and Hill, of London, manufacturers of hydrostatic, hydraulic, pneumatic and acoustic instruments, was absorbed. This was followed by the retirement, in about 1865, of Charles Elliott, leaving his brother Frederick the sole proprietor.

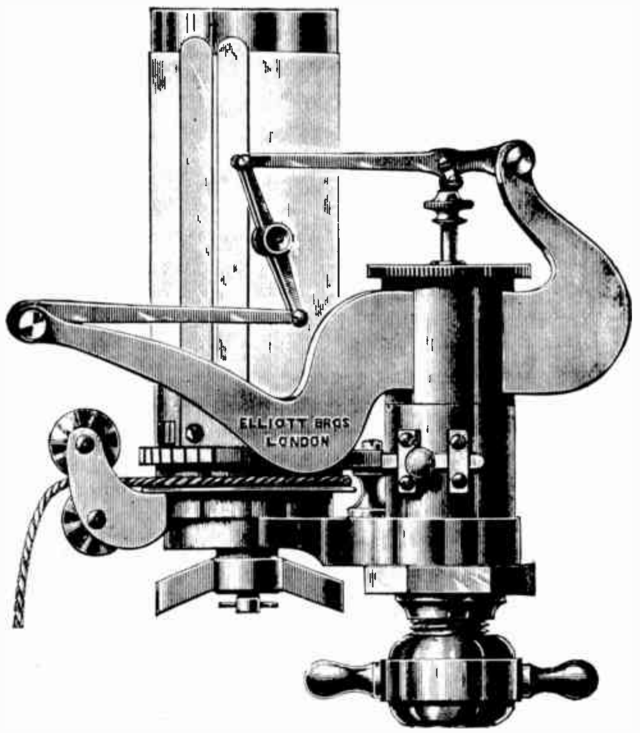
When Frederick died in 1873, he left the business to his widow, who later joined partnership with Mr Willoughby Smith, well known for his work in connection with the Atlantic and other submarine cables as Chief Electrician of the Telegraph Construction and Maintenance Company.

During the middle of the century great developments were occurring in the electrical world, the most important of which were connected with telegraphy. In 1851 the first successful submarine cable was laid across the English Channel and the cable business boomed.

After the initial abortive attempts the Atlantic cable was successfully laid and operated in 1866, and there is ample evidence to show the part played by 'Elliott Brothers' instruments in this connection. It was well established that the manufacture of these cables called for careful testing by reliable instruments, while success in operation depended on the use of sensitive detecting apparatus. The company seized the opportunity created by the demand for this apparatus, and launched into the manufacture of a wide range of morse keys, transmitters, receivers, sounders and galvanometers many of which were initially developed by Wheatstone, Cooke, Morse, Hughes and others.

The firm was commissioned by the British Association Standards Committee, in 1874, to make electrical standards. Measuring and testing instruments were also being manufactured for the electrical industry and it is apparent that the company was well known for the quality, reliability and precision of its galvanometers, Wheatstone bridges, standard resistances and capacitors etc.

The continuing growth of the business necessitated the



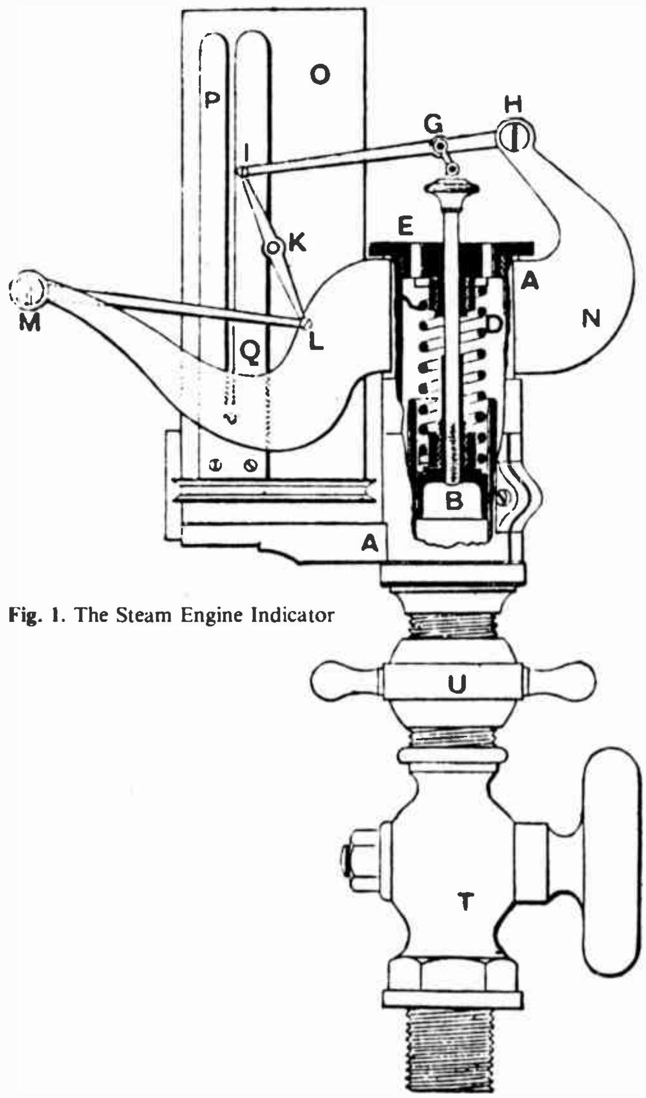


Fig. 1. The Steam Engine Indicator

This instrument, representing the earliest form of the modern indicator, was in every respect a great improvement upon any hitherto constructed. Figure 1 shows the Elliott Brothers instrument, with it shown partly in section in (b). A short spring D is employed, the upper end of which is attached to the cylinder cover E, while the lower end is secured to the piston B, the latter being arranged to move with perfect freedom in the liner or bushing fixed in the steam cylinder A A. The upper extremity of the piston rod is coupled by a short link to a point G in the upper bar H I of the parallel motion. An exactly similar bar M L and a centre link I L complete the parallel motion, the arrangement being such that the pencil or tracing point K describes an approximately straight line, the extent of the movement being four times that of the piston, since the length H G is one-fourth of H I. For the usual travel of the pencil, the stroke of the piston is thus diminished considerably, and a much shorter and stiffer spring may now be employed, resulting in a corresponding reduction of elastic vibration. The two fixed centres of the parallel motion are carried by suitable brackets projecting from, and forming part of, a cylindrical sleeve which fits upon the outside of the steam cylinder, and around which it can turn freely. The joint at the top of the piston rod is arranged to swivel, and this allows the sleeve, together with the parallel motion and pencil, to be rotated upon the cylinder, thus enabling the pencil to be brought into contact with or withdrawn from the paper as desired.

building, in 1876, of new works in St. Martin's Lane, London, which were occupied by 1878; about this time orders were being received from the Admiralty for ship and torpedo directors.

By the 1880s the firm was making instruments for the rapidly expanding electric lighting industry, the progress culminating in 1894 with the introduction into this country of the first permanent magnet moving coil instrument. A year or so later saw the production of the first practical pivoted dynamometer instrument with its accessories for alternating current work, and of current and potential transformers, with the first practical graphic recording voltmeter developed and patented by Professor Mengarini in 1890. Sales of the recorder were considerably increased by the Board of Trade Regulations covering the working of electric tramways. These regulations required tests to be made daily, and the firm made and sold 'Board of Trade Panels' to practically all the electric traction undertakings in the country. These panels mounted the voltmeters, ammeters and recorders needed to monitor the electrical supply to the system. This was the first extensive industrial application of pen recorders. Thereafter switchboard work increased to such an extent that complete switchboards for lighting, traction and power undertakings were supplied, an example of which is in the Museum of London.

In 1881 Mrs Elliott died and in 1891 Mr W. O. Smith entered into partnership with his father, Mr Willoughby Smith. Two years later arrangements were made with Mr G. K. B. Elphinstone (later Sir Keith Elphinstone, K.B.E.) proprietor of Theiler & Co., telegraph and instrument makers of Canonbury, to amalgamate the two concerns under the style of Elliott Brothers. In 1898 a decision was made to purchase land at Lewisham for new works and offices which were completed in 1900, and exactly 100 years after the foundation of the company the new factory was opened under the appropriate title of 'Century Works'.

The new factory and facilities enabled production of all kinds of electrical measuring instruments to be increased. Early in the twentieth century, the company became interested in the production of speed indicators and motor car speedometers, the result of which was the Elliott 'Motormeter', the first British motor car speed and distance measuring instrument which was produced on many occasions in courts of law in defence of motorists accused of exceeding the speed limit. The Royal Automobile Club was supplied with standard speedometer testing gear, and the firm developed standard electrical chronographs for the Club for Brooklands Race Track. Elliott speedometers were fitted in such record breaking cars as Sir Malcolm Campbell's 'Bluebird' and George Eyston's 'Thunderbolt'.

The use of the Motormeter on early high-performance cars is well supported by the accompanying illustration (Fig. 2) which shows the speedometer used by Mr Frank Newton when he drove Mr S. F. Edges' great 90 horsepower, 6-cylinder Napier racing car known as 'Samson' at Brooklands in January 1908, less than one year after the track was opened, when he recorded a speed of 116 miles an hour. Resulting from this Newton wrote to the company in April 1908 and said 'Your latest type of speed instrument with the higher reading than my previous one has again proved most useful and satisfactory, the speed hand is not only accurate but remarkably steady at high speed while the correct registration on the maximum hand has on several occasions been verified by official timing. Yours faithfully, Frank Newton, D. Napier & Sons Limited.'

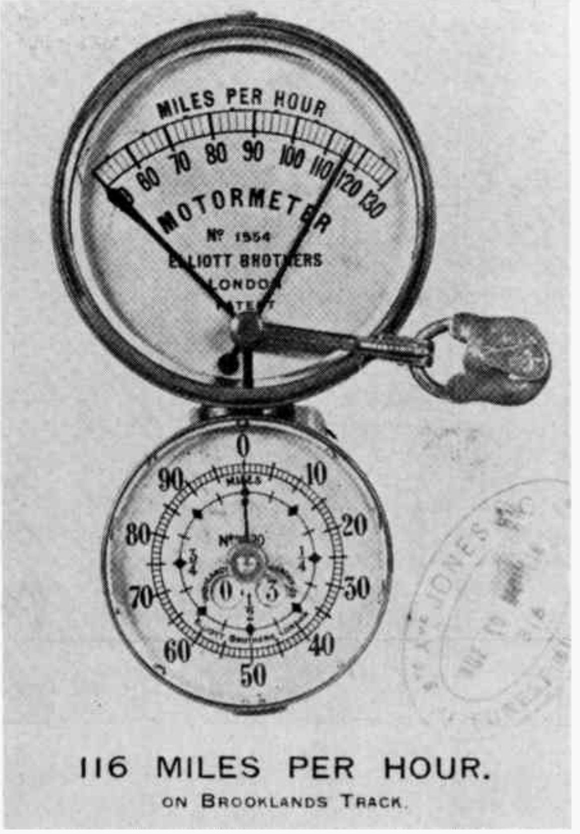


Fig. 2. The Elliott Motormeter.

The instrument and the car were also used and driven by Newton at the 1907 Gallion Hill Climb where he recorded a speed of 84 miles/h up a gradient of 1 in 12 in 26·6 seconds. Mr S. F. Edge also entered races at Brooklands using a 60 horsepower Napier car and in 1907 established a record for the 24 hours endurance tests. The 1581 miles were covered by Edge at an average speed of 65·9 miles/h, casting aside predictions that at this speed he would suffer a heart attack or go mad.

Grateful thanks and testimonials were received not only from the great racing stars of the period but also from many who would not be classed as 'the average motorist' and who were 'saved' by the precision of the Elliott Motormeter. One letter sums this up; 'Dear Sirs, You will be pleased to allow me to thank you for the attendance of your Representative at the South Western Police Court and for the very clear and conclusive evidence which he gave, it is very pleasing to feel that the marvellous accuracy to which your speed recording instruments have attained enabled the Magistrate at this Police Court to take this evidence against that of the Police stop watches which however excellent they may be and however well held one knows they cannot certify with such perfection as your Elliott speedometer. I remain . . . .'

Development of gunnery fire control equipment for the Admiralty was started in 1908 and progressed from the very simple mechanical clocks and plotting tables to the elaborate calculating tables fitted in most capital and other warships through both wars until the late 1950s when they were superseded by radar fire control systems.

The company was also responsible for the design of the distance measuring Forbes Log, the first underwater ships' log to be fitted in this country, and the manufacture of the first gyro compass to be used by the Navy and the first to be installed in a submarine. Other instruments for naval use included the Dumaresq calculator, mounted on a ship's bridge and used to determine the enemy's rate of change in position—the Battenberg Course Indicator, developed by Lord Louis Mountbatten's father in the 1890s—and the Fall of Shot Indication.

The Dumaresq calculator (Fig. 3) is designed to calculate the rate of change of range and deflection by resolving the enemy's virtual course along and at right angles to the line of fire. The course and speed of OWN SHIP are set on the instrument and the estimated course or inclination and speed of the ENEMY are also set. The corresponding range rate and deflection can then be read off the dial.

With the increasing importance of the aeroplane the company turned its attention to the development and manufacture of many aircraft cockpit instruments, much pioneer and development work on bombsights being undertaken for the Royal Air Force with Mr H. E. Wimperis. During World War I equipment of all kinds was manufactured in vast quantities, including bombsights, gunsights, torpedo gyros and altimeters.

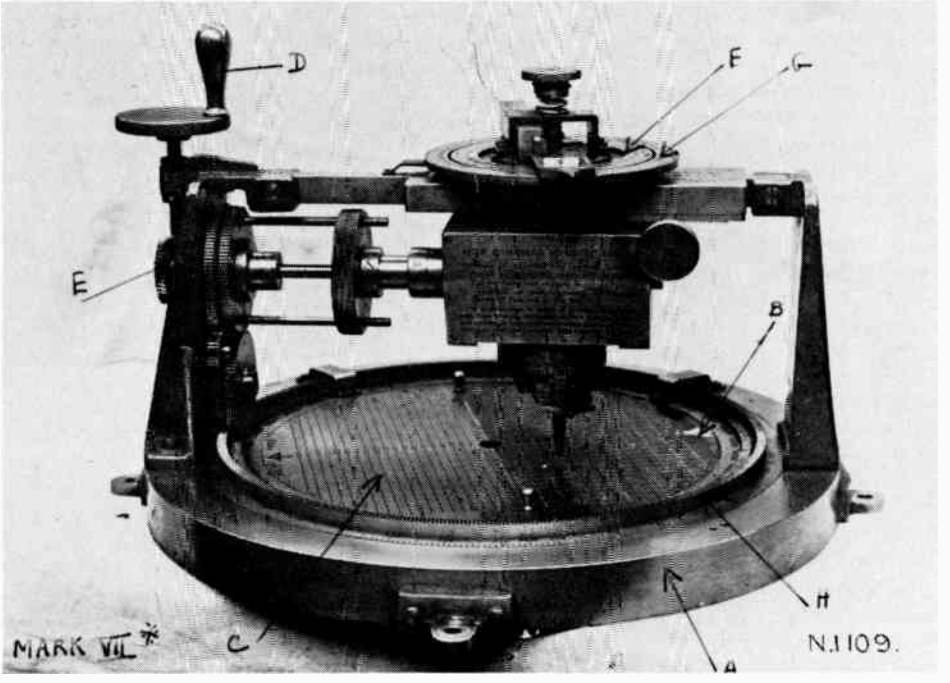


Fig. 3. The Dumaresq Calculator.

A new and important branch was added to the business in 1930 with the manufacture of a range of heat measuring and process control apparatus, which has since assumed a leading position in the company's activities. This was the result of earlier agreements and co-operation with Siemens Brothers which grew until they had a controlling interest in the company. It ended in 1946 when they sold their interest to investment and insurance concerns. Among later developments were remote indication and control systems, the round dial precision deflectional frequency indicator used to monitor the mains supply frequency on the National Grid system, instruments for the measurement of power factor and specialized equipment for the National Physical Laboratory.

When the RMS *Queen Mary* was launched in 1936, the company supplied the complete CO_2 flue gas analysis equipment, combined temperature indicators with multi-way selector switch, together with electrical remote reading thermometers for measuring the temperature at various points in the provision stores, as well as the directional engine revolution indicators.

In the same year the company collaborated with the Air Ministry in the development and production of the 'aircraft position indicator' which was eventually installed at Croydon Aerodrome. The apparatus provided a continuously changing picture, showing at a glance the positions and speeds of all aircraft along three routes to and from Amsterdam, Brussels and Paris.

With the outbreak of World War II, the company's resources were once again directed towards the production of equipment for the three Services, and many thousands of instruments, and other apparatus were produced, including blind landing instruments, true wind speed and direction indicators, thermal units for radar systems, and large quantities of industrial and precision instruments.

Early experience on gyroscopes led the company to develop and manufacture the airborne gyro-operated gunsights, used in fighter and bomber aircraft, as well as a plotting system used in nearly every large coast defence gun battery in the Empire.

The post-war period was a difficult time for Elliotts and in 1947 the company merged with the weighing machine makers, B. and P. Swift. Major and successful re-organization followed and in 1947 the company set up Research Laboratories at Borehamwood, under the direction of John Coales, followed by a manufacturing facility at Rochester. At this time Leon Bagrit (later Sir) became managing director and was the architect of Elliotts' future expansions.

Through the pioneering work of the Borehamwood Research Laboratory on stored program digital computers for the advanced digital real time fire control system, Elliott Brothers became the first British company to exploit their benefits. The Type 152 and 153 computers of 1950–1 led via the 'Nicholas' prototype, so called because it was based on nickel wire delay line registers, to the 400 series of commercial computers.* As well as providing the 'work horses' for the many and diverse applications of automatic control systems (which became the main stream of Elliott Automation's business), the manufacture and sale of computers became a substantial and successful business in its own right, with the transistorized 800 series and the subsequent 500, 900 and 4100 series. Specialized

* A more detailed account of these developments is given in Clarke, S. L. H., 'The Elliott 400 series and before', *The Radio and Electronic Engineer*, 45, no. 8, pp. 415–21, August 1975.

applications work led to military computers for real-time application in mobile and airborne use, the MCS920B and C.

The rapid growth of Elliott during the 1950s was achieved partly by mergers and acquisitions and partly by internal growth achieved in large measure by the setting up of new businesses, some of which are significant in the present activity of Lewisham.

To enhance the company's product base a number of agreements were made, the most important of which concerned Fisher Governor (1948), Bendix Aviation (1953) and Bristol Instruments (1954). The new factory at Rochester was used for the first two and Lewisham (later Maryport) for the latter.

Two important mergers took place in 1957, one with the Rotameter Manufacturing Company of Croydon and the other with Associated Automation, who owned James Gordon and Electroflo Meters. The result of the second merger was the birth of Elliott Automation which for many years was directed from Lewisham and expanded to include many sites, manufacturing divisions and companies, and a product range too vast to mention here. In 1964 the Group's process instrumentation and systems activities were combined to form Elliott Process Automation.

During the 'big is beautiful' era of the mid 60s, the government's Industrial Reconstruction Corporation engineered a series of mergers involving various parts of Elliotts. All of the 'non-real time' business of Elliott Automation Computers was in 1966 split off and merged with English Electric Computers, subsequently, in 1968, to be joined with ICT to form ICL. Also in 1968 all the rest of Elliotts was taken over by English Electric which was itself taken over by the General Electric Company a year later. Under GEC all the real time computing activities associated with process control and military applications of Elliott Automation, English Electric and GEC were brought together at Borehamwood to form GEC Computers.

Recognizing that the products of the component companies were not compatible in architecture and thus did not represent a good base on which to build for the future, GEC Computers made plans to develop progressive ranges of new generation equipments. The outcome of this was the very successful 2050 and the 4000 series of computers of which approximately 400 and 500 respectively have been sold to date.

Another outcome of the company's early control system engineering expertise was the award to Elliott Brothers in about 1950 of a contract to develop an electronic autopilot equipment for drone target aircraft. This work was undertaken at the recently acquired factory at Rochester. Other aviation activities were soon undertaken in the navigation and flight instruments fields, and before long the real-time digital computing techniques being pursued at the Borehamwood Establishment were being successfully applied in these wider and technically demanding fields. From these beginnings grew Elliott Flight Automation, now grouped with the other aviation businesses within GEC as the major establishment of Marconi Avionics, with a work force of nearly 7,000.

Its notable successes have included the Flight Control System for *Concorde*; the autostabilizer and flight control systems for *Tornado*, the world's first aircraft flight control system based on digital computing techniques; the inertial navigation system for the *Blue Steel* weapon, the first inertial navigation system to go into quantity production in Europe, and the forerunner of the inertial platforms supplied for the RAF's *Nimrod* and *Jaguar* aircraft; and certainly worthy of mention, its successful penetration of the tough but immense American aircraft equipment market with a range of products, but particularly its advanced head-up displays.

The Borehamwood Laboratories, over the succeeding decade, became renowned as a centre of scientific invention and expertise. Its initial work on real-time fire control systems entailed advances at the frontiers of radar technology, control system design, precision analogue computing and pioneering developments in stored program digital computing. These together with a host of other innovations generated in the Research Laboratory, and fertilized by the drive and vision of Sir Leon Bagrit, were the seed for the explosive expansion of Elliott Automation over the next decade. From the radar techniques nucleus of the early 1950s has grown, via Elliott Automation Radar Systems in the 1960s, the airborne radar systems activities in the Hertfordshire and Buckinghamshire locations of Marconi Avionics where nearly four thousand employees are currently engaged in two of the largest radar system development projects ever undertaken outside the United States, the advanced pulse Doppler system for the *Tornado* interceptor and the complete mission system avionics for the airborne early warning *Nimrod*, as well as technologically related business in sonar, battlefield sensors, lasers and civil security systems. From the same nucleus grew also the activities on guided weapon homing and control systems, and attitude control systems for the *Skylark* high altitude rocket and for satellites and satellite communications receiving stations. These businesses which moved to Frimley in 1962 as Elliott Space and Weapons, later expanded to Hill End in Scotland, and are now 3,700 strong, and form a substantial and vigorous part of Marconi Space and Defence Systems, whose recent successes include the Blindfire Radar for the highly successful *Rapier* missile system, the FACE artillery fire control system and a range of associated equipments.

Established at Lewisham in 1954 as part of Elliott Brothers the Servo Components Division brought together the special engineering and manufacturing skills needed to make precision servo components required by the Flight Automation divisions based at Rochester. The reputation for reliable work and the expansion in its activities have led to servo components being used in all branches of the armed services, civil aviation, industrial control, post office and the entertainment industry.

The expanding UK nuclear industry and the need for control and safety equipment led to the formation of the Nuclear Controls Division at Lewisham in 1955. Gathering together specialist staff, the division works with national and international organizations to set safety standards, and supply equipment for the nuclear industry. Early contracts included the development and supply of systems for the Royal Navy's first landbased reactor; this experience has led to the division supplying all the control and safety equipment for the Navy's marine reactors. In parallel similar equipment has been manufactured for most of the power generation and experimental reactors in the UK and some overseas countries. Continuous development and manufacturing to the highest Defence Quality Standard ensures reliable equipment which has led to this division becoming a prime contractor in this field.

The remainder of the activities at Lewisham constitute the Field Mounted Instrumentation Group which embraces the traditional process instrumentation business together with others of the activities started 'from scratch' during the 1950s.

The Process Instruments activity was reformed in the 1960s and early 1970s bringing together the products of Elliott, Electroflo, James Gordon, AEI and Bristol. With product rationalization and the change in industry markets the business now concentrates on supplying instruments and schemes on a world wide basis.

In 1952 the Borehamwood Laboratories developed the strain gauge load cell and in 1955 the Industrial Weighing Division was formed at Lewisham to promote electrical industrial weighing. In the next ten years the division pioneered electrical weighing throughout the world. Continuous development and wealth of application experience has led to successful weighing control systems being installed into all branches of Industry.

The company's interest in analysers extends back many years and to consolidate this the company entered in the agreement with Hallikainen for the manufacture and marketing of hydrocarbon analysers. Initially set up at Greenwich the division was moved to Lewisham in 1971. Throughout its life analysers, sampling systems and analyser houses have been supplied to all the major oil extraction and refinery concerns. The need for a thorough industry knowledge was recognized early and since then application and development engineering has been conducted from Lewisham.

There were many changes implemented following the take-over of the Elliott activities by GEC in 1969 but all the companies and associated divisions based on Lewisham and Maryport in 1979 joined Fisher Controls, a part of the Monsanto Group.

The Servo Components and Nuclear Controls Divisions have recently been brought together to form the Nuclear and Servo Instrumentation Group within the Process Instrumentation Division of Fisher Controls.

The foundations laid by William Elliott all those years ago and the formative years under Sir Leon Bagrit have led to a range of activities within GEC and Fisher Controls that must exceed the wildest dreams of the founder and his two sons, the Elliott Brothers.

Acknowledgments

The authors acknowledge, with thanks, the assistance given by the Directors, staff and past employees of Elliott Brothers, Fisher Controls and Marconi Avionics.

Book Review

Optoelectronics
ROWERT G. SEIPPEL
Reston Publishing Company, Reston, Virginia,
1981 18 × 24 cm. 354 pages. £16.45

CONTENTS: Introduction to optoelectronics. Light sourcing, transmitting and receiving. Photodetection. Electroluminescence. Safety. Optoelectronic devices and optical components. Optical fibres, cables and couplings. Fibre-optic systems and applications. Lasers. Photometry/radiometry.

'Optoelectronics' is a book which will find a place on many bookshelves. The author states that it is aimed at 'the public'; in my view the level of treatment and subject coverage is such that it would be of value only to those members of 'the public' who have a particular interest in optoelectronics. It would probably be suitable for interested 'A' level science scholars and would also make a useful introductory text for undergraduates whose graduate course included the study of optoelectronics. Since the book gives a basic treatment of the subject, including adequate definition of many terms in common parlance, it may also be of benefit to engineers and scientists just entering the field and perhaps even to more established workers who have forgotten some of the basics.

The way in which the chapters are ordered gives the impression that the author was not clear in his mind exactly what he wanted to cover in the book. As an example there are chapters on optical sources in four different parts of the book. Moreover one gets the impression that the author could not decide whether to cover just one major application of optoelectronics, namely the subject of optical fibre technology, or whether to make the book a fully comprehensive text on optoelectronics.

Despite these relatively minor criticisms each particular chapter is well written and easy to read. The subjects covered are treated mainly in a qualitative manner with a negligible amount of mathematical treatment.

The bulk of the book discusses optoelectronic devices including all the common optical sources, such as lasers (solid, gas and semiconductor), light-emitting diodes, and various optical detectors. Two chapters on optical fibre systems and cables give a rudimentary coverage of this important subject. The chapter on safety could have been potentially valuable but in practice, in line with much of the rest of the book, it does not go into sufficient detail for the information to be of real value to the practising engineer or scientist. The chapter on photometry/radiometry will be of interest to many since it presents the basic concepts and common terms and their definitions in a very lucid manner.

There is a useful glossary of terms at the end but the bibliography is very short considering the wealth of good publications which exist on the subject which could have been quoted.

In summary it is a basic introductory text for the newcomer to optoelectronics.

C. J. LILLY

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Indexing Terms: Television applications. Aids for the blind.

Teletext and Viewdata for blind people

ROBIN W. KING, B.Eng., Ph.D.*

Based on a paper presented at the IERE Conference on Microprocessors in Automation and Communications held in London in January 1981

SUMMARY

The paper describes the initial stages of the development of microprocessor-based equipment to convert pages of Teletext and Viewdata information into forms suitable for blind users. The paper concentrates on the development of hardware and software to convert the information into Grade I Braille, which is then displayed on a refreshable row of electrically activated pins, arranged in standard Braille configuration. Initial reactions to the device have been encouraging, and the paper concludes with a discussion of development work now in progress.

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1 Introduction

Compared with sighted people, the blind and partially sighted have a relatively limited range of up-to-date information services at their disposal. Sound broadcasting provides a rather heavily selected and edited one-way service, whilst the telephone provides, as it does for sighted people, access to specific information interpreted by a human respondent. Written material is available to the blind only after conversion into sound or tactile forms. Many organizations are concerned with transcription of books and journals into 'talking book' cassettes and Braille, and these transcription processes are costly in terms of human skills and time, and inevitably the material is out-of-date when it is used by the blind listener or reader.

Teletext and Viewdata have offered yet more information sources to the sighted consumer, by making use of the domestic television set to display 'pages' of textual and low resolution graphical information. To the user, the information is 'electronic' in form, and he has no access to it other than via his television set enhanced with the appropriate decoders. Such electronic information has the potential to replace many more traditional media forms; in particular, local publishing is viewed as increasingly under threat from more developed Viewdata services.

In any event, the conversion of the Teletext and Viewdata services into forms suitable for blind users deserves consideration. This paper describes the initial development and preliminary evaluation of a microprocessor-based system to convert the services into such forms.

2 Teletext and Viewdata

A number of systems are available throughout the world, and to speed their adoption international standards are in process of development.[1] In the UK, where much credit can be taken for leadership in the field, the Teletext services currently broadcast by BBC and IBA provide the user with some 400 pages of news magazine type material, as well as programme subtitling facilities.[2] Viewdata services, such as that marketed by British Telecom under the name Prestel, offer access to more than 200,000 pages provided by independent organizations. Despite the differences between their sources and methods of transmission, the two services produce similar looking pages, based on a single character set. Examples of typical pages are given in Fig. 1.

The complete page consists of 24 rows of 40 characters, each of which is specified by a 7-bit code. The displayed information is mostly textual, but the visual appearance is enhanced by the use of 63 'graphics' characters. A number of the codes are used as control codes to specify the colour of subsequent characters, as well as changes between alphanumeric and graphics modes.

There are a number of differences between Teletext and Viewdata which have a bearing on their transcription into forms suitable for blind users; before discussing the possible forms, these differences will be described.

0033–7722/82/040171+06 $1.50/0

(a) (b)

Fig. 1. Examples of (a) Teletext and (b) Viewdata pages. In the Teletext page illustrated the title 'headlines' is constructed from graphics characters. The page numbers following the headlines indicate where more details may be found. The Viewdata page shows considerable use of graphics with text positionally related to it.

2.1 Teletext

Teletext pages are transmitted during the field blanking interval of the normal television broadcasts, taking 12 fields to complete the acquisition of one page. The pages themselves are transmitted sequentially, so that for 100 transmitted pages, the total cycle time is $12 \times 100 \times 0{\cdot}02 = 24$ s. In the worst case of requiring a page just after it has been transmitted, the user suffers a delay of some 24 seconds, although the average delay experienced will be much less than this. A related feature is the use of multiple sub-pages transmitted with the same page number, and automatically updated on the screen at about 24 second intervals, to provide a multiple page sequence of information. Teletext pages are identified by 3-digit numbers, and it may be observed that a significant amount of many pages, which are not specifically index pages, is devoted to identifying further pages on which related information may be sought.

2.2 Viewdata

Once a subscriber has successfully dialled the Viewdata service he requires, his receiver-decoder is connected to the service computer and is dedicated to the reception of Viewdata pages. Their data are transmitted at 1200 baud, thereby taking up to 8 seconds to receive a full page. Page requests are transmitted at 75 baud, and are serviced by the central computer almost instantaneously. Viewdata pages are arranged in a 'tree' form, so that single digit commands facilitate a rapid means of searching through the pages of information to the maximum level of detail available on a given topic. By simple commands, the user is also able to recall the previous two pages he had accessed. For the two reasons that the indexing structure is in a tree form, rather than a magazine form, and that the service is a dedicated one, rather than combined with transmissions of television pictures, it is anticipated that Viewdata services would be easier to adapt effectively for blind users than Teletext.

3 Forms of Information Presentation for Blind Users

It might be thought that a speech output would provide the best form for the information, and such an output has wider applications than the blind community. Development of microprocessor-based phonemic speech synthesizers[3] now makes it possible to consider synthetic speech as an output, although reasonable quality speech at a realistic price may be some way off. Some blind people do not regard speech as the ultimate form, for there is an equivalent neutrality in tactile reading as there is in reading of text by sighted people. An initial evaluation of speech synthesis for the present application is in progress, but the major effort has been devoted to the conversion of the data into tactile form.

Braille is a six-bit tactile code having a single 'cell' of six raised dot positions for each of the alphabetic, numeric and punctuation signs used in written text.[4] The character set used in text contains more than 90-characters, clearly more than 6-bit Braille can represent by single cells; Braille provides for this by having 'shift' characters to indicate subsequent numericals, capitals, or reversion to lower case letters. Grade I Braille is a character-for-character transcription, an example of which is given in Fig. 2(a). Transcription of text to Grade I Braille is thus a relatively simple process, which may be learned quite quickly, or enshrined in a relatively small computer program, such as that described in Section 4.2. English text contains many redundant features, such as common lettergroups (th, ed, ing, etc), and a small number of extremely common words (and, the, for, etc,) whose letter by letter coding into Braille results in a rather inefficient use of Braille cells. Contracted or Grade II Braille uses single-cell representations of certain common letter groups, and very common words, and compound-cell representations of many more common words, to reduce the total number of cells required to transcribe a given amount of

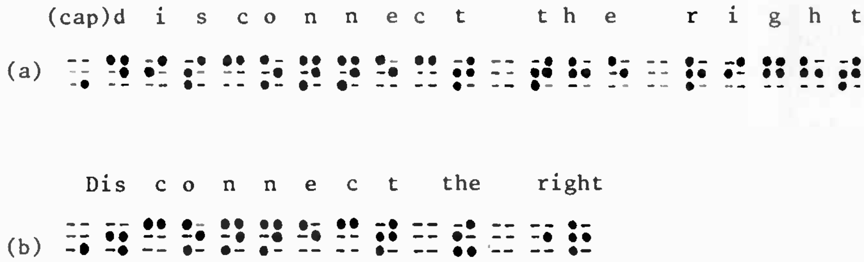

Fig. 2. Examples of Braille: (a) Grade I, (b) Grade II.

text. An example is given in Fig. 2(b). Most people who learn to read Grade I Braille successfully progress to the contracted form and competent readers can read well over 100 words per minute, a rate comparable with that of a slow sighted reader. Computer facilities have been developed for the transcription of text into Grade II Braille.[5]

Normally Braille is embossed in the form of raised dots on specially prepared paper, an A4 page (i.e. the size of this Journal page) containing about 900 cells, equivalent to about 200 words of contracted Braille. The paper thickness and the relatively large cell area makes Braille books extremely bulky, and a number of schemes to reduce the effective bulk of books have been developed. Most of these contain a small refreshable Braille display, which can be activated by data stored on a cassette. The data are normally pre-coded in Braille and the reader controls the rate at which the display is updated. Refreshable displays have also found their place in providing calculator outputs and in specialist terminals for blind computer users.[6] Part of one of these has been used in the present work.

4 Teletext/Viewdata-to-Braille System Development

To evaluate some of the features required of a Braille display, develop transcription techniques and ultimately to develop hardware and software for a self-contained Teletext/Viewdata-to-Braille receiver, work has been conducted around a microcomputer system. Despite the remarks made in Section 2, most of the initial development work has been devoted to the transcription of Teletext, since a Viewdata receiver has not become available until recently. A block diagram of the system is given in Fig. 3.

In order to allow transcription development work and evaluation when Teletext transmissions are not available, the decoder is normally used to store Teletext pages sequentially on a floppy disk. Under the control of a hex-keyboard and certain dedicated switches adjacent to the Braille display, the blind user can then access any stored page and read it, row by row, on the display, as will be described in detail later.

4.1 Teletext Decoder

A standard commercially available decoder[7] has been modified to interface with the microcomputer system. The principal modifications are to drive the control lines from the computer console, and to permit transfer of a page of data from the decoder memory to the microcomputer memory. As the sub-system block diagram in Fig. 4 shows, all access to the decoder is via one of the system parallel ports. The controlling program, written in Fortran, requests acquisition of a page, and interrogates the memory during the normal teletext display period.

When the required page has been written into the decoder memory, it is transferred to system memory, where graphical and control (e.g. colour) characters are turned into '*' and spaces respectively, before being written to disk. These modifications are performed at this stage partly in order that the disk files may be subsequently printed on a normal teletype. Multiple sub-pages are stored on the disk file in the order in which they are acquired. The assembled and loaded program

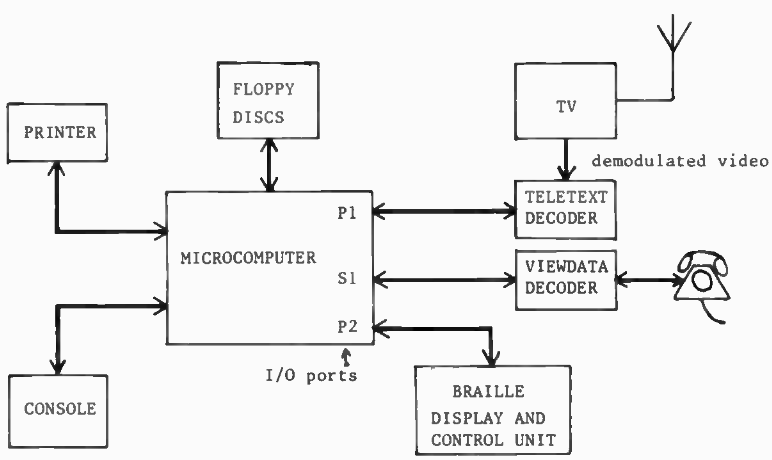

Fig. 3. Block diagram of the Teletext/Viewdata-to-Braille development system.

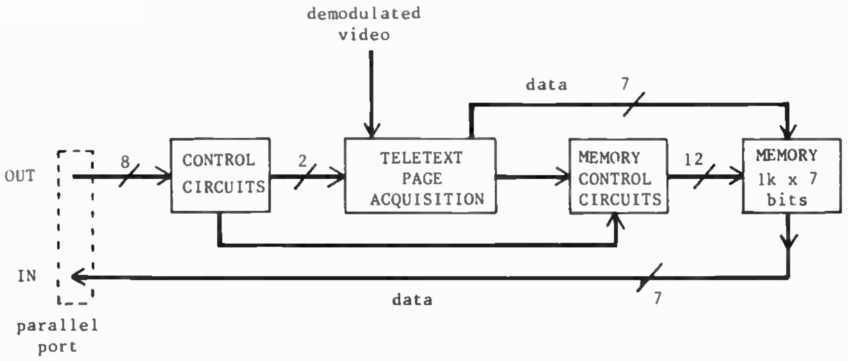

Fig. 4. Block diagram of the Teletext decoder subsystem.

occupies about 12 Kbytes of r.a.m., of which a considerable part is the Fortran run-time routines.

4.2 Braille Transcription and Display

The Braille display is a 48-cell refreshable tactile display, manufactured by Clarke and Smith for their 'Brailink' computer terminal, and kindly loaned for this project. Each cell is separately addressable, and sets up a Braille cell of standard size, but all cells are reset simultaneously. As Fig. 5 shows, six switches are positioned around the display, and a small hex-keyboard is provided. All interconnection between the system and the display unit is via a second parallel port. The keyboard provides an interrupt signal for the subsequent input of cell and page information; the switches facilitate the user's movement about the page by providing the following operations after clearing the displayed row:

1 continue to complete the row, or go to next row,
2 go back one row,
3 go back to top of page,
4 skip to end of page.

Switches 5 and 6 are at present unused.

Apart from the interrupt service routine, the transcription and display programs have also been written in Fortran. It is recognized that Fortran is not ideal for string-handling (which is the essence of Braille transcription) nor does it produce very efficient code; nevertheless, the speed with which the system could be developed to an evaluation state by using Fortran was the over-riding factor in this choice of programming language for the development of the project.

The teletext-page-to-Braille transcription process is a relatively simple one. The page is processed one row at a time, and prior to character transcription, the row is examined for sequences of consecutive spaces, full-stops, and asterisks (graphics replacements). These characters enhance the *visual* appearance of the page, but are largely redundant for the blind user. Such sequences are reduced to three consecutive characters. The Braille transcription converts each row character into its Braille equivalent cell, and on the basis of the preceding and succeeding characters inserts up to two Braille shift cells. This process produces almost perfect Grade I Braille. The insertion of extra cells results in a 40-character source row frequently requiring more than the available

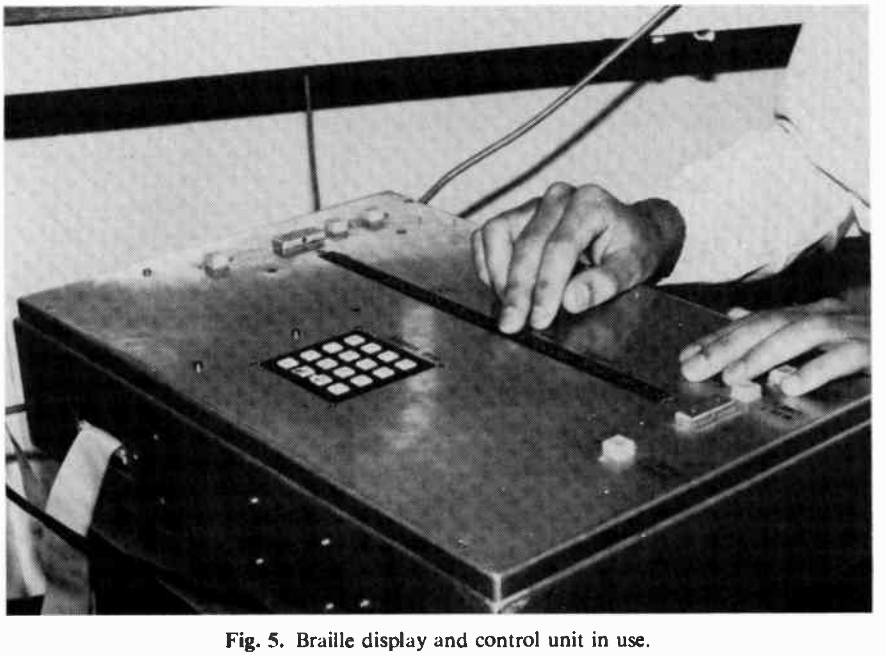

Fig. 5. Braille display and control unit in use.

number of display cells. When an incomplete row is displayed, a hyphen symbol is added, irrespective of whether or not the row was broken at a word boundary, and the remainder of the row can be displayed after operation of switch 1. Further operations of this switch bring up subsequent rows on the Braille display. At any time the user may skip to the end of the page by means of switch 4. If he is reading a multiple page, this will automatically bring up the start of the next sub-page on to the display. At the end of a page, or sequence of sub-pages the control returns a prompt in Braille to instruct the user to request another page by means of the keyboard. The transcription and display program uses about 11K of r.a.m.

The following annotated listing gives an example of the acquisition of the teletext page shown in Fig. 1(a), together with the information actually translated into Braille, showing how it is arranged when 35 Braille cells are used for the display.

Table 1

Acquisition of a Teletext page

The user has selected to display the Teletext page on 35 Braille cells. He is then asked to confirm that this is correct, and is prompted to select a page. After confirming this, the page is transcribed and displayed row by row.

35 cells. Continue or restart (sw4).	
select page : continue, then kybd *xxx#	*Braille prompts*
page 101. Continue or restart (sw4).	
P101 CEEFAX 101 Tue 2 S-	*Braille hyphen is*
ep 09 : 46/02	*inserted to indicate*
NORTHERN IRELAND Town hall dam-	*an incompletely*
aged	*transcribed row.*
in fire bomb attack . . . 102	
POLAND Agreement may be on its w-	
ay	
in miners' strike . . . 105	*At the end of each*
President Carter praises strikers-	*displayed line the*
.106	*user has depressed*
TUC CONGRESS Opposition leader	*switch 1, to complete*
speaks today . . . 104	*the row, or to bring*
UNEMPLOYMENT Poll shows disappro-	*up the next row.*
val	
of Government economic policies .-	
.103	
WEATHER Southern areas of Brita-	
in will	
be dry and warm with sunny periods.-	
The	
north will be mostly cloudy and wet-	
News Index 190 Finance 120-	
Sport 140	

At the end of a page transcription the user is prompted to select another page.

The above listing reveals a number of limitations of the transcription process as it stands, bearing in mind that the blind user has only a single line 'window' available to him at any time. Paramount amongst these is probably the handling of the numbers of the pages on which more detailed information may be found. The splitting of words at the end of the Braille row, on the other hand, could be avoided quite simply with a small program to recognize word boundaries.

4.3 Conversion of Viewdata

The microcomputer system has been interfaced to a Viewdata terminal by taking the serial data stream at the output of the terminal modem into one of the system serial ports, as indicated in Fig. 3. Page requests are also interfaced at the same point in the system. This approach has effected a very simple, and potentially cheap, means of accessing the Viewdata information. Conversion into Braille is then performed as has been described for Teletext.

5 User Evaluation

To date, two well-motivated users have enjoyed several hours with the system as described above. For them, being able to read, instead of hearing some of the day's news was a special pleasure; and they were able to learn to use the keyboard and switch operations, as well as read the refreshable Braille very quickly. The tests revealed some of the problems of having to remember a large amount of indexing information, and it was found that there were fewer problems with Viewdata transcription in this regard. A useful strategy to ease this problem might be to allow for storage of a small number of rows, selected and recalled by the user, as he reads through the pages he has selected.

The users also pointed out a number of improvements which could be implemented at relatively low cost. These include dividing rows only at word (or sensible numeral) boundaries, and filling up the cell row by treating the page as a whole, rather than row by row, for transcription purposes. Whilst the users were able to remember the page numbers of Teletext pages they were particularly interested in, they would have welcomed any means of retention of some of this key information.

6 Conclusions

This paper has set out to describe the early stages of the development of a device to make Teletext and Viewdata services available to blind people. The initial, very limited, evaluation has been favourable to the concept of the device, which, it is believed, could enhance the lives of many blind people. Many aspects of the device demand further attention—display formatting, implementation of efficient Grade II Braille transcription algorithms, local storage of indexing information, and ultimately the incorporation of the complete system from decoder to display, into a single portable unit. The overall cost of such a device is dominated by the costs of the presently available Braille displays, and it remains to evaluate the potential market at current or future prices. Display formatting is particularly interesting; consideration is being given to analysing pages for their content—indexes, graphics, tables and text—and evaluating the ways in which each part can be best displayed on the single row of Braille cells.

The alternative output medium of synthetic speech is worthy of increasing attention for this type of application, for the market is potentially larger, and the techniques of speech synthesis are proving to give a more cost-effective performance.

7 Acknowledgments

The author thanks Clarke and Smith Ltd. for the loan of the tactile display, British Telecom and the Science Research Council for equipment, and Mr Peter White and Mr Brian Payne for their helpful discussions and evaluation of the work.

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(Paper No. 2014/IT1)

Book Review

Microprocessor Fundamentals

F. Halsall and P. Lister (University of Sussex) Pitman Books, London, 1980
18.5 × 24.5 cm. 179 pages. £5.75.

Contents: Computer principles. Microcomputer architecture. Introduction to programming and data transfer. Data manipulation. Transfer of control. Digital input and output. Analogue input/output and interrupts. Application examples. Development aids.

The format and content of this book have resulted from the authors' experience of teaching undergraduates and those released from industry for re-training and their intention is that the book should be used as a back-up text for similar college or university courses.

Although readable in itself the full benefit of its contents—particularly its worked program examples—require the reader to have 'hands-on' access to an Intel 8085, 8080 or Z-80 based training computer. The preface recommends the Intel SDK85 or Feedback Instruments' MAT385. Descriptions of the instruction set are restricted to that of the 8085. The section dealing with I/O techniques concentrates mainly on the use of the Intel PIO chip. It would present difficulties if systems having widely differing instruction sets or Assembly mnemonics were used for support.

The book is clearly laid out with a good index and follows a logical pattern in developing the subject, starting with an overview of computer principles and computer achitecture which leads on to more detailed chapters dealing with instruction sets and I/O applications. A novel approach in its presentation is the highlighting (in bold print) of the more unusual words as they are introduced which are useful hints to the novice that these require careful consideration. They might also serve as useful prompts to the teacher that, perhaps, these items require more careful coverage in the classroom.

It is amply illustrated with simplified block diagrams (no complex circuits), photographs of typical equipment and tables of program listings (in clear type!). As the theme develops into discussions involving software the sample programs are supported by simple algorithm diagrams.

The introductory chapters dealing with the principles of computers are very brief and generalized and only serve as a gentle lead in to the main, and very detailed, sections which describe the mnemonics, machine codes and functions of the 8085's instruction set. The detail of these sections naturally limits the reader's understanding to the '80' range of micro-processors but this is inevitable if a real and proper grasp of the subject is to be obtained. Working examples of programs—written in hand-coded Assembly language with plenty of comments—lead the reader from simple register to register transfers through binary and b.c.d. arithmetic operations to the use of jumps and nested subroutines. These are particularly well presented.

The book slowly moves towards the wider ranging subject of Input and Output and, perhaps, gets a little sidetracked by referring to the use of a specific Programmable I/O (PIO) device but gets back on to course with a well covered, if simple, review of D to A and A to D conversion—including a short section on sampling theory. Relative to the rest of the content a lot of space is given to the principle of interrupt handling within the context of the 8085. As a natural follow-on a whole chapter is devoted to practical example programs to illustrate typical applications ranging from traffic light sequencing to generating analogue waveforms.

In winding up the book reviews what one should expect to find in a 'training' microcomputer and compares the various sorts of controlling software—from Monitors through Interpreters to Emulators; and in an Appendix briefly summarizes the major characteristics of other types of microprocessors.

In summary the book is well written and is easy to read. The authors have been able to cover a lot of ground in a few pages and nothing of major import has been omitted. Because of its condensed nature it moves at high speed but this is of no consequence if used as a course book. Being tied to the 8085 chip it is, of course, limited in its general appeal and a reader not having that type of hardware available is going to find a lot of the book's value out of his reach. Nevertheless it is this feature which makes the book so valuable in practical terms if the right 'hands on' machine is available.

M. J. Hughes

UDC 621.315.212.1: 621.391.827

Indexing Terms: Telecommunication cables, coaxial, Signal interference

Coupling between coaxial cables at radio and microwave frequencies

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and
J. E. SITCH, B.A., M.Eng., Ph.D.†

Based on a paper presented at the IERE Conference on Electromagnetic Compatibility held in Southampton in September 1980

SUMMARY

The work reported here is concerned with measuring and trying to predict coupling between coaxial cables. The surface transfer impedance per unit length, Z_T, is the parameter that determines how the signal gets into and out of the coaxial cables: this is measured in the frequency range from 100 kHz to several GHz in some cases. The third circuit, outside the coaxial cables, consists of the outers of the sending and victim cables and any other conducting and dielectric material in the vicinity. A lumped representation of the tertiary serves well at frequencies for which the length is less than a tenth of a wavelength; distributed circuit models are useful at all frequencies.

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1 Introduction

Coupling between coaxial cables is an acknowledged source of unwanted signals in electronic equipment. The problem is particularly acute where an installation contains several systems which were not designed specifically to go together; the degree of protection from cross-talk that is acceptable for a piece of equipment in a given set-up may be inadequate in another situation. Although trial and error can lead eventually to an acceptable solution, a design process can speed up the subsequent developments and help to minimize the penalties, such as increased cost, size and weight and reduced flexibility, that may accompany the adoption of cables with superior screening properties.

Clearly the complexity of the problem in, for example, an aircraft is such as to make complete analysis impossible, at least in the foreseeable future but any quantitative predictions will prove useful.

The aim of the work being carried out in the University of Sheffield is to investigate ways of predicting coupling in circumstances similar to (although simpler than) those found in practice. This is the first step in the process of designing layouts and choosing cable types.

The work falls naturally into two parts, the study of the leakage properties of individual cables and the investigation of the effects of layout on coupling. The two processes are complementary and closely linked; one cannot measure cable leakage without coupling power from one circuit to another, and the most straightforward way to assess the influence of layout is to perform coupling experiments.

Both aspects of coupling are under investigation, leakage properties for a wide variety of cable types are being measured at frequencies extending from l.f. to microwave and coupling experiments are being performed for a number of different configurations. In both cases the results are compared with theoretical predictions.

In Section 2 the leakage properties of cables are described; this acts as a background to the rest of the paper. Section 3 deals with coupling calculation methods; two circuit models, one lumped and one distributed, are introduced and discussed. Section 4 is concerned with measuring coupling and comparisons of experimental and calculated results.

2 Cable Leakage Parameters

The outer conductor of a coaxial cable performs two functions; it acts as the return path for cable current and it is a screen preventing unwanted signals from getting into or out of the cable. Signals can leak through the screen of a coaxial cable via two mechanisms, surface transfer impedance (Z_T) and through capacitance (C_{12}). Transfer impedance coupling is where a current flowing within the coaxial line (i.e. in the circuit made up of the coaxial inner and outer) gives rise to an e.m.f. in another circuit containing the coaxial outer, or vice-versa. Z_T (measured in $\Omega\,m^{-1}$) is a property of the outer conductor only. C_{12} arises when some electric flux can pass through the outer conductor: it is therefore dependent on conditions inside and outside the screen. An effective surface transfer impedance, Z_F is defined in

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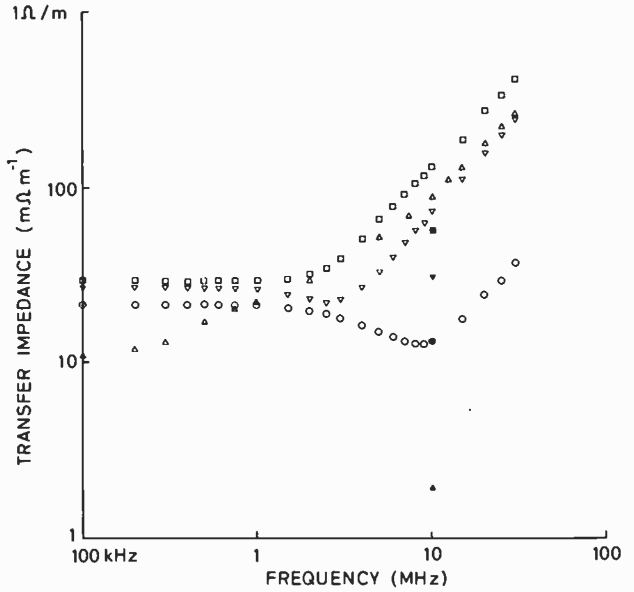

Fig. 1. Leakage properties of cables based on URM43.
The outline symbols are Z_T, solid ones denote Z_F
△—commercial URM43 (95% optical coverage)
○, ▽, □—experimental cables (83%, 77% and 68%, optical coverage respectively).

terms of the through capacitance measured between the inner conductor and a concentric conducting tube. Z_F equals $\omega C_{12} Z_{01} Z_{02}$ where Z_{01} and Z_{02} are the characteristic impedances of the coaxial cable and the coaxial line consisting of the cable outer and the concentric tube. Z_F depends only on the screen and the relative permittivities of the media inside and outside it.

If the outer conductor of a coaxial cable is a homogeneous tube of high conductivity material, the skin effect will result in segregation of the fields inside and outside the cable. Good screening therefore results at frequencies for which the skin depth is a lot less than the screen thicknesses.[1] Solid-jacketed coaxial cable is not very flexible and the screen suffers from fatigue if it is repeatedly bent, so while it is ideal for fixed systems such as community aerial television, many other applications require the use of coaxial cables with braided outer conductors.

A braid woven from wires or tapes is full of holes and it is obvious that energy can pass through these. Z_F decreases with the proportion of the screen area that is holes (allowance has to be made for the number and shape of the holes as well). Z_T on the other hand is not so well behaved; Figure 1 shows Z_T plotted against frequency for a number of cables based in URM 43 and it is clear from these that an increase in optical coverage (i.e. the proportion of screen area that is not holes) does not necessarily result in a reduction in Z_T. The reason for this is that the mutual inductive part of Z_T (the part that rises linearly with frequency) is itself made up of two components with opposite signs, and low values result when the magnitudes of the two components are nearly the same.[2] This process, called optimization, cannot as yet be accurately modelled and part of our work involves trying to find ways of predicting Z_T. Z_T and Z_F are measured over a wide frequency range, as reported elsewhere.[3] At frequencies up to about 150 MHz a simple triaxial tester is used. The outer circuit consisting of the braid and the brass body of the tester is short circuited to cause a current in the braid. The inner circuit is matched at both ends and the induced signal is measured, enabling one to calculate Z_T. At higher frequencies a different approach is used. In this case the outer circuit contains a travelling wave whose phase velocity is equal to that in the inner coaxial. The whole set-up has to be carefully matched at all ends and it is then used at frequencies for which it may be many wavelengths long. The coupling is measured in both directions relative to the direction of the input signal (near end and far end coupling) and Z_T is then found. The linear rise of Z_T with frequency seems to continue up to frequencies of several GHz.

Figure 1 shows one aspect of the optimization process; as the optical coverage is reduced in order to minimize Z_T, so Z_F rises. The rise in Z_F will not be important in most applications where the braid is earthed at both ends, but designers using very high source and load impedances and floating modules need to take this into account.

The transfer impedance of some optimized cables is quite sensitive to twisting,[4] a factor that may reduce their usefulness.

In summary then, it is possible to realize large improvements in transfer impedance by changing some of the parameters of the braid design. The object of new cable designs will be to realize a low, stable value of Z_T without increasing Z_F too much and without making the cable significantly more expensive to produce.

3 Coupling Calculations

In this Section we shall ignore the effects of Z_F, for simplicity and because it is rarely of practical importance. The transport of a signal from one coaxial line to another can be split into three stages: first the current flowing in the source line causes an e.m.f. to appear in the outside of the cable outer, this is governed by Z_T. Then the e.m.f. gives rise to a current in (among other things) the outside of the victim cable's outer conductor, and thirdly the signal gets into the victim cable again through the effect of Z_T. If values of Z_T for the source and victim line are known, and the reasonable assumption is made that the coupling is sufficiently small that the impedances seen by leaked signals do not affect conditions inside the cables, then the problem reduces to that of finding the current in the victim outer due to an e.m.f. in the source outer. Proper account must be taken of phase shifts and attenuation caused by coupling, radiation and resistive losses.

Different approaches to the problem of phase produce different models, if the frequency range is restricted to that over which the cables are electrically short a lumped circuit results. Transmission line (distributed) circuits must be used if a higher upper frequency limit is required. As distributed circuit analysis yields results at frequencies going right down to d.c., lumped models seem superfluous. They are used because they provide a valuable check on the results produced by distributed models and because they can result in improved physical understanding of the problems.

To exemplify the two approaches, consider the simple arrangement of two parallel coaxial cables, matched at each end and with their outer conductors connected together at both ends.

Considering first the lumped model, the source produces a current, I, in the first line that is in phase with the e.m.f. and whose magnitude is equal to the e.m.f. divided by twice the characteristic impedance. The effect of Z_T is to cause an e.m.f. of value IZ_Tl in series with the outer conductor of the source line as it appears in the third circuit (i.e. that consisting of the two cable outers). The current flowing in the third circuit is the e.m.f. divided by the impedance made up of the self-inductance of the loop in series with terms representing coupling, radiation and ohmic losses. The effect of Z_T is to cause an e.m.f. in the victim line, half of which appears across the victim load. For identical lines the coupling factor is:

$$F = \left| \frac{Z_T^2 l}{2Z_0(R_T + j\omega L)} \right| \quad (1)$$

where Z_T = surface transfer impedance per unit length
Z_0 = characteristic impedance of cables
l = coupling length
L = loop inductance of third circuit per unit length
R_T = total loop resistance per unit length of the third circuit
and ω = angular frequency.

In the distributed circuit model the current flowing in each incremental length of source line gives rise to an incremental e.m.f. at the same distance along the third circuit. Two standing waves, one in each direction, are established by the e.m.f. and integrating along the length of the set up yields the third circuit current distribution. This current then couples into the victim line through the effects of Z_T, so another integration yields an expression for the coupling:

$$F = \left| \frac{Z_T^2 e^{-\gamma l}}{2Z_0 Z_{03}} \left(\frac{\gamma^3 l}{\gamma_3^2 - \gamma^2} - \frac{2\gamma^2}{(\gamma_3^2 - \gamma^2)^2} \cdot \frac{\cosh \gamma_3 l - \cosh \gamma l}{\sinh \gamma_3 l} \right) \right| \quad (2)$$

where γ = propagation constant of coaxial lines
γ_3 = propagation constant of tertiary
Z_{03} = characteristic impedance of tertiary.

The two expressions (1) and (2) both yield useful information, for example increasing the spacing increases L in the lumped model and Z_{03} in the distributed circuit, both reducing the coupling. Different aspects of the frequency response are shown in the models. The lumped circuit demonstrates that the coupling is constant at the very lowest frequencies, then starts to fall when ωL takes over from R_T as the dominant factor. At higher frequencies the increase in Z_T causes the coupling to go through a minimum and begin to increase with frequency. These effects are present in equation (2), although they are not so apparent. What are apparent, however, are the long-line effects: different values of phase velocity, as evidenced by differing γ and γ_3, give rise to the possibility of cancellation leading to very small values of coupling at some frequencies. The $(\sinh \gamma_3 l)^{-1}$ term denotes resonances in the third circuit, at frequencies for which the length is an integral number of half wavelengths. The result of this is a series of peaks in the coupling versus frequency characteristic. Figure 2 shows the coupling versus frequency for two URM 43 cables, with the PVC jackets removed, 2 m in length, 1 cm apart and 6 cm above a ground plane. The theoretical coupling is not a smooth curve because experimentally determined values of Z_T have been used. The peaks occur at multiples of 75 MHz, the 300 MHz peak is missing because it coincides with one of the nulls.

In practice the third circuit may be more complicated than in the case discussed above. The simplest extension is to consider a number of conductors (which may themselves be coaxial cable outers) running parallel to the source and victim lines, all of them adjacent to a conducting plane, or in a trough or duct. The method of images may be used to compute the self and mutual inductances per unit length in such a system and so the derivation of a lumped circuit model is straightforward.[5,6]

The influence of a ground plane can be readily incorporated into the distributed circuit model with just two coaxial cables,[7] but after this the problem becomes complicated. Work is at present in progress to find an efficient way to deal with distributed circuit models including several lines and conducting planes. The work reported by Paul[8] is a good starting point here. A general formulation will also be necessary to cope with cable runs involving discontinuities, such as bends or cables entering and leaving the bunch. The effects of dielectrics, particularly the jackets on coaxial cables, are also under investigation.

4 Coupling Experiments and Results

The experiments performed to date have used straight parallel cables, 1 or 2 m in length. The cable outers have been connected together at both ends and cables have been placed above earthed planes or in corners, troughs and boxes, fabricated using aluminium, brass or copper.

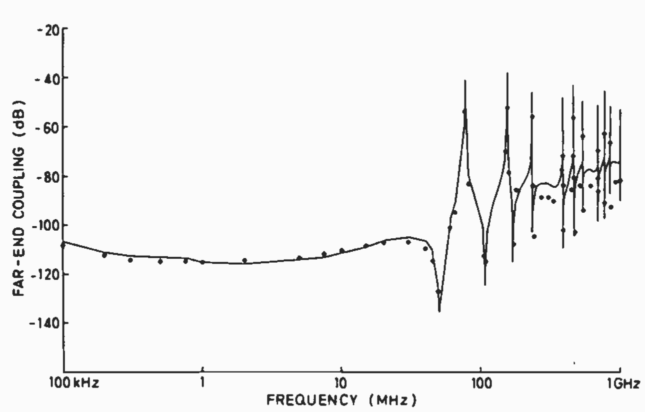

Fig. 2. Coupling versus frequency for 2 m of URM43 (PVC jackets removed). 1 cm apart. 6 cm above a ground plane. The line is predicted coupling. diamonds are experimental points.

The measurement of coupling proceeds in two stages. First, coupling is directly measured using a swept signal source and a spectrum analyser as detector. The spectrum analyser display is photographed to provide a permanent record of the coupling versus frequency. Then the coupling is measured accurately at a number of frequencies using an attenuator substitution method, the results of the swept measurement enabling these frequencies to be chosen sensibly.

Care must be taken to ensure that leakage from other parts of the system does not affect the results. The sending and receiving apparatus are placed about 3 m apart, connections are made using solid-jacketed cable (Andrews 'Heliax') and great care is taken over the assembly of connectors.

Figure 2 shows the results of a distributed circuit model compared with experimentally determined coupling. Agreement concerning the form of the results is complete, and the frequency information is predicted to within a few percent. Amplitudes are not in such good agreement, especially when the tertiary is resonant. Minima often cannot be measured using the present equipment owing to lack of sensitivity, but more important, theory consistently overestimates the magnitude of the coupling maxima. The value of coupling at resonance depends critically on the Q of the resonance, and third circuit losses are difficult to evaluate. A more important cause for concern is the assumption that coupling is a small effect, this may not be true when there is a high Q resonance in the third circuit. The problem becomes rather difficult if a complete analysis has to be performed: a numerical method may be of value here. Agreement is better for 2 m lengths than for 1 m ones which implies that there is an end effect, the nature of which has not yet been determined.

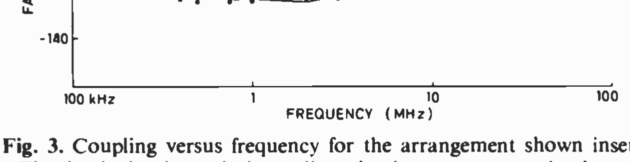

Fig. 3. Coupling versus frequency for the arrangement shown inset. The line is the theoretical coupling, the dots are measured values.

Figure 3 shows the results of the lumped circuit model compared to experiment. Agreement is within 3 dB, and the upper frequency limit for the model is clearly shown by the deviation for frequencies at which the length is more than about one-tenth of a wavelength.

5 Conclusions

The work described above demonstrates that levels of coupling may be accurately predicted using circuit models to describe the effect of the third circuit. At low frequencies agreement is so good that differences between theory and experiment could all be explained by sample-to-sample variations in Z_T of the same order as experimentally determined variations. If resonances occur in the third circuit, the peak levels of coupling may not be accurately predicted, although the frequencies of the peaks are.

6 Acknowledgments

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Thanks are also due to Dr M. M. Rahman, Mr S. Sali and Mr P. Cudd who have all contributed to the programme.

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Indexing Terms: Antennas, Phased arrays

Design considerations for Ruze and Rotman lenses

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SUMMARY

Ruze and Rotman lenses are types of parallel-plate lens which can be used to form multiple beams for antenna arrays. An algebraic analysis is used to relate the different orders of phase aberration to the lens contours, and shows that lenses with zero second- and third-order aberrations can be designed. For a given array length and beam scan angle requirement, the analysis determines the minimum lens size and simplest design which can be used.

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1 Introduction

There are many applications in radar and communications systems which require the generation of a set of multiple beams from a single antenna aperture. Very often a linear array fed by a Maxon or Butler matrix is used, either of which involves many couplers and cross-overs. A useful alternative is to use a parallel-plate lens as a multiple-beam-forming network, as shown in Fig. 1. A signal fed into one beam port produces an array excitation which produces a beam in a particular direction.

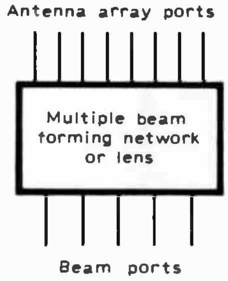

Fig. 1. A multiple beam forming network.

Parallel-plate lenses are, in principle, wideband systems since their design is based upon electrical path length compensation. This means that the directions of the emerging beams from the antenna array will remain fixed as the frequency changes but the beamwidth and cross-over points of the multiple beams will change with frequency. The directional patterns can therefore only be orthogonal at one fundamental frequency. This is important since the spatial orthogonality of the multiple beams results in no mutual coupling between the input ports. Lens systems can usually be designed to have a fairly low (< -20 dB) mutual coupling over wide bandwidths. Butler matrices can be orthogonal over a band of frequencies, but the beam directions are no longer stationary.

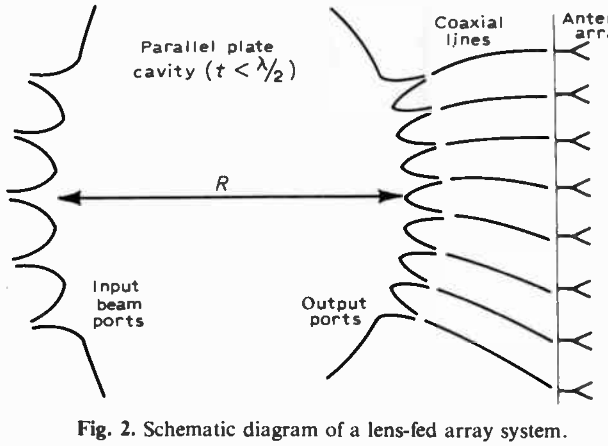

Fig. 2. Schematic diagram of a lens-fed array system.

Figure 2 shows a general parallel-plate lens, which contains a parallel-plate cavity with plate separation less than $\lambda/2$, so that only a TEM mode can propagate. This provides a dispersionless two-dimensional space. If we consider the lens as a transmitting device, there are several input ports, one for each beam, and the number of output ports is equal to the number of elements in the antenna array. Lengths of transmission line (the lengths

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are a lens design variable) connect the output ports to the array elements. The cavity can have air between the plates with either waveguide sectoral horns or probes as inputs and outputs, or can be made (at reduced size) on a dielectric substrate with microstrip lines feeding in and out with flared matching sections.[3,4] By comparison with optics, the 'lens' could be defined to be just the output ports, coaxial lines and the antenna array, with the input ports taking positions on the 'focal arc'. The optical equivalent is shown in Fig. 3. Here we shall define the lens to be the whole structure, including the input beam ports and the parallel-plate cavity.

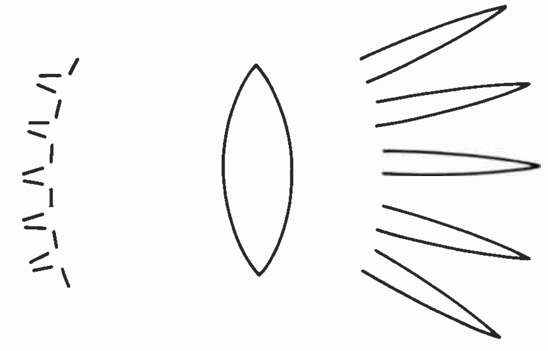

Fig. 3. An optical lens with multiple beams.

Ideally excitation of each input port produces a suitable phase variation across the array elements to produce a beam in a particular direction; for a linear array this is a linear phase variation. In practice, the geometry of the lens produces only an approximately linear phase variation, and the phase aberrations may become important. Various lens designs have been described in the literature[4–8] which have between one and four perfect focal points. A perfect focus is a point on the input contour which provides an exactly linear phase variation along a linear antenna array, and hence produces an undistorted beam in a specific direction. In this paper we only consider linear antenna arrays, for which we can have up to three focal points in the lens. Parallel-plate lenses are also suitable for feeding conformal arrays, but this is beyond the scope of the present paper. Here the phase aberrations for input positions between the foci are analysed in terms of geometrical optics. A power series expansion of the path length formulae is used to describe the different orders of aberration as functions of the lens contours. Ruze[5] derived equations for the contours of various types of lens, including one suitable for feeding a linear antenna array. This has equal line lengths between the lens and the array, and uses an elliptical output contour with two focal points on the input contour. Ruze derived approximate expressions for the second- and third-order aberrations for this lens; here a full power series expansion with exact coefficients is derived. Rotman and Turner[6] derived equations for the contours of a three-focal-point lens, with unequal line lengths. They calculated the aberrations for input positions between the foci numerically. Here a power series expansion is used to give expressions for the different orders of aberration. In both the above cases, the curvature of the input contour (usually taken to be an arc of a circle) is a variable parameter. The algebraic expressions derived here are used to optimize the lens design with regard to phase aberrations. In particular it is shown how the lens parameters can be chosen to give zero second- and third-order aberrations for all input ports.

Previous analyses have allowed the calculation of aberrations for a given lens geometry. Here the aim is to treat the design process where the array length and scan angle required are known, and the minimum lens size and simplest geometry are to be determined. Two criteria are identified which determine the minimum lens size for a given scanning requirement. For a very long lens (large R), only small angles within the lens are needed to give the phase variation required for scanning. The higher-order terms in the expansions, i.e. the aberrations, are consequently very small. As the longitudinal dimension R is reduced, the angles increase and the aberrations may become unacceptably large. This gives one limit on size reduction, which is strongly dependent on the choice of lens contours. The second limit on size reduction is that the subtended angles in the lens should not become so large that the lens becomes wider than it is long. This limit is (approximately) independent of the lens contour, and for small arrays it can be the dominant factor. In these cases simple lens designs give sufficiently low phase aberrations.

Figure 4 shows the general geometrical arrangement for the various lenses considered in this paper. We have symmetry about the x-axis, allowing beam scanning between $+\psi_0$ and $-\psi_0$. We will usually *normalize* all lengths by dividing by R, the distance between the centres of the input and output contours, so that these are at (0, 0) and (1, 0) respectively. We also subtract the line length w_0 from all lengths w. Each lens is then defined by the functions $x_1(y_1)$, $x_2(y_2)$ and $w(y_3)$.

The treatment tacitly assumes that the lens cavity has a relative permittivity $\varepsilon = 1$: if it is constructed on a substrate with $\varepsilon \neq 1$, the dimensions of the lens are reduced by a factor $\varepsilon^{\frac{1}{2}}$.

Only the 'ideal' phase performance of the lens is considered in Sections 2–4 of this paper. Previously published work[1–8] has used geometrical optics to predict phase performance, and this approximation is also used

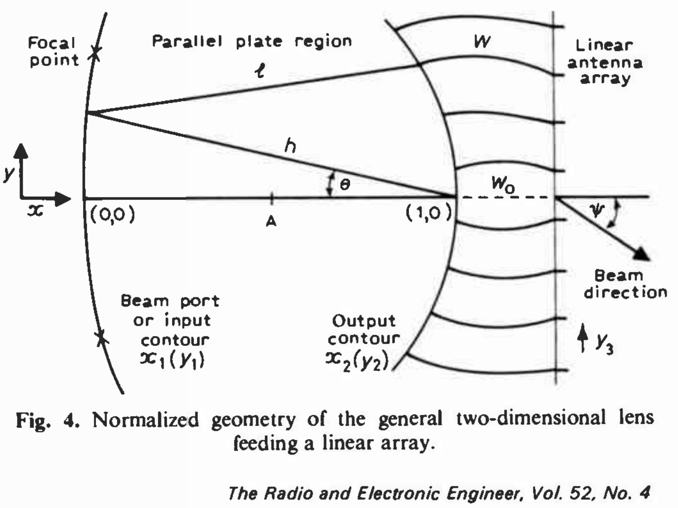

Fig. 4. Normalized geometry of the general two-dimensional lens feeding a linear array.

here. Niazi *et al.*[4] have compared the predictions of geometrical optics with experiment and found reasonable agreement. The limitations of the geometrical optics approach are considered in Section 5.

2 Lenses with Equal Line Lengths (Ruze Lenses)

Ruze[5] proposed a number of lens designs which included a straight front face system (i.e. a linear antenna array) with $w(y_3) =$ constant. This lens has an elliptical output contour with two perfect foci at the foci of the ellipse. In this Section we shall analyse the general case with $w =$ constant, and will show how the Ruze lens[5] and the semicircular lens[3,4] fit in to the general theory.

Referring to Fig. 4, we can express the output contour $x_2(y_2)$ as a power series:

$$x_2 = 1+b_1 y_2^2+b_2 y_2^4 \cdots. \quad (1)$$

The normalized path length from a point (x_1, y_1) on the input contour can then be expressed as:

$$l = \{(x_2-x_1)^2+(y_2-y_1)^2\}^{\frac{1}{2}}.$$

Substituting for x_2 from (1), and expanding l as a power series in y_2, we obtain

$$l = h-\frac{y_1 y_2}{h}+\frac{y_2^2}{2h}\left\{c_1-\frac{y_1^2}{h^2}\right\}+\frac{y_2^3 y_1}{2h^3}\left\{c_1-\frac{y_1^2}{h^2}\right\}+ + \frac{y_2^4}{8h}\left\{4c_2-\frac{c_1^2}{h^2}+\frac{6y_1^2 c_1}{h^4}-\frac{5y_1^4}{h^6}\right\}+O(y_2^5) \quad (2)$$

where

$$c_1 = 1+2b_1(1-x_1), \quad c_2 = 2b_2(1-x_1)+b_1^2$$

and h is the distance from (x_1, y_1) to the centre of the output contour (see Fig. 4).

This expression can be used to analyse the various possible lens configurations with $w(y_3) =$ constant.

The first-order term

$$-\frac{y_1 y_2}{h} = -y_2 \sin\theta$$

provides the wanted linear phase variation across output ports equally spaced in y_2. The higher-order terms are then the unwanted (normalized path length) aberrations.

To scan a linear antenna array through an angle ψ, we require that the path length variation $Ry_2 \sin\theta = Ry_3 \sin\psi$. For array elements spaced by $\lambda_0/2$, the output ports of the lens are spaced by $R.\delta y_2 = C(\lambda_0/2)$, where the constant $C = \sin\psi/\sin\theta$. Thus an input port subtending an angle θ_i in the lens has a corresponding beam direction ψ_i given by $\sin\psi_i = C\sin\theta_i$. If we now consider an array with aperture $N\lambda_0$, the maximum value for y_3 is $N\lambda_0/2R$, so $y_{2(\max)}$ is $(N\lambda_0/2R)(\sin\psi/\sin\theta)$ and we have the geometrical requirement that

$$Ry_{2(\max)}\sin\theta = \frac{N\lambda_0 \sin\psi}{2}. \quad (3)$$

For a maximum scan angle ψ_0, and given array length $N\lambda_0$, (3) is a basic constraint on the lens geometry. We will normally want both $\sin\theta$ and $y_2 \lesssim 0{\cdot}5$ for a practical lens design. This is because (a) the lens would become wider than it is long, and (b) the amplitude performance of the lens would become very difficult to maintain if the distances and angles between different input and output ports become very different. We then require:

$$R/\lambda_0 \gtrsim 2N\sin\psi_0. \quad (4)$$

This requirement is independent of the phase aberration criteria which otherwise determine the minimum R.

[*Note.*—If $\sin\psi_0 < 0{\cdot}5$, the minimum R from (4) uses an implied value of $C < 1$ so that the output port spacing is $< \lambda_0/2$. In this case $C = 1$ and $\sin\theta_0 < 0{\cdot}5$ can be used with $R/\lambda_0 \gtrsim N$.]

If we consider a uniformly illuminated aperture of length $N\lambda_0$, the angular spacing of orthogonal beams (at the frequency corresponding to λ_0) is $\delta(\sin\theta) = 1/N$. It follows that the number of beams required in this case is $2N\sin\psi_0$. (With our choice of angular limits for the lens, this equals $R_{\min}/\lambda_0$.) The spacing of the input ports is then

$$R\,\delta y_1 \simeq 2R\sin\theta_0/(2N\sin\psi_0-1)$$
$$\simeq \lambda_0/(2y_{2(\max)}), \qquad \text{using (3).}$$

For the minimum R from (4), we have $y_{2(\max)} = 0{\cdot}5$, so the spacing is then $\sim \lambda_0$.

The phase aberrations set a second limit on R. Consider a case where $\delta l\,(= l-h+y_2\sin\theta) \simeq Ay_2^2$, i.e. ignoring aberrations of higher order than the second. If θ_0 is the angle subtended by the extreme input port (corresponding to a beam at ψ_0),

$$y_{2(\max)} = \frac{N\lambda_0}{2R}\cdot\frac{\sin\psi_0}{\sin\theta_0}.$$

If we keep $\sin\theta_0 = 0{\cdot}5$ and vary R, the maximum path length aberration is

$$R\,\delta l_{\max} \simeq \frac{A(N^2\lambda_0^2\sin^2\psi_0)}{R}.$$

Thus as we increase R, the aberrations are reduced. We can now estimate the minimum R for a given maximum phase error; for example if we require $|R\,\delta l| \leqslant \lambda_0/16$, we find

$$\frac{R}{\lambda_0} \gtrsim 16|A|(N\sin\psi_0)^2. \quad (5)$$

The minimum R for a lens with a predominant second-order aberration is then the larger of (4) and (5).

The second-order term in (2) could be removed entirely if we can choose $c_1 = y_1^2/h^2$. This requires $b_1 = -\frac{1}{2}$, and

$$(x_1-\tfrac{1}{2})^2+y_1^2 = \tfrac{1}{4} \quad (6)$$

which is a circle radius $\frac{1}{2}$ centred at the midpoint A of the lens.

The third-order term is also identically zero if these conditions are satisfied. The output contour is only specified as

$$x_2 = 1-\tfrac{1}{2}y_2^2+b_2y_2^4+O(y_2^6) \quad (7)$$

so we can construct various lenses with *zero* second- and third-order aberrations.

We are still free to choose b_2, b_3, etc.; this allows us to exercise some control of the higher-order aberrations. With the conditions already specified, the fourth-order term is

$$\frac{y_2^4}{8h}(8(1-x_1)b_2+1),$$

which can only be zero at two symmetrical points where

$$x_1 = 1+1/(8b_2). \tag{8}$$

This demonstrates that there are at most two perfect focal points (where *all* higher-order terms are zero) for a lens with w = constant. We can make all terms zero at these points by correct choice of the constants b_i.

Ruze[5] proposed a number of lens designs which included a straight front face system (i.e. a linear antenna array) with w = constant. His lens has an elliptical output contour with two perfect foci at the foci of the ellipse. In our coordinates these are at

$$(x_1, y_1) = (1-f\cos\alpha,\ \pm f\sin\alpha).$$

The output contour is:

$$(x_2-1+f\cos\alpha)^2+y_2^2\cos^2\alpha = f^2\cos^2\alpha. \tag{9}$$

Ruze considered two possible input contours, (i) a circular arc centred at (1, 0), so that (here) $f = 1$; and (ii) a 'refocused' arc with $f = 1/(1+\alpha^2/2)$. The first case has significant second- and third-order aberrations away from the focal points, and the second case has much reduced aberrations.

First consider case (i). Applying the formulae above, we find the coefficient $b_1 = -\cos\alpha/2$, and the second-order aberration Ay_2^2 to have coefficient

$$A = \tfrac{1}{2}\cos\theta(\cos\theta-\cos\alpha).$$

If we let $\alpha = 20°$, $\theta = 30°$ and $y_2 = \pm 0{\cdot}5$ we find that $|A| = 0{\cdot}032$ and $(\delta l)_{max} \simeq -0{\cdot}008$, taking only the second-order term. Exact calculation of the path lengths between an input port at $\theta = 30°$ and output ports at $y_2 = \pm 0{\cdot}5$ give $\delta l = -0{\cdot}010$ and $-0{\cdot}006$ respectively. The differences are principally due to the third-order term, which is a factor of $y_2 y_1/h^2$ ($=\frac{1}{4}$ here) smaller. If we use equation (5), we find

$$\frac{R_{min}}{\lambda_0} \simeq 0{\cdot}5(N\sin\psi_0)^2.$$

Comparison of this limit with the 'geometrical' limit (eqn. (4)) indicates the scanning capability of this particular lens. The two limits are equal when $N\sin\psi_0 \simeq 4$; for larger $N\sin\psi_0$ the phase aberrations set the minimum size, and a lens design with smaller phase aberrations is needed.

(The limit for this lens could be a 16-element $\lambda_0/2$ spaced array which scans from $-30°$ to $+30°$.)

Now consider case (ii). By comparison with the theory above, we can obtain zero second- and third-order aberrations if the input contour is a circular arc with radius $\frac{1}{2}$. The foci must then lie on the curve of equation (6) so their coordinates are

$$(x_1, y_1) = (\sin^2\alpha,\ \pm\sin\alpha\ \cos\alpha),\text{ whence } f = \cos\alpha.$$

This is very close to Ruze's case (ii) if α is small. Equation (8) now shows that $b_2 = -1/(8\cos^2\alpha)$, as can also be shown by expanding (9) directly. The normalized path length aberrations for $f = \cos\alpha$ start with the fourth-order term By_2^4 where

$$B = (\sin^2\theta-\sin^2\alpha)/\{8\cos\theta\cos^2\alpha\}.$$

If we again let $\alpha = 20°$, $\theta = 30°$, we find that $B = 0{\cdot}022$ and hence for $y_2 = \pm 0{\cdot}5$ that $(\delta l)_{max} \simeq 1{\cdot}4\times10^{-3}$. Exact calculations give $\delta l = 2{\cdot}2\times10^{-3}$ and $1{\cdot}2\times10^{-3}$.

A semicircular lens[3,4] is a degenerate Ruze lens where $\alpha = 0$ ($f = 1$), so that the two focal points have merged into one. The input contours (i) and (ii) above can still be used if they are identified as (i) a circular arc centred at (1, 0) and (ii) a small circle of radius $\frac{1}{2}$ just fitting inside the semicircle.

3 Three-focal-point (Rotman) Lenses

We now consider the case $w \neq$ constant, still keeping to a straight front face system. Rotman and Turner[6] derive equations for the input contour $x_1(y_1)$, the output contour $x_2(y_2)$ and $w(y_3)$, taking the three focal points to be where $\theta = 0, \pm\alpha$. Their co-ordinate system has a different origin, and is normalized to the focal length at $\theta = \pm\alpha$ rather than at $\theta = 0$, and they take the case where the angle in the lens θ is equal to the beam scan angle ψ. A different form of the equations is consequently used here (see Appendix).

It is found that y_2 is no longer linearly related to y_3 when $w \neq$ constant, so we make our series expansion in terms of

$$\zeta = y_3\sin\psi/\sin\theta \tag{10}$$

with $\sin\psi/\sin\theta$ a constant. The linear term in the expansion of the total path length $p = l+w$ will be $-y_3\sin\psi = -\zeta\sin\theta$. For an equally spaced array, we require output ports equally spaced in ζ (rather than y_2). We can find the corresponding positions (x_2, y_2) of the output ports from the equations in the Appendix. The line lengths w can be expanded in powers of ζ as

$$w = K\zeta^2+O(\zeta^4)$$

where (11)

$$K = \frac{\cos\alpha}{2}\frac{(1-g\cos\alpha)}{(1-\cos\alpha)}, \qquad g = 1/f$$

and f is the focal length at angles $\theta = \pm\alpha$. We then find that

$$\begin{aligned} p = h &-\zeta\sin\theta+\frac{1}{2}\frac{\zeta^2}{h}\Big\{2K(h-1)-\sin^2\theta+ \\ &+\frac{h\cos\theta-1}{g-\cos\alpha}(2K(1-g)-g\sin^2\alpha)\Big\}+ \\ &+\frac{1}{2}\frac{\zeta^3}{h^2}\sin\theta\Big\{2K(gh^2-1)-\sin^2\theta+ \\ &+\frac{(h\cos\theta-1)}{(g-\cos\alpha)}[2K(1-g)-g\sin^2\alpha]\Big\}+O(\zeta^4). \end{aligned} \tag{12}$$

The input contour is not yet fully defined. Rotman and Turner took it to be a circular arc through the three focal points. On this assumption, h, the distance from the input contour to (1, 0), is given by

$$gh^2 - h\left\{\frac{(g^2-1)\cos\alpha}{g-\cos\alpha}\right\} - \frac{(1-g\cos\alpha)}{g-\cos\alpha} = 0. \quad (13)$$

Rotman and Turner considered two special cases: (a) $g = 1$ and (b) $g = 1+\alpha^2/2$. First consider (a); this is the circular arc of radius 1 as in (i) for a Ruze lens. Now $h = 1$ for all θ, and the second-order aberration is

$$-\tfrac{1}{2}\zeta^2\{\sin^2\theta-(1-\cos\theta)(1+\cos\alpha)\}.$$

The maximum aberration from an input port between the focal points occurs where $\cos\theta = \frac{1}{2}(1+\cos\alpha)$, giving

$$-\tfrac{1}{2}\zeta^2 \cdot \tfrac{1}{4}(1-\cos\alpha)^2.$$

If we take $\alpha = 30°$, $\theta \simeq 15°$, we find that the coefficient of ζ^2 is $A = -2{\cdot}0\times10^{-3}$, which is appreciably smaller than the coefficient of y_2^2 for the Ruze lens with the same input contour.

The variables y_2 and ζ are not identical for the Rotman lens, but they are of comparable magnitude; the maximum value of $|\zeta|$ is therefore taken as 0·5, and the geometrical limit (4) is still applied. The aberration $(\delta p)_{max} \simeq -5\times10^{-4}$ for $|\zeta| = 0{\cdot}5$, using only the second-order term; exact calculation gives $\delta p = -5{\cdot}5\times10^{-4}$ and $-4{\cdot}5\times10^{-4}$ for $\zeta = \pm0{\cdot}5$. Applying equation (5) we find

$$\frac{R_{min}}{\lambda_0} \simeq 0{\cdot}032(N\sin\psi_0)^2$$

which is equal to (4) when $N\sin\psi_0 \simeq 60$. This suggests that this lens design is capable of feeding quite large arrays (the array length is $N\lambda_0$) with wide angle scanning, using the minimum lens size (4).

The aberrations as functions of θ for $g = 1/\cos\alpha$ are:

$$\delta p = \frac{\zeta^4}{8\cos\theta}\cdot\frac{1+\cos\alpha}{\cos\alpha}\left\{(1-\cos\theta) - (1-\cos\alpha)\frac{\sin^2\theta}{\sin^2\alpha}\right\} - \frac{\zeta^5}{8}\cdot\frac{\sin^2\theta}{\cos^2\theta}\cdot\frac{1+\cos\alpha}{\cos^2\alpha}\times$$
$$\times\left\{\cos^2\theta - \frac{\sin^2\theta}{\cos^2\alpha}\cos^2\alpha - \cos\alpha\left(1-\frac{\sin^2\theta}{\sin^2\alpha}\right)\right\} + O(\zeta^6). \quad (14)$$

If we now evaluate (14) for a typical case, $\alpha = 30°$, $\theta = 15°$, we find the first two terms are

$$-0{\cdot}00051\zeta^4 - 0{\cdot}00962\zeta^5.$$

The fourth-order term only will therefore not be a good approximation for $|\zeta| = 0{\cdot}5$! Evaluation of both terms gives $\delta p = -3{\cdot}3\times10^{-4}$ and $+2{\cdot}7\times10^{-4}$ for $\zeta = \pm0{\cdot}5$; exact calculation gives $\delta p = -6{\cdot}0\times10^{-4}$ and $+3{\cdot}7\times10^{-4}$ (still higher order terms are significant).

Although the maximum aberrations are comparable with the case $g = 1$, the aberrations are dominated by the fifth-order term rather than the second. The effect on the radiation pattern from the antenna array will therefore be very different.

4 Comparison of Scanning Capabilities

Six lens types (A–F) have been analysed in detail, using the theory given above, and are described in columns 2–5 of Table 1. Cases A, C and E have 1, 2 and 3 focal points respectively, and use an input contour with radius equal to the lens diameter; this facilitates equal power transfer between input and output ports. Cases B, D and F use the input contour (6), which has a radius equal to half the lens diameter; this gives zero second- and third-order phase aberrations. However, significant amplitude effects may be introduced due to the high curvature of the input contour.

Table 1. Comparison of lens types

Lens	Input contour	Output contour	Line lengths	No. of foci	Dominant aberration order	$(\delta p)_{max}$†	$(N\sin\psi_0)_{max}$†
A	Circular arc, radius 1	Semicircle	Equal	1	2nd	$1{\cdot}5\times10^{-2}$	2
B	Circular arc, radius ½	Semicircle	Equal	1	4th	$3{\cdot}6\times10^{-3}$	9
C	Circular arc, radius 1	Ellipse ($\alpha = 20°$)	Equal	2	2nd	8×10^{-3}	4
D	Circular arc, radius ½	Ellipse ($\alpha = 20°$)	Equal	2	4th	$2{\cdot}2\times10^{-3}$	14
E	Circular arc, radius 1	Rotman type ($\alpha = 30°$) $g = 1$	Unequal	3	2nd	6×10^{-4}	50
F	Circular arc, radius ½	Rotman type $g = 1/\cos\alpha$	Unequal	3	(4th+) 5th	6×10^{-4}	50

† These assume that $R = R_{min} = 2\lambda_0(N\sin\psi_0)$.

Now consider case (b). Inspection of the equations suggests using $g = 1/\cos\alpha$ rather than $1+\alpha^2/2$ (these are approximately equal for small α). Now we find that $K = 0$ in (11), and that $w = O(\zeta^4)$, $y_2 \simeq \zeta$, $x_2 \simeq 1-\zeta^2/2$. We also have $h = \cos\theta$, and the second- and third-order terms in (11) are both identically zero for all θ. The input contour for this case is identical, and the output contour similar, to case (ii) for the Ruze lens. The fourth-order differences between the two lenses provide the third focal point.

A given scanning requirement can usually be defined by the value of the product $N\sin\psi_0$, where the array has aperture $N\lambda_0$ (this can be simply related to the beamwidth required) and the maximum scan angle is $\pm\psi_0$. The minimum allowed value for the lens diameter

R from equation (4) is

$$R_{\min} = 2\lambda_0 N \sin \psi_0. \qquad (15)$$

If we take $R = R_{\min}$, the normalized path length aberration $(\delta p)_{\max}$ is calculated for $\sin \theta_0 = 0{\cdot}5$ and $|y_2|$ or $|\zeta| = 0{\cdot}5$. If we choose a simple phase aberration criterion

$$R\,\delta p \leqslant \lambda_0/16 \qquad (16)$$

then

$$N \sin \psi_0 \leqslant 1/(32(\delta p)_{\max}). \qquad (17)$$

From the values for $(\delta p)_{\max}$ in the Table, we can find the maximum value for $N \sin \psi_0$ for each lens design. It can be seen that for small arrays the more complex lens designs are unnecessary, so that one could avoid either unequal line lengths (cases E and F) or sharply curved input contours (cases B, D, F).

The lens dimensions given in this paper will depend on the relative permittivity ε_r of the substrate between the parallel plates; if $\varepsilon_r \neq 1$ we replace λ_0 in (15) by $\lambda_s = \lambda_0/\varepsilon_r^{\frac{1}{2}}$; (17) is unchanged.

Further reductions in $(\delta p)_{\max}$ can be made by reducing the curvature of the input contour (6) (used for lenses B, D and F) by a small amount. This introduces small second- and third-order terms which tend to cancel the fourth- and fifth-order terms in (2) or (12) for $|y_2|$ or $|\zeta| \simeq 0{\cdot}5$. For the Ruze lens D with $\alpha = 20°$, increasing f from 0·940 to 0·948 reduces $(\delta p)_{\max}$ to 5×10^{-4}. For the Rotman lens F with $\alpha = 30°$, reducing g from 1·155 to 1·131 reduces $(\delta p)_{\max}$ to 6×10^{-5}. The maximum $N \sin \psi_0$ can then be increased to 40, 60 or 500 for 1, 2 or 3 focal point lenses respectively. However, this assumes that a simple upper bound to $R\,\delta p$ of $\lambda_0/16$ is the aberration criterion required. In these cases the maximum aberration no longer occurs at the ends of the array, and the average aberration is not greatly reduced compared to cases B, D or F.

5 Limitations of the Geometrical Optics Approach

The first obvious limitation of the path length calculations is that they only give information about the *phase* of the signal at each element of the antenna array. The second limitation arises from reflections and scattering within the parallel plate cavity.

We can obtain a qualitative picture of these processes by considering Fig. 2.

The parallel plate cavity can be thought of as a two-dimensional 'free space', as it only propagates a TEM mode. The input and output ports are then two-dimensional antennas with radiation patterns and gains—for a wide aperture (e.g. a flared waveguide) the radiation pattern is narrow, or for a single probe, the pattern is very broad. In the former case, most of the energy from the input beam port is directed towards the output ports, and the sides of the cavity are only weakly illuminated. In addition an amplitude taper is created across the output ports and hence the antenna array. In the case of a broad pattern, reflections from the cavity sides are potentially more serious, and absorbent material is clearly required.

Now consider the output (array) ports. These are now two-dimensional receiving antennas, and the power received is proportional to their own radiation pattern. Some of the energy arriving at the output ports will be reradiated (as from any receiving antenna) depending on the angle of incidence. Some of the reradiated energy may return to the input beam ports and either be received, causing mutual coupling between beam ports, or suffer further scattering.

The phase of the main signal arriving at each output (array) port is given correctly by the geometrical optics, path length calculation. The amplitude of this signal is determined by the radiation patterns of the input and output ports. Both the phase and amplitude of the total signal at each output port will be affected by secondary signals due to the reflections and scattering described above. Niazi *et al.*[4] showed that these cause positive and negative deviations from the 'ideal' phase performance predicted by geometrical optics, while leaving the mean phase variation unchanged. Similar effects will occur in the amplitude distribution of the array, and both the amplitude and phase deviations will affect the beam shapes and sidelobe levels produced by the lens-fed antenna array.

Further work, both theoretical and experimental, is needed to quantify these effects in a parallel plate lens.

6 Conclusions

An analysis has been given of the design criteria for parallel-plate lenses used as multiple beam forming networks for linear antenna arrays. The usual geometrical optics approach and path length analysis have been used, but extended and applied in two new ways. Firstly, the path length formulae have been expanded as a power series, clearly bringing out the wanted linear phase variation plus the higher order phase aberration terms. These are now given explicitly in terms of the lens parameters, enabling us to find lens contours such that the second- and third-order aberrations are identically zero. We can also use the leading aberration terms to give explicit (approximate) formulae for the aberrations of different lens designs.

The second analysis is of the variation of the lens performance with its dimension R (the central distance between the input and output contours). For a given scanning requirement, i.e. array length $N\lambda_0$ and maximum scan angle ψ_0, there is a basic constraint on the lens geometry given by equation (3). This is derived from the linear term in the expansion. As we vary R, the angles subtended within the lens must change, and a minimum R is needed to keep these angles practicable. Analysis of the phase aberrations for this minimum R (Sect. 4) then shows the scanning limitations of one, two and three focus lens designs. For small arrays the more complex designs are found to be unnecessary.

The limitations of the geometrical optics approach are discussed (Sect. 5), and further work on the amplitude performance of Ruze and Rotman lenses is suggested.

7 Acknowledgment

The author would like to thank Professor D. E. N. Davies for valuable discussions and comments on the text.

9 Appendix: Rotman Lens Equations

The results in Section 3 are derived from the following equations for the input contour $x_1(y_1)$, the output contour $x_2(y_2)$ and $w(y_3)$, (see Fig. 1(b)) for a lens with three focal points at (0, 0), $(1-f\cos\alpha,\ \pm f\sin\alpha)$. Defining

$$\zeta = y_3 \sin\psi/\sin\theta, \qquad g = 1/f; \tag{18}$$

the equations are:

$$y_2 = \zeta(1-gw), \tag{19}$$

$$x_2 = 1+\frac{2w(1-g)-g\zeta^2\sin^2\alpha}{2(g-\cos\alpha)}, \tag{20}$$

$$aw^2+bw+c = 0, \tag{21}$$

where

$$a = 1-\frac{(g-1)^2}{(g-\cos\alpha)}-g^2\zeta^2,$$

$$b = -2+2g\zeta^2-\frac{\zeta^2\sin^2\alpha\, g(g-1)}{(g-\cos\alpha)^2}+\frac{2(g-1)}{(g-\cos\alpha)},$$

$$c = \frac{g\zeta^2\sin^2\alpha}{g-\cos\alpha}-\frac{g^2\zeta^4\sin^4\alpha}{4(g-\cos\alpha)^2}-\zeta^2.$$

These equations are identical with Rotman and Turner's[6] if we let $w' = gw$, $y'_2 = gy_2$, $x'_2 = gx_2$, $\zeta' = g\zeta$ and choose $\alpha = \psi_0$ so that $y_3 = \zeta$.

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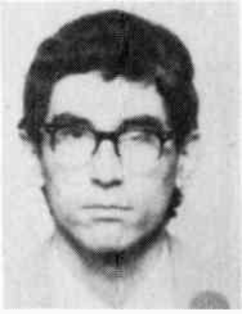

UDC 621.394.14

Indexing Terms: Information theory, Codes, symbolic, Error correction

Burst-error-correcting array codes

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SUMMARY

Classes of array codes for correcting bursts of errors, bursts of erasures, and mixed error-and-erasure bursts, are described. A specific example of a burst-error-correcting array code, and its decoder, is given. These codes have relatively high rates, small decoding delay, simple encoding and decoding algorithms, and are capable of high-speed operation. Array codes have a wide range of application in digital communications.

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1 Introduction to Array Codes

Digital data communication over a noisy channel often requires the provision of an error-detecting-and-correcting (e.d.c.) code to protect the data against errors arising during the transmission. These codes need to have a relatively high rate ($\geqslant \frac{1}{2}$) so that the information transmission capacity of the system is not unduly reduced; and the encoding and decoding circuits for the code must be as simple as possible so as to minimize implementation size, power consumption and cost. In addition, the decoding delay must be as small as possible, and in some cases the decoder must be capable of operating at very high speeds. The burst-error-correcting array codes described in this paper meet all of these rather exacting requirements.

Array codes[1–3] are linear systematic block e.d.c. codes formed by arranging one or more component codes into arrays in two or more dimensions. Array codes may be multi-level (q-nary), but the codes described below are all binary.

The simplest component code that can be used is the single-parity-check code (one-dimensional code) with k_1 information digits and one parity check, which may be represented as shown in Fig. 1.

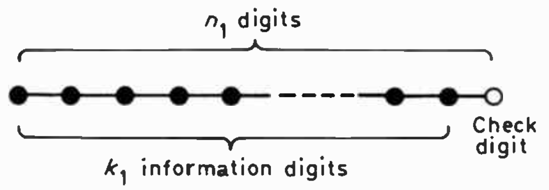

Fig. 1. Single-parity-check code.

The block length of this code is $n_1 = k_1 + 1$, and the Hamming distance is $d_1 = 2$ (single-error-detecting). If information digits are arranged in a $k_1 \times k_2$ rectangular array, and single parity checks are taken across the rows and columns of the array, then the two-dimensional code shown in Fig. 2 results.

This code has block length $n = n_1 \times n_2 = (k_1+1) \times (k_2+1)$, distance $d = d_1 \times d_2 = 4$ and rate $R = k_1 k_2 / n_1 n_2 = R_1 R_2$. It is, of course, the familiar two-coordinate code, or row- and column-parity code,[4]

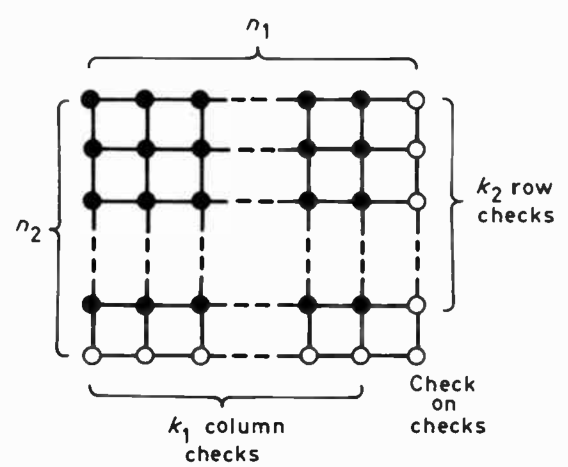

Fig. 2. Two-dimensional code with single parity checks.

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which has been widely used in a number of applications.[5–7] The code is single-error-correcting-double-error-detecting, and detects a high percentage of all possible error patterns. Removal of the check on checks reduces the distance to 3, which still enables single-error-correction. The basis of the random-error-control power of the code is now revealed: the row and column checks form a set of two orthogonal parity check equations on each information digit in the array, in the sense that an information digit is in error if and only if both the row and column checks associated with that digit fail.

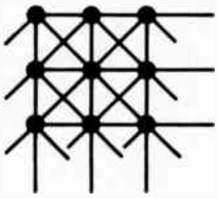

Fig. 3. Diagonal checks on a two-dimensional code.

To obtain an array code with $d = 5$ (double-error-correction), two more orthogonal check sets must be formed on the array: the two main diagonal directions will serve (see Fig. 3). The addition of 'knights move' direction sets will increase the distance to 7 (triple-error-correction), and so on. These codes become lower in rate as direction sets are added, and the checks on information digits at the corners of the array are inefficiently used. There are a number of techniques for improving the rate, however, such as shortening, combining or 'folding back' of direction sets, augmentation and the use of total or overall checks.[1–3] In particular, 'folding back' of parity check direction sets is possible because the information digits involved in a check need not lie on a straight line in the array, but can lie on a crooked line, provided that the orthogonality conditions are not violated. Using this property, efficient array codes can be found.[8] The orthogonality of the parity checks of these codes permits the use of relatively simple forms of majority-logic decoding.[9]

The array codes introduced above are based on single-parity-check component codes, and are designed for random-error-correction. The rest of this paper is concerned with modifying the above array codes into a form suitable for efficient burst-error-correction. Other forms of array code may be derived by using more powerful component codes; these array codes then include the classes of product codes[10–12] and iterated codes.[13,14]

2 Burst E.D.C. with Array Codes

2.1 Burst-error-detection

If the digits of the array code of Figure 2 are transmitted serially in consecutive rows, then bursts of length $b \leqslant n_1$ can be detected, since each digit in error in the burst will cause a column check to fail. The pattern of the error burst will be known, but its location in the rows cannot be determined. It is unnecessary to provide row checks, in fact, since the burst-detection process is done entirely by the column checks (Fig. 4). Thus the code has $b = k_1$,

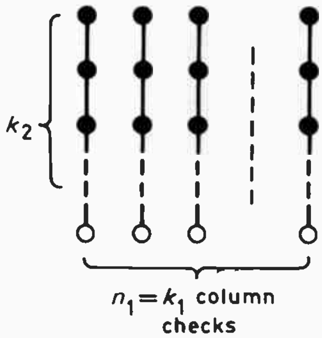

Fig. 4. Column checks on array code.

$n = k_1\ (k_2+1)$, and $R = k_1 k_2 / k_1\ (k_2+1)$. Decoding is extremely simple and fast.

2.2 Burst-error-correction

To correct a burst of errors, an additional set of checks, orthogonal to the column checks, is required, so diagonal checks may be used (Fig. 5). The code has $b = k_1$, $n = k_1(k_2+2)+k_2-1$, and $R = k_1 k_2 / \{k_1(k_2+2)+k_2-1\}$. Folding back, or combination, of the inefficiently used checks improves the rate by reducing the number of checks required.

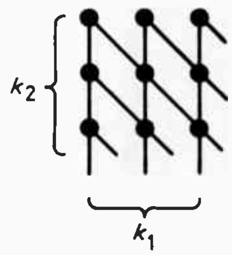

Fig. 5. Diagonal checks on array code.

Correction with a simple majority logic decoder is limited to bursts occurring entirely in one row only, however. (See Fig. 6).

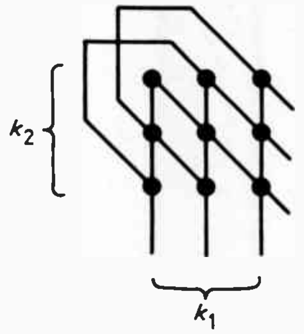

Fig. 6. Folding back of diagonal checks.

An implementation of a 16×16 array code for row-burst-error-correction has been shown to have a performance close to that of an equivalent rate and block length Reed–Soloman code, but with a very much simpler decoding algorithm.[15]

A modified form of the code of Fig. 6, with the digits re-arranged so that the diagonal checks are now row checks, and with a check-on-checks added, leads to a decoding algorithm very little more complex than that of the code of Fig. 5. It is most helpful to think of this form of burst-error-correcting array code as the code of Fig. 2 with diagonal read-out from the array for transmission as shown in Fig. 7.

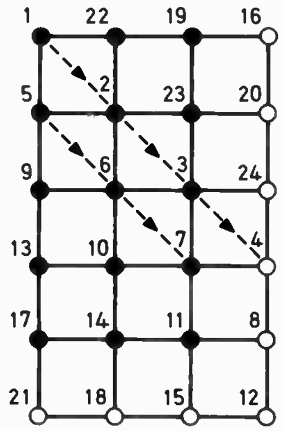

Fig. 7. Array code with diagonal read-out.

In this example, the code has $b = 3$, $k_1 = 3$, $k_2 = 5$, $n = 24$ and $R = 15/24 = 0{\cdot}625$. In general, $b = k_1$, $n = (k_1+1)\ (k_2+1)$ and $R = k_1k_2/(k_1+1)\ (k_2+1)$, just like the single-error-correcting codes of Fig. 2. The error-control properties of this class of burst-error-correcting codes, and their decoding algorithm, depend on the interleaving effect of the diagonal transmission read-out sequence, indicated by the numbers allocated to each digit in the array of Fig. 7. Note that $k_2 \geqslant 2\ (k_1 - 1)$ is required for $b = k_1$.

This form of array code also solves another problem raised in the case of the form shown in Fig. 5, which is: where to place the check digits in the array? It is difficult to find positions for the checks which do not lead to false corrections for some error patterns, particularly those with errors falling on check digits. In the case of the codes of Fig. 6, the checks may be placed in additional rows in the array, and the decoder will operate correctly. For codes of the form of Fig. 7, the checks are an integral part of the array, and are interleaved in the same way as the information digits.

2.3 Encoding and Decoding Algorithms for the Burst-error-correcting Array Code

Encoding consists of computing the row and column checks for the array. This may be done in a serial or parallel implementation (with serial or parallel input, s.i.p.o. or p.i.s.o.), or in a suitable serial/parallel combination. A convenient implementation (Fig. 8) combines the encoding and diagonal read-out processes.

The decoding process consists of four steps:

(i) Computation of the syndrome from the received code word; this gives, in general, (k_1+1) column check syndrome digits, and (k_2+1) row check syndrome digits (note that the check-on-checks can be computed both as a row check and a column check).

(ii) Determination, from the column syndrome digits, excluding the column check-on-checks, of the pattern of the error burst in the information digits, if any.

(iii) Location of the error burst in the code word; this is done by searching sequentially for the error pattern in the EX-OR combination of the $n = (k_1+1)\ (k_2+1)$ row check syndromes and column check syndromes corresponding to the transmission order of the code word digits.

(iv) Correction of the error burst, by adding modulo-2 the error pattern as determined in (ii), in the proper position as determined in (iii), to the received code word. In the code example of

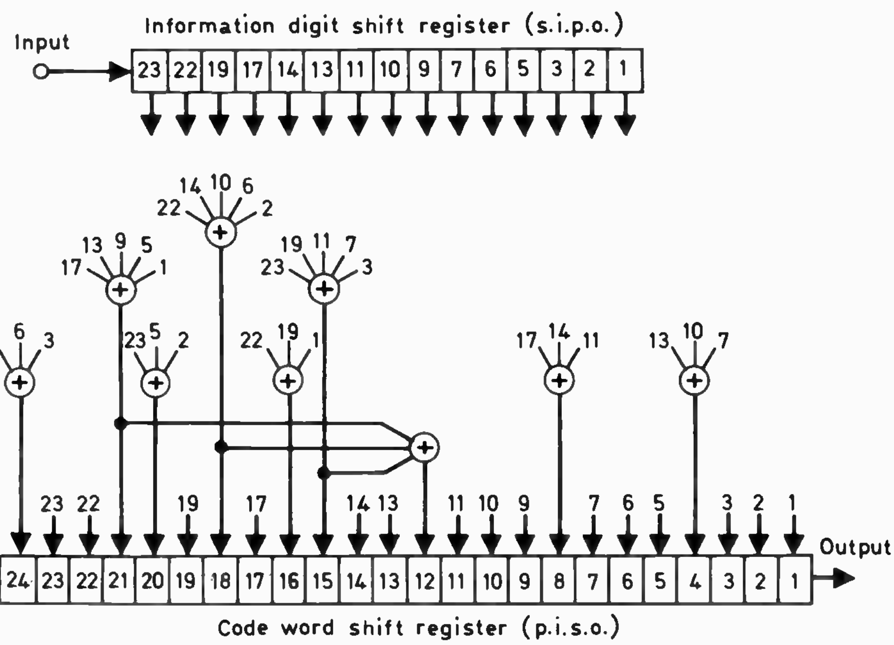

Fig. 8. Combined encoding and diagonal read-out.

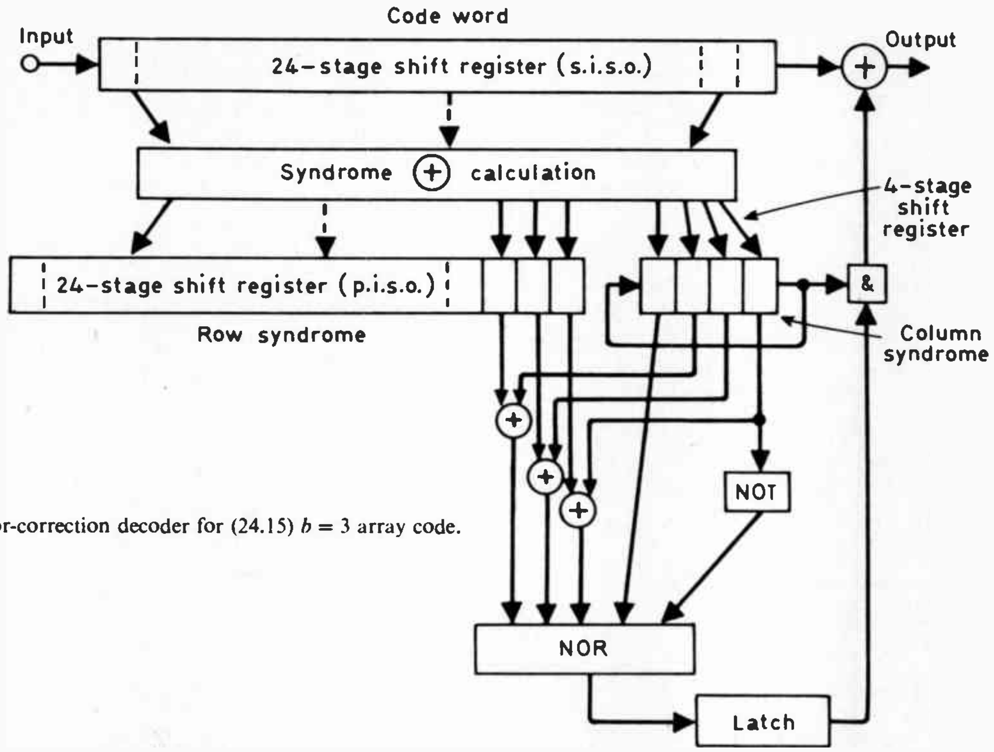

Fig. 9. Burst-error-correction decoder for (24.15) $b = 3$ array code.

Fig. 3, a possible decoder implementation would be as shown in Fig. 9. This decoder may be operated continuously.

3 Burst-erasure Correction with Array Codes

An erasure burst of length $b \leqslant k_1$ can be corrected with a burst-error-detecting array code as in Fig. 4. Since the locations of the possible errors are known (the erasure positions), the column checks can be used to determine the correct digit to place in each position. Thus decoding is quite simple.

A mixed error-and-erasure burst can be corrected, provided that there is at least one erasure in the burst, and the burst length is $b \leqslant k_1$, by interleaved column checks. An example for $b = k_1 = 3$ is given in Fig. 10.

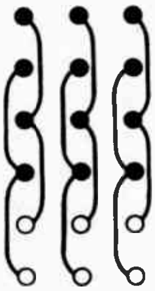

Fig. 10. Error-and-erasure burst correction.

Thus $2k_1$ checks are required, in general. Decoding is relatively simple, since the one or more erasures in the burst locate the row (or adjacent rows) containing the burst pattern.

4 Soft-decision Decoding of Array Codes

A soft-decision decoder has available a confidence measure on each received digit, as well as its demodulated value (possibly in error). Using this confidence information, a decoding performance approaching that of the appropriate matched filter (correlation detector) for the code can be achieved. The decoding algorithm is not complex, because it can be based on the product code feature of an array code. Each component code (row or column) is decoded separately using a soft-decision minimum distance algorithm, and then the results are adaptively combined; this is a much simpler process than soft-decision decoding of the entire code word. Details of the soft-decision decoding algorithm are given in Refs 16 and 17. Interleaving of the digits of a burst-error-correcting array code (e.g., Fig. 7) may not be required if soft-decision decoding is used (just as interleaving is not required for the burst-erasure-correction array code). A soft-decision decoder is capable of correcting error patterns which are a mixture of random and burst errors.

5 Conclusions

Array codes are capable of providing effective solutions to many error-control problems encountered in digital communications. The burst-error-control codes described above have relatively high rate, small decoding delay and simple decoder implementations. For codes of the type of the example given, the decoding delay is one block length (n clock pulse periods).

Faster decoding may be achieved (in less than one clock pulse period) if a syndrome list decoding algorithm is used, at the expense of greater decoder complexity (a r.o.m. is required). A microprocessor implementation of such a decoder is currently being developed, using orthogonal memory, for operation at data rates of up to 500 K bit/s. The decoder example described in Section 2.3 requires 52 shift register stages, and 20 assorted gates (excluding clock circuitry). This is comparable to the complexity of an error-trapping decoder for a shortened cyclic code with the same parameters ((24, 15) and $b = 3$), which requires about 50 shift-register stages and 32 assorted gates.

The particular advantages of the array codes are the ease with which they may be designed (e.g. shortening and shaping the array is very simple); the wide range of parameters for which they exist; their flexibility in use, since random and burst error-control array codes may share the same array structure (e.g. the single-error-correcting, double-error-detecting and burst-error-correcting codes mentioned above, and a soft-decision decoded array code); and the relative implementation simplicity of erasure control and soft-decision decoding techniques when applied to array codes. These properties make array e.d.c. codes useful for a wide range of digital communication applications.

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Indexing Terms: Radio systems, mobile.

Some alternative frequency assignment procedures for mobile radio systems

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SUMMARY

Channel assignment procedures for mobile radio systems are usually based on the assumption of equal spacing in frequency between all available channels, and it is customary to argue that the growing demands for greater numbers of channels in the limited spectrum available must be met by dividing the present separation interval of 12·5 kHz by two.

Such a measure would however demand major changes in the specification and design of equipment and the purpose of the present paper is to consider alternative strategies for channel frequency assignment which might increase the available number of channels while making less stringent demands on improvements in equipment performance. A typical computed result shows that, by reducing channel bandwidth by 20% and utilizing an assignment strategy based on multiples of a 2·5 kHz increment, the bandwidth needed to accommodate eight channels with freedom from third-order intermodulation interference is reduced from 437·5 kHz to 200 kHz.

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1 Introduction

With continually growing demand for mobile radio systems by all manner of service industries and private users, the difficulties of operating many such systems in close proximity have become increasingly acute. A major problem in frequency assignment arises because, due to a number of phenomena, transmissions interact non-linearly to generate intermodulation products on related frequencies which cannot then be assigned to other users without risk of interference. To avoid this problem therefore, it is necessary to choose operating frequencies in any given area which are such that, ideally, no significant intermodulation product from any combination of the frequencies in use falls on any other. Since the available spectrum for mobile radio use is limited and fixed, the growth in the number of users has necessitated reduction in the frequency separation between channels, but, in preserving equal frequency intervals between channels, the restrictions imposed by intermodulation generation have remained and are readily appreciated by reference to a typical site with, for example, eight users. If a block of spectrum is available divided into equispaced channels then if channels I and II are assigned at frequencies f_1 and f_2 then the third-order intermodulation product $2f_2-f_1$ falls on channel III, $3f_2-2f_1$ falls on channel IV and so on. If eight channels are to be assigned in such a way that no third-order product from any two falls on any other then at least 35 channels must be available assigned as follows:[1]

Freedom from 3rd order
8 users, channel nos: 1, 2, 5, 10, 16, 23, 33, 35

If freedom from fifth-order interference is required then 137 channels are necessary assigned thus:

Freedom from 5th order
8 users, channel nos: 1, 2, 8, 12, 27, 50, 78, 137.

The problem of generating these 'interference-free lists' has been tackled by several workers; first by Lustgarten[2] with subsequent improvement by Mifsud[3] who offered a new recurrence formula which was however restricted to third-order products only. Pannell[4] made a further contribution concerned primarily with the significance of frequency assignment procedures from a system effectiveness point of view, while Edwards *et al.*[5] developed a more comprehensive approach for 3rd and 5th orders.

Clearly the process of assigning channels equally spaced produces on-channel intermodulation but a minor modification can be envisaged by which the channel separation is notionally halved and frequencies assigned on the interference-free list basis but numbering half channel intervals as if they were channels.[1] It is thus necessary, of course, to delete one of any pair of adjacent frequencies derived in this manner in order to avoid unrealistic demands on equipment performance. However a number of intermodulation products resulting from transmitter interactions now fall mid-way between channel frequencies and therefore do not cause interference. It was pointed out by Al Hafid and Gardiner[6] that an alternative, but similar, strategy could be envisaged in which frequencies are assigned on

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consecutively 10 and 15 kHz spacing which would require relatively modest improvements in equipment performance to meet a 10 kHz channel separation specification but which prevents any intermodulation product of less than 9th order from falling on a channel centre frequency. This is illustrated in Fig. 1.

It is apparent that the foregoing techniques by no means exhaust all the possibilities and it is therefore appropriate to consider two further aspects; first, whether by taking other basic intervals between channel frequencies more efficient utilization of spectrum can be achieved, without greatly increasing the demand on equipment performance, and second, whether it is possible to introduce much more generalized assignment strategies into the existing radio environment where assignments have already been made by an equispaced channelling process.

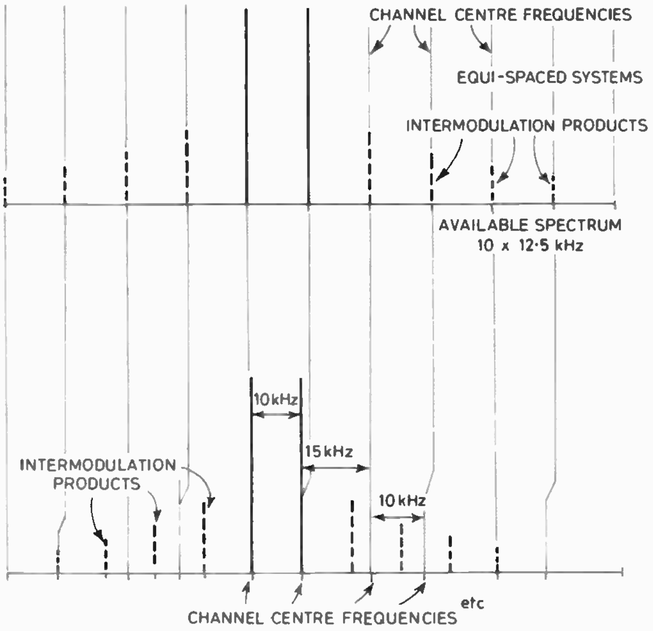


Fig. 1. Comparison of equi-spaced 12·5 kHz and alternate 10/15 kHz channel assignments.

2 Computation of Interference-free Lists

2.1 Intermodulation Frequencies

The frequency, f_{IM} of a typical product generated by interaction between transmissions of frequencies $f_1 \ldots f_n$ is given by:

$$f_{IM} = \alpha_1 f_1 + \alpha_2 f_2 + \alpha_3 f_3 + \ldots \quad (1)$$

where α_1 etc. are positive or negative integers or zero.

The 'order' of this product is:

$$N_c = |\alpha_1| + |\alpha_2| + |\alpha_3| + \ldots \quad (2)$$

Although many such products exist, only those for which

$$\alpha_1 + \alpha_2 + \alpha_3 \cdots = 1$$

lie in the frequency band of interest.

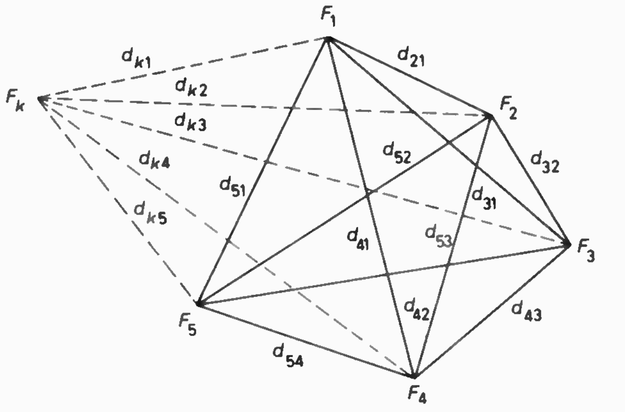


Fig. 2. Graphical representation of channel numbers and all possible differences between them.

It is evident that if products are not to fall on assigned channels then if frequencies $f_1, f_2 \ldots f_k$ are assigned such that $f_1 < f_2 < f_3 \ldots < f_k$

$$d_{ki} = f_k - f_i = \sum_{n=i, i+1, \ldots k-1}^{m=n+1} d_{mn} \quad (3)$$

where the d_{mn} are separation frequencies between f_m and f_n and $d_{21} \neq d_{32} \neq d_{43}$ etc.
This situation is illustrated in Fig. 2.

2.2 Computation Procedure

Equation (2) can be generalized as:

$$|\alpha_i| + |\alpha_j| + |\alpha_k| + \ldots = N_c \quad (4)$$

where α_i, α_j etc. are any positive or negative integers such that:

$$|\alpha_n| < N_c - 1$$

now defining

$$R_i = R_0 + i\Delta f$$
$$R_j = R_0 + j\Delta f \quad \text{etc.} \quad (5)$$

substitution of (5) in (4) results in:

$$R_0(\alpha_i + \alpha_j + \alpha_k + \ldots) + \\ + \Delta f(i\alpha_i + j\alpha_j + k\alpha_k + \ldots) = R \quad (6)$$

In order that R can be made equal to R_i or R_j or R_k etc., two conditions must be satisfied:

$$\alpha_i + \alpha_j + \alpha_k + \ldots = 1 \quad (7)$$

$$i\alpha_i + j\alpha_j + k\alpha_k + \ldots = i, j \text{ or } k \text{ etc.} \quad (8)$$

Then any combination can be considered free from intermodulation interference if it does not satisfy any of the solutions of equation (7). Although this is a simple relationship large numbers of solutions are possible in a practical situation; for example when only two signals have to be tested against third orders alone then $\alpha_i = 2$ and $\alpha_j = -1$ and vice versa are the only solutions, but when five signals are involved then 50 different possibilities are generated for third orders. Table 1 shows the number of possible solutions of the checking

Table 1

The number of possible solutions of the checking equation for various numbers of channels and different degrees of intermodulation freedom

	Degree of IM freedom	Number of channels in each combination 3	4	5	6	7	8
Number of combinations in each degree of intermodulation freedom as a factor of number of channels	3	9	24	50	90	147	224
	5	24	88	250	600	1271	
	7	45	212	775	2370		
	9	72	416	1870			

equation with different numbers of channels and different degrees of intermodulation. Whilst these procedures have been formulated originally with equally spaced channels in mind, it is evident that minor modifications will accommodate cases of unequal channel separation intervals.

3 Alternative Channel Assignment Strategies

3.1 Possible Assignment Procedures

It is now possible to investigate alternative frequency assignment procedures as indicated in Section 1 and an obvious starting point is the scheme alluded to earlier of alternate 10 and 15 kHz channel spacing. It is immediately evident however that such an assignment procedure can only be implemented satisfactorily if channels assigned on this basis can co-exist with channels already assigned on the equispaced 12·5 kHz system. A frequency increment of 2·5 kHz is common to both systems and if a continuous block of spectrum is considered divided into channels then there are several strategies which may be developed, illustrated in Fig. 3, for assigning the frequencies.

(i) Alternate 10 and 15 kHz channelling in isolation from any existing system, Fig. 3(b).

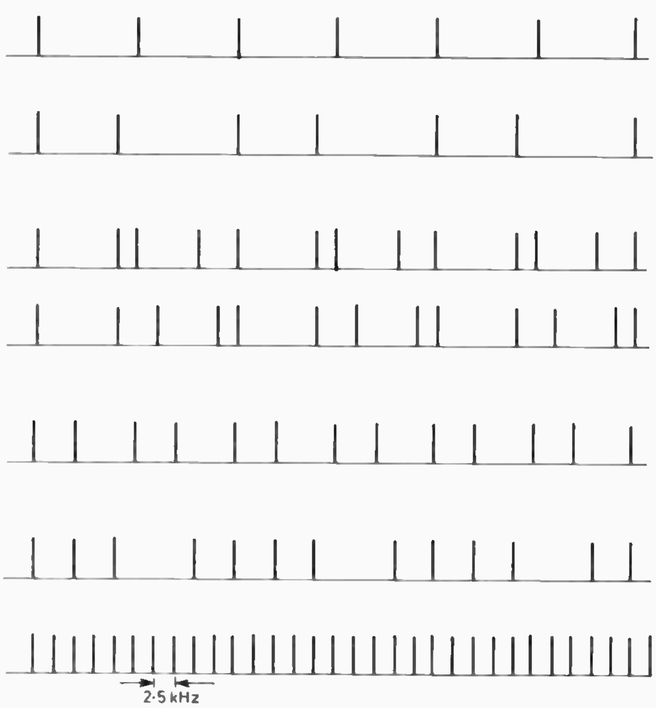
(ii) Superposition of alternate 10 and 15 kHz channelling on the existing system of equi-spaced 12·5 kHz channels, Fig. 3(c). In this case several possibilities exist depending on which channel assignment procedure is adopted for the first channel in the block and where, relative to the first channel, the lowest frequency assignment in the alternative system is set. In Fig. 3(c) two possibilities are shown to illustrate this point.

(iii) Superposition of two equi-spaced 12·5 kHz channelling sequences, Fig. 3(d). Here, only two relative positions in frequency are possible and both produce identical results.

(iv) Superposition of two alternate 10–15 kHz channelling sequences, Fig. 3(e). As with (ii) a number of alternatives exist for relative position of the channel sequences, the one shown being the most efficient.

(v) The final possibility represents an extension of the foregoing to a generalized procedure based on 2·5 kHz increments in frequency.

In all cases the selection program accepts channels for



(a) Equi-spaced 12·5 kHz channelling;

(b) Alternate 10/15 kHz;

(c) Superposition of 10/15 kHz channelling on existing system—two possibilities;

(d) Superposition of two 12·5 kHz equi-spaced systems;

(e) Superposition of two 10/15 kHz alternate systems;

(f) 2·5 kHz frequency increments.

Fig. 3. Vertical lines indicate possible (but not necessarily allowable) channel centre frequencies.

assignment provided that no intermodulation product up to and including the specified order falls on any other channel or within ±5 kHz of any other assigned channel which implies that equipment performance has been upgraded, particularly with regard to transmitter stability and output spectrum, to meet a 10 kHz channelling specification.

3.2 Computed Results

The number of interference-free channels available from a given block of spectrum is a convenient means for comparing the relative efficiency of the various strategies proposed. The Tables (Tables 2 to 5) show the bandwidths required to accommodate the number of operating channels specified with freedom from intermodulation interference up to the specified orders.

In Tables 2 and 3 all the schemes listed in Section 3.1 are compared for third- and fifth-order compatibility. Table 2 is the more comprehensive, dealing with up to 8 required channels, but computing time increases rapidly with both number of required channels and order of products for which compatibility is specified. Tables 4 and 5 are therefore restricted to a maximum of 5 required channels and the most general procedure, based on 2·5 kHz frequency increments, has been omitted. However it is seen from Tables 2 and 3 that although the generalized procedure, method (v), yields a slight improvement in efficiency of spectrum utilization over the other techniques, the advantages are only significant for a large number of required channels when the additional flexibility afforded by the generalization is valuable.

4 Conclusions

The most significant results which emerge from the computation are those which relate the efficiency of the existing system of assignment in spectrum utilization with that of a mixed system superimposing 10–15 kHz alternate spacing onto the existing 12·5 kHz equi-spaced system. It would appear that such an assignment procedure would permit a doubling of the density of assigned channels per unit bandwidth where 5 or more users share a site with 3rd order compatibility, 4 or more for 5th order, and 3 or more for 7th and 9th orders.

Since no intermodulation product falls closer than ±5 kHz from an assigned channel frequency, this improvement is achieved by reducing the bandwidth allocated to individual channels by only 20% of the present figure rather than by 50% as would be necessary to achieve similar gains while preserving equi-spaced channel frequencies.

Of course, it is emphasized that the advantage of the proposed system of assignment would probably be less dramatic in a practical environment in which allowance is made for the performance characteristics of equipment already in service, particularly with regard to oscillator drift in transmission, noise characteristics of

Table 2

Bandwidth required to accommodate specified number of channels with freedom from 3rd-order intermodulation interference

Number of Channels Required	Bandwidth Required in kHz						
	Equi-spaced 12·5 kHz	Alter-nate 10/15 kHz	Mixed 12·5 kHz and 10/15 kHz (a)	Mixed 12·5 kHz and 10/15 kHz (b)	Mixed 12·5 kHz	Mixed 10/15 kHz	2·5 kHz
3	50	37·5	37·5	37·5	42·5	37·5	37·5
4	87·5	62·5	57·5	62·5	67·5	57·5	57·5
5	120	112·5	87·5	87·5	100	82·5	82·5
6	225	187·5	122·5	112·5	137·5	117·5	112·5
7	325	237·5	172·5	162·5	187·5	157·5	152·5
8	437·5	337·5	222·5	222·5	255	207·5	200

Table 3

Bandwidth required to accommodate specified number of channels with freedom from 5th-order intermodulation interference

Number of Channels Required	Bandwidth Required in kHz						
	Equi-spaced 12·5 kHz	Alter-nate 10/15 kHz	Mixed 12·5 kHz and 10/15 kHz (a)	Mixed 12·5 kHz and 10/15 kHz (b)	Mixed 12·5 kHz	Mixed 10/15 kHz	2·5 kHz
3	62·5	37·5	37·5	37·5	42·5	37·5	37·5
4	150	87·5	72·5	72·5	87·5	72·5	72·5
5	300	187·5	137·5	137·5	175	137·5	137·5
6	575	362·5	247·5	247·5		237·5	225

Table 4

Bandwidth required to accommodate specified number of channels with freedom from 7th-order intermodulation interference

Number of Channels Required	Bandwidth Required in kHz					
	Equi-spaced 12·5 kHz	Alter-nate 10/15 kHz	Mixed 12·5 kHz and 10/15 kHz (a)	Mixed 12·5 kHz and 10/15 kHz (b)	Mixed 12·5 kHz	Mixed 10/15 kHz
3	75	37·5	37·5	37·5	42·5	37·5
4	200	87·5	87·5	87·5	100	87·5
5	525	262·5	237·5	227·5	262·5	232·5

Table 5

Bandwidth required to accommodate specified number of channels with freedom from 9th-order intermodulation interference

Number of Channels Required	Bandwidth Required in kHz					
	Equi-spaced 12·5 kHz	Alter-nate 10/15 kHz	Mixed 12·5 kHz and 10/15 kHz (a)	Mixed 12·5 kHz and 10/15 kHz (b)	Mixed 12·5 kHz	Mixed 10/15 kHz
3	87·5	50	47·5	47·5	55	47·5
4	287·5	162·5	132·5	127·5	150	132·5
5	>750	425	382·5	397·5	387·5	382·5

transmitters and so on. Additionally it must be borne in mind that frequencies which cannot be assigned to mobile radio channels may be usable for other services and are therefore not completely lost, but nevertheless it would appear that substantial gains in spectrum utilization are possible.

One of the major problems of implementing changes in licencing regulations for mobile radio operations must be that any new equipment will be introduced into an environment in which existing equipment will continue to operate for a number of years on present channel bandwidths and modulation characteristics and it is argued here that the more flexible approach to frequency assignment proposed provides a valuable additional tool with which to maximize spectrum utilization.

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(Paper No. 2018/Comm 336)

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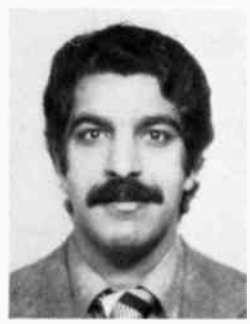
The Authors

J. Gardiner



M. S. A. Magaza

John Gardiner (Member 1971) joined the staff of the Postgraduate School of Electrical and Electronic Engineering at the University of Bradford as a Lecturer in 1968. He was promoted to Senior Lecturer in 1972 and appointed Reader in Electronic Engineering in 1978. He is a graduate of the University of Birmingham, where he received his doctorate in 1964 for a thesis on carrier storage phenomena in non-linear circuits. He was then granted a Racal Research Fellowship from 1964 to 1966 in the Department of Electronic and Electrical Engineering at Birmingham, working on modulators, mixers and step recovery harmonic generation. Between 1966 and 1968 Dr Gardiner was a research engineer with Racal Communications at Tewkesbury.

M. S. A. Magaza obtained an M.Sc. degree from the Leningrad Electrotechnical Institute for Communications in 1968 after which he returned to a teaching post at Baghdad Technical College. He came to England in 1974 and obtained M.Phil. and Ph.D. degrees from Bradford in 1976 and 1980 respectively.

Contributors to this issue

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J. KINNEAR

Trevor Woodman is the Education Manager for the European, Middle Eastern and African world territory of Fisher Controls Limited at Maidstone.

He began his career in 1956 when he joined Elliott Brothers (London) as a student apprentice studying applied physics at South East London Technical College.

After working on Naval fire control and gyroscopic platforms he moved, in 1961, into the field of electronic weighing systems and their application to process plant in the food and manufacturing industries. In 1972 he joined the Sales Management Team of the the GEC Elliot Process Instruments and subsequently the Measurements and Analytics Division of Fisher Controls.

In 1980 he became responsible for his company's customer and staff education on process control instrumentation and systems and is currently a member of the Education and Training Panel of BIMCAM.

John Kinnear (Fellow 1967) has been General Manager, Market Development at Marconi Avionics' Borehamwood establishment since 1969. After initial technical training in electrical and mechanical engineering he served in the Royal Signals, and with the Indian Signal Corps. He gained a degree in Physics at Exeter College, Oxford in 1951, and then he joined the research laboratories of Elliott Brothers, where he was concerned with the development of microwave aerials and components, and, later, of precision microwave instruments.

From 1957 Mr Kinnear became involved with the study and design of radar systems for military and airborne roles, initially in the Company's Radar and Communications Research Laboratory and then, on its formation, as Chief Development Engineer of the Airborne Radio and Radar Division. Throughout most of the 1960s he was at the forefront of the company's successful activities to become the major British supplier of advanced airborne radar systems, which led eventually to the company, now known as Marconi Avionics, securing the major development and production contracts for the multimode airborne interception radar for the *Tornado* fighter and the AEW *Nimrod* radar and mission system.

Robin King graduated in electronics and electrical engineering at Sheffield University in 1967 and then undertook research work in u.h.f. propagation at Imperial College, London, gaining a Ph.D. in 1971. After a number of years as an engineer in the Research Department of the British Broadcasting Corporation, Dr King spent three years as a lecturer at the University of Technology, Lae, Papua New Guinea. He took up his present post of lecturer in the Department of Electronics, University of Southampton in 1976 and has continued his wide interests in the field of communications, including work on aids for handicapped people, and telecommunications in less developed countries.

Professor Frank Benson received the B.Eng. and M.Eng. degrees at the University of Liverpool and the Ph.D. and D.Eng. degrees at the University of Sheffield. After serving as a member of the Research Staff at the Admiralty Signal Establishment, Witley, during the Second World War, he became Assistant Lecturer in Electrical Engineering at the University of Liverpool in 1946. Since 1949 he has been on the staff at the University of Sheffield, first as a Lecturer, then as a Senior Lecturer and later Reader in Electronics. He was elected to a Chair and appointed Head of the Department of Electronic and Electrical Engineering in 1967. Professor Benson was Pro-Vice Chancellor in the University from 1972 to 1976.

Atif Badr was awarded the degree of B.Sc. in electronic and communications engineering from Cairo University in 1973. After two years working for the Egyptian Organization for Broadcast Engineering he became a postgraduate student at the University of Sheffield, gaining the M.Eng. degree in 1976, and a doctorate in 1979; he worked first on losses in braided coaxial cables and then on coupling between cables. Dr Badr continued as a postdoctoral research assistant at the University of Sheffield until the end of 1980, since when he has been with ZADCO, Abu Dhabi.

John Sitch received the degree of B.A. in engineering science from Oxford University in 1969. He then worked as a radio systems development engineer for the Plessey Company until 1971 when he left to continue his studies at Sheffield University, obtaining his master's degree in 1973 and his doctorate in 1975. After spending three years as a Lecturer at the University of Nottingham, Dr Sitch returned to Sheffield University and has been a Lecturer in the Department of Electronic and Electrical Engineering since 1978. His current research interests include computer modelling of semiconductor and electromagnetic devices.

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PROF. F. BENSON

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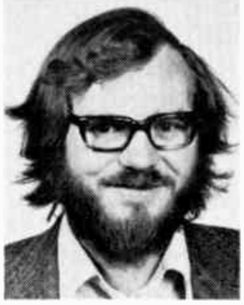

J. SITCH

Conferences, Courses and Exhibitions, 1982-83

The date and page references in italics at the end of an item are to issues of *The Radio and Electronic Engineer (REE)* or *The Electronics Engineer (EE)* in which fuller notices have been published.
The symbol ★ indicates that the IERE has organized the event.
The symbol ● indicates that the IERE is a participating body.
An asterisk * indicates a new item or information which has been amended since the previous issue.

Further information should be obtained from the addresses given.

APRIL

IFFSEC '82 *19th to 23rd April*
International Fire, Security & Safety Exhibition and Conference, to be held at Olympia, London. Information: Victor Green Publications Ltd, 106 Hampstead Road, London NW1 2LS. (Tel. 01-388 7661).

Electronics *20th to 22nd April*
The All-Electronics/ECIF Show, sponsored by the Electronic Components Industry Federation, to be held at the Barbican Centre, City of London. Information: 34–36 High Street, Saffron Walden, Essex CB10 1EP (Tel. 0799 22612 Telex: 81653).

★ **Recording** *20th to 23rd April*
Fourth International Conference on Video and Data Recording, organized by the IERE with the association of AES, IEE, IEEE, IoP, RTS and SMPTE, to be held at the University of Southampton Information: Conference Secretariat, IERE, 99 Gower Street, London WC1E 6AZ (Tel. 01-388 3071) *EE, 18th June, p. 2.*

●**Communications '82** *20th to 23rd April*
Conference organized by the IEE in association with the IEEE and the IERE, to be held at the National Exhibition Centre, Birmingham. Information: IEE Conference Department, Savoy Place, London WC2R 0BL (Tel. 01-240 1871).

Instrumentation in Flammable Atmospheres *22nd April*
A short course on Instrumentation in Flammable Atmospheres, organized by Measurement Technology to be held in Luton Information: Customer Training Department, Measurement Technology Ltd, Power Court, Luton LU1 3JJ. (Tel. (0582) 23633).

***Reliability** *26th to 30th April*
Seminar on Techniques in Reliability Engineering, organized by Plessey Assessment Services, to be held at the Red House Hotel, Barton-on-Sea, Hampshire. Information: Richard Morgan, Plessey Assessment Services, Titchfield, Fareham, Hants, PO14 4QA (Tel. (03924) 43031).

● **Acoustics** *29th to 30th April*
International conference on Spectral Analysis and its use in Underwater Acoustics, organized by the Underwater Acoustics Group of the Institute of Acoustics in association with the IEE, IERE, IMC, IMA, ASA and the IEEE to be held at Imperial College, London. Information: Dr T. S. Durrani, Department of Electronic Science & Telecommunications, University of Strathclyde, Royal College, 204 George Street, Glasgow G1 1WX.

MAY

Acoustics, Speech & Signal Processing *3rd to 5th May*
International Conference on Acoustics, Speech & Signal Processing, sponsored by the IEEE, to be held in Paris. Information: Prof. Claude Gueguen, Département Systèmes et Communications, Ecole Nationale Supérieure des Télécommunications, 46 Rue Barrault, 75634 Paris, Cedex 13 France.

Computers *4th to 6th May*
Compec Europe Exhibition, to be held in Brussels. Information: IPC Exhibitions Ltd, Surrey House, 1 Throwley Way, Sutton, Surrey, SM1 4QQ. (Tel. 01-643 8040).

Insulation *10th to 13th May*
Fourth International Conference organized by British Electrical & Allied Manufacturers Association in association with the EEA to be held at the Brighton Metropole Hotel. Information: BEAMA Publicity Department, 8 Leicester Street, London WC2H 7BN. (Tel. 01-437 0678)

Microcomputers *11th to 13th May*
Microcomputer Show, organized by Online Conferences, to be held at the Wembley Conference Centre. Information: Online Conferences, Argyle House, Joel Street, Northwood Hill, Middlesex HA6 1TS. (Tel. (09274) 282211.

Condition Monitoring Systems *12th May*
One day Symposium on The Reliability and Cost Effectiveness of Condition Monitoring Systems, organized by the British Institute of Non-Destructive Testing, to be held in London. Information: The Secretary, The British Institute of Non-Destructive Testing, 1 Spencer Parade, Northampton NN1 5AA. (Tel. (0606) 30124/5).

Security Technology *12th to 14th May*
1982 Carnahan Conference on Security Technology sponsored by the University of Kentucky, IEEE (Lexington Section and AESS) to be held at Carnahan House, University of Kentucky, Lexington, USA. Information: Sue McWain, Conference Coordinator, Office of Continuing Education, College of Engineering, University of Kentucky, 533S. Limestone Street, Lexington, Kentucky 40506. (Tel. (606) 257-3971).

Instrumentation in Flammable Atmospheres *20th May*
(See item for 22nd April)

Antennas and Propagation *24th to 28th May*
International Symposium on Antennas and Propagation organized by the IEEE in association with URSI, to be held in Albuquerque, New Mexico. Information: IEEE, Conference Coordination, 345 East 47th Street, New York, NY 10017.

Measurements *24th to 28th May*
Ninth Congress on Technological and Methodological Advances in Measurement organized by IMEKO to be held in Berlin. Information: IMEKO, Secretariat, P.O. Box 457, H-1371 Budapest.

Multiple Valued Logic *25th to 27th May*
12th International Symposium on Multiple valued logic sponsored by the IEEE Computer Society, to be held in Paris. Information: Michel Israel, Symposium Chairman, IIE-CNAM, 292 Rue Saint Martin, 75141, Paris Cedex 03, France (Tel. 271 24 14 ext. 511)

Electro *25th to 27th May*
Conference and Exhibition organized by the IEEE, to be held at the Boston Sheraton Hotel and Hynes Auditorium, Boston, Mass. Information: Dale Litherland, Electronic Conventions Inc. 999 N. Sepulveda Blvd., El Segundo, CA 90245 (Tel. (213) 772-2965).

Word Processing *25th to 28th May*
International Word Processing Exhibition and Conference, organized by Business Equipment Trade Association, to be held at the Wembley Conference Centre. Information: Business Equipment Trade Association, 109 Kingsway, London WC2B 6PU. (Tel. 01-405 6233).

Consumer Electronics *30th May to 2nd June*
Consumer Electronics Trade Exhibition sponsored by BREMA together with ICEA and RBA, to be held at Earls Court, London. Information: Montbuild Ltd. 11 Manchester Square, London W1M 5AB (Tel. 01-486 1951).

JUNE

Digital Audio *4th to 6th June*
Conference on The New World of Digital Audio, organized by The Audio Engineering Society, to be held at the Rye Town Hilton, Rye, New York. Information: Audio Engineering Society, 60 East 42nd Street, New York, NY 10165, USA. (Tel. (212) 661-2355/8528).

SCOTELEX '82 *8th to 10th June*
The 13th Annual Scottish Electronics Exhibition and Convention, organized by the Institution of Electronics, to be held at the Royal Highland Exhibition Hall, Ingliston, Edinburgh. Information: Institution of Electronics, 659 Oldham Road, Rochdale, Lancs. OL16 4PE (Tel. (0706) 43661).

● **Reliability** *14th to 18th June*
The fifth European Conference on Electrotechnics, EUROCON '82, sponsored by EUREL, to be held in Copenhagen. Information: Conference Office, (DIEU), Technical University of Denmark, Bldg. 208, DK-2800, Lyngby, Denmark (Tel. 45 (0) 882300)

Microwaves *15th to 17th June*
International Microwave Symposium organized by the IEEE will be held in Dallas, Texas. Information: IEEE, Conference Coordination, 345 East 47th Street, New York, NY 10017.

Office Automation *15th to 17th June*
Office Automation Show and Conference, to be held at the Barbican Centre, London. Information: Clapp & Poliak Europe Ltd, 232 Acton Lane, London W4 5DL. (Tel. 01-747 3131).

Fisheries Acoustics *21st to 24th June*
Symposium on Fisheries Acoustics organized by the International Council for the Exploration of the Sea with the collaboration of the United Nations Food and Agriculture Organization, to be held in Bergen, Norway. Information: General Secretary, ICES, 2-4 Palaegade, 1261 Copenhagen K, Denmark

Infodial *22nd to 25th June*
International Congress and Exhibition on Data Bases and Data Banks, organized by SICOB in association with the French Federation of Data Base and Data Bank Producers, to be held in Paris. Information: Daniel Sik, IPI, 134 Holland Park Avenue, London W11 4UE. (Tel. 01-221 0998).

★ **Microelectronics** *29th June to 1st July*
Conference on The Influence of Microelectronics on Measurements, Instruments and Transducer Design organized by the IERE in association with the IEE, IEEE, IProdE, IOP, IMC, IQA and BES, to be held at the University of Manchester Institute of Science and Technology. Information: Conference Secretariat, IERE, 99 Gower Street, London WC1E 6AZ (Tel. 01-388 3071)

JULY

*●**Man/Machine Systems** *6th to 9th July*
International conference on Man/Machine Systems organized by the IEE with the association of the IERE and other bodies, will be held at the University of Manchester Institute of Science and Technology. Information: Conference Department, Institution of Electrical Engineers, Savoy Place, London WC2R 0BL. (Tel. 01-240 1871)

Materials and Testing *8th and 9th July*
A Symposium on the Inter-Relationship of Materials and Testing, organized by the Institute of Physics, to be held at the University of London. Information: Institute of Physics, 47 Belgrave Square, London SW1X 8QX. (Tel. 01-235 6111).

Simulation *19th to 21st July*
1982 Summer Computer Simulation conference will be held at the Marriott-City Centre, Denver, Colorado. Information: Lawrence Sashkin, 1982 SCSC Program Director, The Aerospace Corporation, P.O. Box 92957, Los Angeles, California 90009. (Tel. (213) 648-5934)

Control *19th to 21st July*
Conference on Applications of Adaptive and Multivariable Control, sponsored by the IEEE in association with the University of Hull, to be held at the University of Hull.

Information: G. E. Taylor, University of Hull, Dept. of Electronic Engineering, Hull (Tel. (0482) 46311 Ext 7113).

● **Image Processing** *26th to 28th July*
Conference on Electronic Image Processing, organized by the IEE in association with the IEEE and the IERE, to be held at the University of York. Information: IEE Conference Secretariat, Savoy Place, London WC2R 0BL (Tel. 01-240 1871).

AUGUST

★ **Software** *25th to 27th August*
Residential Symposium on Software for Real-Time Systems organized by the IERE Scottish Section will be held in Edinburgh. Information: Mr J. W. Henderson, YARD Ltd, Charing Cross Tower, Glasgow.

Satellite Communication *23rd to 27th August*
A Summer School on Satellite Communication Antenna Technology organized by the Eindhoven University in association with IEEE Benelux and the University of Illinois will be held at Eindhoven University. Information: Dr E. J. Maanders, Department of Electrical Engineering, University of Technology, Postbox 513, 5600 MB Eindhoven, Netherlands. (Tel. (040) 47 91 11).

SEPTEMBER

Microwaves *6th to 10th September*
Twelfth European Microwave Conference organized by the IEEE in association with URSI to be held in Helsinki. Information: IEEE, Conference Coordination, 345 East 47th Street, New York, NY 10017.

***BA '82** *6th to 10th September*
Annual Meeting of the British Association for the Advancement of Science, will be held at the University of Liverpool. Information: British Association, Fortress House, 23 Savile Row, London W1X 1AB.

ICCC '82 *7th to 10th September*
Sixth International Conference on Computer Communication, sponsored by the International Council for Computer Communication, to be held at the Barbican Centre, London. ICCC '82 PO Box 23, Northwood Hills HA6 1TT, Middlesex.

***Personal Computer** *9th to 11th September*
Personal Computer World Show, to be held at the Cunard Hotel, Hammersmith, London W6. Information: Interbuild Exhibitions Ltd, 11 Manchester Square, London W1M 5AB. (Tel. 01-486 1951).

***Remotely Piloted Vehicles** *13th to 15th September*
Third Bristol International Conference on Remotely Piloted Vehicles jointly sponsored by The Royal Aeronautical Society and the University of Bristol. To be held at the University of Bristol. Information: Dr R. T. Moses, Organizing Secretary, RPV Conference, Faculty of Engineering, Queen's Building, The University, Bristol BS8 1TR. (Tel. (0272) 24161, ext 846)

Wescon '82 *14th to 16th September*
Show and Convention to be held at the Anaheim Convention Centre and Anaheim Marriott, Anaheim, California. Information: Robert Myers, Electronic Conventions Inc. 999 North Sepulveda Boulevard, El Segundo CA 90245.

● **Broadcasting** *18th to 21st September*
The ninth International Broadcasting Convention, IBC '82, organized by the IEE, and EEA with the association of IERE, IEEE, RTS and SMPTE, will be held at the Metropole Conference and Exhibition Centre, Brighton. Information: IEE, 2 Savoy Place, London WC2R 0BL (Tel. 01-240 1871).

***Non-Destructive Testing** *20th to 22nd September*
National Non-Destructive Testing Conference, organized by the British Institute of Non-Destructive Testing, to be held in York. Information: BInst NDT, 1 Spencer Parade, Northampton NN1 5AA. (Tel. (0604) 30124/5).

★ **Electromagnetic Compatibility** *20th to 22nd September*
Third conference on Electromagnetic Compatibility, organized by the IERE with the association of the IEE, IEEE, IQE and RAeS, to be held at the University of Surrey, Guildford. Information: Conference Secretariat, IERE, 99 Gower Street, London WC1E 6AZ (Tel. 01-388 3071)

Telecommunications and Fibre Optics *21st to 24th September*
Eighth European conference on Telecommunication and Fibre Optics organized by the Electronics Industries Group (GIEL), to be held in Cannes. Information: GIEL 11 rue Hamelin, 75783 Paris Cedex 16

Man-Machine Systems *27th to 29th September*
Conference on Analysis, Design and Evaluation of Man-Machine Systems sponsored by IFAC in association with the IFIP/IFORS/IEA, to be held in Baden-Baden, Federal Republic of Germany. Information: VDI/VDE-Gesellschaft, Mess-und Regelungstechnik, Postfach 1139, D-4000 Dusseldorf 1. (Tel. (0211) 6214215)

Instrumentation in Flammable Atmospheres *30th September*
(See item for 22nd April)

OCTOBER

Electronic Displays *5th to 7th October*
Electronics Displays Exhibition and Conference, to be held at the Kensington Exhibition Centre. Information: Network, Printers Mews, Market Hill, Buckingham. MK18 1JX. (Tel: (0282) 5226).

Defendory Expo '82 *11th to 15th October*
The 4th Exhibition for Defence Systems and Equipment for Land, Sea & Air, organized by the Institute of Industrial Exhibitions in association with the Defence Industries Directorate of The Hellenic Ministry of National Defence to be held in Athens, Greece. Information: Mrs Duda Carr, Westbourne Marketing Services, Crown House, Morden, Surrey SM4 5EB (Tel. 01-540 1101)

Internepcon *12th to 14th October*
Internepcon Conference and Exhibition, organized by Cahners Exposition Group, to be held at the Metropole Exhibition Hall, Brighton. Information: Cahners Exposition Group, Cavridy House, Ladyhead, Guildford, Surrey, GU1 1BZ. (Tel. (0483) 38083).

● **RADAR '82** *18th to 20th October*
International Conference on Radar, organized by the IEE in association with the IEEE EUREL, IERE, IMA, RAeS and RIN, to be held at the Royal Borough of Kensington and Chelsea Town Hall, Hornton Street, London W8. Information: IEE Conference Department, Savoy Place, London WC2R 0BL. (Tel. 01-240 1871).
(Papers by 31st May)

● **Military Microwaves '82** *19th to 22nd October*
Third International Conference and Exhibition organized by Microwave Exhibitions and Publishers, to be held at The Cunard International Hotel. Information: Military Microwaves '82 Conference, Temple House, 36 High Street, Sevenoaks, Kent TN13 1 JG

Multivariable Systems *26th to 28th October*
Symposium on the Application of Multivariable Systems Theory, organized by the Institute of Measurement and Control to be held at the Royal Naval Engineering College, Manadon. Information: The Institute of Measurement and Control, 20 Peel Street, London W8 7PD. (Tel. 01-727 0083).

Instrumentation *26th to 28th October*
Electronic Test & Measuring Instrumentation Exhibition and Conference, to be held at the Wembley Conference Centre. Information: Trident International Exhibitions Ltd, 21 Plymouth Road, Tavistock, Devon PL19 8AU. (Tel. (0822) 4671).

Instrumentation in Flammable Atmospheres *28th October*
(See item for 22nd April)

Pattern Recognition *19th to 22nd October*
Sixth International Conference on Pattern Recognition, sponsored by the IEEE in association with the IAPR and DAGM, to be held at the Technical University of Munich. Information: Harry Hayman, P.O. Box 369, Silver Spring, MD 20901 (Tel. (301) 589-3386).

Broadcasting *19th to 21st October*
Conference on Broadcasting Satellite Systems organized by the VDE(NTG) with the association of the specialized groups of the DGLR and the IRT. Information: Herrn Dipl. Ing. Walter Stosser, AEG-Telefunken, Gerberstrasse 33, 7150 Backnang *(Papers by 28th June)*

Manufacturing Technology *26th to 28th October*
Fourth IFAC/IFIP Symposium on Information Control Problems in Manufacturing Technology organized by the National Bureau of Standards, US Department of Commerce, in association with IFAC/IFIP will be held in Gaithersburg, Maryland. Information: Mr J. L. Nevins, Vice Chairman, National Organizing Committee, 4th IFAC/IFIP Symposium Charles Stark Draper Labs, Inc. 555 Technology Square Cambridge, MA 02139 USA. (Tel. (617) 258 1347)

NOVEMBER

Computers *16th to 19th November*
Compec Exhibition, to be held at the Olympia Exhibition Centre, London. Information: IPC Exhibitions Ltd, Surrey House, 1 Throwley Way, Sutton, Surrey SM1 4QQ. (Tel. 01-643 8040).

Instrumentation in Flammable Atmospheres *25th November*
(See item for 22nd April)

1983

FEBRUARY

MECOM '83 *7th to 10th February*
Third Middle East Electronic Communications Show and Conference, organized by Arabian Exhibition Management, to be held at the Bahrain Exhibition Centre. Information: Dennis Casson, MECOM '83, 49/50 Calthorpe Road, Edgbaston, Birmingham B15 1TH. (Tel. (021) 454 4416).

MARCH

***Component Assembly** *March*
Brighton Electronics Exhibition on matching components with insertion, connection and assembly aids and techniques, to be held in Brighton. Information: The Press Officer, Trident International Exhibitions Ltd, 21 Plymouth Road, Tavistock, Devon PL19 8AU. (Tel. (0822) 4671).

*● **Telecommunications Network** *21st to 25th March*
Second International Network Planning Symposium (Networks '83), organized by the Institution of Electrical Engineers with the association of the IERE, to be held at the University of Sussex, Brighton. Information: IEE Conference Department, Savoy Place, London WC2R 0BL. (Tel. 01-240 1871).

***Inspex '83** *21st to 25th March*
Tenth International Measurement and Inspection Technology Exhibition, sponsored by *Measurement and Inspection Technology* in association with IQA and Gauge and Tool Makers' Association, to be held at the National Exhibition Centre, Birmingham. Information: Exhibition Manager, Inspex '83, IPC Exhibitions Ltd, Surrey House, 1 Throwley Way, Sutton, Surrey SM1 4QQ. (Tel. 01-643 8040).

APRIL

***Engineering Education** *6th to 8th April*
Second World Conference on Continuing Engineering Education, organized by the European Society for Engineering Education, to be held at UNESCO Headquarters in Paris. Information: Mr N. Krebs Ovesen, Danish Engineering Academy, Building 373, DK 2800, Lyngby, Denmark.

SEPTEMBER

***Weightech '83** *13th to 15th September*
Third International Industrial and Process Weighing and Force Measurement Exhibition and Conference, organized by Specialist Exhibitions in association with the Institute of Measurement and Control, to be held at the Wembley Conference Centre. Information: Specialist Exhibitions Ltd, Green Dragon House, 64/70 High Street, Croydon, CR9 2UH. (Tel. 01-686 5741) Conference Information: IMC, 20 Peel Street, London W8 7PD. (Tel. 01-727 0083).

OCTOBER

***Telecom '83** *26th October to 1st November*
Second World Telecommunication Exhibition, organized by the International Telecommunications Union, to be held at the New Exhibition Conference Centre in Geneva. Information: Telecom '83, ITU, Place des Nations, CH-1211 Genève 20, Switzerland. (Tel. (022) 99 51 11).

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The Radio and Electronic Engineer

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EDITORIAL

IERE NEWS AND COMMENTARY

PAPERS

General Interest

Some of the electronic instruments employed in the scientific investigation of criminal activities are described. These techniques include electrophoresis, gas chromatography, particle examination, determination of refractive index, atomic absorption spectrometry, X-ray diffraction and fluorescence, the scanning electron microscope and mass spectrometry.

Underwater Technology

The distorting effects of a helium–oxygen atmosphere on the various parameters of speech are discussed and signal processing techniques which may be used to improve intelligibility are described.

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