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The Ninth Clerk Maxwell Memorial Lecture

'MAXWELL AND THE THEORY OF MAGNETISM'

By H. B. G. Casimir, D.Sc., For.Mem.R.S.

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The eminent physicists and engineers who gave the previous Clerk Maxwell memorial lectures all emphasized that they regarded it as a great honour to have been invited to do so. I certainly share those feelings. But my predecessors have not always openly admitted that they found the task a difficult one, although I am convinced that they too must have felt that way. It is a difficult task for any physicist to have to give a lecture that should be fit tribute to the memory of one of the greatest physicists of the 19th century.

When I started to prepare this lecture I read and re-read much of Maxwell, and at times it seemed to me that the only way to lecture in honour of Maxwell would be to read from Maxwell. But of course that would never do: you did not invite me in order to listen to fragments from this great physicist and great master of English prose rendered with a Dutch accent. Yet I have been unable to withstand entirely the temptation to quote from Maxwell's own writings. (And since I learnt from Maxwell's biographers that he did not speak pure Cambridge English either, even a foreign accent may not be as incongruous as all that.)

For a physicist like myself, who is in a general way interested in the history of the development of modern science, but who is not in any way a professional historian, there are other pitfalls. First of all, he may be inclined to identify all of electrodynamics with Maxwell, to ascribe the whole development of electromagnetic theory to Maxwell. After all, Maxwell's theory, Maxwell's equations are among the most important tools of our trade. Maxwell has, so to say, been moved from the index of names to the index of subjects, and rightly so. Yet, by crediting Maxwell with everything in electrodynamics, we do injustice to many others, and—even more important for this lecture—we do injustice to Maxwell himself. For Maxwell was always most fair and generous in giving credit to others. Take, for instance, the preface to his 'Treatise on Electricity and Magnetism', where he expresses his indebtedness to Faraday on the one hand and to the great mathematicians like Laplace, Poisson, Green and Gauss on the other hand. He does not speak disparagingly about action at a distance, although his own concept is entirely different. One quotation:[1]

> 'I have therefore taken the part of an advocate rather than that of a judge, and have rather exemplified one method than attempted to give an impartial description of both. I have no doubt that the method which I have called the German one will also find its supporters and will be expounded with a skill worthy of its ingenuity.'

This is very impartial although we may detect a touch of irony. To-day we might look at this question in a slightly different way. The notion of an electromagnetic field, described by Maxwell's equations is generally accepted. But at the same time the notion of the ether as a substantial medium has been abolished. Now that the field has become a mathematical abstraction the difference between the two approaches is no longer such a fundamental one.

The Breadth of Maxwell's Interests

Another pitfall is that, rightly impressed by Maxwell's wonderful achievements in electrodynamics, we identify all of Maxwell with electrodynamics. That is an even more unforgivable error. Already a superficial glance at his 'collected papers' reveals the width of his interests.

On closer study one makes again and again surprising discoveries.

There is, for instance, his paper 'On governors'[2] probably the first mathematical paper on a subject later merchandized as 'cybernetics' (a neologism derived from the same Greek word as governor). There is his lucid paper on scientific instruments,[3] containing an excellent description of what was much later referred to as 'kinematic design' and was by many believed to be a recent innovation.

Surprisingly 'modern' are his remarks on units right at the beginning of his Treatise. I quote:[4]

> 'In the present state of science the most universal standard of length which we could assume would be the wavelength in vacuum of a particular kind of light, emitted by some widely diffused substance such as sodium, which has well-defined lines in its spectrum. Such a standard would be independent of any changes in the dimension of the Earth, and should be adopted by those who expect their writings to be more permanent than that body.'

Similarly, on time:

> 'A more universal unit might be found by taking the periodic time of vibration of the particular kind of light whose wavelength is the unit of length.'

and finally, on mass:

> 'If we expect soon to be able to determine the mass of a single molecule of a standard substance, we may wait for this determination before fixing a universal standard of mass.'

It took almost a century before the first two suggestions could be followed up; as to the third one, the accuracy obtained so far is as yet insufficient.

Many papers deal with colour vision: Maxwell was a pioneer in what is now usually called perception research. By the way, he also repeated many of the experiments of Cavendish, who made fairly quantitative measurements by judging the intensity of the electric shocks he experienced; a very special form of perception research!

Maxwell's work on the kinetic theory of gases may be second in importance to his work on electrodynamics, but it is a very major contribution to molecular theory. The Maxwell distribution of velocities is again a matter for the index of subjects and an indispensable element in any book or paper dealing with kinetic theory.

Molecular Charges; Electrons

But, although he was a great believer in molecular theories—and the quotation where he discusses the possibility of using the mass of a molecule as a universal unit shows how 'real' molecules were to him—in his Treatise he does in general not try to explain the electric properties of matter by molecular kinetics. The time for that had not yet come. There is a curious passage in his treatise at the end of Article 260.[5] After a clear description of electrolysis in terms of 'molecular charges' he writes:

> 'This theory of molecular charges may serve as a method by which we may remember a good many facts about electrolysis. It is extremely improbable however that when we come to understand the true nature of electrolysis we shall retain in any form the theory of molecular charges, for then we shall have obtained a secure basis on which to form a true theory of electric currents and so become independent of these provisional theories.'

Here, for once, Maxwell has not correctly anticipated future developments. It was left to his successors to vindicate the notion of 'molecule of charge', to discover free electrons, to measure with ever higher precision their mass and charge. It was the Dutch theoretician, Hendrik Antoon Lorentz, who showed how electrodynamic theory can be completed and how remaining difficulties can be solved by ascribing all electric and magnetic properties of matter to the displacement and motion of electrons. That was quite some time after Maxwell's death—Lorentz's most important papers appeared between 1895 and 1905—although the thesis of Lorentz, in which he applied Maxwell theory to the reflection and refraction of electromagnetic waves, was published in 1875. Maxwell must have learnt to read Dutch when studying the thesis of Van der Waals, which appeared in 1873. In a lecture given at the Chemical Society on 18th February 1875 he states:[6]

> '(this thesis) has certainly directed the attention of more than one inquirer to the study of the Low-Dutch language in which it is written.'

That Maxwell had also read Lorentz's thesis appears from his paper 'On Ohm's law' (British Association Report, 1876),[7] where he mentions that Lorentz expects deviations from Ohm's law at very high frequencies because of the inertia of the charge carriers. I shall come back to this later. The paper begins with the statement:

> 'The service rendered to electrical science by Dr. G. S. Ohm can only be rightly estimated when we compare the language of those writers on electricity who were ignorant of Ohm's law with that of those who have understood and adopted it.'

In this connection it may interest you that only yesterday afternoon I participated in a seminar at Cologne where the 150th anniversary of Ohm's law was celebrated. An excellent idea, which, when generally emulated for all the laws of nature, might lead to a gratifying number of festive events.

Maxwell and Ampère's Theory of Magnetism

I now come to my main subject: the theory of magnetism. In 1820 Hans Christian Oersted had discovered the action of an electric current—produced by a large battery—on a compass needle. Ampère had further studied this effect and had then formulated the hypothesis that *all* magnetism is due to electric currents. In Chapter XXII of his treatise, 'Ferromagnetism and diamagnetism explained by molecular currents', Maxwell appears as a strong defender of this idea. Again I quote:[8]

> 'It is possible to produce an exact image of the action of any magnet on points external to it, by means of a

sheet of electric currents properly distributed on its outer surface. But the action of the magnet on points in the interior is quite different from the action of the electric currents on corresponding points. Hence Ampère concluded that if magnetism is to be explained by means of electric currents, these currents must circulate within the molecules of the magnet, and must not flow from one molecule to another. As we cannot experimentally measure the magnetic action at a point in the interior of a molecule, this hypothesis cannot be disproved in the same way that we can disprove the hypothesis of currents of sensible extent within the magnet.'

'Besides this, we know that an electric current, in passing from one part of a conductor to another, meets with resistance and generates heat; so that if there were currents of the ordinary kind round portions of the magnet of sensible size, there would be a constant expenditure of energy required to maintain them, and a magnet would be a perpetual source of heat. By confining the circuit to molecules, within which nothing is known about resistance, we may assert, without fear of contradiction, that the current, in circulating within the molecule, meets with no resistance.

'According to Ampère's theory, therefore, all the phenomena of magnetism are due to electric currents, and if we could make observations of the magnetic force in the interior of a magnetic molecule, we should find that it obeys exactly the same laws as the force in a region surrounded by any other electric circuit.'

In explaining diamagnetism Maxwell uses the idea of spherical molecules of infinite conductivity. Students of superconductivity may be surprised to find that the formula $\mu/H = -\frac{1}{2}R^3$ for the magnetic moment of such a sphere is used as a matter of course.[9] They may be even more surprised by the article on the 'Induction of electric currents in a sheet of infinite conductivity'. The conclusion arrived at is:[10]

'If at first there is no magnetic action, and no currents in the sheet, then the normal component of magnetic induction will always be zero at every point of the sheet . . . If the sheet forms a closed or infinite surface no magnetic actions which may take place on one side of the sheet will produce any magnetic effect on the other side.'

Now I think that if you had some young physicists guess the origin of these lines, almost all of them would vote for some early book or paper on superconductivity.

Let us reflect for a few more moments on these quotations: 'As we cannot experimentally measure the magnetic action at a point in the interior of a molecule . . .' But to-day we *can* measure the field inside a molecule (or inside an atom, Maxwell often says molecule where we would say atom). Somewhat indirectly perhaps, but with a high degree of accuracy. Then '. . . the molecules, within which nothing is known about resistance . . .;' to-day we know a good deal about resistance-less currents flowing in atoms and molecules in a stationary quantum state. And superconductivity was discovered, so that Maxwell's theory is no longer a mere mathematical speculation.

Maxwell's Equations

And now it is time we looked at present day theory. Maxwell's equations in empty space but with a charge density ρ and a current density s read, well, here I am right away in a quandary. I know that most radio engineers and electronic engineers use the SI system of units and that even the Royal Society advocates the use of this system. But I am myself a staunch defender of the Gaussian system and although I would be willing just for once to forsake my principles out of gratitude to the organization that invited me here, I cannot help feeling that I would be guilty of lack of respect for the memory of Clerk Maxwell if I were to use a notation I detest. And so I write:

$$\operatorname{div}\mathbf{E} = 4\pi\rho \qquad \operatorname{curl}\mathbf{E} = -\frac{1}{c}\dot{\mathbf{B}}$$

$$\operatorname{curl}\mathbf{B} = \frac{1}{c}\dot{\mathbf{E}} + \frac{4\pi}{c}\mathbf{s} \qquad \operatorname{div}\mathbf{B} = 0$$

Now these equations hold also for the field inside material media provided **B** and **E** are interpreted as average values and ρ and s are the total charge and current density. We can write

$$\rho_{\text{tot}} = \rho_{\text{ext}} + \rho_{\text{displ}}$$

and

$$\mathbf{s}_{\text{tot}} = \mathbf{s}_{\text{cond}} + \mathbf{s}_{\text{atomic}}$$

The total charge density is the sum of an external charge density and of the result of internal polarizations. Similarly, the total current is the sum of a 'true' conduction current and an atomic current. Further, we can write:

$$\rho_{\text{displ}} = -\operatorname{div}\mathbf{P}$$

where **P** is the polarization vector and similarly

$$\mathbf{s}_{\text{atomic}} = \dot{\mathbf{P}} + c\operatorname{curl}\mathbf{M}$$

where **M** is the magnetic moment density.

It should be mentioned that neither the splitting into external charge and displacement charge, nor the splitting into conduction current and atomic current is under all circumstances unambiguous. Also, the same atomic current density may sometimes be described either way: as a $\dot{\mathbf{P}}$ or as a $c\operatorname{curl}\mathbf{M}$. It follows that the quantities

$$\mathbf{D} = \mathbf{E} + 4\pi\mathbf{P}$$

and

$$\mathbf{H} = \mathbf{B} - 4\pi\mathbf{M}$$

are not uniquely defined (although they are on occasion very useful auxiliaries). Moreover, in many cases **M** can be given a clear-cut physical meaning as an average magnetic moment density.

Molecular Currents and Quantum Theory

How about the molecular currents? In the atom of Rutherford-Bohr (and we have to-day excellent reasons to believe that this model is essentially correct), electrons, all of them identical with one another, are circulating around the heavy nucleus. But it is by no means obvious that such motion should be free of resistance. After all, electrons might lose energy in collisions with other atoms, and even if there were no collisions they would radiate, or, in radio terminology, they would have radiative resistance. Why then does an electron in the fundamental state of an atom not radiate until it falls into the nucleus? To explain this, to explain the stability of the atom, to explain why an atom after having been ionized or excited always returns to exactly the same state, to explain why atoms of sodium always emit the same spectral lines, to explain all that required entirely new ideas, required in fact quantum theory. Maxwell himself was well aware of and deeply impressed by this remarkable stability and by the identity of, for instance, hydrogen atoms on Earth or in Sirius or Arcturus, as witnessed by the spectral lines they emit. He saw clearly that an explanation was quite outside the scope of the physics of his day. I am not going to quote again but would advise you to read at least the last pages of his British Association lecture at Bradford.[11] He sees no other solution but to invoke creation: molecules were created as permanent, unchangeable entities. What Maxwell could not know is the fact that molecules and atoms can be broken up and then formed again. So it is no solution to say that hydrogen atoms and hydrogen molecules were created in a definite way; if we throw protons and electrons together they will always finally settle down in the same configuration: the fundamental state. The stability of atoms and molecules, this stability that is alien to the properties of any system in classical mechanics, is accounted for by quantum theory which allows only a discrete number of states, one of them the lowest in energy.

One direct consequence of this atomic model is that there should be a constant ratio between the angular momentum **J** of the circulating electrons and the magnetic moment. If the current is carried by electrons with mass m and charge e and can be written as

$$\mathbf{s} = c \operatorname{curl} \mathbf{M}$$

then the angular momentum is

$$\mathbf{J} = \frac{mc}{e} \iiint [\mathbf{r} \wedge \operatorname{curl} \mathbf{M}]\, \mathrm{d}\tau = \frac{2mc}{e} \iiint \mathbf{M}\, \mathrm{d}\tau$$

The corresponding effect is called the Einstein–De Haas (or Einstein–Richardson–De Haas effect). Einstein and De Haas found an angular momentum of the right order of magnitude, but more accurate later experiments showed that in most ferromagnetic substances our simple formula is wrong by a factor 2; one finds

$$\mathbf{J} = \frac{mc}{e} \iiint \mathbf{M}\, \mathrm{d}\tau$$

We know to-day that this is because in most ferromagnetic materials the magnetism is not due to the orbital motion of the electrons, but to spin. So it is about spin that we must now speak.

Electron Spin and Dirac's Theory of Hyper-fine Structure

The notion of a spinning electron, of an electron with an angular momentum and a magnetic moment, was introduced just half a century ago by my compatriots Uhlenbeck and Goudsmit. (Another reason for a celebration, happily made use of by the American Physical Society.) They, that is Goudsmit and Uhlenbeck, postulated an angular momentum of $\frac{1}{2}\hbar$ and a magnetic moment of $e\hbar/2mc$. This idea gave its final form to the semi-quantitative vector model for the line spectra of atoms, a model that soon afterwards found its quantitative formulation in quantum mechanics and whose qualitative features turned out to correspond to properties of the irreducible representations of the rotation group.

But did this not mean that we had to forgo Ampère's and Maxwell's idea? We had learnt to think happily about the interior of an atom, but can we really consider the interior of an electron? And in any case, if we regard an electron as a small clod of electric charge, like Lorentz did in his theory of electrons, then it becomes difficult to imagine speeds of rotation and currents large enough to account for the magnetic moment.

So it looked for a while as if there are real dipoles. Now here Dirac's relativistic theory of the electron, while on the one hand a momentous breakthrough that led the way to the discovery of the positive electron and pair creation and many other things, at the same time restored the old situation as far as currents and magnets are concerned. Dirac showed that there exists a current density

$$\mathbf{s} = \psi^* \gamma \psi$$

by which all the magnetic interactions of the electron can be described.

How does this look in the ground state of hydrogen for instance? There is a spherically symmetrical charge density, or, in a more sophisticated interpretation, probability density, given by the square of the wave function and decreasing exponentially if we get away from the proton, the hydrogen nucleus. It is given by

$$|\psi|^2 = \rho = \frac{1}{\pi a_B^3} \mathrm{e}^{-2r/a_B}$$

where a_B is the Bohr radius, 0·053 nm. By the way, this can easily be remembered by remembering that $137^2 a_B$ is, to within 1%, 1 micron. And 137 is the famous, and as yet unexplained magical and dimensionless number $\hbar c/e^2$, that plays such an important role in atomic physics. (In my formula I have neglected some small higher-order relativistic corrections.) In this ground state there is only spin magnetism. And the current? It is most easily explained by stating that the charge in every spherical shell is rotating as a solid body around the z-axis with such an angular velocity that the linear speed at the equator is always the same, namely 1/137 times the velocity of light. So we cannot say there is a rotating point charge. It is rather as if the whole charge- (or probability-) density is rotating. Now the magnetic field produced by such a current distribution inside the atom, and especially at the nucleus can easily be calculated and is found to be

$$\mathbf{B}_{\mathrm{nucl}} = \frac{e\hbar}{2mc} \frac{8\pi}{3} \rho(0)$$

Can this field be measured? Indeed it can. For the proton itself has a magnetic moment. It can have two orientations in the magnetic field of the electron and the energy difference corresponds to the famous 21 cm line that is so assiduously observed by radio-astronomers. The proton spin is doing exactly what Maxwell considered impossible for a molecule or an atom, what we at first sight might consider impossible for an electron, it is measuring the magnetic field inside, well, not really inside an electron perhaps, but inside the probability distribution corresponding to an electron.

All the big radio telescopes, like the ones here at Cambridge, those in my own country and so on, are bringing in cosmic testimonies to the correctness of the idea: there are no magnetic dipoles, magnetic fields are originating from currents.

There are of course other ways of measuring the magnetic field at the nucleus. In the case of ferromagnetic materials most interesting results have been obtained by means of the Mössbauer effect.

Curiously enough we do not really need Dirac's theory to arrive at the formula for the hyper-fine splitting of hydrogen. We can simply apply the formula

$$\mathbf{s} = c \operatorname{curl} \mathbf{M}$$

to a magnetization

$$\mathbf{M} = \frac{e\hbar}{2mc} |\psi|^2 \mathbf{e}_z$$

where $\mathbf{e}_z$ is the unit vector in the z-direction. It is then almost a tautology that the field in the centre is

$$\mathbf{B}(0) = \frac{8\pi}{3} \mathbf{M}(0) = \frac{8\pi}{3} \frac{e\hbar}{2mc} |\psi(0)|^2$$

from which the splitting can be calculated.

The Maxwell-Ampère Approach is Confirmed

There have been some recent claims that magnetic poles have been observed, but their existence is still very doubtful. Even if it should be confirmed, such poles must be very rare particles and although their existence might thoroughly change our ultimate ideas about electromagnetic fields and particles, I do not see that from the point of view of the electronic engineer or the solid-state physicist this will make much difference. In any case not in my lifetime.

Thus we have seen that modern ideas about magnetism are a complete vindication of the Maxwell–Ampère approach. We have also seen that the existence of magnetic moments that are characteristic for an atom or a molecule can only be explained in the framework of entirely new concepts: quantum theory. Quantum theory provides a description of the remarkable feature of permanence and stability of atomic systems, a feature for which Maxwell could not envisage an explanation within the realm of physics.

Recent Developments

Let me terminate by making some further remarks about the present state of magnetism. In diamagnetism Maxwell's formula

$$\mu/H = -\tfrac{1}{2}R^3$$

for the induced moment does not apply. The reason is that the inertial terms, introduced by Lorentz, prevail. The correct formula is

$$\mu/H = -\frac{1}{6}\frac{e^2}{mc^2} \cdot R^2$$

and since

$$\frac{e^2}{mc^2} = \left(\frac{1}{137}\right)^2 a_B$$

where a_B, the Bohr radius, is about the dimension of an atom, the diamagnetic moment is at least four orders of magnitude smaller than according to the original idea. For a macroscopic superconducting sphere the formula holds with a slight correction for penetration depth.

There are three ways to produce magnetic fields: by ferromagnetic materials, by currents in superconductors and by currents in normal materials.

I have already mentioned that the magnetism in ferromagnetic materials derives from the electron spin. The best we can do is to put all free spins in parallel. In ferromagnets this happens because of a special interaction of electrostatic nature, the exchange interaction. Even in unmagnetized soft iron the spins are parallel in small domains, somewhat of the size of a living cell. When the iron is magnetized all the domains are lined up and their boundaries disappear. The saturation B so obtained is about 20 000 gauss (or 2 tesla). We may increase the externally produced field above B by the trick of using pole-pieces in the form of truncated cones. Since the gain is proportional to the logarithm of the ratio between smallest and largest radius we cannot go very far in this direction; 100 000 gauss is about the useful limit.

When superconductivity was discovered, in 1911, Kamerlingh Onnes's first thought may well have been: now I can make very large magnetic fields with little or no energy. It did not work out that way: soon it was found that the magnetic field destroys superconductivity. With the 'classical' superconductors, lead, mercury, tin, something like 1000 gauss is about the upper limit, which is not spectacular. In the 'thirties it was found that there exist alloys with a much higher critical field and it was realized that in such alloys the transition for 'resistance coming back' and for 'field is penetrating' can be widely different. But it was only after the second world war that really useful materials were developed. To-day coils producing 100 000 gauss are fairly standard, at least in scientific laboratories. But one can go higher. We do not know the upper limit, yet it seems improbable that one shall be able to go above half a million. As for theory of superconductivity, let me only remark that in a way it vindicates Maxwell's remarks about resistanceless currents in molecules. We have to regard the situation of a superconductive ring in which a persisting current is circulating as one quantum state of a very large system. In a way then, the whole ring must for this purpose be regarded as one molecule. Such are the marvels of modern quantum theory.

We can also produce fields by brute force, that is by circulating very large currents through vigorously-cooled coils or by having very large but very short current pulses. The order of magnitude of fields reached that way is none too different from the fields I mentioned before.

It is indeed curious that three rather different mechanisms should give results that are so similar. I see no profound physical reason for that: it just happens that way.

It is also curious that there has not been an enormous progress in the fields obtained. Compare this with particle accelerators: Cockcroft and Walton did their first experiments here at Cambridge with particles accelerated by voltages well below one million volts. To-day we can accelerate particles to voltages of hundreds of milliards of volts. But before Cockcroft and Walton built their accelerator here at Cambridge, Kapitza, also at Cambridge, had already pulsed fields of several hundred thousand gauss.

These last remarks should not be interpreted in the sense that there has been no progress in the field of magnetism. On the contrary, there has been an enormous advance in our understanding of the properties of magnetic materials, in the quality of permanent magnets and of soft magnetic materials, there have been striking developments in magnetic memory devices and so on. Similarly, there has been great progress both in our understanding of the basic phenomenon of superconductivity and in our mastery of materials. And there have been technological advances in the handling of great current densities.

And so you might well ask whether it would not have been a better plan if I had concerned myself primarily with these modern developments.

But however that may be, my present approach was born out of my profound admiration for the vision, for the way of looking at nature, for the style of exposition of that great scientist, that fascinating and noble figure, James Clerk Maxwell.

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The author

Hendrik Brugt Gerhard Casimir, who was born in 1909 in The Hague, studied theoretical physics at Leyden with Ehrenfest, at Copenhagen with Niels Böhr and at Zürich with Pauli. He received his Ph.D. from Leyden University in 1931, and he worked in various research positions at Leyden from 1933 to 1942, when he joined the staff of the Philips Research Laboratories at Eindhoven. Dr. Casimir became a director of these laboratories in 1946 and a member of the 'Board of Management' of the Philips Company in 1957. In this capacity he supervised the research activities of all Philips laboratories throughout the world until his retirement in 1972. He is the author of many papers on theoretical physics, applied mathematics and low-temperature physics.

A Member, and since 1973 President, of the Royal Netherlands Academy of Sciences and Letters, Dr. Casimir has been honoured by many other bodies in Europe and the United States. He is a Foreign Member of the Royal Society of London, and the Institution of Mechanical Engineers awarded him its Alfred Ewing Medal. Dr. Casimir has been elected to Honorary Fellowships by the Institute of Physics, the Institution of Electrical Engineers and the University of Manchester Institute of Science and Technology, and he has been awarded honorary degrees of Doctor of Science by the Universities of Leuven and Edinburgh, the Technical Universities of Copenhagen and Aachen, and Cranfield Institute of Technology. He has been President of the European Physical Society and Chairman of the Advisory Committee on R & D of the EEC.

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Submillimetre Waves

A survey of the 'state of the art' and some recent developments in research

R. J. BATT, B.Sc., Ph.D., M.Inst.P.*

and

Professor D. J. HARRIS, O.B.E., B.Sc.(Eng)., Ph.D., C. Eng., F.I.E.E., F.I.E.R.E.†

Based on a paper given before the Southern Section of the Institution in Portsmouth on 13th February 1974

SUMMARY

A review is presented of submillimetre wave generators and detectors, propagation properties of materials and the atmosphere, wave guiding structures and components, and present and potential applications for the waveband. Existing practice and active research areas are described and discussed.

Department of Electrical and Electronic Engineering, Portsmouth Polytechnic, Anglesea Road, Portsmouth PO1 3DJ.

†*Department of Physics, Electronics and Electrical Engineering, University of Wales Institute of Science and Technology, King Edward VII Avenue, Cardiff, CF1 3NU.*

1 Introduction

The submillimetre wave region of the electromagnetic spectrum, considered here to lie roughly in the 1–0·1 mm range, is not a new subject for research. Rubens for example published many papers at the beginning of this century on far infra-red. With Van Baeyer[1] he reported measurements in 1911 at wavelengths up to 0·3 mm using a mercury discharge lamp as source and a bolometer as detector, while Glagoleva-Arkadyeva[2] used a spark source generating from 50 to 0·082 mm wavelength in 1924. Such sources are non-coherent, unstable and low power, however, and hence have somewhat limited applicability.

Effective quantitative work was initiated by an extension of microwave techniques using harmonic generators driven by microwave sources, together with modified microwave point-contact diodes for detection. Gordy and his co-workers[3] for example used the 18th harmonic from a 32 GHz klystron to generate 0·55 mm wavelength radiation in 1958. Power levels were very small, e.g. fractions of a microwatt, but in spite of this some very refined spectroscopic work was carried out. Attempts to generate submillimetre waves directly by electron beam devices, including relativistic beams, were initially not very successful but the later development of backward wave oscillators has led to generation at wavelengths down to 0·35 mm, and recently to 0·22 mm.

In parallel with the above development considerable research activity was directed at optical and near infra-red wavelengths, especially in the 0·3–0·6 μm (visible) region and around 10 μm, corresponding to the peak intensity at human body temperatures. This research led to the development of lasers, giving coherent radiation, and of a number of sensitive quantum detectors. In the mid-1960s, laser operation was extended to submillimetre wavelengths by using H_2O or HCN as the active molecules, making available milliwatt power levels at a number of discrete wavelengths. Some fast response quantum detectors, operated at liquid helium temperature, can be extended to these wavelengths, and room temperature but slower response thermal detectors of good sensitivity such as the Golay cell and pyroelectric detector, are also available.

Existing sources and detectors have serious limitations that hamper their applicability, but they allow effective experimentation and development of techniques to take place. Two International Conferences on submillimetre waves have occurred during the past five years,[4,5] and several texts are available dealing with submillimetre waves[6,7] the far-infra-red[8–12] and quasi-optics.[13]

In this paper we survey the 'state of the art' and some research currently being carried out at submillimetre wavelengths, from an engineering point of view and with the potential application of the wavelength range in mind.

2 Submillimetre Wave Energy Sources

There are three main categories of submillimetre generators:

Thermal type sources

Sources using a microwave approach

Sources using optical, or quasi-optical approaches.

2.1 Thermal Sources

Although all hot bodies emit submillimetre radiation, the power densities are exceedingly low as indicated in Fig. 1, and they are non-coherent. The mercury vapour lamp (approximate temperature 3000K) has been extensively used as a broadband source, but sophisticated detection techniques are then required.

2.2 Microwave-type Sources

Reference has been made previously to the generation of very low powers by harmonic techniques, and will not be considered further.

Conventional cavity-type electron tubes like the klystron have been developed into the short-millimetric region[14] by decrease of dimensions and increase of electron beam energy to reduce transit time effects, but little further progress is likely. Travelling wave oscillators using the backward wave mode (b.w.o.), however, have achieved greater success. Backward wave space harmonics of a periodic propagation structure can have a relatively low phase velocity for a given periodicity, and give a built-in feedback mechanism when coupled to an electron beam. They have been exploited by Thomson-CSF[15] who generated milliwatt power levels down to 0·35 mm wavelength by 1965. The fine-detail slow-wave structure closely coupled to a high energy electron beam (e.g. 40 mA at 10 kV) results in a high cost and low life expectancy for these tubes, however. Backward wave tubes have been constructed down to 0·2 mm in the Soviet Union,[16] and are widely used there. A b.w.o. has also been reported by Siemens[17] operating over the frequency range 320–480 GHz (0·94–0·63 mm wavelength) at milliwatt power levels.

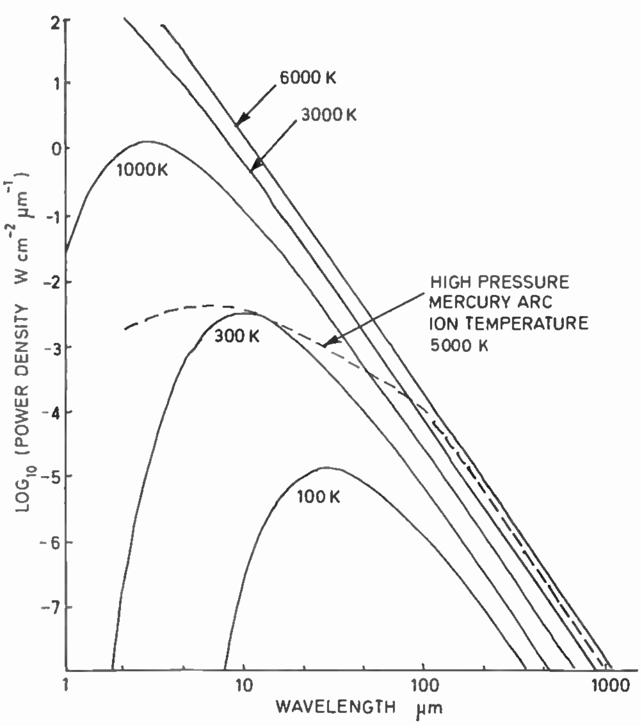

Fig. 1. Hot body thermal emission.

There have been many reports of the use of relativistic electron beams to generate submillimetre waves. The high energy beam is made to interact with a periodic slow-wave structure, a dielectric structure, or a transverse magnetic field with periodicity. A super-high energy electron beam system at the Naval Research Laboratory, Washington, has recently been reported[18] as generating high pulse powers in the submillimetre region. A beam power $> 10^{11}$ watts (80 kA at 3·3 MV) is obtained for a duration of 10–100 ns. Interaction with a rippled magnetic field of 1·5 Wb/m^2 yields GW powers at around 10 GHz, and pulses at kilowatt peak level in a pass-band of 390–540 μm wavelength. Such an installation is not easily constructed, however!

Whilst the operating frequency of solid-state microwave-type sources has been progressively increased in recent years, and powers of 100 mW can be generated at 100 GHz, there appears to be only one report[19] of such a generator at a wavelength less than 1 mm. An avalanche diode gave an output power of about 1 mW at 341 GHz (0·88 mm wavelength). The diode was made by diffusion of boron into arsenic-doped single-crystal silicon, with a junction depth of about 3 μm, and a junction diameter of about 7·5 μm was used. No further progress on this has been reported.

2.3 Laser-type Sources

Laser-type sources fall into three main categories:

Gas discharge lasers

Optically pumped lasers

Tunable sources

2.3.1 *Gas discharge lasers*

The generation of submillimetre waves by laser action was first reported in 1964,[20,21] an electric discharge being used to excite the gaseous laser medium. Hydrogen cyanide[22] or water vapour were initially used as the medium, and subsequently other media, e.g. D_2O, H_2S and SO_2 have been used. Table 1 indicates some of the lines that can now be generated, with milliwatt power levels for the stronger transitions.

Table 1

Molecule	Laser emission lines λ (μm)
HCN	311, 337, 373
H_2O	28, 32, 47, 55, 78, 118, 120, 220
D_2O	36, 56, 73, 84, 107, 172
H_2S	33, 61, 80, 87, 103, 162, 225
SO_2	141, 151, 193, 215

This type of laser is a convenient laboratory source being basically simple to construct and to operate, and requiring a power supply of about 1 ampere at 1–2 kV. The 337 μm line for HCN is particularly convenient, and commercial lasers are now available. Higher power levels of 50–100 mW have been reported under c.w. operation for HCN and H_2O lasers used in special applications, with peak powers at kW level under pulsed operation.[23]

2.3.2 *Optically pumped lasers*

A major disadvantage of electrical discharge pumping of the laser medium is that many potentially valuable media suffer molecular destruction by the discharge, and the number of available lines is therefore limited. This disadvantage can be overcome by using the optical pumping mechanism pioneered by Chang and Bridges[24] at Bell Laboratories in 1970. They found emission of radiation at 496 μm as a result of transitions between rotation levels of the higher vibration state to which the gas had been excited, i.e. pumped, by CO_2 laser radiation. Each submillimetre line of an optically pumped laser results from the excitation of a particular molecular gas by an appropriate emission line from the CO_2 laser. The CO_2 laser must therefore be tunable, and to date over 300 optically pumped lines have been identified. Lines available at milliwatt level from a number of media are given in Table 2, and additional lines may be found in the literature.[25–28]

These multi-wavelength lasers, consisting of a tunable CO_2 laser of some 5–20 watts output power and an optically pumped resonant gas cell, as shown for example in Fig. 2, can generate radiation across the spectrum from 40 μm to almost 2 mm wavelength.

Further developments of the optically pumped laser are being made in a number of research laboratories, especially in the U.S.A. and Japan, and may be summarized as follows:

(1) The inconvenient size of the system in Fig. 2 may be reduced[29,30] and the efficiency increased by using metal tube waveguides between the mirrors of both the CO_2 laser and gas cell.

(2) The number of available lines can be increased by achieving a larger number of coincident matchings between transitions of the pumped medium and output emission lines from the CO_2 laser. This has resulted from Stark tuning[31,32] where a high electric field is applied across the medium or from use of very high-power pumping in the 'skirt' region at the edge of a near coincident line.[31]

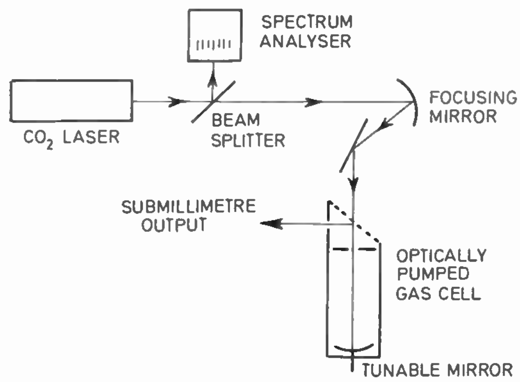

Fig. 2. Optically pumped submillimetre laser.

(3) Very high-power optically pumped molecular gas lasers can result from super-radiant laser action.[33] This process requires no end mirrors to form a resonant cavity but uses very high pump powers (e.g. 10 MW) which cause the individual dipoles to align and then coherently emit at peak power levels up to 100 kW. Transverse optical pumping (t.o.p.) of the gas cell is also being investigated.

2.3.3 *Tunable sources*

Optically-pumped submillimetre laser sources, although with superior ranges of wavelength and power to the electrical discharge lasers, are nevertheless limited since their laser emissions occur at discrete wavelengths. A continuously-tunable laser with significant output power would give greater flexibility and lead to wider application. A number of schemes to produce a quasi-tunable source are now being investigated, involving the interaction of laser beams with solid dielectric materials. Frequency mixing can be achieved in a non-linear crystal, the sum and difference frequencies being generated. The difference frequency can be in the submillimetre range and three schemes are summarized in Table 3.

Table 2

λ (μm)	Molecule	λ (μm)	Molecule	λ (μm)	Molecule
37·5	CH_3OH	251·9	CH_3F	496·1	CH_3F
40·2	CH_3OH	277	$CH_2OH\ CH_2OH$	512	HCOOH
41·7	CH_3OH	369·1	CH_3OH	520	CH_3OCH_3
70·1	$CH_2OH\ CH_2OH$	372·7	CH_3F	533	CH_3CHF_2
70·6	CH_3OH	372·9	CH_3CN	554	CH_2CF_2
95·8	$CH_2OH\ CH_2OH$	388	HCOOH	568	CH_2CF_2
117·1	$CH_2OH\ CH_2OH$	392·3	CH_3OH	570·5	CH_3OH
118·8	CH_3OH	393·6	HCOOH	647·9	CH_3CCH
118·9	$CH_2OH\ CH_2OH$	414	HCOOH	713·7	CH_3CN
147	CH_3NH_2	415	CH_2CF_2	884	CH_2CF_2
170·6	CH_3OH	428	HCOOH	1174·9	CH_3CCH
192·8	CH_3F	458	CH_3CHF_2	1221·8	$C^{13}H_3F$
197	$CH_2OH\ CH_2OH$	492	CH_3OCH_3	1814·4	CH_3CN

Table 3

Sources	Non-linear crystal	Submillimetre range	Output power
Two tunable CO_2 lasers[34]	GaAs, CdTe at 80 K	70 μm–2 mm (3000 discrete steps)	10^{-7} W c.w. 100 mW pulse
Two dye lasers	$LiNbO_3$	50 μm–500 μm continuous	200 mW pulse
Two beams from InSb spin flip Raman laser with magnetic field[35]	InSb at 15 K	90 μm–110 μm continuous	20 mW pulse

A continuously-tunable submillimetre wave source recently reported[36] uses a high power single frequency (1·064 μm wavelength) input radiation beam which interacts with a lithium niobate crystal mounted in a mirror resonator. The input consists of 20 ns pulses at 1·7 MW from a Nd-YAG laser, and output powers of 10–100 watts peak are obtained in the wavelength range 150–700 μm. Tuning is achieved by varying the angle of incidence of the input beam to the axis of the lithium niobate crystal.

2.4 General Comment on Generation of Submillimetre Waves

It is clear from the above discussion on sources that the ideal generator does not yet exist. The thermal source is cheap and compact, but non-coherent and very low power. The backward-wave oscillator satisfies the requirements of tunability and reasonable power, especially for the upper wavelength part of the region, but is expensive as a device, and requires an expensive power supply. The discharge-pumped laser is relatively easy to construct but choice of wavelength is limited to a few lines. The optically-pumped submillimetre laser is attractive in giving radiation at discrete wavelengths over the extensive range 50 μm to 2 mm, but is bulky, expensive and non-tunable. The tunable laser type sources described are also complex, expensive and generally low power. They are not yet developed for conventional laboratory use. Solid-state avalanche devices have oscillated below 1 mm wavelength, but only just! It is here, however, that we must hope for a break-through in the future if rapid exploitation of the region is to occur.

3 Detection of Submillimetre Waves

Detectors fall into three main categories:

Thermal detectors,
Photo-detectors,
Rectifying detectors.

The effectiveness of detectors can be expressed in several different ways. The sensitivity, or responsivity, gives the output voltage per unit input power, i.e. volts/watt. The minimum detectable incident power depends upon the noise power of the device itself, and the capability of the detection system in extracting the signal from the background noise. The noise equivalent power (n.e.p.) expresses the power level equivalent to the noise of the device, referred to unit bandwidth, and is expressed in $W/Hz^{\frac{1}{2}}$. The detectivity, given by the inverse of the n.e.p., is also widely used.

3.1 Thermal Detectors

Thermal detectors depend upon the variation of some physical property with temperature and include the Golay cell, thermocouples and thermopiles in which the voltage changes with temperature, bolometers which use resistance change, and pyroelectric detectors.

The Golay cell[37] operates at room temperature. Incident radiation is absorbed by gas in an enclosed cell and the pressure change is measured by an optical/electronic system. The wavelength range is restricted by the input window material, usually quartz, from about 50 μm to a maximum wavelength defined by the window aperture (e.g. 3 mm to 5 mm). The quoted n.e.p. of about 3×10^{-10} $WHz^{-\frac{1}{2}}$ is very close to the ideal limit for room temperature detectors. Advantages are flatness of response over the submillimetre region and convenience, reliability and ease of use; disadvantages are a long time constant (15 ms) and sensitivity to vibrations (microphony).

The application of thermopiles[38] is limited at the longer wavelengths to the monitoring of those higher powers which would damage more sensitive detectors.

Several types of resistive bolometers, listed in Table 4, are used as submillimetre detectors.

Table 4

Type	Detectivity $W^{-1}Hz^{\frac{1}{2}}$	Response time	Operating temperature
Bismuth-lead alloy[39]	4×10^8	35 μs	room temp.
Carbon[40]	10^{11}	10 ms	liquid He
Superconducting tin[41]	3×10^{11}	50 ms	liquid He
Germanium[42,43]	10^{13}	10 ms	liquid He
Thallium selenide[44]	10^{14}	20 ms	liquid He

A recent addition, the pyroelectric detector,[45] is the only competitor to the Golay cell as a sensitive room temperature detector in the submillimetre region. It is a thermal-sensitive ferroelectric bolometer. The first pyroelectric material to be extensively used was triglycine sulphate (TGS), but various other materials,[46] e.g. barium titanate and other ceramics like PZT which are non-hygroscopic, are also being used. These detectors have a flat response throughout the submillimetre region with detectivities around $10^9 W^{-1}Hz^{\frac{1}{2}}$, approaching that of the Golay cell. Fast pyroelectric detectors may now be obtained giving a flat response at modulation frequencies up to 100 kHz.

3.2 Photo-detectors

Photoconductivity produced by impurity ionization extends from 10 to 130 μm. Such extrinsic detectors[9] use various types of doping in germanium, e.g. Ge:B; Ge:Ga; Ge:Sb. In the region 100 to 1000 μm photoconductivity is produced by free electron absorption within the conduction band. The important materials here are InSb,[47] used in the Putley detector, and GaAs.[48] The advantage of photoconductive detectors is that they combine very fast speed of response (typically 10^{-7}–10^{-8}s) with high detectivities (in the range 10^{10}–$10^{13}W^{-1}Hz^{\frac{1}{2}}$), but they have the disadvantage that they must be liquid-helium-cooled to ensure that the number of thermally excited electrons or holes is small compared with the number excited by the radiation.

Photon-drag detectors[49] have the advantage of room temperature operation combined with fast response (e.g. 10^9Hz) and high damage threshold necessary for use with pulsed lasers, but have a poor detectivity, e.g. $10^4W^{-1}Hz^{\frac{1}{2}}$. Their operation depends on the mobile charge-carriers being driven down a semiconductor rod (e.g. Ge, InSb, GaAs) by the radiation pressure, thereby creating an electric field along the rod which may be detected. This type of detector may be used especially for pulse power at the shorter wavelength region of the spectrum.

The performance of various thermal and photo-detectors is summarized in Fig. 3.[9]

3.3 Rectifying Detectors

Point contact detectors use silicon, germanium or gallium arsenide semiconductors as the crystal, in conjunction with a tungsten whisker. Silicon, with its high hardness value, appears to have advantages for these frequencies, with the tungsten point reduced to a minimum (e.g. < 1 μm dia.) to reduce capacitance effects. Comparative sensitivity values for such a detector using p-type silicon as semiconductor have been given[50] as 10^2, 1, 10^{-1} and 5×10^{-3}V/W at 94 GHz, 890 GHz, 474 THz and 28 THz respectively. Detectors in which a tungsten point is in contact with a 3–5 μm thick silicon film deposited on a molybdenum base have also recently been reported[51] to have a sensitivity similar to that of an InSb detector.

A rectifying action may also occur at the interface between two metals if an ultra-thin insulating layer exists between the metals, giving the m.i.m. (metal-insulator-metal) and m.o.m. (metal-oxide-metal) diodes. A tungsten point is usually chosen as one metal contact, and natural oxidation of the metals is usually sufficient for insulation, but stability of the surface state is a basic problem. Detection and mixing[52,53] have been reported over a wide range of frequencies.

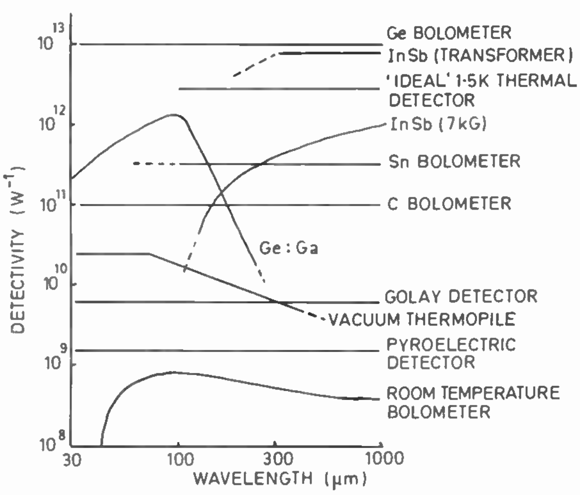

Fig. 3. Detectivity of infrared detectors.[9]

The Josephson effect was reported in 1962, and its application to detection and mixing in the submillimetre region was described[54] in this Journal. The effect concerns the tunnelling of electrons across a thin layer between superconducting surfaces. Niobium is usually used at liquid helium temperature. These detectors give a combination of high sensitivity (up to 10^5 V/W), low noise, and a response time less than 10 ns. They have been used successfully for high frequency mixing, e.g. of the 401th harmonic of a 9·5 GHz klystron with the 3·82 THz output from a H_2O laser, but suffer from problems of stability and lack of accessibility when immersed in liquid helium.

Considerable success has been achieved in the development of Schottky barrier diodes as convenient detectors and mixers, using GaAs. Capacitance effects are reduced by using contact areas of 1 μm diameter.[55] A sensitivity of 15 V/W at 890 GHz was obtained, and mixing between the 33rd harmonic of a 74 GHz klystron and the output of a 118·8 μm water vapour laser readily observed. A major advantage claimed is ruggedness, stability and freedom from critical adjustments.

3.4 Detector Summary

As in the case of the energy source, no ideal device for detection has yet materialized, i.e. fast response, high sensitivity and room temperature operation. A comparison between four of the most widely used detectors is given in Table 5. The detection level is an approximate indication of the minimum power that can be readily detected.

Table 5

Detector	Sensitivity, V/W	Detection level, W	Modulation frequency limit, Hz	Operating temperature
Golay cell	10^5	10^{-9}	20	room
Pyroelectric	10^2	10^{-7}	10^4	room
Point-contact	1	10^{-5}	10^8	room
Photoconductor	10^3	10^{-9}	10^8	4 K

The pyroelectric detector is cheap, sensitive, and easy to use, but has a low frequency response. The Schottky diode is fast in response but much lower in sensitivity. The Golay cell at present gives the greatest sensitivity but the modulation frequency is limited to a few hertz, whilst the photoconductive detectors give good response and sensitivity, but at the cost of liquid helium temperature operation.

4 Measurement of Submillimetre Wave Power

It is more difficult to measure power level than to detect it. A measurement device must be capable of being calibrated, and then maintain that calibration with life. There must also be some standard against which it can be calibrated.

The Golay cell is often used to estimate power levels. The calibration can be carried out at near infra-red wavelengths where other standards exist, and it is then assumed that the calibration is maintained into the submillimetre region. Care must be taken over the transmission characteristic of the window and coupling through the window aperture also introduces an element of uncertainty.

Commercial calorimeters are now available, which enable pulse power levels greater than 10 mJ to be measured.

The National Physical Laboratory is developing a power measuring device of greater sensitivity for the submillimetre region.

5 Properties of Materials and Propagation Media at Submillimetre Wavelengths

The transmission and absorption characteristics of matter can be very sensitive to wavelength in the submillimetre region. Even in the microwave region molecular resonance and subsequent high absorption in the atmosphere can occur at some discrete frequencies, e.g. O_2 absorption at 118·5 GHz and H_2O absorption at 183·3 GHz, but there is a vast number of such resonances at wavelengths less than 1 mm. This makes prediction of media characteristics by extrapolation difficult other than on a quantum basis from a detailed knowledge of molecular structure.

5.1 Material Properties

The measurement of material properties has been approached from two points of view: (a) Techniques aimed primarily at determining the molecular and electronic structure of the material. This will be indicated later. (b) Determination of the properties of materials and media for applications at submillimetre wavelengths, e.g. for windows, filters, lenses, detectors, modulators, etc. The range of material being investigated for these applications is very large and space does not permit any detailed discussion, but some important materials being used at present will be indicated.

Several dielectrics are known to have low loss, resulting in good transmission, and have been carefully measured even at these short wavelengths.[10,56,57,58] Three such materials are TPX, polyethylene and polypropylene, with relative permittivities between 2·1 and 2·3 over most of the submillimetre range. The loss tangent of these materials[10] is given in Fig. 4. TPX is available in rod form and can be machined and polished into windows and lenses, with the advantage of low dispersion and loss. Since TPX is transparent in the visible region, alignment is possible using a visible laser. Polyethylene and polypropylene are both very cheap and readily available. Polyethylene can be moulded and is available in sheet form. Polypropylene is used widely as a wrapping material and can be obtained as a thin film of thickness down to about 10 μm. Some recent work[59] has shown that loss tangents of 8×10^{-4} and 4×10^{-4} can be achieved for polypropylene and polyethylene respectively by special preparation (vacuum melting, extraction and casting) of the material. A thickness of 1 mm of any of these materials has a trans-

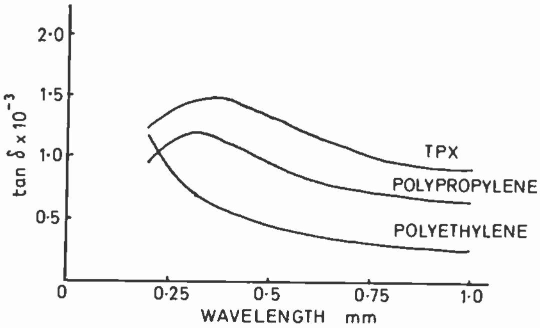

Fig. 4. Loss tangent of dielectrics.[10]

mission in excess of 75% over the submillimetre region. Thin sheets, e.g. down to 40 μm, of black polyethylene can be used to filter out the visible region whilst being about 80% transparent over the submillimetre region, for applications such as radio-astronomy. Thick sheets are used as attenuators, and 3 mm gives about 10% transmission, i.e. 10 dB attenuation.

Diamond has good transparency[10] over the entire region of 10–1000 μm, and although expensive is used as a window for Golay detectors. Less expensive is sapphire,[4] where a 0·63 mm thickness has a transmission in excess of 35%. For the 50–1000 μm region crystalline quartz[60,10] ($\varepsilon_r = 4{\cdot}5$, $\alpha \simeq 0{\cdot}1$ to $1{\cdot}0\ \text{cm}^{-1}$) is used because of the added advantage (besides cheapness) of filtering out the 4–40 μm radiation. If these materials are used as windows they should preferably be in the form of wedged plates because of interference effects. Beyond 100 μm various Irtran[9] materials become transmitting again and may be used as window/filters in this region.

Semiconductors such as silicon[4] ($\varepsilon_r \simeq 10$, $\alpha \simeq 0{\cdot}5\ \text{cm}^{-1}$) and germanium may have transmissions in excess of 50%, especially if they are bloomed. Lenses of these materials may be used for example in conjunction with the pyroelectric vidicon for far infra-red imaging applications. The variation of absorption with charge carrier density in the semiconductor may be used to give amplitude modulation.

Various other materials, such as the alkali halides, ADP, KDP, TGS, TiO_2 and $LiNbO_3$, have been studied[4,9,61,62] for windows, filters and components. TGS ($\varepsilon_r \simeq 9$) is of interest as a pyroelectric material and as a polarizer. TiO_2 has a very high permittivity ($\varepsilon_r \simeq 1000$). $LiNbO_3$ is birefringent ($\varepsilon_r \simeq 25$ and 50), piezoelectric and pyroelectric, has electro-optic properties, and has possible application for detectors, modulators, mixers and for interaction with surface acoustic waves.

The transmission and Faraday rotation properties of various ferrites have been investigated[63,64] for application to non-reciprocal devices and modulators. Several rare-earth iron garnets and spinel ferrites have been investigated and yttrium ferrite is known to have low loss at the longer wavelength end of the submillimetre region.

5.2 Atmospheric Properties

The propagation characteristics of the atmosphere will be critical for any application involving free-space propagation. Low-loss transmission is not possible, however, under normal atmospheric conditions because of the absorption of submillimetre waves by the water vapour content that is usually present. Water vapour molecules have a large number of resonance lines throughout this part of the spectrum. The frequencies of these lines are known, and the broadening of these lines by atmospheric constituents can be calculated. A typical result of such calculations[65,66,67] is shown in Fig. 5, from which it can be seen that no low-loss windows exist in this range. Experimental verification has been obtained at many points on this characteristic. Techniques include a folded long path[68] and an open resonator[69,70] in controlled atmospheres. Results obtained so far generally substantiate the theoretical values for wavelengths below 1 mm, although anomalous high attenuations[71] have been measured in the short-millimetric region for which a satisfactory explanation has yet to be found.

It is clear that free-space propagation will have limited application except for short path lengths or outer space conditions. Any enclosed waveguide will require a dry gaseous medium. Propagation through water droplets, e.g. fog, would be expected to be intermediate between the poor penetration for optical waves and the good penetration of microwaves. Measurements have been made and some figures are available for fog,[4,72] rain[73] and snow[74] conditions.

The variation of refractive index with air pressure, temperature and water vapour content has also been measured.[75]

6 Submillimetre Waveguides and Components

Techniques for guided wave propagation used at microwave and optical frequencies face severe limitations in this intermediate region. Microwave techniques of dominant H_{10} mode rectangular guide and H_{01} circular guide for distant transmission may not be carried over because of the high loss and small dimensions of the H_{10} mode (> 50 dB/m at 1 mm wavelength and increasing with frequency) and possible launching and moding problems of the H_{01} mode. Optical guides make use of the low-loss transmission property of glasses, for which there is no equivalent in the submillimetre region.

Alternative techniques include beam guides, overmoded guides and hybrid guides with higher-order mode suppression.

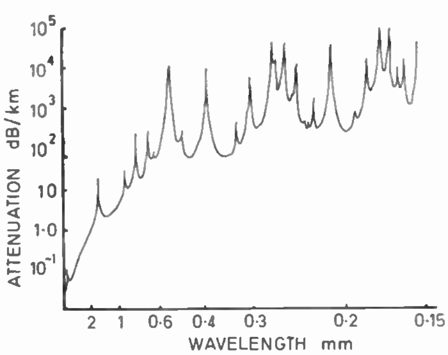

Fig. 5. Atmospheric absorption.[65]

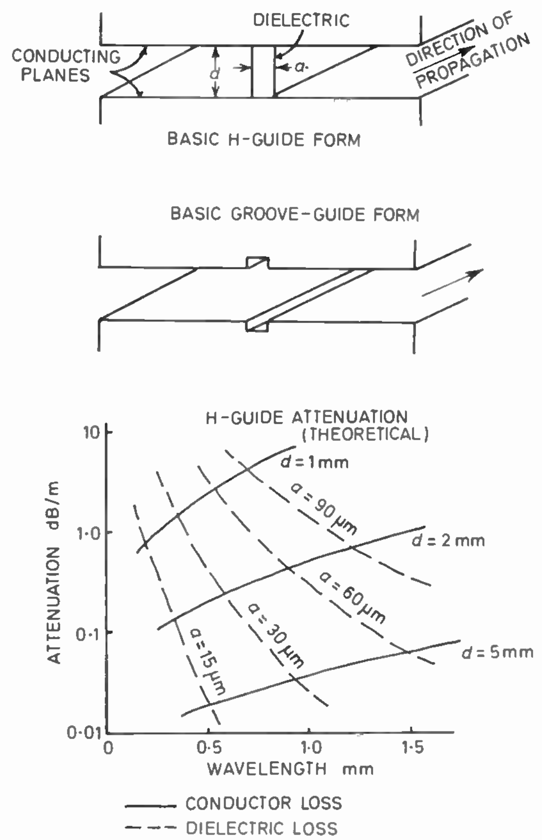

Fig. 6. H and groove guide.

Beam guides[76] use iterative phase front correction by an aperture or lens system to get beam confinement. Experimental systems have been investigated[77] and losses of 2 dB/m measured at 0·8–1·0 mm wavelength. The accuracy and alignment requirement is severe, however, and dimensions are large, especially if an artificial atmosphere is to be used. Overmoded rectangular guide,[78] with the electric field parallel to the broad face, has been used and the attenuation measured.[79,80] Losses of 1·4 dB/m and 1·6 dB/m are reported for a guide of dimensions 7·2 × 3·4 mm and 10 × 22 mm for wavelengths of 0·8 mm and 0·65 mm respectively. Some control of higher order modes has been achieved by replacing a broad conducting face by a wire grid or a dielectric strip, but at the expense of higher losses. Another approach[81,82,83] is to use the low-loss mode in H-guide or groove-guide, shown in Fig. 6 together with theoretical losses for H-guide. Scaled-up model measurements show that moding can be controlled in otherwise overmoded guides, and that low-loss propagation may therefore be possible. These guides could replace the H_{10} rectangular guide and be used in conjunction with the H_{01} circular guide, or form a complete new system. The only submillimetre attenuation measurements on H-guide gave a loss less than 8 dB/m at 0·34 mm wavelength. Dielectric tube guide, with a pressurized polypropylene tube large compared with the wavelength, and using total internal reflection as for some optical guides, is also being investigated. The development of a suitable guiding system for both short-millimetric and submillimetric wavelengths is vital for the engineering exploitation of these regions.

The non-availability to date of convenient low-loss guide has resulted in quasi-optical techniques being mainly used. Standard techniques using, for example, mirrors, lenses and beam-splitters can be applied directly. A number of adaptations to provide variable attenuators, phase-shifters, couplers etc. have been described.[84] Simple attenuators can be made of carbon impregnated (black) polyethylene.

Filters[85] and variable attenuators[86] have been constructed by variable-separation and rotatable wire mesh and grids. Transmission and rejection filters can be constructed, the basic element being produced by photolithography and etching techniques. Thin TGS plates have also been used as polarizer screens.

Modulation techniques are in their infancy, room temperature devices being limited to a few megahertz. Two approaches have been reported. One uses Faraday rotation[63] and is therefore limited by the rate at which the magnetic field can be switched. The other[87] also has a magnetic field, which is used to switch the charge carriers in a current-carrying germanium specimen from a 'surface-worked' face to an etched surface. The difference in recombination sites results in a difference in charge-carrier density and therefore in attenuation of the submillimetre wave passing through the specimen. A liquid helium temperature modulator[88] has a frequency range up to 100 MHz. In this device freeze-out of charge-carriers in a germanium sample is obtained at the low temperature. The application of a voltage to the specimen gives an avalanche formation of charge-carriers and subsequent attenuation of a wave transmitted through a specimen.

The advent of the pyroelectric detector has led to the development[89, 90] of the pyroelectric vidicon for visualization of infra-red radiation. A single domain TGS plate of high quality is used in place of the normal target plate of a vidicon tube which can replace a normal tube with slight modifications to gain and bandwidth because of the smaller signal. The choice of optics for the camera lens and window of the tube limits the wavelength range and generally this has been optimized for the 8–14 μm range with germanium components. These tubes have been used also at submillimetre wavelengths, and a pictorial cross-section together with a displayed mode pattern of a HCN laser is shown in Fig. 7.

At present other methods of visualization[91,92,123] of submillimetre radiation using for example liquid crystal and microwave techniques are still in the early stages of investigation.

7 Progress with Applications

It is probably fair to say that there is at present no application of outstanding importance that can only be met by the use of submillimetre waves. Nevertheless, the waveband does have its own distinct characteristics and advantages, and it will undoubtedly be exploited when components and techniques become established. The distinguishing features include: the distinctive properties of some materials due to a matching of some molecular resonance with the wave frequency; the comparable magnitudes of the wavelength and some other dimension, e.g. water droplet size or some mechanical tolerance or dimension; the large variation of atmospheric absorption with relatively small frequency change; the high frequency and therefore the large potential bandwidth; the possibility of a microwave approach using fine tolerance but otherwise conventional construction techniques; the possibility of a penetration through fog better than optical radiation combined with an image resolution better than for microwaves; and better penetration through an ionized medium than microwaves. Radiators of convenient dimensions but large compared with the wavelength can also be constructed.

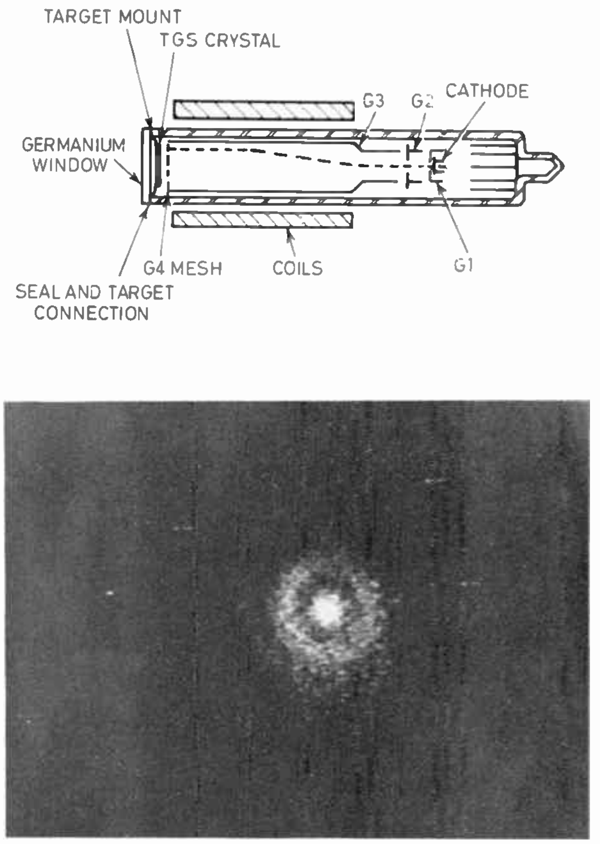

Fig. 7. Pyroelectric vidicon and HCN laser mode display (English Electric Valve Co.).

Current and potential applications under investigation can be summarized under the following categories:

Molecular structure and characteristics determination.

Atmospheric investigations.

Far infra-red astronomy.

Plasma interactions and plasma diagnostics.

Communications.

High resolution radar, radar modelling and imaging techniques.

Metrology.

Measurement of frequency and the speed of light.

7.1 Molecular Structure and Characteristics Determination

There is considerable research activity in this field, being made possible by the strong interaction between many molecules and submillimetre waves of appropriate frequency. Fourier transform spectroscopy is well established. Commercial instruments are available[93] and high resolution[94] is obtainable to give precise measurement of the absorption spectrum of gas and other transparent media. A recent extension of the technique is dispersive Fourier transform spectroscopy which also yields the permittivity of the medium as a function of wavelength. Techniques [95, 96, 97] are available for solids, liquids and gases, and both transmission and reflection methods may be used. The attenuation characteristics and relative permittivity of many materials and media of practical importance can be determined.

Other active areas of work include solid state magneto-spectroscopy and cyclotron resonance measurements,[98–101] investigations into antiferromagnetic effects[102, 103] and general interactions with semiconductors.[104, 105] These investigations include a wide range of materials, e.g. Si, Ge, InSb, GaAs, III-V and II-VI compounds. Observations are made of absorption, reflection and transmission spectra, photoconductive effects, impurity and doping effects, free charge carriers, exciton and phonon effects.

A recent technique[106, 107] is that of laser magnetic resonance spectroscopy for the detection of electronic states of very short-lived species.

7.2 Atmospheric Investigations

The National Physical Laboratory has been making an extensive investigation into the composition of the atmosphere,[108, 60] with particular emphasis on the stratosphere and the concentration of trace gases. Fourier transform spectrometers measuring submillimetre gas emission spectra have been used, carried in *Concorde* aircraft or by research balloons to altitudes of 35 km. Measurements have included concentration of water, ozone, oxides of nitrogen and nitric acid, even with concentrations as low as 1 part in 10^{11}.

The strong absorption by water vapour would allow atmospheric humidity to be monitored, either in a limited volume using an open-resonator technique, or over a given path using a line-of-sight absorption technique.

7.3 Far Infra-red Astronomy

Radioastronomy is now being extended into the submillimetre region.[60, 109, 110] The problems of atmospheric attenuation are being overcome by the use of balloons, rockets and aircraft as observing platforms, and high altitude ground based observatories through the atmospheric 'windows'. This spectral region is of interest because of new information which can be obtained on the 3 K background cosmological radiation, galaxy and star formation and on solar and planetary atmospheres. A recent result[110] on the 2·7 K background radiation is shown in Fig. 8. The difficulty in distinguishing the galactic radiation from the spectrometer window emission is clearly evident.

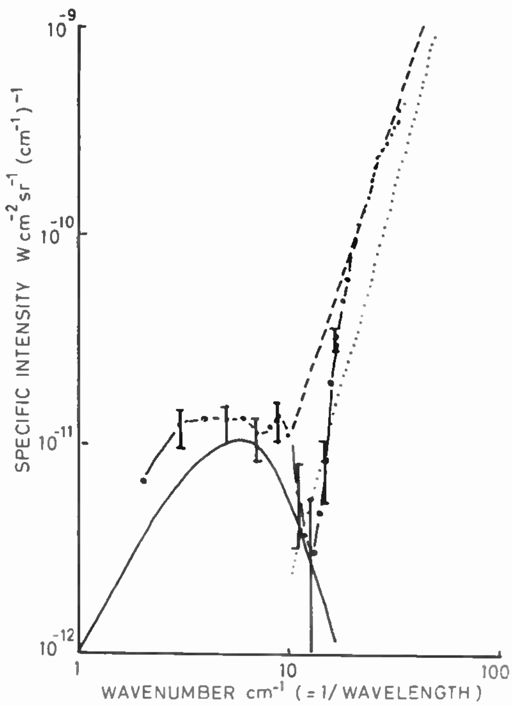

Fig. 8. Cosmic background spectrum at 1 cm^{-1} resolution.[110]
— . — observed spectrum
- - - - predicted window emission
.... window emission from results of Chantry
——— blackbody radiation for 2·7 K minus 1·4 K (interferometer temperature)

The submillimetric observation of extragalactic sources is still in its infancy, but radiating objects at 1 mm, 350 μm and 100 μm wavelength have been identified.

7.4 Plasma Interactions and Diagnostics

High-frequency interferometric techniques may be used to determine plasma parameters such as electron density, collision frequency and electron temperature. The electromagnetic wave frequency should be greater than the plasma oscillation frequency ω_p, given by $\omega_p^2 = e\rho/\varepsilon_0 m$ where ρ is the electronic charge density. Thus for a high density plasma a high diagnostic frequency must be used to give penetration through the plasma, but not too high since the resultant phase shift is then small and the accuracy of measurement becomes low. This is illustrated in Fig. 9. Submillimetre waves are particularly suited for plasma electron densities of 10^{19}–$10^{21} m^{-3}$. Such concentrations exist in thermonuclear discharges, where this wavelength region has found particular application.[111, 112, 113] The phase shift through the plasma yields the electron concentration, the attenuation gives the collision frequency, and the electron temperature is obtainable from the amplitude of the interferometer fringes.

The emission spectrum of radiation from a plasma also yields information[114, 115] on the plasma parameters. For a thermonuclear plasma the radiation loss may be an important element. The presence of a strong magnetic

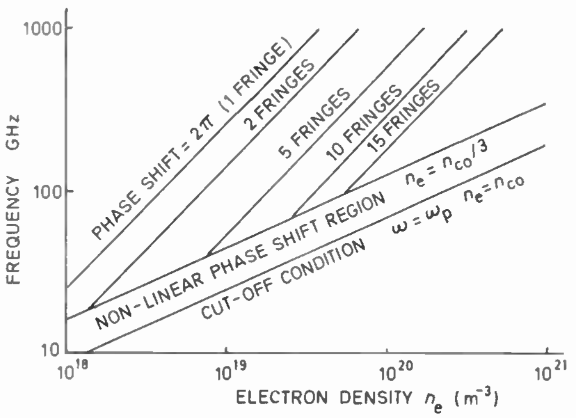

Fig. 9. Relationship between phase change and probe frequency through a plasma.[113]

field for confinement also clearly leads to cyclotron effects. High density, high temperature plasmas are invariably transient phenomena, and fast time resolution techniques are required. Submillimetre wave reflection methods[116] can give information on plasma profile changes and instabilities.

The recent development of more intense pulsed submillimetre sources has led to the possibility of additional techniques, such as Thomson scattering measurement to yield ion temperatures,[117] and measurement of plasma thermal conductivities. Laser induced breakdown at these frequencies may also be investigated.

7.5 Communications

The search for increased bandwidth for communications and high data-rate transmission has led to an increase in operating frequency into the millimetric region through use of the H_{01} low-loss circular guide or by free-space propagation. Further development could be into the short-millimetric and submillimetric regions, or directly to optical wavelengths. One advantage of the former approach is that by using microwave techniques a very large operating bandwidth might be achieved. For this, a suitable guiding system and components would need to be developed, and the H or groove guide system discussed earlier might satisfy this requirement. It is clear from the atmospheric attenuation characteristic that propagation will have to be in a water-free medium, i.e. either in an 'artificial' atmosphere in a closed guide, or in an environment such as that for inter-satellite comminications. For this latter application the narrow beamwidth from an antenna of modest dimensions at submillimetre wavelengths would also be an advantage. Other applications would be for communication through an ionized gas, as for example at re-entry from a space vehicle, or for secure communications between two points with signal level or frequency adjusted to just maintain the link without fear of 'eavesdropping' at greater distances.

7.6 High Resolution Radar, Radar Modelling and Imaging Techniques

There are applications where some picture quality to a radar display would be an advantage. Examples would be blind landing aids for aircraft or anti-collision aids for ships in fog conditions. Such resolution would require wavelengths of about a millimetre or less. A compromise is required to match the increasing resolution and the decreasing penetration through fog as the wavelength is decreased. An optimum condition might be a window in the submillimetre range, although even here attenuation will limit the range to a short distance. The development of imaging devices such as the pyroelectric vidicon discussed earlier would aid the realization of these schemes.

One possible application for short-wavelength radiation is in the scale modelling of electromagnetic problems where large structures are involved. For example, a phase-sensitive radar at 890 GHz (0·34 mm) has been developed by EMI Electronics for use in radar modelling. The amplitude and phase of scattered signals are measured with high precision.

7.7 Metrology

The Teramet[118] is a Michelson interferometer designed by the National Physical Laboratory for sensing the position of a surface or for measuring strip thickness. A schematic diagram is shown in Fig. 10. This instrument which is available commercially uses a broadband submillimetre source and interference techniques to allow remote measurement (22 cm to 1·5 m) of thickness or variations of surface position to be measured to within ± 0·025 mm.

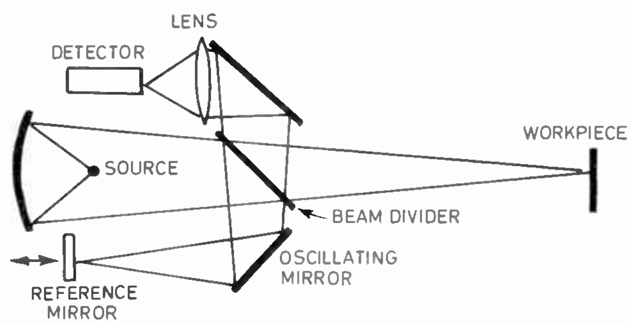

Fig. 10. NPL Teramet surface position indicator.[118]

7.8 Measurement of Frequency and the Velocity of Light

The frequencies of the HCN, H_2O and CO_2 molecular gas lasers and the He-Ne laser have been determined at the National Physical Laboratory[119] and at the National Bureau of Standards (Boulder, Colo.)[120] in order to establish the speed of light. The value of 299 792 458 ± 4 ms^{-1} is one hundred times less uncertain than the previously accepted value.

The frequency measurement technique used at the National Physical Laboratory is indicated in Fig. 11 where a series of oscillators is used to measure directly the CO_2 laser frequency (32·176079482 THz) by mixing and beat frequency techniques. Independent measurement[121] of the CO_2 laser wavelength (9·317246348 μm) relative to the ^{86}Kr primary length standard gives the speed of light. This is in agreement with the National Bureau of Standards value where the He-Ne laser has

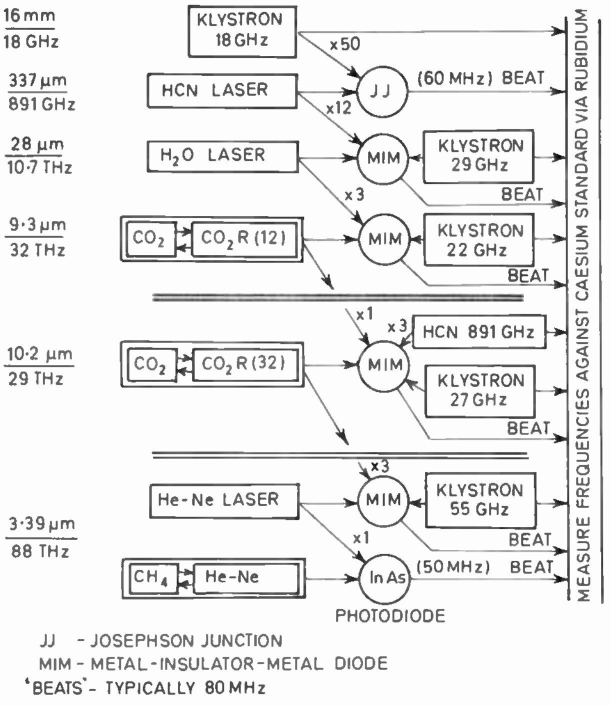

Fig. 11. Laser frequency measurement chain.[119]

been used as another step in the chain. As a result of these measurements the CCDM[122] have recommended the above value for general use.

8 Conclusions

It is clear that, whilst a great deal of work has been carried out, the investigation into the potential of the submillimetre region is still in the exploratory stage. A commercial breakthrough could be triggered either by the development of a relatively cheap and convenient source with a usable power level, or by the appearance of an urgent requirement which could be satisfied by this part of the spectrum because of its particular characteristics. This would then stimulate the development of a suitable source and associated components. Examples might be short-range picture quality radar with fog penetration capability, or communications with a higher data-rate requirement or with a plasma penetration capability. Applications at present are largely limited to specialist requirements such as plasma diagnostics or measurement techniques such as spectroscopy.

Although ideal sources and detectors are not yet available, means of generation and detection do exist to enable work to proceed. Discharge lasers can be readily constructed if the actual frequency is not important, and other more expensive sources such as the b.w.o. and the optically pumped laser are available if necessary. New laser-type sources are being developed which promise tuning and therefore increased flexibility, but it is likely that avalanche diodes or similar devices could be extended further into the submillimetre region if effort was concentrated in that direction. A fast-response high-sensitivity detector is available if liquid helium operation can be tolerated. Otherwise a choice has to be made between sensitivity and speed of response.

By use of existing techniques the properties of many materials and of the atmosphere at submillimetre wavelengths have been determined. Several materials have good transmission or combine interesting properties with reasonable transmission. The atmosphere, however, gives severe attenuation over the submillimetric range and propagation schemes must be short-range unless in a closed dry region, such as a waveguide, or in outer space. Conventional waveguide techniques are not applicable, but alternative guide types such as H-guide and groove guide look encouraging even at such short wavelengths. Further work on guides and components is required, however.

Some areas of application of submillimetre waves have been outlined. There are some aspects in which this part of the spectrum is unique and some applications for which it is optimum. Further development of components and techniques in the next few years will allow more of this potential to be exploited.

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A modular approach to the hardware implementation of digital filters

M. A. BIN NUN, B.Sc., M.Sc.*

and

M. E. WOODWARD, B.Sc., Ph.D.*

SUMMARY

Recent advances in the technology of medium and large scale integrated circuits (m.s.i. and l.s.i.) have made possible economical hardware implementations for real-time digital filtering. A flexible design approach for such implementations is presented. The processing mode can be varied to give any hybrid structure between the purely serial and parallel realizations. This leads to a design approach which can be adjusted to suit hardware availability. The resulting structures are modular and are in line with current trends in m.s.i. and l.s.i. technology in that they lend themselves readily to implementations using semiconductor read-only or random access memories.

*Department of Electronic and Electrical Engineering, University of Technology, Loughborough, Leicestershire LE11 3TU.

1 Introduction

The theory in the analysis and design of digital filters is well established, and their advantages over conventional analogue filters, made up of resistors, capacitors, inductors and crystals, have been widely discussed.[1,2] Until quite recently, the implementation of digital filtering has been confined mainly to simulation on general-purpose computers. The rapid development in the technology of medium and large-scale integrated circuits (m.s.i. and l.s.i.) however, is making possible the construction of special-purpose hardware for real-time digital filtering. Conventional implementations reported in the literature invariably compute the filter algorithm in the familiar binary arithmetic, either in the serial[3] or in the parallel[4] mode. Furthermore, the actual hardware synthesis is usually at the discrete gate level, and the structures proposed are mainly for specific configurations.

In this paper, a modular approach to the hardware implementation of digital filters is proposed. This approach is general, flexible and is at the system and sub-system level, and is thus very suited to m.s.i. and l.s.i. devices. In this approach, a basic second-order digital filter section may be constructed as a regular interconnection of simple identical 'sub-filter modules'. The structure of a typical module and the processing mode of the overall section are flexible and may be adjusted to suit specific requirements. As there is a very wide range of logic families (t.t.l., e.c.l., m.o.s., etc.) and of m.s.i. and l.s.i. devices currently on the market, only a general guide as to the trade-off between circuit complexity and operating speed will be described.

The hardware implementation of the proposed approach using semiconductor memories is also discussed.

2 Digital Filtering

In general, the term 'digital filter' refers to any device which operates on an input number sequence to produce a second sequence of numbers by means of a computational algorithm. If the digital filter is part of a signal processing system, like that shown in Fig. 1, the input number sequence is usually the digital version of an analogue signal. The output sequence may be converted to the analogue form if required.

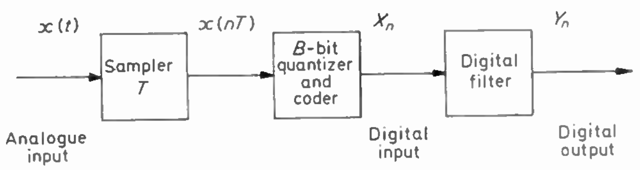

Fig. 1. Block representation of a digital signal processing system.

High-order digital filters are normally realized as either a cascade or a parallel network of basic second-order sections,[1,2] which, in the former case, are ordered for minimum round-off noise and have outputs suitably scaled.[5,6]

A typical second-order section is shown in Fig. 2. The input and output sequences, (X_n) and (Y_n) respectively, are related by the following difference equation:

$$Y_n = \sum_{i=0}^{2} A_i X_{n-i} - \sum_{i=1}^{2} B_i Y_{n-i} \qquad (1)$$

where A_i and B_i are the filter coefficients obtainable from its transfer function.

The filter network in Fig. 2 consists of a non-recursive and a recursive part. Both are essentially the same in both structure and operation in that each may be represented by an expression of the form

$$V_n = \sum_{i=0}^{2} C_i U_{n-i} \qquad (2)$$

where, for the recursive part, $C_0 = B_0 = 0$.

In the subsequent discussion of the proposed design approach, it is therefore only necessary to consider the more general non-recursive part, which has the input-output relationship

$$Z_n = \sum_{i=0}^{2} A_i X_{n-i} \qquad (3)$$

3 Design Approach

The proposed design approach is based on computing the filtering algorithm given by equation (3), not only in the conventional binary system, but in the general radix R arithmetic, where R is an integer power of 2, i.e.

$$R = 2^p, \quad p = 1, 2, 3, \ldots \text{ etc} \qquad (4)$$

It is assumed that fixed-point arithmetic is used, and that, in order to process equation (3) to a specified accuracy, B' and B'' binary digits (bits) are required to represent each of the data and coefficient words respectively. Also, to simplify the discussion on the design approach, the data and coefficient words are assumed to be non-negative integers, i.e.

$$0 \leqslant X_{n-i} \leqslant 2^{B'}-1$$

and

$$0 \leqslant A_i \leqslant 2^{B''}-1$$

In practice, the data and coefficients are represented as binary fractions and the two's complement[5, 6, 8] notation is most commonly used to handle negative numbers.

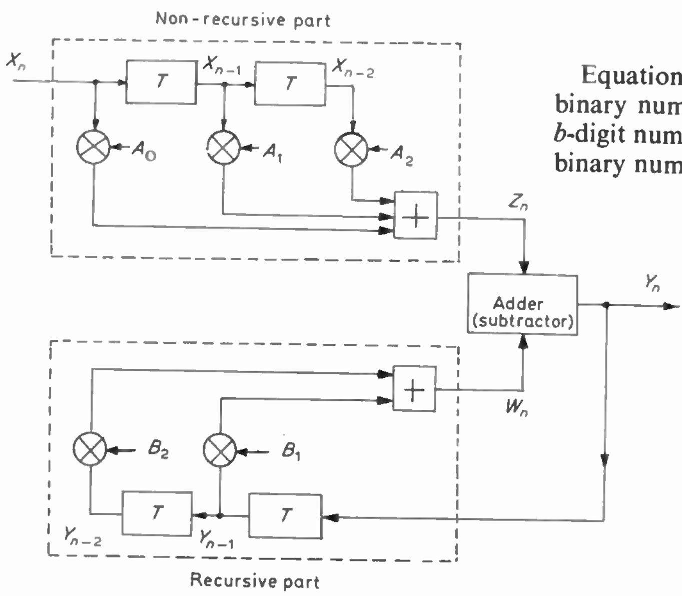

Fig. 2. Second-order digital filter section with sample period T.

Since any B-bit binary number M can be represented in the form

$$M = \sum_{r=0}^{B-1} m_r 2^r, \quad m_r = 0 \text{ or } 1 \qquad (5)$$

the binary forms of the data and coefficients will be

$$X_{n-i} = \sum_{k=0}^{B'-1} x_{n-i,k} 2^k \qquad (6)$$

and

$$A_i = \sum_{j=0}^{B''-1} a_{i,j} 2^j \qquad (7)$$

where

$$i = 0, 1, 2, \quad x_{n-i,k}, a_{i,j} = 0 \text{ or } 1$$

Conventionally, equations (6) and (7) are substituted directly into equation (3) for the subsequent computation of the filter output Z_n. A comprehensive discussion on the possible hardware organizations and processing modes for implementations based on binary arithmetic is given by Freeny in his tutorial paper.[7]

In the proposed modular approach, a B-bit binary number M is first partitioned into b blocks, each of p bits, where

$$B = b \times p, \quad b \text{ and } p \text{ being integers} \qquad (8)$$

($p = 3$, and $p = 4$ result in the familiar octal and hexadecimal systems respectively).

Thus equation (5) may now be represented as

$$\begin{aligned} M = {} & (m_{B-1} 2^{p-1} + \ldots + m_{B-p+1} 2^1 + m_{B-p} 2^0)(2^p)^{b-1} \\ & + \ldots + (m_{p(k+1)-1} 2^{p-1} + \ldots + m_{pk+1} 2^1 \\ & + m_{pk} 2^0)(2^p)^k + \ldots + (m_{p-1} 2^{p-1} \\ & + \ldots + m_1 2^1 + m_0 2^0)(2^p)^0 \end{aligned}$$

or

$$M = \sum_{k=0}^{b-1} M_k (2^p)^k \qquad (9)$$

where

$$M_k = \sum_{h=0}^{p-1} m_{pk+h} 2^h \qquad (10)$$

and

$$0 \leqslant M_k \leqslant 2^p - 1$$

Equations (9) and (10) simply mean that the B-bit binary number in equation (4) is now represented as a b-digit number in the radix 2^p, where each digit is a p-bit binary number.

3.1 Example

Let M be the 6-bit ($B = 6$) binary number, 1 0 1 1 0 1. Expressing this in terms of equation (5), then,

$$M = 1\times 2^5 + 0\times 2^4 + 1\times 2^3 + 1\times 2^2 + 0\times 2^1 + 1\times 2^0.$$

If M is partitioned into three blocks, each of two bits ($b = 3$, $p = 2$), then M can be expressed as

$$M = (1\times 2^5 + 0\times 2^4) + (1\times 2^3 + 1\times 2^2) + (0\times 2^1 + 1\times 2^0)$$

or, in terms of equation (9)

$$M = (1\times 2^1 + 0\times 2^0)(2^2)^2 + (1\times 2^1 + 1\times 2^0)(2^2)^1 + (0\times 2^1 + 1\times 2^0)(2^2)^0$$

Thus, M is now represented as a 3-digit number in the radix 2^2, where the digits, M_k of equation (9), are 2-bit binary words, and, using equation (10) are given by

$$M_0 = 01, \quad M_1 = 11 \quad \text{and} \quad M_2 = 10$$

3.2 Computing in the Radix 2^p

In general, each data word may be partitioned into b' blocks each of p' bits, and each coefficient word into b'' blocks of p'' bits.

Using equation (9), equation (3) can be rewritten, in which Z_n, the output of the non-recursive filter section, is expressed as a triple sum,

$$Z_n = \sum_{i=0}^{2}\left[\sum_{k''=0}^{b''-1} A_{i,k''}(2^{p''})^{k''}\right]\left[\sum_{k'=0}^{b'-1} X_{n-i,k'}(2^{p'})^{k'}\right] \quad (11)$$

where

$$A_{i,k''} = \sum_{h''=0}^{p''-1} a_{i,p''k''+h''}\,2^{h''} \quad (12)$$

and

$$X_{n-i,k'} = \sum_{h'=0}^{p'-1} x_{n-i,p'k'+h'}\,2^{h'} \quad (13)$$

for $i = 0, 1, 2$, and

$$(b'')(p'') = B'', \quad (b')(p') = B'$$

The order of summation in equation (11) is then changed, resulting in

$$Z_n = \sum_{k'=0}^{b'-1}(2^{p'})^{k'}\sum_{k''=0}^{b''-1}(2^{p''})^{k''}\sum_{i=0}^{2}(A_{i,k''})(X_{n-i,k'}) \quad (14)$$

Equation (14) forms the basis of the proposed modular approach to the hardware implementation of digital filters.

3.2.1. *Example*

Consider a second-order non-recursive filter having the coefficients

$$A_0 = 6_{10}, \quad A_1 = 13_{10} \quad \text{and} \quad A_2 = 9_{10}$$

Also, suppose that at a particular sampling instant the data consists of

$$X_n = 12_{10}, \quad X_{n-1} = 5_{10} \quad \text{and} \quad X_{n-2} = 7_{10}$$

If both data and coefficients are represented by 4-bit binary numbers, ($B' = B'' = 4$), then

$$A_0 = 0\,1\,1\,0, \quad A_1 = 1\,1\,0\,1, \quad A_2 = 1\,0\,0\,1$$

and

$$X_n = 1\,1\,0\,0, \quad X_{n-1} = 0\,1\,0\,1 \quad \text{and} \quad X_{n-2} = 0\,1\,1\,1$$

Each of these words is now split into two blocks ($b' = b''$ = 2), each of two bits ($p' = p'' = 2$), say. The filter output Z_n at this particular sample instant may then be computed by the substitution of the actual values of the data and coefficients, now represented in the radix 2^2, into equation (3). This computation is illustrated by Table 1.

Table 1

	$R^3\ R^2\ R^1\ R^0$	$R^3\ R^2\ R^1\ R^0$	$R^3\ R^2\ R^1\ R^0$	Sum of partial products in like rows
Coefficient	A_0 01 10	A_1 11 01	A_2 10 01	
	×	×	×	
Data	X_n 11 00	X_{n-1} 01 01	X_{n-2} 01 11	
	00 00	00 01	00 11	01 00
	00 00	00 11	01 10	10 01
	01 10	00 01	00 01	10 00
	00 11	00 11	00 10	10 00

Each 4-bit partial product is the result of a 2-bit by 2-bit parallel multiplication, i.e. the data and coefficient blocks are multiplied in radix $R = 2^2$ arithmetic. The partial products in like rows are now added. This corresponds to the first summation of equation (14). The remaining stages of summation, as specified by equation (14) for the computation of the section output Z_n, are shown in Table 2.

Table 2

Second, final summation according to equation (14) $R^3\ R^2\ R^1\ R^0$	$R^3\ R^2\ R^1\ R^0$	Filter output Z_n $R^3\ R^2\ R^1\ R^0$
01 00 + 10 01	10 10 00	
	+	11 00 10 00
10 00 + 10 00	10 10 00	

As a result, the original filter, whose data and coefficients are represented by 4-bit binary words, is now regarded as being made up of four simpler units whose data and coefficients consist of only 2-bit binary words.

4 Possible Realizations

Two possible realizations for the computation of equation (14) are shown in Figs. 3 and 4. They differ both in hardware complexity and operating speed.

4.1 Parallel Processing

In the direct realization illustrated in Fig. 3, the second-order non-recursive section consists of a parallel interconnection of, what will be termed, sub-filter modules.

These modules, enclosed by the broken lines in Fig. 3, are organized into b' groups each group containing b'' modules, where b' and b'' are the number of partition blocks as described by equation (11). For the overall section, $b' \times b''$ modules would be required in all.

A typical module has the same general structure and computing algorithm as that of the overall section. Each of the data and coefficients of a module, however, are now only p' bit and p'' bit words respectively.

In operation, these sub-filter modules implement the first summation in equation (14). The output of each group is obtained by adding the weighted outputs of all the modules in that particular group. Similarly, the section output Z_n is obtained by summing the weighted outputs of all the groups, as specified by the outer summation of equation (14).

In this direct realization, the output weightings are done by hard-wired shifts.

4.2 Sequential Processing

In contrast to the realization shown in Fig. 3, where $b' \times b''$ modules operate concurrently, a single module, performing $b' \times b''$ module computations in time succession, may be used.

This sequential mode of processing is illustrated in Fig. 4, in which a basic sub-filter module is time-shared among the data and coefficient blocks. The accumulator keeps a running sum of successive module outputs and also incorporates the required weightings to them.

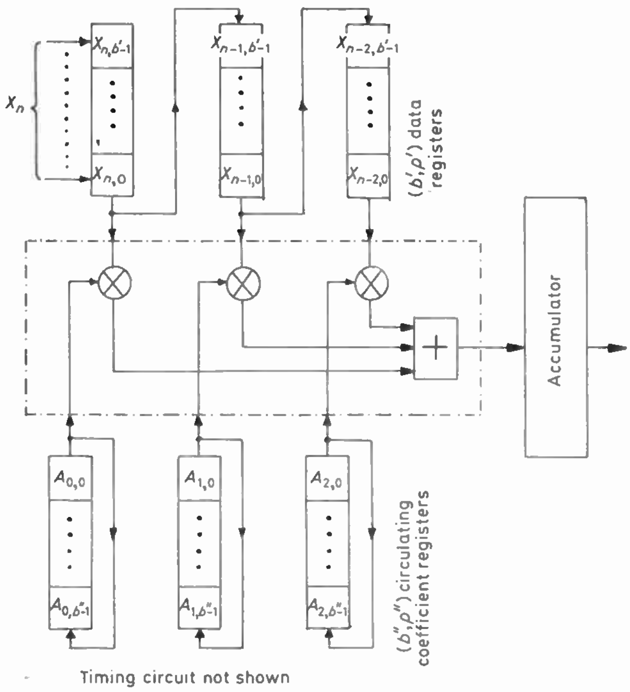

Fig. 4. Time-sharing of a single sub-filter module.

The blocks of each of the data words are accommodated in a (b', p') register store while those of each of the coefficients are stored in a (b'', p'') circulating register store, where a typical (b, p) register is one having b stages, each stage accommodating a p-bit word, as shown in Fig. 5(a).

For every clock shift of the data registers these circulating coefficient stores go through a complete cycle of b'' shifts. Since the data registers have to be clocked b' times, the required section output, Z_n, will be obtained in $b' \times b''$ register clock periods after the arrival of the section input, X_n, at a particular sampling instant.

The data and coefficient blocks are so arranged as to be in increasing order of significance at the start of every sampling instant.

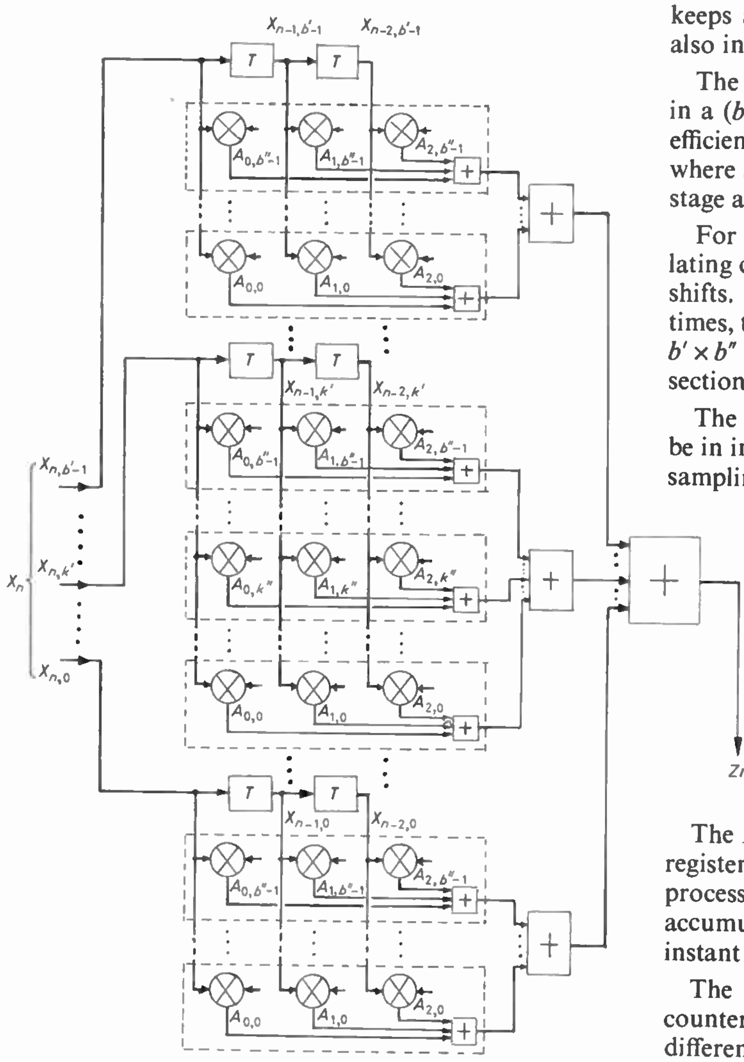

Fig. 3. Modular circuit configuration of a non-recursive digital filter section.

The B'-bit input, X_n, is loaded in parallel into an input register of the form shown in Fig. 5(b). In the subsequent processing, the blocks of X_n are accessed sequentially, the accumulator being reset to zero prior to every sampling instant nT.

The control of the overall section can consist of a counter and simple logic circuitry to account for the different clock rates of the data and coefficient registers.

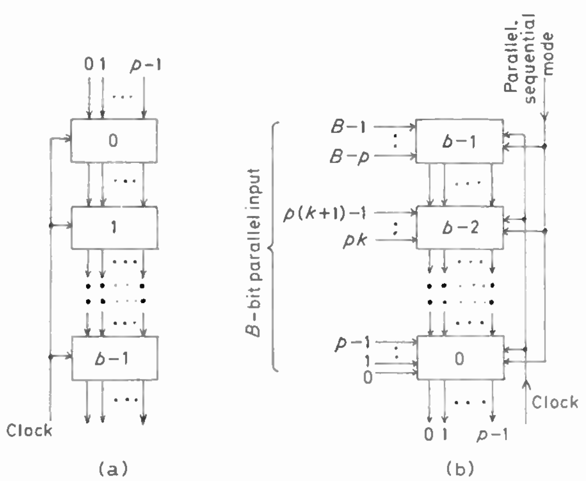

Fig. 5. Store and input registers.

4.3 Features

In the direct realization, as shown in Fig. 3, the circuit configuration of the overall filter section is highly modular. All the component units have an identical structure, and the interconnection between them is very regular. In consequence, the hardware implementation of the section is systematic and straightforward. Furthermore, testing and fault diagnosis are greatly simplified.

Since a typical module has the same computing algorithm as that of the original section, the 'feel' for the overall filtering operation is retained when interconnecting modules. Also, the hardware requirement of a module is determined only by the manner in which the original data and coefficient words have been partitioned. The structure is therefore easily adjusted to suit particular requirements and available hardware components. To illustrate this, consider a non-recursive section, whose data and coefficients are represented by 6-bit and 4-bit binary words respectively. Then Table 3 shows the possible ways in which these words may be partitioned into blocks, according to equation (8).

Table 3

	Data				Coefficient		
Number of blocks	6	3	2	1	4	2	1
Number of bits/block	1	2	3	6	1	2	4

The structure of the basic module depends very much on the size of its component multipliers. For this particular filter section there are, altogether, $4 \times 3 = 12$ different multiplier sizes, which range from a 1-bit × 1-bit to a 6-bit × 4-bit configuration, with one convenient size being the 2-bit × 2-bit one. An interesting size is the 1-bit (data) × 4-bit, as it is of the type used in the familiar shift-and-add technique for multiplication.[3, 7, 8, 9]

A final feature of the proposed approach is that, after the structure of the basic module has been decided upon, the actual mode of processing the filter algorithm is flexible. The parallel and sequential realizations, discussed previously and shown in Figs. 3 and 4, are just two extremes, hybrid forms being possible. For example, one hybrid realization might consist of a set of basic modules, operating concurrently, this being regarded as a basic time-shared unit for subsequent sequential processing. Another hybrid form might be one in which sets of data blocks are processed in parallel by a number of time-shared basic modules each operating sequentially.

In general, in between the parallel and the completely sequential realizations there is a spectrum of hardware structures and processing modes, the final choice being left to the system designer.

4.3.1. *Example*

Consider a non-recursive section having 8-bit data and coefficient words, (i.e. $B' = B'' = 8$). If each of these words are partitioned into four blocks, each of two bits ($b' = b'' = 4$, $p' = p'' = 2$), the resulting basic module has a word length of 2 bits. The direct realization of this section, as in Fig. 3, would require $b' \times b'' = 16$ of these basic modules. The completely sequential mode is shown in Fig. 6(a), while Figs. 6(b) and (c) illustrate two possible hybrid realizations. In the former, two basic modules make up the time-shared unit, while in the latter the input X_n is split into two parallel halves, each of which are then processed sequentially. It is seen that when both examples of hybrid processing are compared with the completely sequential one, two basic modules are required. Their computing time, however, is reduced by half. The parallel mode, of course, has an even shorter computing time which, in this example, is sixteen times as fast as that of the completely sequential mode.

5 Practical Considerations

The performance of the overall filter section depends primarily on the structure of the basic module and the manner in which the computing algorithm is processed. The hardware requirement and implementation of a typical sub-filter module are described below, and the computation time for the section output is derived for the two extreme modes of processing. The trade-off between circuit complexity and operating speed is also discussed.

5.1 Hardware Implementation of Sub-Filter Module

The hardware organization of a typical module is shown in Fig. 7. The required arithmetic operations are three p' bit × p'' bit multiplications and two $(p'+p'')$ bit additions. These operations may be implemented by any suitable m.s.i. multiplier and adder chips currently on the market. An attractive alternative, however, is to implement the module using semiconductor memories, (either read-only (r.o.m.) or random access (r.a.m.)), acting as stored look-up arithmetic tables.[12]

One way of using these memory chips is to replace each p' bit × p'' bit multiplier, shown in Fig. 7, by a r.o.m. or r.a.m. of suitable storage. Variable and fixed coefficient multiplications using r.o.m.s are illustrated in Fig. 8(a) and (b). The former offers versatile operation at the expense of large memory storage when the word lengths of the data and coefficient blocks are large. The fixed coefficient multiplication requires less memory storage but is less versatile.

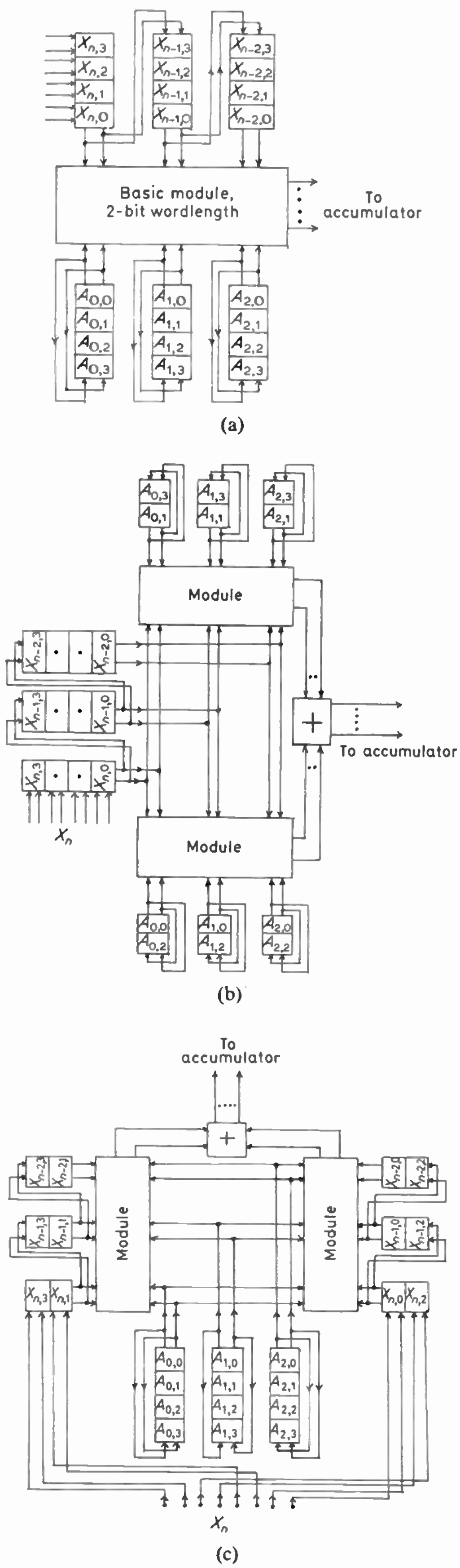

Fig. 6. Processing modes using 2-bit basic modules.
(a) Completely sequential
(b), (c) Two possible hybrid forms

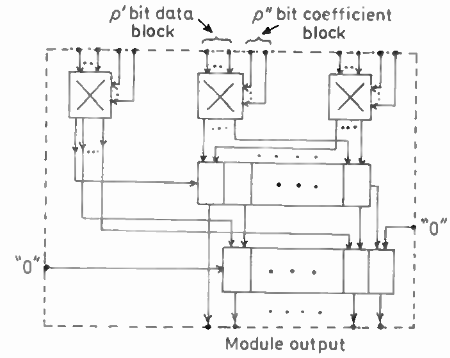

Fig. 7. Hardware configuration of a sub-filter module.

The configuration in Fig. 8(c), however, combines partially-variable coefficient capability with reasonable memory storage requirements. A total of 2^q different coefficients can be stored in the r.o.m.

For data and coefficient blocks of short lengths, i.e. p' and p'' small, even the complete sub-filter modules may be implemented as a look-up store using a r.o.m. of sufficiently large memory storage, as shown in Fig. 9. There is thus no necessity for the two P-bit ($P = p'+p''$) adders previously required.

In general, the implementation of digital filters using l.s.i. semiconductor memories is simple, straightforward and incorporates programmability. It also offers the possibility of volume production of digital filter i.c. chips using existing manufacturing facilities. As digital filters are still not being used extensively enough, there is obviously a reluctance to custom-design and manufacture special i.c.s apart from very simple filter configurations.[10] The market demand for semiconductor memories, however, is great enough to support its own technology.

5.2 Operating Speed of Filter Section

The minimum value of the sampling period T for the basic nonrecursive section depends on the time it takes to compute the output Z_n after the arrival of a particular input X_n.

If t_M is the time to compute the output of a typical sub-filter module, then

$$t_M = t_a + t_s \tag{15}$$

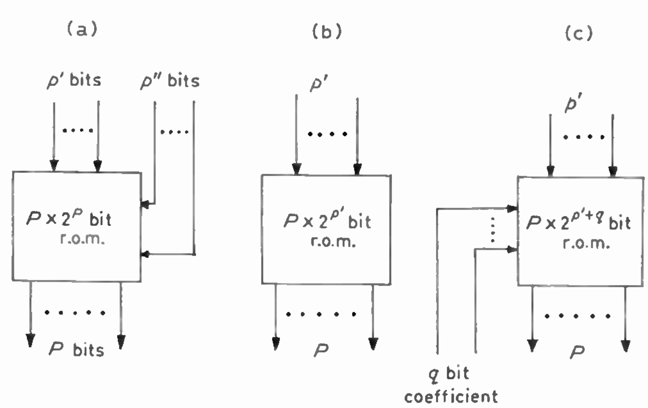

Fig. 8. R.o.m. realizations of p' bit $\times$ p'' bit multipliers.

where t_a = time to perform a p' bit $\times p''$ bit multiplication, and

t_s = time to sum three $(p'+p'')$ bit words.

For the realizations shown in Figs. 8(a) to (c), t_a will be the access time of any particular r.o.m. used. Similarly, for the realization shown in Fig. 9, t_M corresponds to the access time of the r.o.m. implementing the complete sub-filter module.

For the direct realization shown in Fig. 3, the total time, T_p, required to compute Z_n is given by

$$T_p = t_M + t_g + t_y \qquad (16)$$

where t_g = time to sum the outputs of all the modules in any particular group

and t_y = time to sum the outputs of all the groups.

Details on the propagation delay during the process of addition can be found in any standard text on digital arithmetic (e.g. Ref. 8).

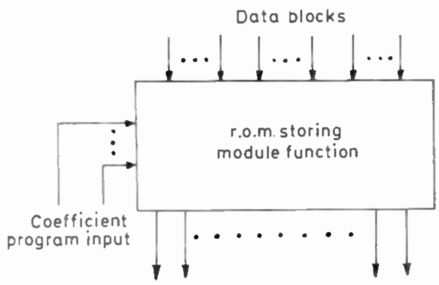

Fig. 9. R.o.m. realization of a sub-filter module.

If equation (14) is processed sequentially (see Section 4.2, Fig. 4), the computing time, T_q, is given by

$$T_q = (t_M + t_r) \times (b') \times (b'') \qquad (17)$$

where t_r = time to add the module output at time $k\Delta_t$ to the accumulator output Δ_t previously, Δ_t being the period of the register clock (see Fig. 4).

In equation (17), it is assumed that the time taken to clock the accumulator output is much less than the computation time for the module output.

If f_p, f_q are the maximum possible sampling frequencies for the section in the parallel and sequential realizations respectively, then

$$f_p \leqslant \frac{1}{T_p} \quad \text{and} \quad f_q \leqslant \frac{1}{T_q}$$

The computation time for hybrid realizations may be determined using the general principles discussed.

5.3 Trade-off Between Circuit Complexity and Operating Speed

The relative advantages of the various processing modes depend on their respective circuit complexity, module count and operating speeds. The parallel mode has the fastest processing speed and requires virtually no control circuitry. The number of sub-filter modules needed, however, is a maximum (being $b' \times b''$ modules in total). At the other extreme, the sequential mode requires only one module and an accumulator, but operates $b' \times b''$ times slower than the parallel realization. Also, some control logic is necessary for the proper accumulation and weighting of the module output. The hybrid mode offers a compromise by enabling the designer to select the most suitable combination of module count and processing speed to match his specific requirement.

6 General Second-order Section

As the recursive and non-recursive parts of the general second-order digital filter section (Fig. 2) have basically the same structure, the modular approach already discussed can be directly applied to realize this general section.

The resulting basic module then consists of two modules, each similar to that shown in Fig. 7. The block diagram of the direct modular realization of the general second-order section is shown in Fig. 10.

Since Y_n, the section output, is now in a feedback loop, it has to be truncated or rounded off to prevent the number of bits required for its representation from increasing indefinitely. Also Y_n has to be scaled, usually by simple powers of two.[4, 11] Other general practical considerations such as overflow detection, limit cycle oscillations, and manipulation of negative numbers using the two's complement code, have been adequately discussed by previous authors.[5, 6, 7]

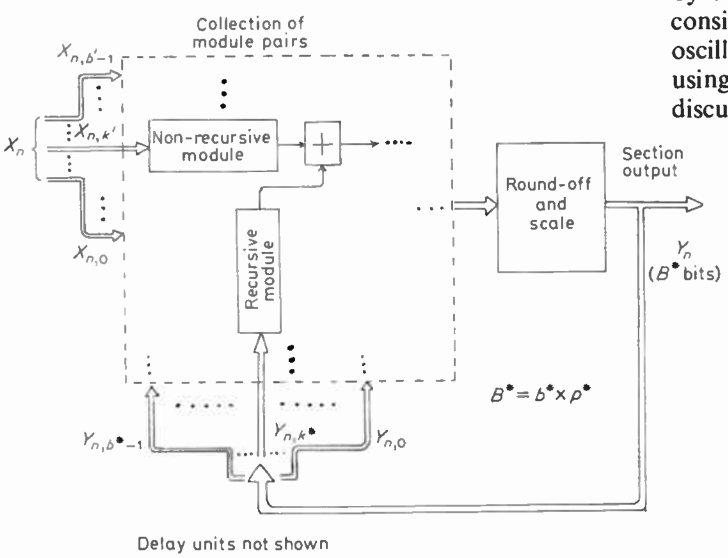

Fig. 10. Modular organization of a general second-order filter section.

7 Conclusions

A method has been presented for the hardware design of general second-order digital filter sections. The procedure is systematic, flexible, and is in accordance with current hardware trends in that it makes use of m.s.i. or l.s.i. technology. The resulting hardware structures are modular, have uniform interconnection patterns, and variable processing modes.

The versatility and flexibility of the proposed technique should make possible the economical design of special-purpose digital filter hardware for any applications requiring real-time processing.

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Optimum detection and signal design for v.l.f. channels

S. B. PATEL, B.Sc.*

and

R. L. BREWSTER, M.Sc., Ph.D., C.Eng., M.I.E.E.*

SUMMARY

A new generalized model for atmospheric radio noise is briefly described and justified by comparison with observed probability distributions. A special case of this generalized model is then compared to the observed noise statistics at the very low frequency end of the spectrum. This model is then applied to the detection of known signals in in the presence of noise to determine the optimal receiver structure. The performance of the detector, specified by the upper bound on the probability of error, is assessed and is seen to depend on the signal shape, the time-bandwidth product, and signal-to-noise ratio. The optimal signal to minimize the probability of error is then determined.

* Department of Electrical Engineering, University of Aston in Birmingham, 19 Coleshill Street, Birmingham B4 7PB.

Nomenclature

A	signal amplitude
$A(t)$	scaling process
B	system bandwidth
$B(\alpha, \beta \vert Z)$	incomplete beta functions
E	signal energy
$E(t)$	envelope of process $X(t)$
$G^1(t)$	generalized Gaussian random process
$G(t)$	envelope of process $G^1(t)$
m_i	message set ($i = 0, 1$)
$\hat{m}$	estimate of the transmitted message
M	number of independent samples
$p_X(\xi)$	probability density function of process $X(t)$
$p_{X,Y}(x, y)$	joint probability density function of X and Y
$p_y(y/x)$	conditional probability density of y given x
P	signal power
$P_X(x)$	cumulative distribution of $x = \int_{-\infty}^{x} p_X(\xi)\,d\xi$
$P_0(e)$	$1-P_E(e)$ probability of exceeding level e
$Q(t)$	scaling process
$S_j(t)$	signal sets ($j = 0, 1$)
$\mathbf{S}$	signal vector
$\hat{S}(t)$	lowpass signal
$\hat{S}_{op}(t)$	optimal signal
t	time variable
T	signal duration
$\omega_0 = 2\pi f_0$	carrier frequency
$X(t)$	interference process in the receiver
$\mathbf{X}$	noise vector
$X^1(t)$	in-phase component of $X(t)$
$\hat{X}(t)$	quadrature component of $X(t)$
α	common parameter of random processes $G^1(t)$ and $Q(t)$
β, γ	parameters of scaling process $Q(t)$
σ, σ^1	parameters of generalized Gaussian random process
ϕ	phase
$\Gamma(\beta)$	gamma function of β
$\langle\ \rangle$	statistical average
i.n.	impulsive noise
P_e	probability of error
p.d.f.	probability density function

1 Introduction

The increasing demand for very reliable long-range communication and navigation systems and the realization of the capabilities of very low frequency (v.l.f.) radio in meeting these demands have done much to arouse a keen interest in this area of the radio frequency spectrum.[1] The performance of a digital data modem in a v.l.f. link is strongly influenced by the impulsive nature of noise.[1-5]

There has been a considerable amount of research to devise methods for improving the design and performance of receiving systems in order to minimize the undesired effect of impulsive noise (i.n.).[2–23] This problem of digital signalling in the presence of i.n. is made especially difficult due to the lack of a mathematically tractable i.n. model whose consistency with measured noise data can be verified. Generally, the proposed improvement attempts to counteract either the large amplitude or aperiodic nature of the i.n. and will be classified as either an amplitude or a time-based modification to existing receivers.

The amplitude-based modifications act to suppress the large amplitude excursions of the i.n. by including a non-linear device in the receiver. Synder[5] and Rappaport and Kurz[6] have used likelihood ratio to investigate optimum receivers for specific i.n. models. Each design resulted in the use of a non-linear device to suppress large amplitude excursions in conjunction with a linear receiver. The specification of the non-linear device depends on the noise statistics and must be changed if the noise description changes. Sub-optimum receiver designs using non-linear devices have been proposed with either intuitive or empirical justification. Specifically, several authors[4,7,8,9,23] have proposed clipping devices which limit the maximum magnitude of the received signal. It has been postulated that the reduction in noise power achieved through the use of clipping devices yields improved error performance; however, there is no such guarantee because of the possibility of improving the signal-to-noise crosscorrelation. Bello and Esposto[7] have reported the performance improvement obtained using a clipping device with p.s.k. signalling and an atmospheric noise model. They assumed that the amplitude of the noise was much greater than that of the data signal.

The time-based modifications exploit the aperiodic and frequency spectrum properties of the i.n. Examples of this technique are smearing-desmearing[18] and swept-frequency modulation.[19,20]

These systems use a special modulator or filter to destroy the phase relationship of the components in the transmitted signal. At the receiver the inverse of this operation is performed which yields the original phase relationship for the data signal, but destroys the relationship of the channel noise components. These techniques have not been employed extensively because of their poor performance.[21] One possible explanation for the poor performance is that the true characteristics of i.n. are not well represented by a model whose amplitude peaks are caused by a phase relationship of noise components.

The plan of the paper is basically very simple. In Section 2, we present the generalized noise model. This is a plausible empirical model, which is used to replace the exact but often complex probability distributions. This model is then justified by comparison with observed probability distributions. A special case of this generalized model is then compared with the observed noise statistics at the very low frequency end of the spectrum. In Section 3, this noise model is applied to the detection of known signals in the presence of noise to determine the optimal receiver structure and its performance. We can observe, from the upper bound on the probability of error, that the receiver performance depends upon the signal-to-noise ratio, the time-bandwidth product, and the particular signal used. Consequently, a solution for an optimal signal to achieve the minimum probability of error is derived in Section 4, this resulting from the solution of the non-linear differential equation.

2 V.L.F. Atmospheric Radio Noise Model

Major sources of interference to the reception of v.l.f. signals are atmospheric noise, power line radiation, receiver noise, antenna noise, and potentially deliberate jamming. Under most operating conditions, atmospheric noise is the limiting factor to receiver performance. The dominant source of atmospheric noise in the v.l.f. band is attributed to radiation induced by lightning.[24–33] Due to the low attenuation rate[1] which makes long-range communication possible in this band, noise characteristics are affected not only by local thunder storms but also by storms thousands of miles away. The effect of local thunderstorms is to produce large spikes while the effect of distant storms is a background noise with occasional spikes.[11–25]

In view of the greater influx of large amplitude pulses, Omura and others[4,7] formulated log-normal models of noise. One of the models includes Rayleigh distributed atmospheric radio noise at low levels and log-normal distribution at high levels. Beckmann[30] has given a physical argument which supports this empirical noise model, particularly in the situation where there is little thunderstorm activity. It is noted that several workers have proposed models similar to that considered by Beckmann, although they differ in regard to how the two distributions should be combined to give the best resultant model. Another category is comprised of the filtered-impulse models of i.n. These models are based on the fact that the i.n. at the output of any one channel/filter is the response of the latter to noise, such noise models including the additional assumption that either the number of pulses consisting of a time sequence of amplitude distributed impulses occurring at the receiver is known or that the noise pulses occur in Poisson fashion.[30,31] The Poisson model for occurence of noise pulses fails to show the observed statistical dependence between adjacent i.n. pulses.[24] A Poisson-Poisson model of i.n. was formulated by Furutsu and Ishida[32] to represent observed clustering of noise pulses. Source distributions, propagation conditions and a multiple stroking mechanism have been used by Giordano and Haber[29] to derive Poisson related noise models.

Although a physical description of the noise process forms the basis of the filtered impulse model, the various forms of its probability distribution are too complex to be handled analytically in statistical communication theory to predict system performance. Recently, Hall[12] postulated a descriptive mathematical model for atmospheric noise as a narrow band Gaussian process which is modulated by a slowly varying stochastic process. This postulation leads to the so called t noise model for which the probability density function (p.d.f.) of the atmospheric noise is a modified students' t distribution. This model explains some of the observed properties of the noise. A model of similar form has also been found by Giordano and Haber[29] from different considerations.

2.1 Noise Model

In view of the shortcomings of the models mentioned above a new model has been derived taking into consideration the known properties of the burst form of atmospheric radio noise. This model is then compared with the available data for verification.

In order to incorporate the impulse nature of the noise with a large dynamic range in the model it is proposed to predict the clustering of atmospheric pulses by

$$X(t) = A(t)G^1(t) = G^1(t)/Q(t) \qquad (1)$$

where $A(t)$ is a comparatively broad-band random process, slowly varying *vis-à-vis* $G^1(t)$, and which effectively sets the unit, or scale of $G^1(t)$.

The statistical properties of $A(t)$ are to be determined empirically. To begin with, this is done by choosing $p_A(a)$, the first-order p.d.f. of $A(t)$, so that it gives the first order p.d.f. of $X(t)$ for large amplitudes, as is observed empirically. $G^1(t)$ is a zero-mean generalized Gaussian process,[34] independent of $A(t)$, with p.d.f.

$$p_{G^1}(g) = \frac{\alpha}{2\sqrt{2}\Gamma(1/\alpha)\sigma^1} \exp\left[-\left(\frac{g}{\sqrt{2}\sigma^1}\right)^{\alpha}\right] \qquad (2)$$

where

$$\sigma^1 \triangleq \frac{\sigma}{\sqrt{2}}\sqrt{\frac{\Gamma(1/\alpha)}{\Gamma(3/\alpha)}},$$

σ, α are distribution constants and $\Gamma(x)$ is a gamma function of x. For $\alpha = 2$ this density reduces to the Gaussian density, whereas for $\alpha = 1$ it becomes the Laplace density. Furthermore, according to Algazi and Lerner,[35] densities representative of certain atmospheric i.n. can be obtained by picking $0{\cdot}1 < \alpha < 0{\cdot}6$.

For large amplitudes of $X(t)$ it is known empirically that $p_X(x)$ falls off much more slowly than it would if $X(t)$ were Gaussian only. This is because of the more or less discrete large impulsive transients that greatly exceed the background noise and tend to take on the amplitude distributions of the transients themselves. To generate a class of first-order p.d.f. in $A(t)$ that yields the proper behaviour at large amplitudes in $X(t)$, we follow the procedure suggested by Hall[12] for his t model. Accordingly, we consider the reciprocal non-Gaussian random process

$$Q(t) = |A(t)|^{-1}. \qquad (3)$$

The first-order p.d.f. of $Q(t)$ is assumed to be

$$p_Q(q) = \frac{\alpha}{2\Gamma(\beta)\gamma^{\beta}} |q|^{\alpha\beta-1} \exp\left[-\frac{|q|^{\alpha}}{\gamma}\right], \quad -\infty < q < \infty \quad (4)$$

with parameters α, β, γ. For $\alpha = 2$; $p_Q(q)$ is a chi distribution with 2β degrees of freedom. Using (4) in (3) one can readily show that the p.d.f. of $A(t)$ is

$$p_A(a) = \frac{\alpha}{2\Gamma(\beta)\gamma^{\beta}} |a|^{1-\alpha\beta} \exp\left[-\frac{1}{\gamma}\frac{1}{|a|^{\alpha}}\right], \; -\infty < a < \infty \quad (5)$$

For large values of a, the distribution behaves as

$$\lim_{a\to\infty} p_A(a) = \lim_{a\to\infty} |a|^{1-\alpha\beta} \quad \text{for } \gamma > 0,$$

which is the desired form of large amplitude dependence for $X(t)$, since $|a| \to \infty$ implies $x \to \infty$. It is seen that the hyperbolic distribution specified by the above equation is asymptotically identical in form to perhaps the simplest of the empirical models[21, 28] proposed from observation of measured data on the envelope of received atmospheric noise.[28] Thus is is concluded that the above equation gives a reasonable specification of the asymptotic behaviour of the first-order statistics of $A(t)$.

To obtain the p.d.f. for $X(t) = A(t).G^1(t)$ we make use of[36]

$$p_X(x) = \int_{-\infty}^{\infty} \xi p_Q(\xi) p_{G^1}(x\xi)\,d\xi, \qquad -\infty < x < \infty \quad (6)$$

Substituting values of $p_Q(\xi)$ and $p_{G^1}(x\xi)$ from (4) and (2) respectively in the above equation and making a change in variable $\zeta = \xi^{\alpha}$ yields

$$p_X(x) = \frac{\alpha}{2\sqrt{2}\Gamma(\beta)\Gamma(1/\alpha)\gamma^{\beta}\sigma^1} \int_0^{\infty} \zeta^{(\alpha\beta+1)/\alpha} \exp\left(\frac{-\zeta}{K(x)}\right) d\zeta$$

where

$$K(x) \triangleq \left[\left(\frac{x}{2\sigma^1}\right)^{\alpha} + \frac{1}{\gamma}\right]^{-1}.$$

Referring to standard integral tables (Dwight item 860.07),[37] i.e.,

$$\int_0^{\infty} \omega^c \exp(-\omega/d)\,d\omega = d^{c+1}\Gamma(c+1)$$

the p.d.f. of process $X(t)$ becomes

$$p_X(x) = \frac{\alpha\Gamma[\beta + (1/\alpha)]}{2\Gamma(\beta)\Gamma(1/\alpha)} \frac{\sigma_0^{\alpha\beta}}{(|x|^{\alpha} + \sigma_0^{\alpha})^{\beta+(1/\alpha)}}, \quad -\infty < x < \infty \quad (7)$$

where we have defined

$$\sigma_0^{\alpha} \triangleq \frac{(\sqrt{2}\sigma^1)^{\alpha}}{\gamma}. \qquad (8)$$

Equation (7) defines the p.d.f. of i.n. component of the atmospheric noise below 100 MHz. To illustrate the density of (7), a set of curves is given in Fig. 1 for $\sigma_0^2 = 1{\cdot}0$, $\beta = 2{\cdot}0$, and $\alpha = 1{\cdot}0$, $2{\cdot}0$, $3{\cdot}0$, $4{\cdot}0$.

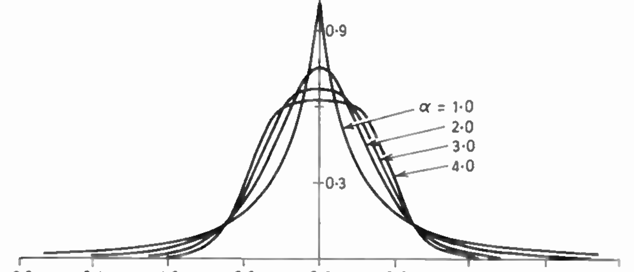


Fig. 1. Probability density function of interference process in the receiver.

Evidence that the generalized density of (7) is a reasonable one to consider in communication problems is provided by the densities proposed by Mertz[21] and Hall[12] for the amplitude distribution of i.n. Mertz assumed that noise amplitude is given by

$$p_m(x) = \beta h^{\beta}(x+h)^{-(\beta+1)}, \qquad x \geqslant 0$$

where h is a small constant and β ranges from just over 2 to about 5. This equation is precisely the p.d.f. of (7) with $\alpha = 1$ and $\sigma_0^2 = 2h^2/\beta^2$. For $\alpha = 2$ and $\beta = 0{\cdot}5$ we have a Cauchy density. This density function has been used in several previous papers, such as Rappaport and Kurz,[6] to represent severe noise.

Since the p.d.f. of $X(t)$ is an even function, all odd moments are zero. The various even moments, when they exist, are found most easily from

$$\langle x^k \rangle = \int_{-\infty}^{\infty} x^k p_X(x)\,\mathrm{d}x$$

where $\langle\ \rangle$ denotes statistical average.

Using (7) in the above equation yields

$$\langle x^k \rangle = \frac{\Gamma[\beta+(1/\alpha)]}{\Gamma(\beta)\Gamma(1/\alpha)}\frac{1}{\sigma_0}\int_0^{\infty}\frac{x^k}{[(x/\sigma_0)^{\alpha}+1]}\,\beta+\frac{1}{\alpha}\,\mathrm{d}x$$

$$= \frac{\sigma_0^k\Gamma[\beta-(k/\alpha)]\Gamma[(k+1/\alpha)]}{\Gamma(\beta)\Gamma(1/\alpha)} \quad \text{for } \alpha\beta > k. \qquad (9)$$

The distribution $P_X(x)$ can easily be obtained from

$$P_X(x) = \int_{-\infty}^{x} P_X(\xi)\,\mathrm{d}\xi.$$

Utilizing (7) and performing the integration yields

$$P_X(x) = \tfrac{1}{2}\left[1 \pm \frac{\Gamma[\beta+(1/\alpha)]}{\Gamma(1/\alpha)\Gamma(\beta)}\left\{\frac{\Gamma(\beta)\Gamma(1/\alpha)}{\Gamma[\beta+(1/\alpha)]} - B\left(\beta, 1/\alpha \,\middle|\, \frac{1}{[1+(x/\sigma_0)^{\alpha}]}\right)\right\}\right] \qquad (10)$$

where $\pm$ refers to $x \gtrless 0$; $B(\ )$ is an incomplete beta function[38] defined by

$$B(\alpha, \beta|z) \triangleq \int_0^{z} \xi^{\alpha-1}(1-\xi)^{\beta-1}\,\mathrm{d}\xi.$$

2.2 First-order Distribution of Envelope

Since the noise is always observed through the passband of some receiver filter we now develop the first-order distribution of the envelope of the noise. If the receiver bandwidth is sufficiently narrow, the noise at the receiver output can reasonably be assumed to be modelled well as a Gaussian process. This follows from the fact that narrow-band filtered noise is the sum of contributions from many independent lightning discharges, none of which is dominant at the filter output. Experimental data indicate, however, that the bandwidth required to achieve this condition at v.l.f. is less than 50 Hz, so a Gaussian assumption is not always physically viable at v.l.f. The modelling problem can be simplified by noting that for communication applications the receiver bandwidth is substantially smaller than the band centre frequency. This fact enables the received atmospheric noise to be regarded as a narrow-band random process. This assumption is always satisfied for communication problems and is not nearly as strong as a Gaussian assumption. Almost all the available experimental data[24, 26, 28, 32, 33] have been obtained in narrow-band conditions.

The statistical independence of $A(t)$ and $G^1(t)$ requires, at least, that their spectra do not noticeably overlap. As mentioned before, $A(t)$ will be of quite low frequency, while $G^1(t)$ is comparatively narrow band, centred about some carrier frequency ω_0, even when the radio-frequency stage of the receiver, which is broad compared to the usual communication practices, is used. The resulting process $X(t)$ is, therefore, narrow band and can be expressed as

$$\begin{aligned} X(t) &= G_1^1(t)A(t)\cos\omega_0 t + G_2^1(t)A(t)\sin\omega_0 t \\ &= X^1(t)\cos\omega_0 t + \hat{X}(t)\sin\omega_0 t \\ &= |A(t)|G(t)\cos(\omega_0 t+\phi) \\ &= E(t)\cos(\omega_0 t+\phi) \end{aligned} \qquad (11)$$

where

$\hat{X}(t)$ and $G_2^1(t)$ = quadrature component corresponding to $X(t)$ and $G^1(t)$ respectively

$X^1(t)$ and $G_1^1(t)$ = in-phase component corresponding to $X(t)$ and $G^1(t)$ respectively

$\phi = \tan^{-1}\left(\dfrac{G_2^1(t)}{G_1^1(t)}\right)$ is the phase

$\omega_0 = 2\pi f_0$

$G^2(t) \triangleq G_1^{12}(t)+G_2^{12}(t)$ is the envelope of process $G^1(t)$ $(\geqslant 0)$

$E(t) = G(t)|A(t)|$ $(\geqslant 0)$ is the envelope of $X(t)$

$X^1(t)$ and $\hat{X}(t)$ at the instant t are independent and identically distributed random variables.

For general values of α it is impossible to obtain a closed form expression for the p.d.f. of the envelope. However, for $\alpha = 2$ a closed form can be obtained. In what follows we assume that $\alpha = 2$, $Q(t)$ reduced to chi-density and $G^1(t)$ to Gaussian density. Since $G^1(t)$ is Gaussian, $G_1^1(t)$ and $G_2^1(t)$ are also Gaussian processes, the phase $\phi(t)$ must in the first order be uniformly distributed over 2π. The envelope $G(t)$ will likewise have a Rayleigh distribution in the first order, but the envelope $E(t)$ will, in general, not. For $A(t) = [Q(t)]^{-1}$ the p.d.f. of $A(t)$ is[39]

$$p_A(a) = \frac{1}{a^2}\,p_Q\left(\frac{1}{a}\right).$$

Using (4) and $\alpha = 2$ in the above equation yields

$$p_A(a) = \frac{1}{\Gamma(\beta)\gamma^{\beta}}\left(\frac{1}{a}\right)^{2\beta+1}\exp\left\{-\frac{1}{\gamma}\frac{1}{a^2}\right\}. \qquad (12)$$

The joint p.d.f. of $X^1(t)$ and $\hat{X}(t)$ is easily obtained by using

$$\begin{aligned} p_{X^1(t),\hat{X}(t)}(x^1,\hat{x}) &= p_{A(t)G_1^1(t),\,A(t)G_2^1(t)}(x^1,\hat{x}) \\ &= \int_{-\infty}^{\infty}\frac{1}{\xi^2}\,p_A(x^1)p_{G_1^1}\left(\frac{x^1}{\xi}\right) \times p_{G_2^1}(\hat{x}/\xi)\,\mathrm{d}\xi. \end{aligned} \qquad (13)$$

Substituting

$$p_{G_1}^{1}\left(\frac{x^1}{\xi}\right) = \frac{1}{\sqrt{2}\Gamma(\frac{1}{2})\sigma^1} \exp\left[-\left(\frac{x^1}{\sqrt{2}\sigma^1\xi}\right)^2\right],$$

$$p_{G_2}^{1}\left(\frac{\hat{x}}{\xi}\right) = \frac{1}{\sqrt{2}\Gamma(\frac{1}{2})\sigma^1} \exp\left[-\left(\frac{\hat{x}}{\sqrt{2}\sigma^1\xi}\right)^2\right]$$

and $p_A(x^1)$ from (12) and defining $e^2 \quad x^{12}+\hat{x}^2$, we get

$$p_{X^1,\frac{1}{4}}(x^1, \hat{x}) = \frac{1}{[\Gamma(\frac{1}{2})\sigma^1]^2} 2\Gamma(\beta)\gamma^\beta \int_0^1 \xi^\beta \exp\left[-\xi/k(e)\right] \mathrm{d}\xi$$

where

$$k(e) \triangleq \left(\frac{2\sigma^{12}}{\gamma} + e^2\right)^{\beta+1}.$$

Using (8) and evaluating the integral yields

$$p_{X^1,\hat{X}}(x^1, \hat{x}) = \frac{\Gamma(\beta+1)\sigma_0^{2\beta}}{\Gamma^2(\frac{1}{2})\Gamma(\beta)} \frac{1}{(\sigma_0^2+e^2)} \beta+1. \qquad (14)$$

The joint probability density of envelope and phase of the narrow-band received noise is given by

$$p_{E,\phi}(e, \phi) = e p_{X^1,\hat{X}}(x^1, \hat{x}).$$

Using (14) in the above equation to obtain

$$p_{E,\phi}(e, \phi) = \frac{\Gamma(\beta+1)\sigma_0^{2\beta}}{\Gamma^2(\frac{1}{2})\Gamma(\beta)} \frac{e}{(\sigma_0^2+e^2)^{\beta+1}}.$$

Since the phase is uniformly distributed over 2π, the p.d.f. of the $E(t)$ is

$$p_E(e) = 2\beta\sigma_0^{2\beta} \frac{e}{(\sigma_0^2+e^2)^{\beta+1}} \qquad 0<e<\infty. \qquad (15)$$

The noise model recently proposed by Shinde *et al.*[14] for h.f. atmospheric noise can be obtained from (15) by substituting $\beta = 1{\cdot}5$ and $\sigma_0^2 = 1{\cdot}0$. Before applying this general model to v.l.f. atmospheric radio noise we obtain the various moments and the distribution function of (15).

The various first-order moments of the envelope are easily obtained directly from

$$\langle e^k \rangle = 2\beta\sigma_0^{2\beta} \int_0^\infty \frac{e^{k+1}}{(\sigma_0^2+e^2)^{\beta+1}} \mathrm{d}e$$

$$= \frac{\beta\sigma_0^k \Gamma[\beta-(k/2)]\Gamma[(k/2)+1]}{\Gamma(\beta+1)} \quad \text{for } 2\beta>k. \qquad (16)$$

The probability $P_0(e)$ that the envelope intensity exceeds level e is given by

$$P_0(e) = 1-P_E(e) = \int_e^\infty p_E(\xi)\,\mathrm{d}\xi$$

$$= \frac{\sigma_0^{2\beta}}{(\sigma_0^2+e^2)^\beta}. \qquad (17)$$

This model is compared with the experimental results. The new model results with $\beta = 1$ and the results obtained from the published work[26,27,30] are also plotted in Fig. 2. This shows a close agreement between the observed values and values calculated from the above model. In what follows we apply this noise model to detection of known signals in the presence of atmospheric radio noise alone.

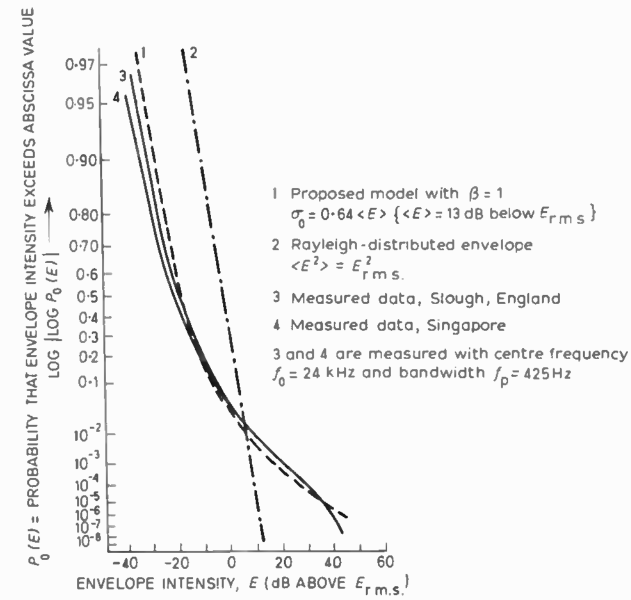


Fig. 2. Composite probability distribution function of the envelope of received v.l.f. atmospheric noise. Comparison of 'model' results with data measured at Singapore and Slough, England.

3 Detection of Known Signal in V.L.F. Noise

V.l.f. is basically an amplitude and phase-stable medium which is disturbed by additive atmospheric noise. Hence an appropriate system model as shown in Fig. 3 consists of a message set, $\{m_j\}$ (j = 0, 1), corresponding signal set, $\{S_j(t)\}$, additive noise, $X(t)$, and a receiver which operates on the received signal to arrive at an estimate of the transmitted message. The receiver is optimum if its decision rule results in minimum probability of error.

Describing the transmitted *a priori* equal probability known signal by

$$\begin{aligned} S_0(t) &= 0 \\ S_1(t) &= \hat{S}(t)\cos\omega_0 t \end{aligned} \qquad 0 \leqslant t \leqslant T \qquad (18)$$

where $\hat{S}(t)$ is a real low-pass waveform of duration T, and ω_0 is the carrier frequency, we assume that the highest frequency component of significance of $\hat{S}(t)$ is much less than the carrier frequency ω_0. In each signalling interval the transmitter inserts either $S_0(t)$ or $S_1(t)$ into the channel. We assume that each element of the transmitted sequence is statistically independent of all other elements. The decision problem becomes that of choosing between the hypothesis

$$\begin{aligned} H_0&: y(t) = X(t)+S_0(t) \\ H_1&: y(t) = X(t)+S_1(t) \end{aligned} \qquad 0 \leqslant t \leqslant T \qquad (19)$$

where $X(t) = X^1(t)\cos\omega_0 t + \hat{X}(t)\sin\omega_0 t$ = noise component.

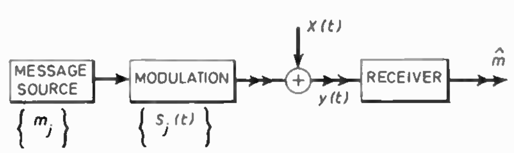


Fig. 3. System model.

D

To simplify the analysis, assume that there is a discrete representation of the problem, whether obtained from sampling or orthonormal expansions. Although this is a severe restriction, it still leads to useful results. Therefore, with M the dimension of the discrete representation space, the receiver observes

$$\begin{aligned} \mathrm{H}_0 &: \mathbf{y} = \mathbf{X}+\mathbf{S}_0 \\ \mathrm{H}_1 &: \mathbf{y} = \mathbf{X}+\mathbf{S}_1 \end{aligned} \tag{20}$$

where

$$\mathbf{S}_0 = \begin{bmatrix} S_{01} \\ S_{02} \\ \vdots \\ S_{0M} \end{bmatrix}; \quad \mathbf{X} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{bmatrix}.$$

The number of samples M is dependent on the bandwidth in which the signal of duration T is observed.

For statistically independent samples the conditional p.d.f. of the received signal under hypothesis H_1 is given by

$$p_y(\mathbf{y}|\mathrm{H}_1) = \prod_{k=1}^{M} p_{x_k^1 \cdot \hat{x}_k}(y_k, {}^1\hat{y}_k|\mathrm{H}_1)$$

With $\beta = 1$ it can be shown that

$$p_y(\mathbf{y}|\mathrm{H}_1) = \prod_{k=1}^{M} \left\{\frac{\sigma_0^2}{\pi}\right\}^M \frac{1}{[\sigma_0^2+\hat{y}_k^2+|y_k^1-S_{1k}|^2]^2}. \tag{21}$$

Similarly, for H_0: $\mathbf{y} = \mathbf{X}+\mathbf{S}_0$, substituting S_{0k} instead of S_{1k} in (21), to obtain

$$p_y(\mathbf{y}/\mathrm{H}_0) = \prod_{k=1}^{M} \frac{\sigma_0^2}{\pi} \frac{1}{[\sigma_0^2+\hat{y}_k^2+|y_k^1-S_{0k}|^2]^2}. \tag{22}$$

The likelihood ratio $\Lambda(\mathbf{y})$ is given by

$$\Lambda(\mathbf{y}) = \frac{p_y(\mathbf{y}/\mathrm{H}_0)}{p_y(\mathbf{y}/\mathrm{H})} = \prod_{k=1}^{M} \psi^2(y_k) \tag{23}$$

where

$$\psi(y_k) \triangleq \frac{\sigma_0^2+\hat{y}_k^2+|y_k^1-S_{0k}|^2}{\sigma_0^2+\hat{y}_k^2+|y_k^1-S_{1k}|^2}. \tag{24}$$

Thus the Bayes rule is choose $\hat{m} = s_1(t) = m$, if:

$$\sum_{k=1}^{M} \log[\sigma_0^2+(y_k-S_{0k})^2] \geqslant \sum_{k=1}^{M} \log[\sigma_0^2+|y_k-S_{1k}|^2]. \tag{25}$$

When the sample size M is large enough (25) can be approximately represented in integral form as follows:

$$\int_0^T \log[\sigma_0^2+|y(t)-S_0(t)|^2]\,\mathrm{d}t \geqslant \int_0^T \log[\sigma_0^2+|y(t)-S_1(t)|^2]\,\mathrm{d}t$$

where

$y(t)$ = complex envelope of the signal plus noise

$S_i(t)$ = complex envelope of the narrow band signal corresponding to m_i

T = signalling interval

$\hat{m}$ = estimate of the transmitted message.

The receiver structure which implements this rule is shown in Fig. 4.

4 Performance of Optimum Detector

In the previous Section we have been concerned primarily with the structure of the optimal detection system. In this Section we shall investigate the receiver performance that is completely specified by the probability of detection error P_e.

In many cases of interest, the test likelihood ratio can be derived but an exact performance calculation is sometimes impossible. For our noise model we encounter this difficulty. Therefore it is useful to search for another measure that may be weaker than the probability of error but that is easier to evaluate. We shall use the upper bound given by Chernoff.[40] The probability of error for equally likely signal is

$$P_e = Pr\{\log\Lambda(\mathbf{y}) = \sum_{k=1}^{M} \psi^2(y_k) \geqslant 0/\mathrm{H}_1\}.$$

The quantities $\psi(y_k)$ are statistically independent. Using the Chernoff bound the P_e expression becomes

$$P_e \leqslant \prod_{k=1}^{M} \langle\psi^{\lambda_0}(y_k)\rangle \tag{26}$$

where λ_0 is a constant which is chosen to make the upper bound exponentially tight. To find λ_0 we solve the equation

$$\sum_{k=1}^{M} \frac{1}{\langle\psi^\lambda(y_k)\rangle} \langle(\mathrm{d}/\mathrm{d}\lambda)\psi^\lambda(y_k)\rangle\Big|_{\lambda=\lambda_0} = 0. \tag{27}$$

Using (24) and (14) when $\beta = 1$ to obtain

$$\langle\psi^\lambda(y_k)\rangle = \frac{\sigma_0^2}{\pi} \int \int_{-\infty}^{\infty} \mathrm{d}y^1\,\mathrm{d}\hat{y} \left\{\frac{(y^{12}+\hat{y}^2+\sigma_0^2)^{\lambda-2}}{[(y^1-S_1)^2+\hat{y}^2+\sigma_0^2]^\lambda}\right\}. \tag{28}$$

Substituting (28) in (27) and solving (27) for λ yields

$$\lambda_0 = 1{\cdot}0. \tag{29}$$

Utilizing (29), (26) becomes

$$P_e \leqslant \prod_{k=1}^{M} \frac{\sigma_0^2}{\pi} \int_{-\infty}^{\infty} \mathrm{d}\hat{y}_k \int_{-\infty}^{\infty} \mathrm{d}y_k^1 \left\{\frac{(y_k^{12}+\hat{y}_k^2+\sigma_0^2)^{-1}}{[(y_k^1-S_{1k})^2+\hat{y}_k^2+\sigma_0^2]}\right\}.$$

Solving the inner integral by contour integration technique and introducing a new variable

$$\xi_k = \frac{\hat{y}_k^2}{\hat{y}_k^2+\sigma_0^2}$$

yields

$$P_e \leqslant \prod_{k=1}^{M} \frac{4\sigma_0^2}{S_{1k}^2+4\sigma_0^2} \tfrac{1}{2} \int_0^1 \xi_k^{-\frac{1}{2}} \left(1 - \frac{\xi_k(S_{1k}/\sigma_0)^2}{4+(S_{1k}/\sigma_0)^2}\right) \mathrm{d}\xi_k.$$

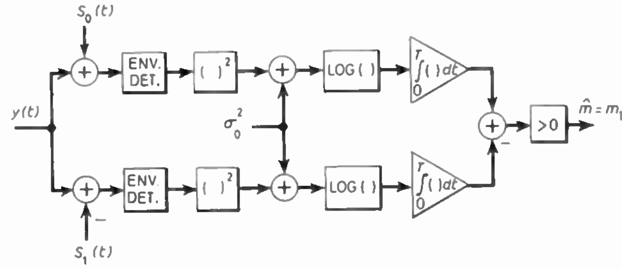


Fig. 4. Optimum receiver for v.l.f. channels.

Using standard integral tables[41] the above equation can be expressed in a series form:

$$P_e \leqslant \prod_{k=1}^{M} \frac{4}{(S_{1k}^2/\sigma_0)+4} \sum_{n=0}^{\infty} \frac{1}{(2n+1)} \left(\frac{(S_{1k}^2/\sigma_0^2)}{4+(S_{1k}^2/\sigma_0^2)}\right)^n \quad (30)$$

For $M \gg 1$, (30) can be approximated in the following integral form

$$\frac{\log P_e}{2BT} \leqslant \frac{1}{T}\int_{-T/2}^{T/2} \left\{\log\left[\sum_{n=0}^{\infty} \frac{1}{(2n+1)}\left(\frac{S_1^2(t)/\sigma_0^2}{4+S_1^2(t)/\sigma_0^2}\right)^n\right] - \log\left(\frac{S_1^2(t)}{4\sigma_0^2}+1\right)\right\} dt. \quad (31)$$

For small values of $S^2(t)/4\sigma^2$ (<1) the above equation can be simplified to

$$\log |P_e| \leqslant a_2 F(s) \quad (32)$$

where

$$F(s) \triangleq \int_{-T/2}^{T/2} [S_1^4(t) - aS_1^2(t)]\, dt,$$

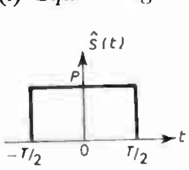
$$a = 6\sigma_0^2 \quad \text{and} \quad a_2 = \frac{B}{18\sigma_0^4}.$$

From the error probability expressions it is seen that the performance does not only depend on the signal power as in the case of Gaussian noise but also depends on the particular signal as well as the time-bandwidth product $2BT$. These bounds have obvious significance in assessing detector performance. Perhaps less obvious is the fact that, since it is known that the particular signal which minimizes the upper bound on the probability of error is also the signal which minimizes the actual probability of error,[22,42] the formulas for error bound may be used to determine an optimal signal. Since the transmitted signal must generally have finite energy, an average energy constraint

$$P^2 T = \int_{-T/2}^{T/2} \hat{S}^2(t) \cos^2 \omega_0 t \, dt$$

will be required. For any chosen signalling waveform a plot of the normalized parameter on the right-side of (31) as a function of $(P/\sigma)^2$ can therefore be obtained. For given $(P/\sigma_0)^2$ the signalling waveform that maximizes the r.h.s. of (31) is optimal. In order to obtain an idea of the effect of the signalling waveform on system performance, several basic waveforms will be considered. The details for the signal optimization will then be presented in Section 5.

(i) *Square Signals*

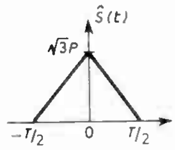


$$\hat{S}(t) = \begin{cases} P & |t| \leqslant T/2 \\ 0 & |t| \geqslant T/2 \end{cases} \quad (33)$$

Substituting (33) in (31) yields

$$-\frac{\log(P_e)}{2BT} \leqslant \log\left(\frac{P^2}{4\sigma_0^2}+1\right) - \log\left(\sum_{n=0}^{\infty} \frac{1}{2n+1}\left[\frac{P^2/\sigma_0^2}{4+(P^2/\sigma_0^2)}\right]^n\right) \quad (34)$$

(ii) *Triangular Signals*

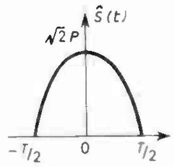


$$\hat{S}(t) = \begin{cases} \sqrt{3}P\left(1-\dfrac{2|t|}{T}\right) & |t| \leqslant T/2 \\ 0 & |t| \geqslant T/2 \end{cases} \quad (35)$$

Using (35) in (31) and using a substitution $\xi = 2t/T$ yields

$$-\frac{\log(P_e)}{2BT} \leqslant \int_0^1 \left\{\log\left[\frac{3P^2}{4\sigma_0^2}(1-\xi)^2+1\right] - \log\left[\sum_{n=0}^{\infty}\frac{1}{2n+1}\left(\frac{3P^2/\sigma_0^2(1-\xi)^2}{4+(3P^2/\sigma_0^2)(1-\xi)^2}\right)^n\right]\right\} d\xi \quad (36)$$

(iii) *Half-wave sinusoidal signals*



$$\hat{S}(t) = \begin{cases} \sqrt{2}P\cos(\pi t/T) & |t| \leqslant T/2 \\ 0 & |t| \geqslant T/2 \end{cases} \quad (37)$$

Using (37) in (31) and using a substitution $\xi = 2t/T$ yields

$$-\frac{\log(P_e)}{2BT} \leqslant \int_0^1 \left\{\log\left[\frac{P^2}{2\sigma_0^2}\cos^2\left(\frac{\pi\xi}{2}\right)+1\right] - \log\left[\sum_{n=0}^{\infty}\frac{1}{2n+1}\left(\frac{P^2/2\sigma_0^2\cos^2(\pi\xi/2)}{4+(P^2/2\sigma_0^2)\cos^2(\pi\xi/2)}\right)^n\right]\right\} d\xi \quad (38)$$

Equations (34), (36) and (38) are plotted in Fig. 5 which shows the uniformly superior performance of square signals for a system of equal time-bandwidth products. The advantage is most pronounced for large signal-to-impulsive noise ratio $(P/\sigma_0)^2$. It should be realized, however, that square signals generally require more bandwidth than other signals. This point will be discussed further in developing an optimal signal in the next Section.

From (31) and Fig. 5 it is seen that for large $2BT$, the optimum receiver is significantly superior to the per-

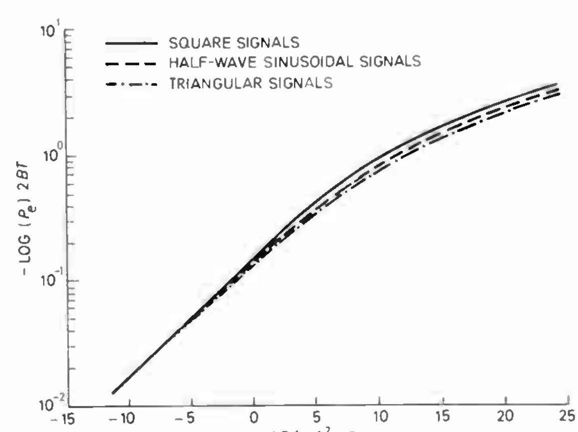


Fig. 5. Signal-to-impulsive noise radio.

formance of an optimal matched-filter receiver in the presence of additive Gaussian noise with the same average noise power. This superiority is consistent with the notion that a channel perturbed by additive atmospheric noise has a higher capacity than an otherwise similar channel perturbed by additive Gaussian noise having the same average power.

5 Signal Design

In this Section we consider the problem of minimizing the upper bound on the probability of error by a choice of transmitting signal. We shall develop the optimal signal design, subject to some physically meaningful constraints. In the first case we minimize the P_e with only an energy constraint. The second case considered is to minimize P_e subject to energy and the mean-square bandwidth.

Here we define the energy and the mean-square bandwidth of the envelope signals as

$$E = \int_{-T/2}^{T/2} \hat{S}^2(t)\,dt \tag{40}$$

and

$$W^2 = \int_{-T/2}^{T/2} \left(\frac{d\hat{S}(t)}{dt}\right) dt \tag{41}$$

respectively. As shown by Abramson,[43] the mean-square bandwidth is the bandwidth that contains the major part of the signal energy. Since the optimal signal is difficult to obtain using the actual probability of error bound (31) we consider an asymptotic expression of error bound for small $S(t)\sigma_0$ (32). This is justified since optimality is usually no longer the primary concern at stronger input signal levels.

From (32) it is obvious that to minimize P_e we need to minimize the performance index $F(s)$. We first consider the simpler case when the mean-square bandwidth W^2 is allowed to take any value and the signal energy is required to be finite.

To carry out the minimization, using the calculus of variation[44] technique, we let

$$\hat{S}(t) = \hat{S}_{op}(t) + \varepsilon \hat{S}_A(t) \tag{42}$$

where $\hat{S}_{op}(t)$ is the optimum signal envelope and $\hat{S}_A(t)$ is an arbitrary function. We impose the energy constraint (40). From (32) the index that we have to minimize becomes

$$F_1(S) = \int_{-T/2}^{T/2} \hat{S}^4(t)\,dt. \tag{43}$$

Using the standard technique in constrained minimization theory,[44] we define the function

$$I(S) = F_1(S) + \lambda_1 \left[\int_{-T/2}^{T/2} \hat{S}^2(t)\,dt - E\right], \tag{44}$$

where λ_1 is a Lagrange multiplier, and E is the energy. Then on substituting (42) in (44) and carrying out

$$\left.\frac{dI(S)}{d\varepsilon}\right|_{\varepsilon=0} = 0 \tag{45}$$

the final result becomes

$$\int_{-T/2}^{T/2} \hat{S}_A(t)[\lambda_1 \hat{S}_{op}(t) + 2\hat{S}^3_{op}(t)]\,dt = 0. \tag{46}$$

Since $\hat{S}_A(t)$ is arbitrary, the terms in the brackets must be identically zero, in which case

$$\lambda_1 \hat{S}_{op}(t) + 2\hat{S}^3_{op}(t) = 0, \qquad -T/2 \leqslant t \leqslant T/2 \tag{47}$$

we use the given constraint on E of (40) to evaluate the constraint λ_1 as $-2\hat{S}^2_{op}(t)$. Finally the solution for optimal signal, found by integrating $\lambda_1 = -2\hat{S}^2{}_{op}(t)$ and substituting for λ_1 into (47) becomes

$$\hat{S}_{op}(t) = \sqrt{(E/T)} \qquad -T/2 \leqslant t \leqslant T/2. \tag{48}$$

The optimal signal, for this case, is a rectangular signal with given energy E and W^2 of (41) $= \infty$. This is shown in Fig. 6. Note that the signals considered in the last Section agree with the results obtained here. However, it is obvious that the rectangular signal never exists in practice at the receiver, owing to the band-limited nature of any physical communication channel. Actually, the transmitting signal appears distorted due to loss of high frequency components.

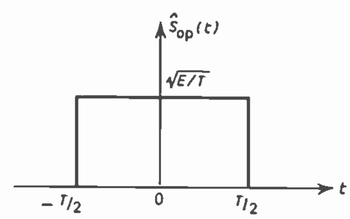


Fig. 6. Optimal signal with energy constraint.

The problem of signal optimization is more meaningful if we constrain both the energy and bandwidth of $\hat{S}(t.)$ We define the bandwidth as in (41) and the energy as in (40) and then assume that both are bounded by fixed finite values. We require in addition the end point assumption

$$\hat{S}_{op}(\pm T/2) = 0 \tag{49}$$

in order to avoid discontinuities at the end points.

Then for this case the index $I(S)$ for minimization is

$$I(S) = F(S) + \lambda^1 \left[\int_{-T/2}^{T/2} \hat{S}^2(t)\,dt - E\right] + \lambda_2 \left[\int_{-T/2}^{T/2} \left(\frac{d\hat{S}(t)}{dt}\right)^2 dt - W^2\right] \tag{50}$$

where λ_1 and λ_2 are Lagrange multipliers.

The details of the minimization process are similar to the first case. Using the calculus of variations with the boundary condition (49) we obtain the equation that specifies $\hat{S}_{op}(t)$ in the following form

$$\frac{d^2}{dt} \hat{S}_{op}(t) + \mu \hat{S}_{op}(t) = \rho \hat{S}^3_{op}(t) \tag{51}$$

where

$$\mu = -\frac{\lambda_1}{\lambda_2}; \quad \rho = \frac{2}{\lambda_2}.$$

This is the non-linear differential equation that is known as the Duffings equation.[45] In general the above equations will involve elliptic integrals and elliptic functions. Since an analytical analysis to yield μ and ρ in terms of the constraint parameters E and W^2 is not possible in practice, μ and ρ are chosen to meet the required energy E and the bandwidth W^2 using trial and error.

For $|\rho|$ small we could use the method of perturbation to obtain an approximate solution of (51). For $\rho = 0$, (51) possesses the periodic solution:

$$\hat{S}_{op}(t) = A \cos \sqrt{\mu} t \tag{52}$$

where the constants A and μ can be determined from the constraint equations (40) and (49). Let us characterize (52) as the solution of the initial-value problem

$$\hat{S}_{op}(t) = A$$
$$\frac{d}{dt}(\hat{S}_{op}(t)) = 0 \tag{53}$$

for $t = 0$. If we apply the Poincare theorem,[46] we know that for sufficiently small $|\rho|$, the solution of (51) satisfying (53) may be expressed as a power series in ρ. Let

$$\hat{S}_{op}(t) = S_a(\omega t) + \rho S_b(\omega t) + \rho^2 S_c(\omega t) + \cdots \tag{54}$$

be the expansion, where S_a, S_b, . . ., is to be a periodic function $\tau = \omega t$ of period 2π. The quantity ω is introduced as the true fundamental frequency and will be an analytic function of ρ. To determine ω, we introduce an expansion of the form

$$\omega = 1 + \omega_1 \rho + \omega_2 \rho^2 + \cdots \tag{55}$$

where the first term is unity since the fundamental frequency reduces to unity for $\rho = 0$. In terms of the new variable $\tau = \omega t$, (51) becomes

$$\omega^2 \frac{d^2 \hat{S}_{op}(\tau)}{dt^2} + \mu \hat{S}_{op}(\tau) = \rho \hat{S}^3_{op}(\tau). \tag{56}$$

If we substitute (54) and (55) in (56) and equate coefficients of corresponding powers of ρ, we obtain a sequence of nested differential equations in $S_a(t)$, $S_b(t)$, ... The first three are

$$\frac{d^2 S_a(\tau)}{d\tau^2} + \mu S_a(\tau) = 0 \tag{57}$$

$$\frac{d^2 S_b}{d\tau^2} + \mu S_b = S_a^3 - 2\omega_1 \frac{d^2 S_a}{d\tau^2} \tag{58}$$

$$\frac{d^2 S_c}{d\tau^2} + \mu S_c = 3S_a^2 S_b - (\omega_1^2 + 2\omega_2)\frac{d^2 S_a}{d\tau^2} - 2\omega_1 \frac{d^2 S_b}{d\tau^2}. \tag{59}$$

Solutions of the above differential equations are

$$S_a(\tau) = A \cos \sqrt{\mu}\tau \tag{60}$$

$$S_b(\tau) = \frac{A^3}{32\mu}(\cos \sqrt{\mu}\tau - \cos 3\sqrt{\mu}\tau) \tag{61}$$

$$S_c(\tau) = \frac{3A^5}{128\mu^2} \times \left\{\frac{23}{24}\cos\sqrt{\mu}\tau - \cos 3\sqrt{\mu}\tau + \frac{1}{24}\cos 5\sqrt{\mu}\tau\right\}. \tag{63}$$

In obtaining the above solutions we have eliminated all the secular terms by imposing

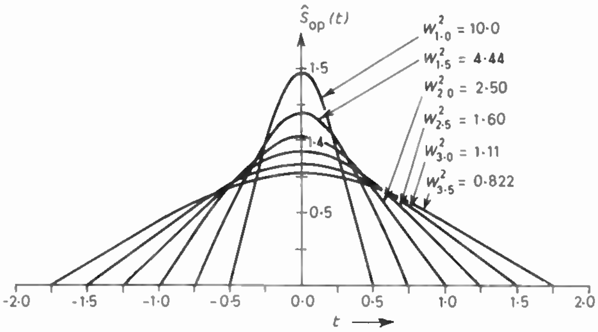


Fig. 7. Optimal signals with equal energy $E = 1\cdot0$.
W_T^2 = mean square bandwith of a signal of duration T
T = signal duration in 10^{-2} s
W^2 = mean square bandwidth in 10^4 (Hz)^2
E = energy in volt^2

$$\omega_1 = \frac{3A^2}{2\mu}; \quad \omega_2 = -\frac{21A^5}{256\mu^2}. \tag{64}$$

In a similar manner, the remaining terms of the two expansions (54) and (55) are determined by the initial conditions and the requirement of periodicity.

It should be noted that the convergence of (54) will not be uniform in t for all t unless ω is exact, although it may be uniform in $\tau = \omega t$ for all τ.

Using (60), (61) and (63) in (54) and using the two integral constraints (40) and (41) the optimal signal for given signal energy, signal duration and given mean-square bandwidth can be computed. Using the phase-plane trajectories of (51) it is seen the general shape of the optimal signal with duration T is symmetrical about $t = 0$. The absolute value of the slope of $\hat{S}_{op}(t)$ takes the maximum value at the end points ($t = \pm T/2$) and monotonically decreases and reaches the minimum value of zero at $t = 0$.

For given energy E, mean-square bandwidth W and the signal duration T, the optimal signal is unique. Some typical optimal signals with equal energy, equal bandwidth and equal duration are shown in Figs. 7, 8, 9 respectively. Relation between the signal energy E and signal duration for given bandwidth is shown in Fig. 10.

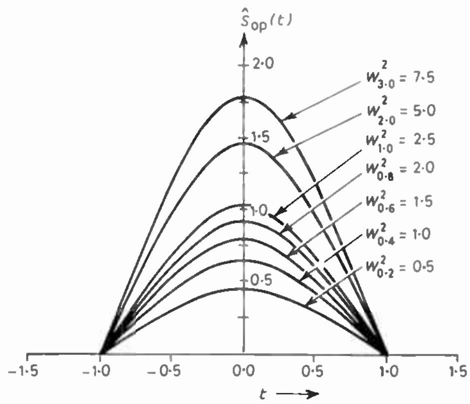


Fig. 8. Optimal signals on the duration $T = 2\cdot0 \times 10^{-2}$ s
W_E^2 = mean square bandwidth of a signal of energy E

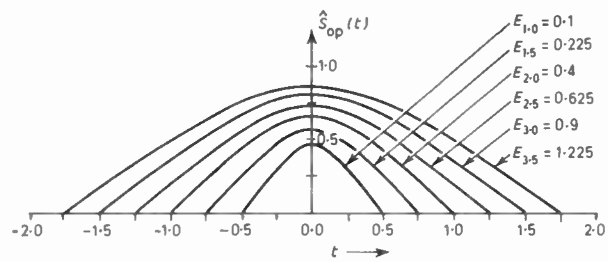


Fig. 9. Optimal signals with mean-square bandwidth $1\cdot0 \times 10^4$ (Hz)^2 E_T = energy of a signal of duration T

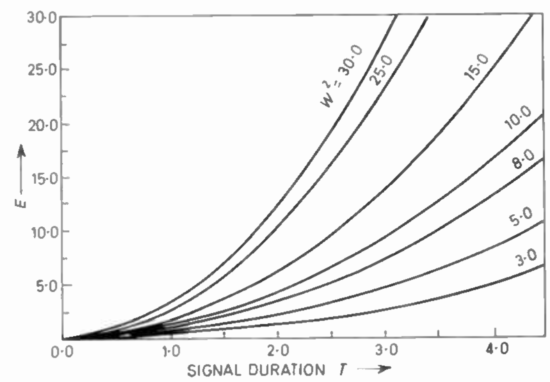


Fig. 10. Energy-duration curves for optimal signals.

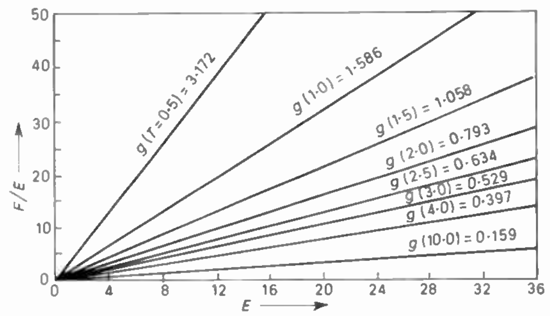


Fig. 11. F/E vs. E curves.

Another property of the optimal signal $\hat{S}_{op}(t)$, which is useful in the calculation of system performance, is that

$$F = g(T)E^2 \tag{67}$$

where F is defined by

$$F \triangleq \int_{-T/2}^{T/2} \hat{S}^4_{op}(t)\,dt \tag{68}$$

and $g(T)$ is a function of T. Figure 11 shows the straight line plots of F/E vs. E for various values of T.

6 Concluding Remarks

A general noise model that has the important advantage of direct analytical tractability in its probability distributions has been constructed. A special case of this generalized model has been applied to the detection of known signals in the presence of noise to determine the optimal-receiver structure. The important result suggested by the model is that the performance of an optimal receiver in the presence of non-Gaussian interference is sensitive to the signal shape. We have developed a signal design only for the case of small signal-to-noise ratios. This is justified since the optimality is usually no longer the primary concern at stronger signal-to-noise ratios. It is also observed that the optimum receiver is significantly superior to the performance of an optimal matched-filter receiver in the presence of additive Gaussian noise with the same average noise power.

7 Acknowledgments

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The Authors

Ronald Brewster studied electrical engineering part-time at South East Essex Technical College whilst working as an apprentice with the Kelvin Hughes Division of Smiths Industries. After completing his National Service in REME in 1955, he joined Standard Telecommunication Laboratories where he worked for several years on the development of microwave stripline techniques. He returned to Kelvin Hughes for a period to work with the marine radar development team but subsequently re-joined STL to carry out research into equalization techniques for data modems. He obtained his M.Sc. degree at the University of Aston in 1967 and his doctorate at the same university in 1972. Dr. Brewster joined the staff of the University in March 1971 as Lecturer in Telecommunications and has continued his research interest in the field of data transmission.

S. B. Patel received his early education in Uganda and in 1969 he went to the Department of Electrical Engineering at the University of Aston in Birmingham, from where he graduated in 1972 with a first-class honours degree in electrical engineering. He is currently a doctoral student at the same university. Mr. Patel's research interests are in the area of statistical communication theory and its applications.

World Radio History

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Signal processing applications of charge-coupled devices

J. MAVOR, B.Sc., Ph.D., M.Inst.P. Mem.I.E.E.E., C.Eng., M.I.E.E., M.I.E.R.E.*

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SUMMARY

The charge-coupled device is essentially a sampled-data, analogue shift register which permits many signal processing functions to be implemented in analogue form. This paper reviews the development of these devices for communication, radar and sonar applications, and summarizes the advantages of the charge-coupled concept over digital techniques

Electrical Engineering Department, School of Engineering Science, King's Buildings, Mayfield Road, Edinburgh EH9 3JL.

1 Introduction

Charge-coupled devices (c.c.d.s) are extremely versatile electronic components which have considerable potential uses for communications systems, radar, sonar and data processing. They can perform a variety of analogue, sampled-data signal processing functions including time delay, multiplexing, transversal and recursive filtering. When operated in a digital mode, they can lead to extremely high density memories and have considerable potential as arithmetical processors. In common with other semiconductor devices, the c.c.d. is sensitive to light. Thus information can be introduced optically, as well as electrically, which should lead to many novel opto-electronic developments.

The first c.c.d. was announced in 1970.[1] Since that time the concept has been developed until, currently, exceptionally complex integrated circuits are being designed and evaluated for applications in the areas of imaging, memory and signal processing. Where the c.c.d. is applicable, these devices offer considerable advantages in terms of cost, power consumption, size and reliability over conventional digital processors. Perhaps the key to their acceptance and penetration into these applications areas stems from the fact that the vast majority of c.c.d.s are fabricated using silicon technology. Many laboratories exist worldwide with extensive silicon-slice processing facilities, and potentially all of these could be used to fabricate c.c.d. integrated circuits.

A previous paper[2] covers c.c.d. technological developments in some detail, and treats the basic charge-coupling concepts. This paper outlines the development of c.c.d.s specifically for analogue signal processing. No attempt is made to summarize digital data processing developments, which will lead inevitably to higher performance processors, essentially as replacements for existing digital sub-systems. The analogue c.c.d. approach leads to many original applications, some of which were visualized earlier but not realizable, until the unique features of the c.c.d. were available.

2 C.C.D. Performance

For signal processing applications, the primary c.c.d. operating parameter is the charge-transfer inefficiency, ε, which represents the fractional charge loss per transfer. This parameter limits the number of transfers possible for a given degradation of the signal. Values of ε for surface channel c.c.d.s are usually in the 10^{-3} to 10^{-5} range. Buried channel[3] and peristaltic technology[4] c.c.d.s allow these efficiency levels to be maintained to above 10 MHz, and some laboratory peristaltic c.c.d.s[4] have been operated at bandwidths above 100 MHz. Total delay times of 10 ms to several seconds or more are possible, limited primarily by the inherent thermal generation current or 'dark' current which is continually trying to fill the c.c.d. 'wells' and thus corrupting the signal. Thus the potential time-delay–bandwidth products achievable with c.c.d.s should be above 1000.

Although there is some debate as to the ultimate upper frequency limit of the c.c.d., from many practical points of view 10–30 MHz seems a sensible maximum for current technology. On-chip logic circuits can be designed to produce c.c.d. waveforms at low frequency. The external clock driving circuitry requirement is one problem that must be simplified before devices can be operated easily at high frequencies. However, 4-phase c.c.d. structures (4 gates per bit) can be operated with sine-wave clocks, which eases this problem considerably.

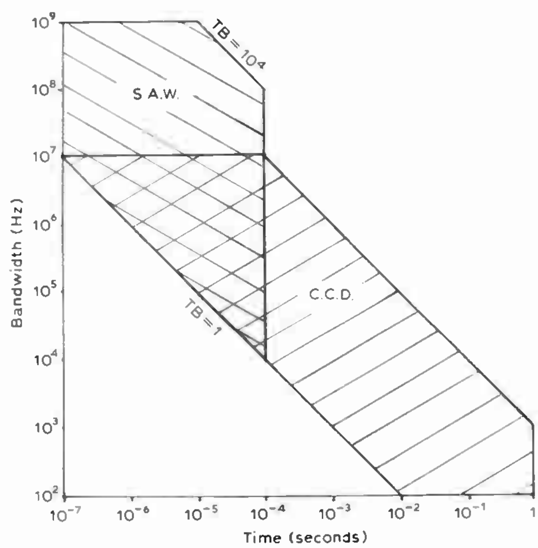


Fig. 1. Current parameter bounds for s.a.w. and c.c.d. filters.

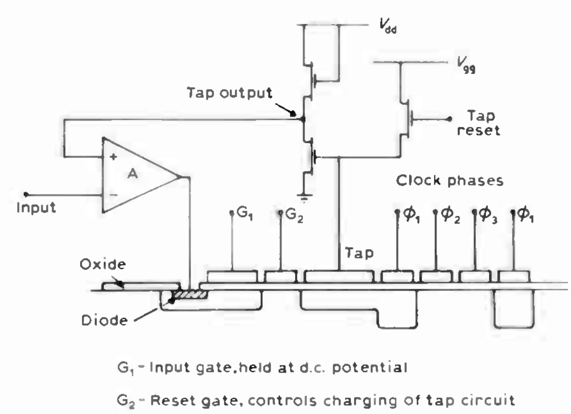
The c.c.d. operating range overlaps to an extent with surface-acoustic wave (s.a.w.) devices[5] which have operating frequencies from 50 MHz into the gigahertz region, but only a total delay of about 100 μs and an operating bandwidth of about 10 MHz because they are i.f. components. As s.a.w. devices are passive, the problem of clock generation does not arise and therefore no clocking problem exists. However, for a given s.a.w. device the total delay is limited by the propagation characteristics of the material used in the device fabrication. Whereas for the c.c.d., delay is controlled by the clocking period rather than the characteristics of the substrate.

Figure 1 shows a comparison between the practical operating limits of both these components. An upper limit of 10 MHz for the c.c.d. allows many applications to be satisfied in the sonar, radar and communications areas. For many c.c.d. integrated circuit designs, it is likely that the upper frequency limit is set by the on-chip or off-chip peripheral electronics or both. It is particularly convenient to be able to design, monolithically, m.o.s. transistors to perform ancillary functions such as (a) signal summation, (b) buffering and sensing signals, and (c) sample-and-hold. These circuits will probably limit the performance of the c.c.d./m.o.s.t. sub-system to below 10 MHz, but nevertheless permit many useful signal processing operations to be achieved within a single integrated circuit.

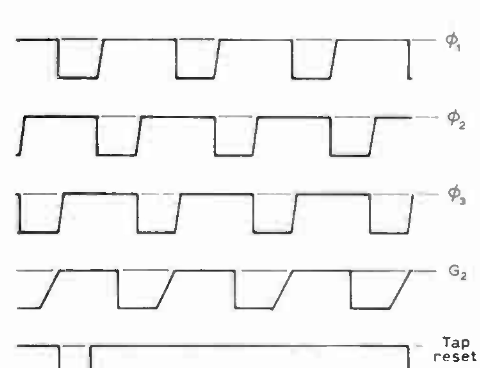
3 C.C.D. Input Circuits

The desirable low noise, wide dynamic range and good linearity cannot be achieved from a c.c.d. unless care is exercised in the design of the input and output circuits. Considerable effort has been placed on the input technique with the emphasis on linearity between the input signal voltage and the quantity of injected charge.[6–8] This process is inherently non-linear if the signal is applied directly to the input diode and leads to errors at all but very low signal levels. An improved technique[6,7,8] involves setting an auxiliary input gate at a desired level, injecting an excess of charge from an input diode pulse into the c.c.d., and then extracting it back out of the c.c.d. limited by the surface potential of the substrate under the auxiliary gate. This method extends the linearity of the c.c.d. over a wider dynamic range, perhaps 50% of the full range as dictated by the c.c.d. design. However, when the signal is removed from the device, any non-linearity of the charge-to-output voltage characteristic will reflect a non-linear overall transfer function.

A different approach[9] to the problem is to use a feedback loop at the input of a c.c.d. to account for input/output non-linearities and result in low-harmonic distortion, as illustrated in Fig. 2. With this technique, the quantity of charge that is injected is that required to force the output voltage to follow the input signal. The amount of charge may be a non-linear function of the input voltage but the output voltage will be a linear function of the input.

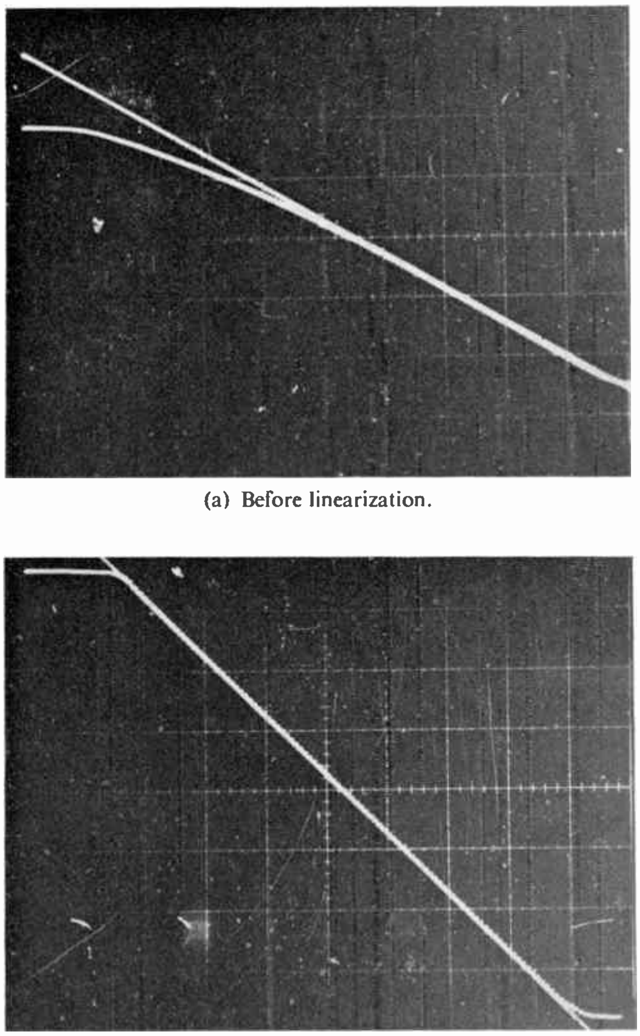


(a) Circuit arrangement.



(b) Timing diagram.

Fig. 2. Feedback technique for c.c.d. linearization.



(a) Before linearization.

(b) With linearization. Overall loop-gain = 25.

Fig. 3. Results of linearizing a c.c.d. transfer characteristic.

Vertical scale: 200 mV/div; horizontal scale: 5 ms/div.

Fundamental	0 dB
2nd harmonic	<-40 dB
3rd harmonic	$\ll -50$ dB
4th harmonic	-50 dB
5th harmonic	$\ll -50$ dB

at 95% of maximum output voltage.

A non-destructive sensing technique has been used[10] to demonstrate the efficacy of the method. The quantity of charge sensed is controlled in such a way as to produce a voltage V_0 at the tap amplifier output which follows closely the input voltage V_i:

$$V_0 = V_i \Big/ \left(1 + \frac{1}{A}\right) \qquad (1)$$

where A is the open loop gain of the system. The magnitude of A determines the linearity of the response. Figure 3 shows the improvement in linearity, to almost over the full dynamic range, of a c.c.d. operated with an open-loop gain of 25, using this technique. A useful feature of this linearity arrangement is that if output taps are connected along the c.c.d. which are replicas of the first tap amplifier, then the input to any output tap transfer characteristic will be essentially linear. Charge loss in the c.c.d. will limit this relationship, but for good devices this is very small and is only a problem in very long registers.

4 C.C.D. Signal Processing Applications

C.c.d. analogue elements can be configured in three basic formations: (a) serial in/serial out, (b) parallel in/serial out, and (c) serial in/parallel out. Each arrangement can be used to form a variety of signal processing functions according to any specific requirement within the operating range.

4.1 Serial-in Serial-out Devices

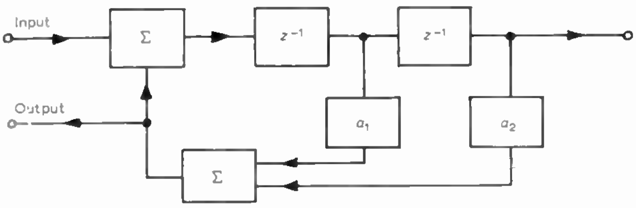
The basic property of a c.c.d., that its data rate is a direct function of the clock rate, and thus its total delay is variable, can be exploited in many applications. When used with a variable frequency oscillator, the delay can compensate multi-path transmission characteristics, a typical application being for echo suppression or ghosting in television reception. Its time-compression property can be used, for example, in receiving analogue transient data at a low frequency, and then clocking it out at a much higher frequency for subsequent processing. This up-conversion in frequency could be used to buffer a low-frequency signal into an s.a.w. processor or, for example, speed up a sampled audio signal so that it can be transmitted in the blank lines of a television video signal.[11] The necessary speed increase of about 400/1 is obtainable with current c.c.d. technology.

Because the digital processing of signals at high bandwidth is very involved and costly, great improvements in system hardware can result when a c.c.d. register is used to input data at a high rate and then output it into an analogue-to-digital converter at a much lower rate for subsequent digital processing.[12]

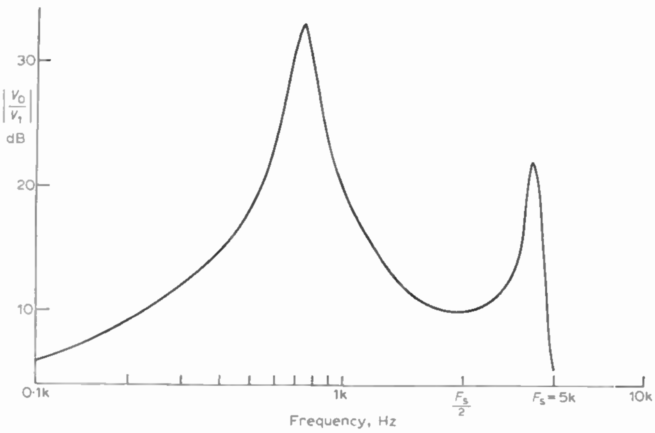
With the application of feedback around stages of the c.c.d. analogue devices can be made recursive and produce a useful class of filters. The basic type are integrators and cancellers. Video integrators[13] and m.t.i. clutter cancelling filters[14] have been implemented with c.c.d. technology.

Low-pass, band-pass and high-pass filters can be designed using a c.c.d. recursive approach, which are tunable according to the clock frequency. The filter characteristics can be programmed by adjusting the weighting resistors in the network. The accuracy and stability of the summing amplifiers and other components makes monolithic fabrication difficult. However, the recursive approach does offer an infinite impulse response which leads to good out-of-band rejection necessary for spectral filters.

Figure 4(b) shows results for a two-pole recursive filter operated as a resonator. The filter bandwidth is half the clock frequency, $F_s = 5$ kHz. Notice that aliasing occurs between this frequency and the filter bandwidth as for all sampled-data systems. The filter performance can be improved by including feedforward, as well as feedback, which would alter the circuit schematic shown in Fig. 4(a).



(a) Basic scheme $\frac{Y}{X} = \frac{a_1 z^{-1} + a_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}}$.



(b) Response of second-order c.c.d. resonator. Clock rate 5 kHz.

Fig. 4. Two-pole recursive filter suitable for c.c.d. implementation.

4.2 Multiplexed C.C.D.s

In normal operation, the n-phase per bit c.c.d. samples at $1/n$ times the clock rate. Thus the potential bandwidth of the c.c.d. is not normally used. Figure 5 shows a photograph of a 3-phase, 128-bit c.c.d. where the full bandwidth of the c.c.d. is realized.[15] Each of the three registers is sampled at a phase time, one after the other. Two important factors emerge for this phase-multiplexed device; firstly, the possible data rate is three times the equivalent rate for a 3-phase, linear, 128-bit c.c.d., and secondly, the equivalent length of the device is reduced by 2/3.

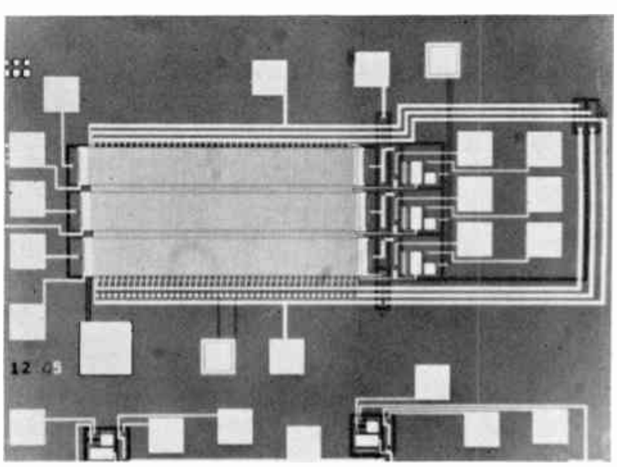


Fig. 5. Phase-multiplexed c.c.d.

Another multiplexed approach has led to the development of serial-parallel-serial-configuration memories suitable for the storage of analogue data. The features and design of these structures have been detailed elsewhere.[16]

4.3. C.C.D. Transversal Filters

The c.c.d. arrangement which satisfies many signal processing applications is the serial in/parallel out configuration. This structure can be used to perform beam focusing and beam forming for sensor arrays as in sonar applications.

For the device to be particularly useful, the tapping method must be non-destructive such that it does not appreciably affect the signal charge within the c.c.d. The dimensions of the tap circuit must be such that it can be located in a bit length of the c.c.d. (typically, a minimum size of 20 µm). However, in device designs where taps can be located each side of the device channel then this topology restriction can be relaxed. Also where recursive filters are required, perhaps only two or three taps are required which results in further relaxed layout restrictions.

When the output signals of the parallel taps are weighted and summed a general purpose transversal filter can be implemented. A schematic representation of a transversal filter is shown in Fig. 6. The delays, D_n, represent stages of an analogue, c.c.d. shift register clocked at frequency f_c. An input signal V_{in} is sampled

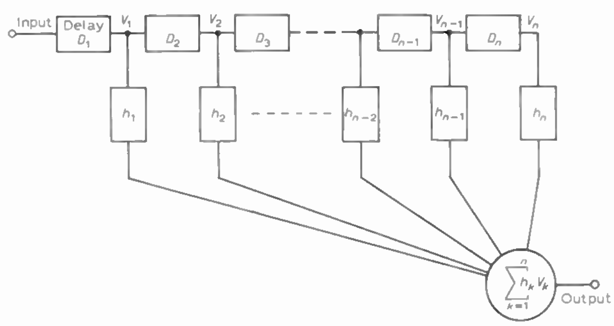


Fig. 6. Block diagram of sampled-data, transversal filter.

(by the first clock phase of an n-phase per bit c.c.d.) and these samples transferred along the register. The signals V_n at the nodes are non-destructively tapped, multiplied by the weighting coefficients, h_n, and then summed. For an N-stage device, the output response during the pth clock period can be given as a function of the filter parameters:

$$V_{out}(pT_c) = \sum_{k=1}^{N} h_k V_{in}(pT_c - kT_c) \qquad (2)$$

where T_c is the clock period. This type of filter is non-recursive and has a finite impulse response which is a function of the number of delay stages.

The transversal filter can be regarded as the basic electronic sub-system for many signal processing applications. The advantage of the c.c.d. microelectronic approach is that the possibility exists for performing the weighting, summing and sample-and-hold peripheral operations on-chip with the c.c.d. Applications of the c.c.d. transversal filter include:

(a) Code generators: p.n. sequence, chirp and analogue codes, for example.

(b) Waveform generators:

  (i) Chirp generation for sonar and ultrasonic applications.

  (ii) Hilbert transform realization: broadband 90° phase shifters for single sideband systems.

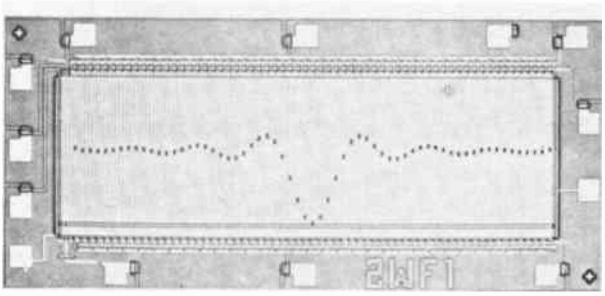
  (iii) The real and imaginary parts of complex linear chirps for performing the discrete Fourier or cosine transformations using the chirp-z transform algorithm.

(c) Broadband differentiators and integrators for synthesizing sampled-data control loops.

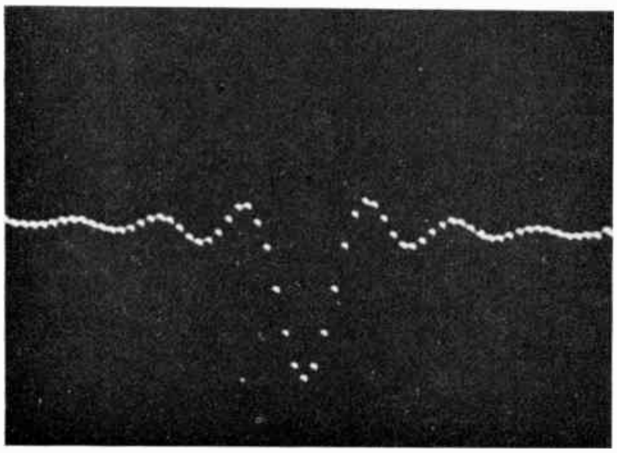
(d) Matched filter systems: Barker-coded, p.n. sequence and chirp waveforms, etc.

Two basic approaches exist for implementing c.c.d. transversal filters which broadly satisfy two filter types: (a) fixed filter,[17] and (b) variable filter.[15,18] Depending upon the application, the weights themselves may be made binary or analogue, fixed or variable. The techniques for performing the weighting and summing may be implemented monolithically or off-chip.

With the c.c.d. approach the impulse response of the filter which is required can be specified arbitrarily, as illustrated[19] in Fig. 7. The designed filter impulse response agrees very closely with the practical results.



(a) Photomicrograph



(b) Observed impulse response.

Fig. 7. Low-pass transversal filter. (GE, USA).

This good agreement simplifies the design of filters specified in the frequency domain, since the desired impulse response is the Fourier transform of the specified frequency response. The impulse response required in a matched filtering application can be obtained by a reverse procedure.

A powerful technique[17] for the realization of transversal filters obtains the result in one operation (see Fig. 8). The signals in the c.c.d. are non-destructively tapped, weighted and then summed, by monitoring the differential current in the clock lines. The scheme has

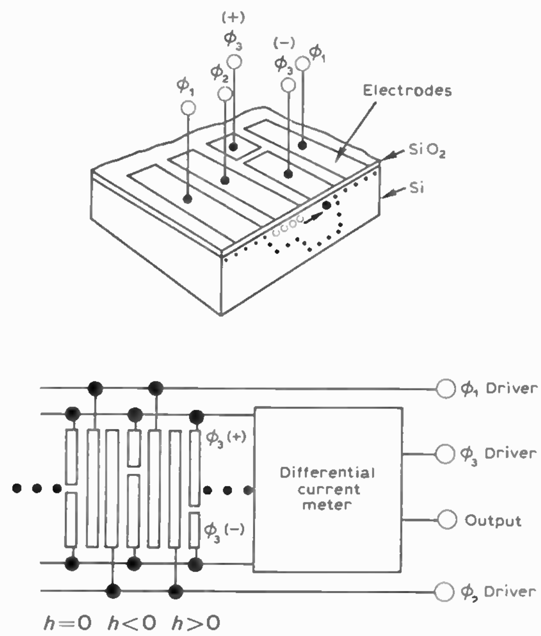
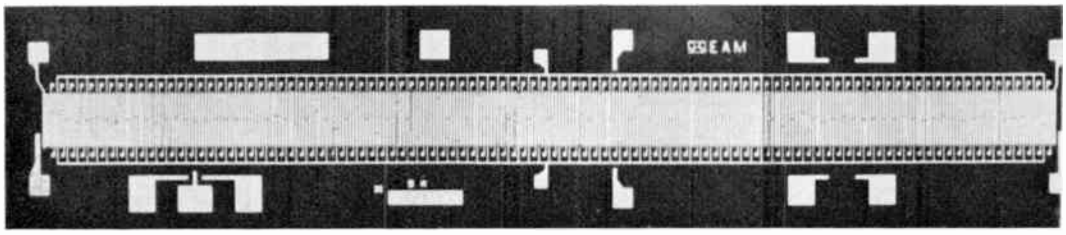
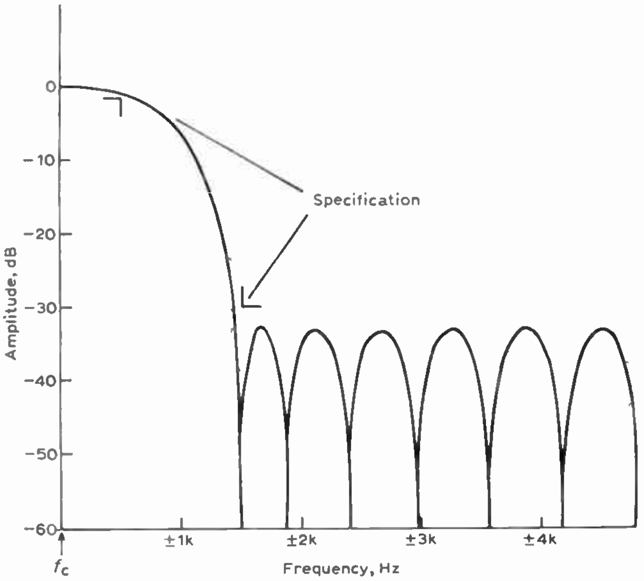


Fig. 8. Split-electrode technique for a c.c.d. transversal filter.

the advantage of great simplicity, low cost and high stability. However, once fabricated, the filter cannot be adjusted or trimmed. To achieve the signal weighting, one part of a split electrode goes to a 'positive' summing line and the other part to a 'negative' line. When the entire gate electrode is connected to the negative summing line, a weight of $h_k = -1$ results, whereas connecting the whole gate electrode to the positive line an $h_k = +1$ exists. By adjusting the position of the split all weighting values between $+1$ and -1 are possible, determined by the photolithography. Mask precision usually limits the tap weights to be rounded-off to an error of one part in 600. A surface, n-channel aluminium gate c.c.d. transversal filter is shown in Fig. 9(a), which has 99 fixed tap weights to give a bandpass characteristic. Practical results for this filter have been very close to theory, giving consistent results of greater than the specified 30 dB stop-band attenuation. This compares favourably with the 32 dB theoretical value as given in Fig. 9(b), indicating that the actual accuracy of the tap weights is considerably better than 1 %. Filters have been fabricated using this split-gate technique to over 800 bits in length.[20] For an n-phase c.c.d., it is possible to build n split-gate filters in one device[21] by tapping the device on each of the n-phases per bit. This gives limited programmability



(a) 99-bit, N-channel c.c.d.: channel width 200 μm, length 3·6 mm.



(b) Theoretical amplitude response. Centre frequency $f_c = 15{\cdot}5$ kHz.

Fig. 9. Bandpass filter implemented using a c.c.d. transversal filter with fixed tap weights. (GEC, UK).

with no additional cost or complexity, although the characteristics of the n filters must be specified before fabrication.

An alternative approach to the realization of transversal filters is to connect to a voltage amplifier each gate electrode to be sensed. Thus each tap is individually accessible. Different designs of sense amplifier exist and the tapping techniques are called variously floating-gate[22] and biased-gate.[10] Weighting of each sensed signal can be achieved, on-chip, by adjusting the gains of each tap or by modifying a weighting conductance with which it is in series. In one implementation[18] the weighting conductance is the source-to-drain conductance of an m.n.o.s. transistor. Essentially, with this technique, the possibility exists to manually switch or electronically program the weights. This approach is therefore especially applicable in secure communication links where a code can be periodically adjusted, and for adjusting the characteristics of a filter used in a variable parameter medium, for instance in sonar applications.

Figure 10 shows a 16-bit c.c.d. which has each tap individually accessible. This device is cascadable and can be used in time-variable weighting applications. Figure 11 shows the correlation peak of a c.c.d. matched filter receiver using the 13-bit Barker code. The peak-to-sidelobe ratio is about 13 : 1 which is the theoretical prediction. The sidelobe structure can be improved by careful design.

The relative merits of c.c.d. filters made with fixed and variable tap weights, as realized by split-gate and bit-accessible taps, are listed in Table 1. Where very long filters with fixed characteristics are required then c.c.d.s using the split-gate tapping technique have considerable advantages. For applications requiring programmable filter characteristics, with a much shorter register length, then individually accessible taps are necessary. It is possible to increase the electrical length of a programmable filter by changing the weighting coefficients appropriately after every N-clock pulses for

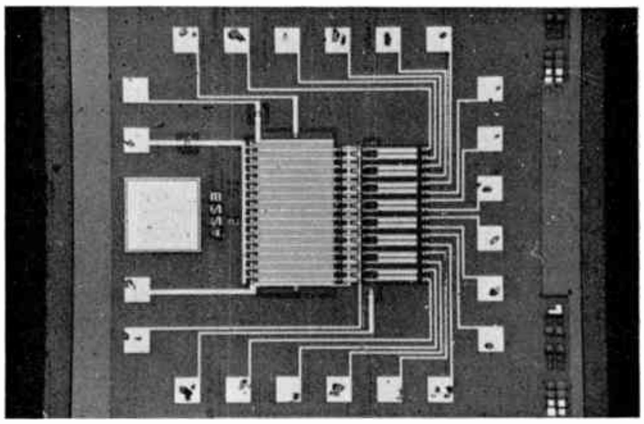


Fig. 10. 16-bit c.c.d. tapped delay line for programmable applications.

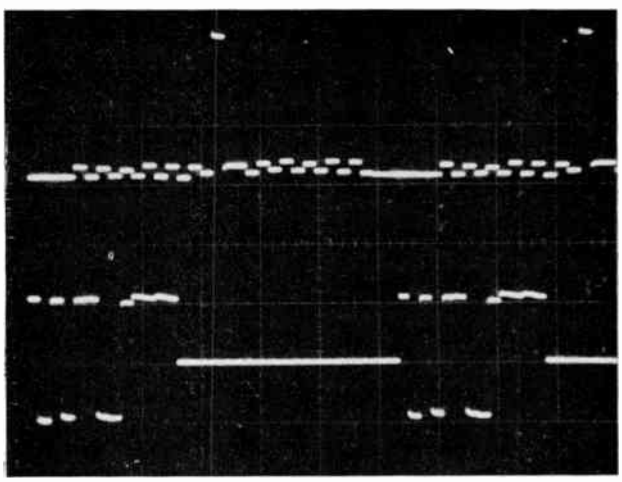


Fig. 11. Correlation response of a 13-bit Barker-coded matched filter using device of Fig. 10.
Vertical scale: 500 mV/div; horizontal scale 50 μs/div.

Table 1
Features of fixed tap weight and variable tap weight c.c.d. filters

	Fixed tap weight	Variable tap weight
Electronically programmable	n-filters possible for n-phase c.c.d.	yes
Simultaneous generation of multiple impulse responses	no	yes
Filter length (published)	800-bit	32-bit (long, using sequential programming of weights)
Cascadable	possible	yes
Cost for minor adjustments to filter characteristics	high	low
Serial correlator implementation	possible	directly
Feedback linearization	no	yes
Recursive filter implementation	no	yes

an N-gate electrode c.c.d. The code or impulse response is generated sequentially by successive impulsing of the c.c.d.

4.4. C.C.D. Correlators

In many applications the required basic component is the parallel correlator. This useful signal processing function can be achieved[23] by using two c.c.d.s, each with their individual tap outputs connected to 4-quadrant multipliers. The basic scheme is illustrated in Fig. 12. Sample-and-hold can be applied to each of the tap outputs of one c.c.d. to permit data to be clocked in at different rates into each register. The registers can be thought of as a reference register and a data register. The former can be programmed to condition the impulse response of the filter.

Figure 13 shows a chip photograph of a prototype c.c.d. integrated circuit with 32-stages for this purpose. In addition to two c.c.d.s, 32 m.o.s. multipliers and 32 sample-and-hold amplifiers are integrated monolithically. The impulse response of the filter can be programmed electronically by incorporating a digital-to-analogue converter with the reference register. Thus the filter can be controlled digitally.

The applications of this general signal processing sub-system are many-fold. It could be used as a key

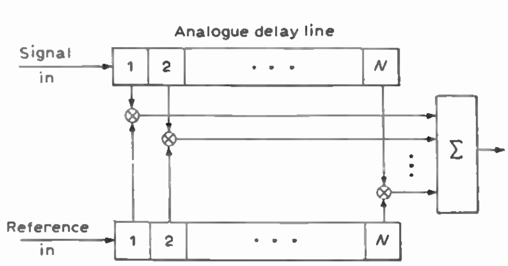


Fig. 12. C.c.d. parallel correlator schematic.

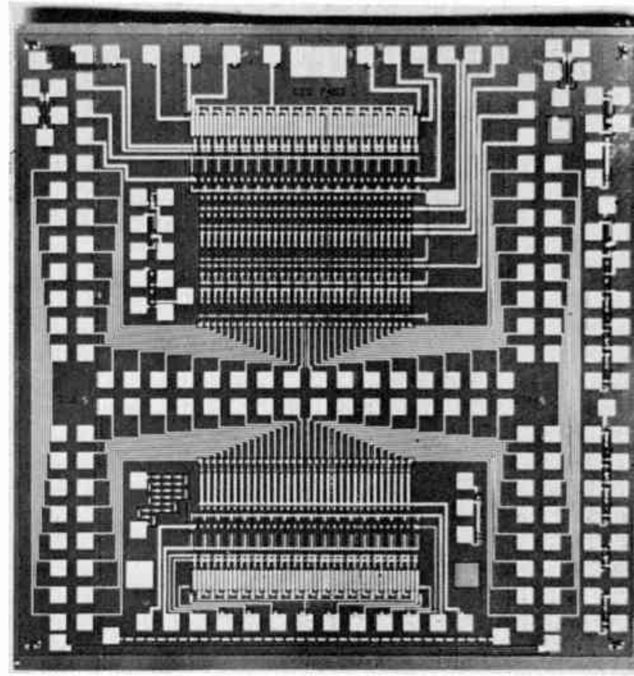


Fig. 13. 32-bit c.c.d. analogue correlator.

component in an adaptive filtering situation, or in any application where a time-varying pattern is to be generated or recognized. This component is fabricated using standard silicon-slice processing techniques and can be made in large quantities very cheaply. Where it can be used in a system, great advantages in cost, reliability and size over digital methods can result.

The main limitation to this direct method for realizing a transversal filter is likely to be the sensitivity of the various functions, i.e. delay, multiplication and summation, to manufacturing spreads and to the ambient conditions. Dispersion in the filter due to finite charge transfer efficiency could be compensated by careful design. Conditioning of the filter response due to variations in threshold voltage and the change in device parameters due to temperature are more serious. However, it should be possible to reduce these effects to an insignificant level for many applications.

4.5 C.C.D. Fourier Analysers

C.c.d. transversal filters can be used for the real-time computation of the discrete Fourier transform (d.F.t.) for a signal.[24] The d.F.t. can be found by digital implementation using the fast Fourier transform (f.F.t.) algorithm. However, by using the so-called chirp-z transform algorithm[25] (c.z.t.) the c.c.d. analogue computation of the d.F.t. can be made at 10 MHz data rates. This implementation of the c.z.t. in c.c.d. form has application in spectral analysis and bandwidth compression. The c.z.t. algorithm is derived from the definition of the discrete Fourier transform:[25]

$$F_k = \sum_{n=0}^{N-1} f_n \exp\left(-\mathrm{j}2\pi k_n/N\right) \qquad (3)$$

where f_n is the nth input sample, N is the number of transform points, and F_k is the kth Fourier coefficient.

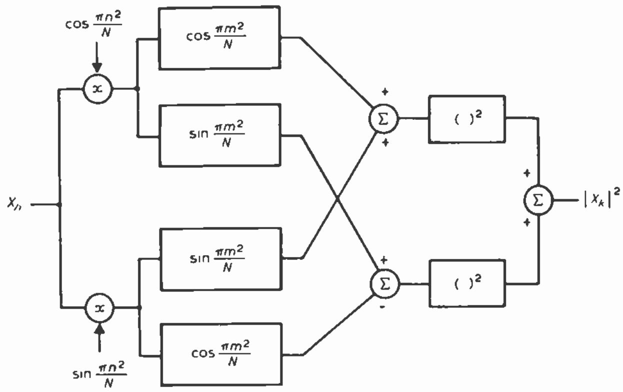


Fig. 14. Power spectrum analyser using chirp-z transform approach.

The derivation yields:

$$F_k = \exp(-j\pi k^2/N) \sum_{n=0}^{N-1} [f_n \exp(-j\pi n^2/N)] \times \times \exp[j\pi(n-k)^2/N] \quad (4)$$

The result of the c.z.t. algorithm allows the d.F.t. computation to be thought of as a series of operations involving the so-called chirp waveform $\exp(-j\pi n^2/N)$. The three-step sequence is (a) premultiply the signal f_n by a chirp waveform, (b) then perform a convolution between the resulting signal and a chirp waveform, and lastly (c) postmultiply the resulting signal by a chirp. In many applications, the power spectrum is required rather than the signal, component amplitude and phase. The postmultiply chirp operation can then be replaced by a squaring operation.[24] Figure 14 shows the system operations when only the power spectrum of a signal is to be found.

5 Conclusions

Charge-coupled devices offer unique advantages to signal processing systems technology. However, because of the high cost of custom integrated circuit design and the subsequent fabrication of c.c.d.s the advantages of the concept may not be commensurate with the development funding. These costs can be reduced substantially by the electronically programmable transversal filter as a general-purpose signal processing element. Weighting may be altered to synthesize an arbitrary impulse response by the selection and trimming of the weighting components. Such a technique exists using a thick film hybrid technology, where resistors values can be trimmed precisely even with the filter in operation. This approach should lead to the realization of a wide range of signal processing functions. The c.c.d. correlator provides an electronic means of obtaining an arbitrary impulse response.

Table 2
Charge-coupled devices versus digital processors

C.C.D. (Analogue)	Digital
low cost (m.o.s. microcircuit production)	flexible long time delays
small size	proven technology
low power	high precision
high reliability	good noise immunity high stability

For many applications the c.c.d. offers significant advantages over digital processors, as summarized in Table 2. The analogue c.c.d. processor can achieve the advantages of low cost, small size, low power and increased reliability. However, the digital approach will undoubtedly dominate in areas where high precision of computation is required.

In many systems it seems very likely that the advantages of several approaches could be combined to form a hybrid system. For example, a c.c.d. time compressor combined with an s.a.w. processor, or a c.c.d. buffer and a digital system via an analogue-to-digital converter. Another distinct possibility for future systems results from using c.c.d. digital processors, which are predicted to combine all the advantages presented in Table 2.

6 Acknowledgments

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The synthesis of ladder networks with resistances at both ends by the recurrent-continuant method

DHIRENDRA KUMAR JHA,
B.Sc., M.Sc., Ph.D.*
and
SHYAMA CHARAN PRASAD,
B.Sc., M.Sc., Ph.D.*

SUMMARY

The recurrent-continuant method of synthesizing a ladder network due to Holbrook is limited to the lossless quadrupoles terminated in resistance at only one end. The technique has been modified to cover the general class of lossless quadrupoles terminated in resistances at both the ends. The proposed synthesis procedure starts with a given realizable polynomial which is separated into two realizable component polynomials, one of the same order and the other of one order less under the condition that the continuants corresponding to the component polynomials are such that one becomes the first minor of the other. By applying simple mathematical manipulations, the final continuant is formed out of these continuants. The element values of the final continuant are evaluated by solving certain sets of equations. The sensitivity of the transfer function of the network with respect to the terminal resistance, the non-realizability of the characteristic polynomial for a given terminal resistance ratio, and the multiple sets of values of the circuit elements for a given characteristic have also been investigated.

In the case of active *RC* low-pass ladder networks Nesbitt has presented a technique for transforming the recurrent determinant into the continuant determinant provided the elements of the main diagonal of the latter are specified. His method however does not provide a solution for active *RC* ladder networks which are terminated in a resistance at the output end. In this paper a modified transformation technique, applicable to resistively-terminated active *RC* ladder networks, is proposed.

* *Department of Physics, Langat Singh College, University of Bihar, Muzaffarpur 842001, Bihar, India.*

Part 1: Passive Lossless Networks

1 Introduction

The reciprocal of the voltage transfer function (r.v.t.f.) of a low-pass ladder network may be represented by determinants of special forms termed the recurrent and the continuant. The recurrent to the continuant transformation is one of the convenient methods of synthesizing a ladder network. The Holbrook technique[1] of accomplishing such a transformation is well known. It has been applied to the simple case of a passive, lossless, low-pass ladder network terminated in resistance at only one end (s.t.l.l.l.) and it does not seem to apply directly to the general class of passive, lossless, low-pass ladder networks terminated in resistance at both the ends (d.t.l.l.l.). In this paper a modified technique of accomplishing the recurrent-continuant transformation is proposed by the authors which may be used to synthesize the general class of d.t.l.l.l. There are a few interesting aspects of this synthesis procedure. It explains the non-realizability of a response polynomial for certain (usually high) values of the terminal resistance ratio. It also provides different sets of values of the network elements corresponding to the same response polynomial. The sensitivity of the transfer function of the network with respect to the terminal resistance could be easily obtained through this synthesis technique. Another novelty of the method lies in the fact that it correlates the output voltages of two s.t.l.l.l. of orders n and $n-1$ with that of an nth order d.t.l.l.l. in a very simple manner. The method has been illustrated for 2nd and 3rd-order filters.

2 The Continuant and the Recurrent

2.1 The Circuit and the Continuant

An nth order low-pass lossless ladder network terminated in resistances R and unity at the input and output ends is shown in Fig. 1. The inductances and the capacitances in the series and shunt branches of the network are labelled h_i. All the element values are normalized with respect to the resistance at the output end. R equals the ratio of the input and output end resistances and it is termed the terminal resistance ratio.

The continuant corresponding to the reciprocal voltage transfer function $T(s)$ of the network is given by

$$T(s) = \begin{vmatrix} R+h_1 s & 1 & 0 & . & 0 & 0 & 0 \\ -1 & h_2 s & 1 & . & 0 & 0 & 0 \\ 0 & -1 & h_3 s & . & 0 & 0 & 0 \\ . & . & . & . & . & . & . \\ 0 & 0 & 0 & . & h_{n-1} s & 1 & 0 \\ 0 & 0 & 0 & . & -1 & h_n s & 1 \\ 0 & 0 & 0 & . & 0 & -1 & 1 \end{vmatrix} \qquad (1)$$

In the d.c. case ($s = 0$) and

$$T(0) = R+1. \qquad (2)$$

2.2 The Recurrent

The $T(s)$ of an nth order low-pass network will be an nth order polynomial in s belonging to the Hurwitz class and the recurrent corresponding to this polynomial

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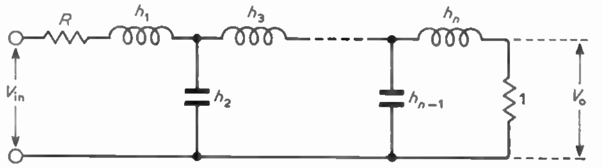

Fig. 1. An nth-order low-pass lossless ladder doubly terminated in resistances.

will be an $(n+1)$th order determinant whose first row is constituted by the coefficients of the response polynomial, the main diagonal (excluding the first element) consists of the polynomial variable s, the lower adjacent diagonal is made up entirely of -1 elements and all other elements are zero.

3 The Synthesis Procedure

3.1 The R.V.T.F. $T(s)$ of a D.T.L.L.L.

Let the transfer function required to be synthesized be described by a polynomial $\bar{P}_n(s)$:

$$\bar{P}_n(s) = \sum_{i=0}^{n} \bar{a}_i s^i. \tag{3}$$

As the d.c. level of the d.t.l.l.l. is $R+1$, the $T(s)$ of the desired network may be described by a polynomial $P_n(s)$ such that

$$T(s) = P_n(s) = \sum_{i=0}^{n} a_i s^i \tag{4}$$

where

$$a_i = \frac{R+1}{\bar{a}_0}\bar{a}_i \quad (i = 0, 1, 2, \ldots, n). \tag{5}$$

3.2 Polynomial Decomposition

The polynomial $P_n(s)$ is separated into two realizable polynomials $P_n(s)$ and $P''_{n-1}(s)$ of orders n and $n-1$ respectively under the restriction that the continuants Δ' and Δ'' corresponding to the polynomials $P'_n(s)$ and $P''_{n-1}(s)/(a_0-1)$ are such that Δ'' becomes the first minor of Δ' (i.e. $\Delta'' = \Delta'_{11}$).

Let the component polynomials be written as

$$P'_n(s) = \sum_{i=1}^{n} b_i s^i + 1$$

$$P''_{n-1}(s) = \sum_{i=1}^{n-1} c_i s^i + (a_0 - 1) \tag{6}$$

such that

$$P_n(s) = P'_n(s) + P''_{n-1}(s).$$

The relations (5) and (6) impose the conditions:

$$\begin{aligned} a_0 &= R+1 \\ a_i &= b_i + c_i \quad (i = 1, 2, \ldots, n-1) \\ a_n &= b_n \end{aligned} \tag{7}$$

It is to be noted that the coefficients a_i, b_i and c_i are all real, positive and obey the Hurwitz condition.

3.3 The Continuants of the Component Polynomials

The continuants Δ' and Δ'' corresponding to the polynomials $P'_n(s)$ and $P''_{n-1}(s)/(a_0-1)$ are obtained by applying Holbrook's technique[1] and these may be written in the form:

$$\Delta' = \begin{vmatrix} h'_1 s & 1 & 0 & \cdot & 0 & 0 & 0 \\ -1 & h'_2 s & 1 & \cdot & 0 & 0 & 0 \\ 0 & -1 & h'_3 s & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \cdot & h'_{n-1} s & 1 & 0 \\ 0 & 0 & 0 & \cdot & -1 & h'_n s & 1 \\ 0 & 0 & 0 & \cdot & \cdot & -1 & 1 \end{vmatrix} \tag{8}$$

and

$$\Delta'' = \begin{vmatrix} h''_1 s & 1 & 0 & \cdot & 0 & 0 & 0 \\ -1 & h''_2 s & 1 & \cdot & 0 & 0 & 0 \\ 0 & -1 & h''_3 s & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \cdot & h''_{n-2} s & 1 & 0 \\ 0 & 0 & 0 & \cdot & -1 & h''_{n-1} s & 1 \\ 0 & 0 & 0 & \cdot & 0 & -1 & 1 \end{vmatrix} \tag{9}$$

Since Δ'' is the first minor of Δ', it implies that

$$h'_{i+1} = h''_i \quad (= h_{i+1}) \quad (i = 1, 2, \ldots, n-1). \tag{10}$$

3.4 The Final Continuant

The continuant Δ corresponding to the polynomial $P_n(s)$ is obtained through the relation:

$$\Delta = P_n(s) = \Delta' + (a_0 - 1)\Delta''. \tag{11}$$

The term $(a_0-1)\Delta''$ is now written as a determinant of $(n+1)$th order by increasing the order of Δ'' by one and absorbing the factor (a_0-1) inside it. It then takes the form:

$$(a_0-1)\Delta'' = \begin{vmatrix} (a_0-1) & 1 & 0 & \cdot & 0 & 0 & 0 \\ 0 & h_2 s & 1 & \cdot & 0 & 0 & 0 \\ 0 & -1 & h_3 s & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \cdot & h_{n-1} s & 1 & 0 \\ 0 & 0 & 0 & \cdot & -1 & h_n s & 1 \\ 0 & 0 & 0 & \cdot & 0 & -1 & 1 \end{vmatrix} \tag{12}$$

The addition of the determinants Δ' and $(a_0-1)\Delta''$ given by relations (8) and (12) is easily achieved since both are of the same order $(n+1)$ and except for the elements in the first column, all other elements are identical (relation 10).

The final continuant Δ takes the form:

$$\Delta = \begin{vmatrix} (a_0-1)+h_1 s & 1 & 0 & \cdot & 0 & 0 & 0 \\ -1 & h_2 s & 1 & \cdot & 0 & 0 & 0 \\ 0 & -1 & h_3 s & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \cdot & h_{n-1} s & 1 & 0 \\ 0 & 0 & 0 & \cdot & -1 & h_n s & 1 \\ 0 & 0 & 0 & \cdot & 0 & -1 & 1 \end{vmatrix} \tag{13}$$

The elements h'_i and h''_i are explicit functions of b_i and c_i. The solutions of equations (7) and (10) give the values of b_i and c_i and of these only those values are acceptable which are positive real. The determination of the coefficients of the component polynomials then lead to the values of h'_i or h''_i. The synthesis is thus completed.

4 Illustration

4.1 The Second-order Network

Let a realizable second-order polynomial be given by

$$\bar{P}_2(s) = \bar{a}_2 s^2 + \bar{a}_1 s + \bar{a}_0. \qquad (14)$$

If the prescribed terminal resistance ratio be R, its $T(s)$ will be given by

$$T(s) = P_2(s) = a_2 s^2 + a_1 s + a_0 \qquad (15)$$

where

$$a_i = \frac{R+1}{\bar{a}_0}\bar{a}_i \quad (i = 0, 1, 2). \qquad (16)$$

The component polynomials will be

$$P_2'(s) = b_2 s^2 + b_1 s + 1, \quad P_1''(s) = c_1 s + R \qquad (17)$$

where

$$a_1 = b_1 + c_1 \quad \text{and} \quad a_2 = b_2. \qquad (18)$$

Also

$$\Delta' = P_2'(s) = \begin{vmatrix} b_1 s & 1 & 0 \\ -1 & \frac{b_2}{b_1}s & 1 \\ 0 & -1 & 1 \end{vmatrix} \qquad (19)$$

and

$$\Delta'' = \frac{P_1''(s)}{R} = \begin{vmatrix} \frac{c_1}{R}s & 1 \\ -1 & 1 \end{vmatrix} \qquad (20)$$

so that

$$P_1''(s) = \begin{vmatrix} R & 1 & 0 \\ 0 & \frac{c_1}{R}s & 1 \\ 0 & -1 & 1 \end{vmatrix} \qquad (21)$$

Further from the condition (10),

$$b_2/b_1 = c_1/R. \qquad (22)$$

The continuant Δ is obtained by adding equations (19) and (21):

$$\Delta = \begin{vmatrix} R+b_1 s & 1 & 0 \\ -1 & \frac{b_2}{b_1}s & 1 \\ 0 & -1 & 1 \end{vmatrix} \qquad (23)$$

In order to draw the physical network corresponding to Δ (relation 23) it is reduced from the third-order (odd) to second-order (even) continuant:

$$\Delta = \begin{vmatrix} R+b_1 s & 1 \\ -1 & 1+\frac{b_2}{b_1}s \end{vmatrix} \qquad (24)$$

Δ now represents a ladder network shown in Fig. 2 whose element values are

$$h_1 = b_1 \quad \text{and} \quad h_2 = b_2/b_1. \qquad (25)$$

The coefficients b_i $(i = 1, 2)$ are solved through the relations (18) and (22):

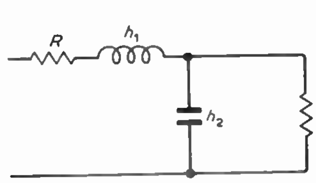

Fig. 2. A second-order d.t.l.l.l.

$$b_1 = \tfrac{1}{2}(a_1 \pm \sqrt{a_1^2 - 4a_2 R}) \qquad (26a)$$

$$b_2 = a_2. \qquad (26b)$$

It is evident from relation (26a) that b_1 may have two acceptable solutions so that the component polynomials as well as the circuit elements may have two different sets of values in this case.

4.1.1 *Numerical example*

Let the transfer function to be synthesized be a Chebyshev characteristic with a ripple factor 2 dB:

$$\bar{P}_2(s) = s^2 + 0{\cdot}8038\, s + 0{\cdot}6368. \qquad (27)$$

If the terminal resistance ratio of the network to be synthesized be 0·3, then according to relations (15) and (16) $T(s)$ will be given by

$$T(s) = P_2(s) = 2{\cdot}0415\, s^2 + 1{\cdot}7410\, s + 1{\cdot}3000. \qquad (28)$$

The coefficients b_i $(i = 1, 2)$ of one of the component polynomials (relation 17) are now evaluated by solving the relation (26). These are found to be

$$b_1 = 1{\cdot}2517 \quad \text{or} \quad 0{\cdot}4893$$

and

$$b_2 = 2{\cdot}0415. \qquad (29)$$

Since b_1 has two acceptable values the component polynomials (relation 17) and the circuit elements (relation 25) will have two sets of values:

$$\begin{aligned} &\text{First set} \\ &P_2'(s) = 2{\cdot}0415s^2 + 1{\cdot}2517s + 1{\cdot}0000 \\ &P_1''(s) = 0{\cdot}4893s + 0{\cdot}3000 \\ &h_1 = 1{\cdot}2517 \\ &h_2 = 1{\cdot}6310 \\ &\text{Second set} \\ &P_2'(s) = 2{\cdot}0415s^2 + 0{\cdot}4893s + 1{\cdot}0000 \\ &P_1''(s) = 1{\cdot}2517s + 0{\cdot}3000 \\ &h_1 = 0{\cdot}4893 \\ &h_2 = 4{\cdot}1723 \end{aligned} \qquad (30)$$

4.2 The Third-order Network

Corresponding to the third-order realizable polynomial

$$\bar{P}_3(s) = \sum_{i=0}^{3} \bar{a}_i s^i,$$

the $T(s)$ of the d.t.l.l.l. to be synthesized is written as

$$T(s) = P_3(s) = \sum_{i=0}^{3} a_i s^i \qquad (31a)$$

where

$$a_i = \frac{R+1}{\bar{a}_0}\bar{a}_i \quad (i = 0, 1, 2, 3) \qquad (31b)$$

R being the terminal resistance ratio.

As usual the component polynomials $P_3'(s)$ and $P_2''(s)$ are given by

$$P_3'(s) = \sum_{i=1}^{3} b_i s^i + 1$$

and

$$P_2''(s) = \sum_{i=1}^{2} c_i s^i + R, \tag{32}$$

where

$$a_3 = b_3$$
$$a_i = b_i + c_i \quad (i = 1, 2).$$

By applying Holbrook's technique Δ' and Δ'' corresponding to polynomials $P_3'(s)$ and $P_2''(s)/R$ are obtained as

$$\Delta' = \begin{vmatrix} \frac{b_1 b_2 - b_3}{b_2} s & 1 & 0 & 0 \\ -1 & \frac{b_2^2}{b_1 b_2 - b_3} s & 1 & 0 \\ 0 & -1 & \frac{b_3}{b_2} s & 1 \\ 0 & 0 & -1 & 1 \end{vmatrix} \tag{33}$$

and

$$\Delta'' = \begin{vmatrix} \frac{c_1}{R} s & 1 & 0 \\ -1 & \frac{c_2}{c_1} s & 1 \\ 0 & -1 & 1 \end{vmatrix} \tag{33b}$$

On imposing the condition $\Delta'' = \Delta'_{11}$, the following conditions are to be fulfilled:

$$\frac{b_2^2}{b_1 b_2 - b_3} = \frac{c_1}{R}$$
$$\frac{b_3}{b_2} = \frac{c_2}{c_1}. \tag{34}$$

The final continuant Δ is found to be

$$\Delta = \begin{vmatrix} R + \frac{b_1 b_2 - b_3}{b_2} s & 1 & 0 & 0 \\ -1 & \frac{b_2^2}{b_1 b_2 - b_3} s & 1 & 0 \\ 0 & -1 & \frac{b_3}{b_2} s & 1 \\ 0 & 0 & -1 & 1 \end{vmatrix} \tag{35}$$

The network corresponding to this continuant is shown in Fig. 3.

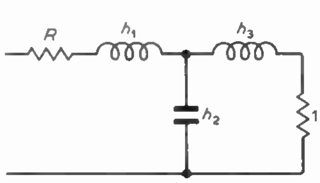

Fig. 3. A third-order d.t.l.l.l.

The network elements h_i are given by

$$h_1 = \frac{b_1 b_2 - b_3}{b_2} \tag{36a}$$

$$h_2 = \frac{b_2^2}{b_1 b_2 - b_3} \tag{36b}$$

$$h_3 = \frac{b_3}{b_2}. \tag{36c}$$

The solutions for the coefficients b_i $(i = 1, 2, 3)$ are obtained as

$$b_1 = \frac{(a_2 - b_2) b_2}{b_3} \tag{37a}$$

$$b_2^4 - 2a_2 b_2^3 + (a_1 a_3 + a_2^2) b_2^2 - (a_1 a_2 a_3 + 2a_3^2 - a_3^2 R) b_2 + a_2 a^3 = 0 \tag{37b}$$

$$b_3 = a_3. \tag{37c}$$

The equation (37b) is a quartic in b_2. According to Descartes's rule of signs it can have only positive real or imaginary roots. The number of positive roots will be 4 or 2. Of these roots only those will be accepted whose values are less than a_2.

Once b_2 is known b_1 is found from the relation (37a) and the synthesis is completed.

4.2.1 *Numerical example*

Let the transfer function to be synthesized be the Butterworth characteristic:

$$\bar{P}_3(s) = s^3 + 2s^2 + 2s + 1.$$

If the terminal resistance ratio of the network to be designed be unity then according to the relation (31), $T(s)$ will be given by

$$T(s) = 2s^3 + 4s^2 + 4s + 2. \tag{38}$$

Equation (37b) now reduces to

$$(b_2 - 2)^4 = 0 \tag{39a}$$

while

$$b_3 = 2. \tag{39b}$$

Equations (39a, b) and (37a) yield $b_2 = 2$ and $b_1 = 2$.

The equation (36) now gives

$$h_1 = 1, \quad h_2 = 2, \quad h_3 = 1. \tag{40}$$

It is to be pointed out that equation (39a) has four positive real roots all of which are coincident so the circuit elements h_i have only single set of values.

5 Special Features of the Technique

5.1 The Terminal Resistance Ratio and the Realizability

As the polynomials $\bar{P}_n(s)$, $P_n(s)$, $P_n'(s)$ and $P_{n-1}''(s)$ belong to the Hurwitz class, their coefficients must be positive real. It is seen from the equations (26a) and (33b) that the solutions for b_i involve R, and b_i may become imaginary for certain value of R although $\bar{a}_i$ and a_i remain always positive and real. A d.t.l.l.l. having a prescribed realizable frequency response $\bar{P}_n(s)$ may not therefore be realizable for all arbitrary values of R.

For example, in the second-order case, the network is synthesized only if

$$R \leqslant \frac{\bar{a}_1^2/\bar{a}_0}{(4\bar{a}_2 - \bar{a}_1^2/\bar{a}_0)}. \tag{41}$$

If R be greater than this limiting value, the coefficient b_1 becomes complex and the network is non-realizable.

The limiting values of R for different types of polynomial are provided in Table 1.

Table 1

Polynomial	Limiting value of R
Bessel	3·000
Butterworth	1·000
Chebyshev, 1/10 dB ripple	0·737
Chebyshev, 1/4 dB ripple	0·646
Chebyshev, 1/2 dB ripple	0·504
Chebyshev, 1 dB ripple	0·376
Chebyshev, 2 dB ripple	0·336
Chebyshev, 3 dB ripple	0·171

5.2 Different Sets of Network Elements

The evaluation of b_i involves the solution of non-linear equations of high order. For instance, in the cases of 2nd and 3rd networks, the equations for b_1 and b_2 are respectively quadratic and quartic (equations (26a) and (37b)). As the network elements are controlled by the coefficients b_i, there could be various sets of element values corresponding to a given response polynomial.

In the case of the 2nd-order network, two sets of element values have been obtained. In this case it has also been found that one of the set of values is not contained explicitly in Weinberg's table of element values.[2]

5.3 Sensitivity

The sensitivity of the transfer function $T(s)$ of a given network with respect to a network parameter x is defined by

$$S_x^T = \frac{x}{T}\frac{\partial T}{\partial x},$$

so that

$$S_R^T = \frac{R}{T}\frac{\partial T}{\partial R} = \frac{R}{T}\frac{\partial \Delta}{\partial R} = \frac{R}{T}\Delta_{11}$$

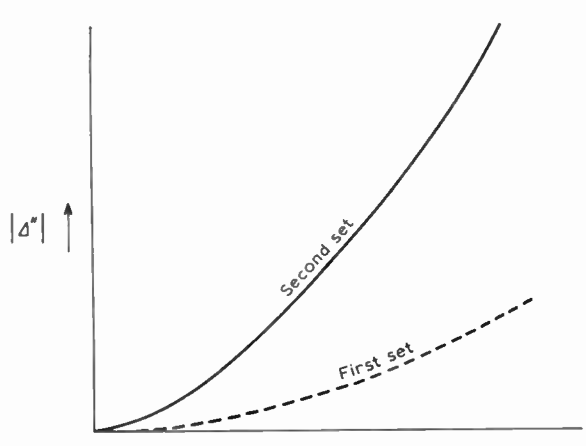

Fig. 4. $|\Delta''|$—frequency characteristics of a d.t.l.l.l.

or,

$$S_R^T = \frac{R}{T}\Delta'' = \frac{P''_{n-1}(s)}{T(s)}. \tag{42}$$

The sensitivity with respect to the terminal resistance ratio R of the various realizable ladder network having the same response polynomial $P_n(s)$ is therefore directly dependent on their respective component polynomial $P''_{n-1}(s)$. A plot of $|\Delta''|$ against the frequency for two alternative networks in the 2nd-order case having a Chebyshev frequency characteristic with a 1/4 dB ripple and terminal resistance ratio 1/2 is shown in Fig. 4. The sensitivity of the network designed from the second set of element values is high.

5.4 Voltage Transfer Characteristics of a Doubly and Two Singly Terminated Low-pass Ladders

In Section 3.4 it has been shown that

$$\Delta = \Delta' + R\Delta''$$

so that one could write

$$\left[\frac{V_{\text{in}}}{V_0}\right]_n^D = \left[\frac{V_{\text{in}}}{V_0}\right]_n^S + R\left[\frac{V_{\text{in}}}{V_0}\right]_{n-1}^S \tag{43}$$

where the superscripts D and S denote the double and single termination in resistance of the networks and the subscripts n and $n-1$ the orders.

If V_0 be kept unity then the equation (43) reduces to

$$[V_{\text{in}}]_n^D = [V_{\text{in}}]_n^S + R[V_{\text{in}}]_{n-1}^S. \tag{44}$$

Thus for a unit output voltage, equation (44) provides a relationship between the input voltages of a d.t.l.l.l. of order n and two s.t.l.l.l. of orders n and $n-1$, the latter networks being formed from the given d.t.l.l.l. by deleting the input end resistance in the first case and the input end resistance together with the first reactive element in the second.

6 Conclusions (Part 1)

The recurrent-continuant transformation method of synthesizing a ladder network has been extended to the general class of low-pass lossless ladder networks with resistance at both the input and output ends. Since there exists a simple frequency transformation[3] between low-pass and the high-pass, band-pass etc. networks, the treatment applies to these classes of networks as well. The method has the advantage that the sensitivity of the r.v.t.f. of the network with respect to the terminal resistance is obtained in terms of the component polynomial which is determined explicitly in the synthesis procedure. The limiting value of the terminal resistance ratio for a realizable characteristic polynomial has been calculated for the 2nd-order filter networks. It has been shown that the Chebyshev characteristic with a ripple factor 2 dB is realizable for $R = 0·25$. In fact it has been realized with $R = 0·3$. Weinberg's table[2] does not provide the element values for $R \geqslant 0·25$. The method also provides various sets of element values for the same transfer characteristic and terminal resistance ratio.

Part 2: Active *RC* Networks

7 Introduction

An active configuration whose reciprocal of the voltage transfer function (r.v.t.f.) may be represented by a continuant has been proposed by Holbrook.[1] An active *RC* ladder network employing feedback amplifiers may be developed from this configuration and the synthesis of such a network may be achieved through the recurrent-continuant transformation. Nesbitt[4] has described a procedure to accomplish this transformation when the passive elements of the network are specified. However, this procedure may be used with low-pass networks having only a capacitance at the output end. This limitation has been overcome by proposing a modified transformation procedure which is applicable to networks with resistive elements both at the output and input ends. The third-order Butterworth filter has been realized as an illustration.

8 The Continuant and the Recurrent

8.1 The Circuit and the Continuant

The proposed nth-order low-pass active *RC* ladder network is shown in Fig. 5. The immittances R_i and C_i ($i = 1, 2, \ldots, n$) are normalized with respect to the output terminal resistance R_0 which is fixed to be unity. A_i ($i = 1, 2, \ldots, n-1$) is the amplification factor of the feedback amplifier whose input and output impedances equal infinity and zero respectively.

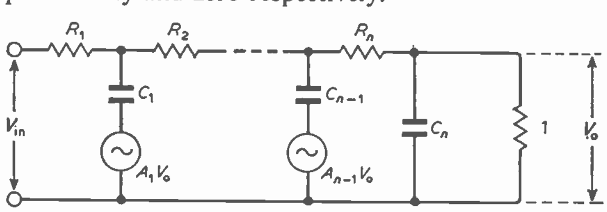

Fig. 5. Active *RC* ladder network with resistance at both ends.

The r.v.t.f. $T(s)$ of this network (Fig. 5) may be written as a continuant determinant of order $2n$ given by

$$T(s) = \begin{vmatrix} R_1 & 1 & 0 & . & 0 & 0 & 0 \\ -1 & C_1 s & 1 & . & 0 & 0 & -A_1C_1 s \\ 0 & -1 & R_2 & . & 0 & 0 & 0 \\ . & . & . & . & 0 & 0 & . \\ 0 & 0 & 0 & . & C_{n-1}s & 1 & -A_{n-1}C_{n-1}s \\ 0 & 0 & 0 & . & -1 & R_n & 1 \\ 0 & 0 & 0 & . & 0 & -1 & 1+C_n s \end{vmatrix} \tag{45}$$

In the d.c. case ($s = 0$)

$$T(0) = R+1 \tag{46}$$

where R denotes the ratio of the total resistance in the series branches of the network and the output terminal resistance.

8.2 The Recurrent

The $T(s)$ will be an nth-order polynomial

$$P_n(s)\left(=\sum_{i=0}^{n} a_i s^i\right)$$

and it may be described as usual by a recurrent determinant of order $n+1$. The recurrent is modified by introducing dummy rows and columns such that its order rises to $2n$. The modified recurrent is given by

$$T(s) = \begin{vmatrix} a_n & a_{n-1} & 0 & a_{n-2} & . & 0 & a_1 & 0 & a_0 \\ -1 & s & 0 & 0 & . & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & . & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & s & . & 0 & 0 & 0 & 0 \\ . & . & . & . & . & . & . & . & . \\ 0 & 0 & 0 & 0 & . & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & . & 0 & s & 0 & 0 \\ 0 & 0 & 0 & 0 & . & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & . & 0 & -1 & 0 & s \end{vmatrix} \tag{47}$$

Evidently

$$a_0 = R+1. \tag{48}$$

9 Synthesis Procedure

9.1 The R.V.T.F. $T(s)$ of the Network

The r.v.t.f. $T(s)$ of the network to be synthesized may be obtained from the prescribed characteristic and the passive elements by the method described in Part 1. Once (Ts) is known, the modified recurrent (relation (47)) may be written simply by inspection.

9.2 The Transformation Procedure

The transformation procedure involves certain mathematical manipulations which do not affect the value of the determinant but change its form.

In order to explain these operations the following notations are introduced.

1. $R_{p,q}(x)$ denotes the operation of adding x times the elements of the pth row of the determinant to its corresponding elements in the qth row.
2. $C_{p,q}(x)$ denotes the operation of adding x times the elements of the pth column of the determinant to its corresponding elements in the qth row.
3. $M_q^p(x)$ denotes the division of each of the elements of the pth row by x and the simultaneous multiplication of every element of the qth column by the same factor.

In all these operations x stands for real numbers.

The required transformation is now achieved through operations which are performed in successive steps in the manner outlined below:

(The notation $d_{i,j}$ will be used to denote the element in the ith row and jth column of the determinant.)

Step 1. The lower adjacent diagonal elements of the determinant (47) are set to -1 value and all other elements in the lower half of the determinant to zero. These are achieved through the operations

(a) $C_{p,q}(-1)$ and (b) $R_{p,q}(-1)$ where $p = 3,5,\ldots, 2n-1$ and $q = p-1$ in case (a) and $q = p+1$ in case (b).

Step 2. The magnitude of the element $d_{i,i}$ ($i = 1, 2, \ldots, 2n$) of the determinant is adjusted to the specified value of the corresponding passive element. For this the operations $M^p_{p-1}(x)$ $(p = 2, 3, \ldots, 2n)$ are carried out, the factor x in each case being suitably chosen.

Step 3. This requires the single operation $C_{2n-1,2n}(-1)$.

Step 4. The values of the upper adjacent diagonal elements of the determinant are fixed to $+1$ value and the rest of the elements in the upper-half right-hand-side of the determinant are made zero. The last column is however excluded from these operations.

It is essential that the operations should proceed from left to right and start with the element $d_{1,2}$ and before any $d_{i,i+1} (i = 1, 2, \ldots, 2n-2)$ is made unity, all the elements above $d_{i,i+1}$ in the $(i+1)$th column be made to vanish.

This involves the operations $R_{p,q}(x)$ and $C_{p,q}(x)$ where appropriate values of x are selected.

These operations yield the determinant of the following form:

$$T(s) = \begin{vmatrix} R_1 & 1 & 0 & . & 0 & 0 & g'_1 \\ -1 & C_1 s & 1 & . & 0 & 0 & g'_2 + g''_2 s \\ 0 & -1 & R_2 & . & 0 & 0 & g'_3 \\ . & . & . & . & . & . & . \\ 0 & 0 & 0 & . & C_{n-1} s & 1 & g'_{2n-2} + g''_{2n-2} s \\ 0 & 0 & 0 & . & -1 & R_n & -1 \\ 0 & 0 & 0 & . & 0 & -1 & 1 + C_n s \end{vmatrix} \quad (49)$$

The symbol g_i (primed or unprimed) denotes real numbers.

Step 5. All the singly primed g terms are eliminated from the last ($2n$th) column of the determinant (49), and the element $d_{2n-1\ 2n}$ is adjusted to $+1$ value. The adjustment and elimination process starts from $d_{2n-1,2n}$ and proceeds to $d_{1,2n}$. This involves the operation $C_{p,2n}(x)$, (where $p = 2n-2, 2n-3, \ldots, 1$) and in each case the factor x is chosen suitably.

The determinant now assumes the form:

$$T(s) = \begin{vmatrix} R_1 & 1 & 0 & . & 0 & 0 & 0 \\ -1 & C_1 s & 1 & . & 0 & 0 & g_2 s \\ 0 & -1 & R_2 & . & 0 & 0 & 0 \\ . & . & . & . & . & . & . \\ 0 & 0 & 0 & . & C_{n-1} s & 1 & g_{2n-2} s \\ 0 & 0 & 0 & . & -1 & R_n & 1 \\ 0 & 0 & 0 & . & 0 & -1 & 1 + C_n s \end{vmatrix} \quad (50)$$

This is the required continuant.

The values of the amplification factors are obtained through the relation:

$$A_i = -\frac{g_{2i}}{C_i} (i = 1, 2, \ldots, n-1). \quad (51)$$

10 Illustration

Consider the synthesis of a third-order low-pass Butterworth filter using equal-valued resistors and capacitors:

$$R_1 = R_2 = R_3 = 1\Omega$$
$$C_1 = C_2 = 4{\cdot}4085\text{F}. \quad (52)$$

The polynomial to be synthesized is then given by

$$P_3(s) = 4s^3 + 8s^2 + 8s + 4. \quad (53)$$

$P_3(s)$ is written as the following modified recurrent (relation (47)):

$$T(s) = P_3(s) = \begin{vmatrix} 4 & 8 & 0 & 8 & 0 & 4 \\ -1 & s & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & s & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & -1 & 0 & s \end{vmatrix} \quad (54)$$

The steps described in Section 9.2 are now carried out in succession. The various operations performed in these steps are the following:

Step 1. It requires the operations (i) $C_{3,2}(-1)$, (ii) $C_{5,4}(-1)$, (iii) $R_{3,4}(-1)$ and (iv) $R_{5,6}(-1)$.

Step 2. The operations (i) $M^2_1(0{\cdot}2500)$, (ii) $M^3_2(1{\cdot}102125)$, ((iii) $M^4_3(1{\cdot}102125)$, (iv) $M^5_4(4{\cdot}858718)$ and (v) $M^6_5(4{\cdot}858718)$ are performed.

Step 3. The operation $C_{5,6}(-1)$ is carried out.

Step 4. This step involves the operations (i) $R_{3,1}(7{\cdot}8170)$, (ii) $C_{1,3}(-7{\cdot}8170)$, (iii) $R_{4,2}(6{\cdot}8170)$, (iv) $C_{2,4}(-6{\cdot}8170)$, (v) $R_{5,1}(32{\cdot}0528)$, (vi) $R_{5,3}(5{\cdot}8170)$, (vii) $C_{1,5}(-32{\cdot}0528)$, (viii) $C_{3,5}(-5{\cdot}8170)$, (ix) $R_{6,5}(26{\cdot}2358)$ and (x) $R_{6,3}$ $(4{\cdot}8170)$.

Step 5. The operations (i) $C_{4,6}(-2{\cdot}0000)$, (ii) $C_{3,6}(4{\cdot}8170)$, (iii) $C_{2,6}(-3{\cdot}0000)$ and (iv) $C_{1,6}(31{\cdot}0528)$ are carried out.

These steps yield the following continuant:

$$T(s) = \begin{vmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ -1 & 4{\cdot}4085s & 1 & 0 & 0 & -7{\cdot}9262s \\ 0 & -1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 4{\cdot}4085s & 1 & -7{\cdot}8257s \\ 0 & 0 & 0 & -1 & 1 & 1 \\ 0 & 0 & 0 & 0 & -1 & 1 + 0{\cdot}2058s \end{vmatrix} \quad (55)$$

The amplification factors are given by (relation 51)

$$A_1 = 1{\cdot}7979$$
$$A_2 = 1{\cdot}7751 \quad (56)$$

The synthesized circuit is shown in Fig. 6.

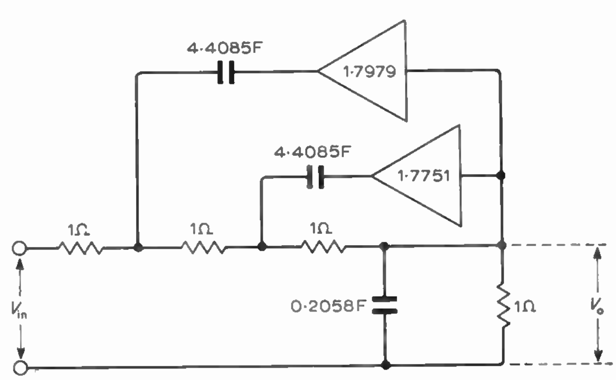

Fig. 6. The third-order low-pass Butterworth filter.

11 Conclusions (Part 2)

A recurrent-continuant transformation technique for the synthesis of active low-pass *RC* ladder networks having a resistance at both input and output ends has been proposed. The other filter networks (e.g. high-pass, band-pass, etc.) may be derived from this class through the frequency transformation methods.[5]

In the high-pass case, the RC element at the output end would be unaffected and therefore, this network could be used with a capacitive load. It is interesting to note that Nesbitt's circuit cannot be used with a capacitive load in the high-pass case and a resistive load in the low-pass case. Thus the proposed networks (Fig. 5) have a distinct advantage over those proposed by Nesbitt. The applicability of such networks becomes wider and the modification provided leads to the generalization of the recurrent-continuant method for the synthesis of active RC ladder networks.

12 Acknowledgments

The authors would like to thank Dr. N. C. Bhagat, Department of Physics, University of Bihar, Muzaffarpur and Mr. R. C. Prasad, Department of Aeronautical Engineering, I.I.T., Kanpur for many helpful discussions. The financial assistance provided by the University of Bihar is also gratefully acknowledged.

13 References

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14 Appendix: The analysis of active RC ladder networks with resistances at both ends

The analysis of ladder network (Fig. 5) involves the transformation of its continuant into the recurrent. This transformation is carried out in two steps and each of the steps includes a number of operations.

In the first step, the elimination of the term independent of s from all elements save the $d_{1,2n}$ of the $2n$th column of the continuant (relation (50)) is achieved. For this, the operations $C_{i,2n}(x)$ $(i = 2n-1, 2n-2, \ldots, 1)$ are carried out in succession, the factor x being chosen appropriately. It is remarkable that $d_{1,2n}$ would always be finite and in fact would represent the coefficient a_0 of the polynomial $P_n(s)$ describing the $T(s)$.

The second step involves all the operations of Nesbitt and has not been included here.

The analysis of the network synthesized in Section 10 is carried out to study the effect of the variation of the terminal resistance R_0 on the performance of the circuit.

The continuant of the network when the terminal resistance rises to 10/9 Ω is given by

$$T'(s) = \begin{vmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ -1 & 4{\cdot}4085s & 1 & 0 & 0 & -7{\cdot}9262s \\ 0 & -1 & 1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 4{\cdot}4085s & 1 & -7{\cdot}8257s \\ 0 & 0 & 0 & -1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0{\cdot}9+0{\cdot}2058s \end{vmatrix} \tag{57}$$

$T'(s)$ being the changed value of the r.v.t.f.

Step 1. The operations (i) $C_{5,6}(0{\cdot}9)$, (ii) $C_{4,6}(1{\cdot}9)$, (iii) $C_{3,6}(0{\cdot}9)$, (iv) $C_{2,6}(2{\cdot}8)$ and (v) $C_{1,6}(0{\cdot}9)$ are carried out in succession.

Subsequent to the Nesbitt operations, which are carried out in the second step, the determinant becomes

$$T'(s) = \begin{vmatrix} 3{\cdot}9997 & 6{\cdot}0464 & 0 & 6{\cdot}1365 & 0 & 3{\cdot}7000 \\ -1 & s & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & s & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 & s \end{vmatrix}$$

or,

$$T'(s) = 3{\cdot}9997s^3 + 6{\cdot}0464s^2 + 6{\cdot}1365s + 3{\cdot}7000. \tag{58}$$

Therefore, the variation ΔT produced in $T(s)$ due to a small change ΔR_0 in the load resistance R_0 is found to be

$$\Delta T = 1{\cdot}9536s^2 + 1{\cdot}8635s + 0{\cdot}3000. \tag{59}$$

The sensitivity

$$S_{R_0}^{T} = \frac{R_0}{T} \frac{\partial T}{\partial R_0} \tag{60}$$

of the r.v.t.f. of the network with respect to the terminal resistance may thus be found.

The continuant-recurrent transformation technique has been used to study the effect of the load resistance on the r.v.t.f. of the network. It may be used to evaluate the sensitivity of this function with respect to any other parameter (immittances of the passive elements or the amplification factors of the active elements) of the network.

Manuscript first received by the Institution on 23rd May 1974, in revised form on 2nd December 1974 and in final form on 21st May 1976. (Paper No. 1733/CC 263.)

Contributors to this issue*

Raymond Batt was appointed in 1971 as Research Associate in the Department of Electrical and Electronic Engineering, Portsmouth Polytechnic, where he is now Research Fellow. He graduated in physics from the University of Southampton, which also awarded him the Ph.D. degree after research at Southampton and Queen's University, Belfast. Previous to his Portsmouth appointment, Dr. Batt spent two years as postdoctoral research assistant in the Physical Chemistry Department at the University of Cambridge. His main research interests now are submillimetre wave techniques and atmospheric propagation measurements.

Douglas Harris was appointed Professor and Head of the Department of Electrical and Electronic Engineering at the University of Wales Institute of Science and Technology, Cardiff, in 1975. His previous appointments included a Readership at Portsmouth Polytechnic, Professor and Head of Department at Ahmadu Bello University, Nigeria, for seven years, and a Lectureship at the University of Sheffield. Shorter term appointments have been held at University College London, Stanford University, USA, and the Services Electronics Research Laboratory. Professor Harris is a graduate of London University (Queen Mary College), which also awarded him the Ph.D. degree. He has a wide range of research interests which include microwaves and atmospheric electricity, but the main emphasis at present is on short millimetric and submillimetric waves.

John Mavor received the B.Sc. degree in electrical engineering from City University, London, in 1964 and the Ph.D. degree from London University in 1968 for research on m.o.s. transistors. During a period of over five years he obtained considerable experience in the semiconductor industry in research, development and production of many processes and design techniques. Since 1971 Dr. Mavor has been a Lecturer in Electrical Engineering at the University of Edinburgh, where he teaches and researches in m.o.s. and c.c.d. technology with special applications interests in memories and signal processing. He was the prime mover in establishing the Annual International Conference on Charge-Coupled Devices.

* See also page 411.

Arif Bin Nun graduated from the West Ham College of Technology in 1971 with a University of London B.Sc. honours degree in electrical engineering. In 1973 he obtained from Loughborough University of Technology an M.Sc. degree for which, as a partial fulfilment, he designed and constructed a system for decoding error bursts in digital scramblers. At present, he is doing research for his doctorate at Loughborough on decomposition techniques for digital filter hardware.

Michael Woodward was employed by British Rail Signal and Telecommunications Department from 1960 to 1964. He then went to the University of Nottingham where he obtained a first class honours degree in electronics in 1967 and a Ph.D. in 1970 for research into the structural properties of sequential control systems. Since 1970 he has been at the Department of Electronic and Electrical Engineering, Loughborough University of Technology, where he at present holds the post of Baker-Perkins Lecturer in Industrial Instrumentation. Dr. Woodward's current research interests are in the fields of switching and automata theory, and he also supervises a small research team engaged in developing logical design techniques for use with m.s.i./l.s.i. modules.

Dhirendra Kumar Jha received his B.Sc. and M.Sc. degrees in physics from L.S. College, University of Bihar, Muzaffarpur, in 1961 and 1963 respectively, and he was appointed as Lecturer in Physics in the same college in 1964, the post he still holds. He received his Ph.D. degree in 1973 from Queen Mary College, University of London. Dr. Jha has worked in theoretical physics on the many-body problem and contributed papers on subjects related with solvable aspects of quantum mechanical models in magnetics and statistical physics. His recent publications are in the field of circuit theory.

Shyama Charan Prasad studied at L.S. College, University of Bihar, Muzaffarpur, for his B.Sc. and M.Sc. degrees in physics, which he received in 1962 and 1964 respectively. He served temporarily as a Lecturer in Physics at L.S. College from January 1965 to May 1966, and then joined Bhagalpur University as a Lecturer in July 1966. He was appointed to his present position as a Lecturer in Physics at L.S. College in August 1967. Mr. Prasad's research fields are network theory and filter design.

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

Notice of Annual General Meeting

NOTICE IS HEREBY GIVEN that the FIFTEENTH ANNUAL GENERAL MEETING of the Institution since Incorporation by Royal Charter will be held on WEDNESDAY, 6th OCTOBER, 1976, at 6.00 p.m. in the Large Theatre at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London W.C.1.

AGENDA

1. To receive the Minutes of the Fourteenth Annual General Meeting of the Institution since Incorporation by Royal Charter held on 8th October 1975 (Reported on pages 688–691 of the November 1975 issue of *The Radio and Electronic Engineer*).
2. To receive the Annual Report of the Council for the year ended 31st March, 1976 (Published in the August/September 1976 issue of *The Radio and Electronic Engineer*).
3. To receive the Auditor's Report, Accounts and Balance Sheet for the year ended 31st March 1976 (Published in the August/September 1976 issue of *The Radio and Electronic Engineer*).
4. To confirm election of the Council for 1976–77.

   In accordance with Bye-Law 49 the Council's nominations were sent to Corporate members by a Notice dated 16th June 1976 in the June 1976 issue of *The Radio and Electronic Engineer*. As no other nominations have been received under Bye-Law 50 for the following offices, a ballot will not be necessary in these cases and the following members will be elected:—

The President

P. A. Allaway, C.B.E., D.TECH.

The Vice-President

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

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

For Election: Professor W. Gosling, A.R.C.S., B.SC., R. C. Hills, B.SC.

The Honorary Treasurer

For Re-election: S. R. Wilkins

Ordinary Members of Council

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

FELLOWS

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

ASSOCIATE MEMBER

Lieutenant-Commander J. Domican RN

ASSOCIATE

T. D. Ibbotson

MEMBERS

As a nomination for election to the Council from the Class of Members has been received from the requisite number of Members, a ballot became necessary to elect three Members from the following:

N. G. V. Anslow, K. Copeland, C. J. Lilly, Gp. Capt. J. M. Walker, RAF

The results of this ballot will be declared at the meeting.

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

5. To appoint Auditors and to determine their remuneration. (Council recommends the re-appointment of Gladstone, Jenkins & Co., 50 Bloomsbury Street, London W.C.1.)
6. To appoint Solicitors. (Council recommends the re-appointment of Braund and Hill, 6 Gray's Inn Square, London W.C.1.)
7. Awards to Premium Winners.
8. Any other business. (*Notice of any other business must have reached the Secretary not less than forty-two days prior to the meeting.*)

By Order of the Council,

GRAHAM D. CLIFFORD, *Secretary.*

30th August 1976

The 50th Annual Report of the Council of the Institution

For the year ending 31st March, 1976

Publication of the 50th Annual Report marks a milestone in the history of the Institution; it also coincides with the 15th anniversary of the granting of the Institution's Royal Charter. The following account of the Institution's progress is presented by the Council for approval at the Annual General Meeting, to be held on Wednesday, 6th October 1976 at the London School of Hygiene and Tropical Medicine, commencing at 6 p.m.

INTRODUCTION

The fiftieth year of the Institution has proved, economically, to be as difficult as any in the history of the Institution. This fact was fairly faced by the Institution's President, His Royal Highness The Duke of Kent, who, when speaking at the Institution's Golden Jubilee celebrations in London's Guildhall in October 1975, said:—

> 'I think those who back in 1925 set out to establish this new professional body must have had great courage and determination. In the first place, theirs was a very young science—remember that public broadcasting had only been in existence for three years, radio as a technology was in its infancy and there were very few engineers who could qualify for membership.
>
> 'Secondly, the economic conditions were not exactly propitious, with interest rates rising, more than 2 million unemployed and business confidence at a low ebb—(does this sound familiar?). But our founders were determined enough to go ahead. . . . '

Through his multi-disciplinary activities the Golden Jubilee President has brought to that office expertise and understanding of the Institution's problems; moreover, His Royal Highness shares the enthusiasm of the present generation of members to build on past achievements, as shown in the reports of the Finance and Executive Committees, who have moved Council to go ahead with acquiring permanent headquarters. There is every reason to believe that the present membership will be as enterprising as their predecessors in achieving this new goal in the Institution's history. Indeed, there has already been a heartening response from senior members and other Institution supporters who have so pledged their support of this important project that a 'House Committee' has been appointed to report to Council on sites suitable for permanently housing the Institution. The 1977 Council will report as soon as possible to the entire membership on both the selected site and financing thereof.

Amidst the worries of inflation, the jubilation of half a century of progress and continual determination to ensure the future of the Institution, the Council shares with other Institutions (of engineers and other professions) great concern about recruitment—not only in actual membership but on the quantity and even quality of new entrants. As evidenced by university and technical college enrolments the recruitment of students of technology continues to decline with consequent effect on manufacturing production and technical innovation.

It is true that inadequate recognition of the qualified engineer contributes to lack of interest in engineering as a profession. Solving this problem was one of the functions—if not the most important object —of the CEI. It is arguable whether resolution of this question lies in restricting professional recognition to those whose training has been confined to the academic mill of a university and then too often in science rather than technology. There will, of course, always be a need for this type of recruit but not to the exclusion of those whose alternative—and often more difficult—training and experience have been gained away from a university. There is ample historical evidence of the value of those engineers who have emerged by the 'hard route'—a fact stated by the first President of CEI and continually reiterated in the lay and technical press.

Solution of such problems is as important to the younger and future member as the need to stabilize the future of their Institution by investment in a permanent home.

These and other problems as well as achievements are ventilated in the following report.

EXECUTIVE COMMITTEE

Co-ordination of all Institution activities was, for over thirty years, the responsibility of the 'Professional Purposes Committee', composed of the President, the immediate two Past Presidents, the Vice-Presidents and other senior Fellows with special experience of one or more Standing Committees. The present Executive Committee has continued, with similar membership, to integrate all Institution activity and to act, where required, on behalf of the Council.

Satisfying the claims of various Standing Committees and therefore all members in relation to the future housing and staff needs of the Institution has been a major feature of the Committee's work in the past year. Equally the Committee has laid before Council views on the re-organization of the Council of Engineering Institutions (CEI) and in consultation with other Committees, comment on policy affecting other Standing Committees whose work is reported in this account.

Council of Engineering Institutions. CEI is being re-organized so that it may better serve the engineering profession in the light of its experience since it was founded ten years ago. It has been a Herculean task to co-ordinate the disparate views of all the fifteen Institutions.* IERE representatives have played a full part in all CEI affairs; indeed two out of the ten elected Chairmen of CEI have been Fellows of the IERE (Sir Arnold Lindley retired as Vice-President of the IERE in 1970 on being elected Vice-Chairman of CEI and subsequently served as Chairman in 1972; Major-General Sir Leonard Atkinson, President IERE 1968-69 was elected Chairman of CEI in 1974).

The Institution has, in these and other ways, amply demonstrated its belief that CEI should continue as a federal body but that, as stated in the 49th Annual Report, individual Institutions should retain responsibility for their own election of members, their own learned society functions and their own finances.

As shown in the report of the Education and Training Committee there continues to be disquiet not only with the results achieved by candidates sponsored by the Institution taking the CEI examinations but with the standard and general suitability of the examination for students wishing to qualify as radio and electronic engineers. Similarly the range of exempting examinations has had to be revised; meanwhile the Membership Committee is rightly concerned with the effect on future membership of the present CEI examination and exemption regulations.

Through its representative on CEI Standing Committee A and those serving as academic and industrial representatives, the Council will continue to press for the CEI examination papers to represent a fair test of the academic knowledge to be expected of any candidate for corporate membership of the IERE.

On the future of CEI there have been two important matters in which it has been difficult to obtain unanimity of opinion among the member Institutions of CEI: firstly the composition and rules of CEI; secondly on whether Chartered Engineers wished CEI to be associated with and promote a trade union to help Chartered Engineers to achieve parity of recognition with other professions.†

* Royal Aeronautical Society: Institution of Chemical Engineers: Institution of Civil Engineers: Institution of Electrical Engineers: Institution of Electronic and Radio Engineers: Institute of Fuel: Institution of Gas Engineers: Institute of Marine Engineers: Institution of Mechanical Engineers: Institution of Mining Engineers: Institution of Mining and Metallurgy: Institution of Municipal Engineers: Royal Institution of Naval Architects: Institution of Production Engineers: Institution of Structural Engineers.

On the last matter the IERE representation has been mandated by the Special General Meeting of the Institution held on 14th June 1972.‡

On the future role and constitution of CEI, members have been kept informed of developments through *The Radio and Electronic Engineer* and will therefore know that a compromise was eventually reached which culminated in the issue of a draft CEI Supplemental Charter and new By-laws. Copies of these documents were circulated to corporate members with the March 1976 issue of *The Radio and Electronic Engineer*. In a covering letter, corporate members were invited to comment on the revised Charter and By-laws. The outcome of the consideration given by the CEI Board to these comments will be published in the Autumn.§

There has also been some discussion on a new name for CEI. The firm opinion has been in favour of retaining the present title of 'Council of Engineering Institutions' as being a more accurate definition of the CEI role as a federal body rather than the alternative title of 'Chartered Engineering Institute' which suggests autonomy as a single Institution for engineers.

As indicated, keeping the interests of the radio and electronic engineer in the forefront of recognition of the professional engineer has again occupied much of the time of the Executive Committee.

Appointment of a Secretary-Designate. The Committee was asked by Council to recommend the appointment of a Secretary to succeed Graham D. Clifford, who was initially elected as Honorary Secretary in March 1937 and thereafter continued to serve the Institution full time as its permanent Secretary. He was confirmed in that appointment in the Institution's Royal Charter of Incorporation in 1961. Subsequently the 1969 Council, anticipating an early appointment of a Secretary-designate, made an agreement to appoint Mr. Clifford as Director and Secretary until February 1978.

In the event, the present Council resolved to appoint a successor as Secretary and an advertisement to this effect was published in the April 1975 issue of the Journal and in the public press. This had a most encouraging response.

A number of candidates were called before a Selection Committee presided over by H.R.H. The Duke of Kent, assisted by Sir Ieuan Maddock and the Vice-Presidents of the Institution. The Executive Committee subsequently recommended that Air Vice-Marshal S.M. Davidson (Fellow) should be appointed Secretary-designate with effect from 1st April 1977. This was unanimously approved by Council on 22nd January 1976.||

1925–1975. The Golden Jubilee Year of the Institution was inaugurated by a banquet held in Guildhall, London, on 23rd October 1975, at which His Royal Highness The Duke of Kent presided following his election as President of the

† A report entitled 'Professional Engineers and Trade Unions' is available from CEI, 2 Little Smith Street, London SW1P 3DL, provided a stamped and addressed 8in × 5in envelope is sent.

‡ Notice of Meeting, *The Radio and Electronic Engineer* May 1972, p. S67. Report of Meeting—*The Radio and Electronic Engineer* July 1972, p. S89.

§ A summary of the finally agreed Resolution relating to the Supplemental Charter appears on page 456 of the August/September 1976 Journal.

|| Air Vice-Marshal S. M. Davidson is currently a Vice-President of the Institution and a member of the Executive Committee. A brief biography appeared in the August 1975 issue of *The Radio and Electronic Engineer*.

Institution at its Annual General Meeting on 8th October 1975. Over 600 members and guests were present at this special occasion when His Royal Highness proposed the toast to the founders and first members of the Institution, to which Admiral of the Fleet The Earl Mountbatten of Burma (President 1947–48 and 1961–63) replied. The toast to the guests was proposed by Sir Ieuan Maddock (Immediate Past President), and Alderman Sir Robert Bellinger responded.*

*A report of these speeches is given in the December 1975 issue of *The Radio and Electronic Engineer*.

An account of other events arranged to celebrate the 50th anniversary of the Institution is given later in this report.

Acknowledgments. This report of the Executive Committee reflects only the main facets of its work for the Institution. The following reports from the other Standing Committees illustrate the scope of Institution activities. It is not possible to over-estimate the invaluable help given by so many member who serve on these committees, and on behalf of Council the Executive Committee would like to record its appreciation.

OVERSEAS RELATIONS

There has been some change of attitude within CEI on the activities of its member Institutions in accepting proposals from overseas applicants. In broad terms, CEI no longer circumscribes the activities of individual Institutions in enrolling members residing outside Great Britain other than, of course, in limiting the admission of such members to the register of Chartered Engineers to those applicants who comply with the post-1973 CEI regulations now incorporated in the admission rules of all the Chartered Engineering Institutions. In general present policy is toward a more liberal interpretation of the better standards available in other countries—especially in the developing countries where, for instance, teaching and training over the whole field of electronics is not so widely developed as in Great Britain, Europe, Canada and the USA.

Appraisal of these problems is best left to the Institutions which are wholly concerned with the development of the specialized branches of engineering; British relationship with other federal bodies, for economic and other reasons, rightly rests with CEI in representing the chartered (British) engineering profession as a whole. Thus, CEI is an active member of the World Federation of Engineering Organizations (WFEO), the Commonwealth Engineers' Council (CEC) and the European Federation of National Associations of Engineers (FEANI). The UK section of the FEANI Register, which provides a credential for qualified engineers wishing to work in other European countries, is run by CEI on behalf of the British National Committee of FEANI.

The Institution has continued in membership of EUREL (Convention of National Societies of Electrical Engineers of Western Europe). The last General Assembly was held in Milan in November 1975 and the Institution was represented by Professor W. Gosling (Fellow) and Mr. F. W. Sharp (Editor of *The Radio and Electronic Engineer*). A report of the meeting was published in the January 1976 issue of the Journal.

As reported in *The Radio and Electronic Engineer*, the IERE continues to have very active Sections throughout the world, and again reference must be made to the successful operation of the Ottawa Office of the Institution, which the Immediate Past President and Secretary visited at the beginning of the year. The Ottawa office cares for the interests of members in Canada, the USA and South America. As with other offices of the Institution outside Great Britain, the members and staff make a very considerable contribution to promoting the circulation of the Institution's Journal, Conference Proceedings and other publications.

The three divisions and the principal five sections of the Institution outside Great Britain are regularly noted in *The Radio and Electronic Engineer*. In 1977 the Council intends adding to this advice details of individual members who, in other countries, not only advise candidates seeking admission but supply information on the careers, background and appointments of candidates from their areas who apply for membership. The importance of this help is best appreciated against the background that *The Radio and Electronic Engineer* is sent to members and subscribers in over eighty countries. The Council therefore thanks all Overseas Representatives for the help they have given during the year toward making the Institution a truly international body for the radio and electronic engineer.

Council regrets to report that after eight years of sharing the use of the Bangalore (India) office of the Institution, the Institution of Electrical Engineers has given notice to terminate the arrangements whereby the Bangalore office assisted in providing information about the IEE, sales of its publications and the collection of subscriptions. The Bangalore office will therefore revert to being an entirely IERE office, although it still gives some assistance in the work of the Institution of Production Engineers in India.

PROFESSIONAL ACTIVITIES COMMITTEE

Meetings, colloquia and conferences organised on a national basis are normally promoted by one or other of the eight Specialized Group Committees or by the Education and Training Committee in association with the Professional Activities Committee which has overall responsibility for co-ordinating the learned society activities of the Institution. This arrangement not only ensures that the annual programme of meetings is reasonably balanced but also enables the Group Committees to discuss any omission of current topics so that future programmes can be planned in advance. The Group structure is kept under continual review and the fields of the various groups are redefined if Council feels that modification is necessary in order to take account of the changing needs of the members and developing technology.

As examples, two new Groups, 'Measurements and Instruments' and 'Electronics Production Technology' have been established and both have held inaugural colloquia. A programme of meetings for both these Groups has now been planned and should prove of considerable interest to members of the Institution working in these fields whose needs have not been wholly catered for by meetings of the other Specialized Groups.

Local Section Activity in Great Britain. The 16 Local Sections which operate in Great Britain outside London have again been very active in promoting technical meetings and have organised a total of 109 meetings. Over 50 of these were held jointly with other Institutions.

The inaugural meeting of the Bedfordshire and Hertfordshire Section was held in October 1975 at Hatfield Polytechnic when Professor W. Gosling of the University of Bath presented a lecture 'Prospects for Radio Communication'. The new Section has held four meetings in the past session and the support demonstrates the local demand for meetings in an area not previously served.

Of the other local section activities the most noteworthy was the Yorkshire Section's 'Microprocessor Colloquium and Exhibition' held at Leeds Polytechnic in December 1975. This event attracted a large number of delegates and the Yorkshire Section are to be congratulated on its initiative in organizing such an ambitious event.

In London there has been a continuation of the trend for attendances at evening meetings to decline but not to the extent of recent years. The popularity of colloquia has continued to increase and during the year from April 1975 until March 1976 14 colloquia and 6 evening lecture meetings were held in London. Although the total number of meetings held was fewer than in previous years attendances have been very much higher and in three instances the lecture room in the Institution's headquarters in Bedford Square was filled to capacity. This response amply justified the work put into programme planning by the committees concerned and suggests that popular topics might well be the answer to declining attendances even if the subject does not warrant extensive reporting in the Journal.

Particular mention should be made of the first Memorial Lecture for Sidney Alfred Hurren, O.B.E., M.C., who was President of the Institution in 1938. Held on 20th May 1975 at the Polytechnic of North London it consisted of a group of short lectures by members of the staff of the City University on 'Electronic Music: The Sound and the Technology'.

Five of the colloquia held during the year are worthy of special mention. 'Recent Developments in High Quality Sound' and 'Electronic Aids for the Deaf' were both held at University College, London, and each attracted audiences of over 100. The second meeting was held jointly with the Institution of Electrical Engineers, the Biological Engineering Society and the Royal National Institute for the Deaf, and provided a forum for electronics engineers and medical specialists without particular knowledge of electronics to come together and discuss all aspects of the problems experienced by the deaf and the near-deaf.

A colloquium on calculator based instrument systems, 'Wedding Calculators to Instruments' in November 1975 was accompanied by a small exhibition in the Institution's library.

Early in January 1976 a colloquium on 'Teaching Electronics', organized by the Education and Training Committee in conjunction with the Professional Activities Committee, was held at the Hatfield Polytechnic. Representatives from educational establishments and industry throughout the country were present and the papers read covered all aspects of the teaching of electronics in contemporary society.

Finally, in March 1976 a very successful colloquium was held in the Institution's Headquarters on 'Tropospheric Scatter Communications'.

Conferences Organized by the Institution. During the year the Institution organized four major conferences. The first of these, 'Advances in Automatic Testing Technology' was held in April 1975 at the University of Birmingham. An international event, of the 33 papers presented 7 were by overseas authors and the attendance of 240 included 28 engineers from USA, France, Sweden, Germany, Netherlands, Denmark, Hungary, Czechoslovakia, Canada and India. Co-sponsors of the Conference were the Institution of Electrical Engineers, the Institution of Mechanical Engineers, the Institution of Production Engineers, the Royal Aeronautical Society, the Institute of Electrical and Electronics Engineers, the Institute of Measurement and Control and the Institute of Quality Assurance.

The Conference on 'Hybrid Microelectronics' held at Loughborough University of Technology in September 1975 was the second to be organized in collaboration with the International Society for Hybrid Microelectronics. Other co-sponsors of the Conference were the Institution of Electrical Engineers, the Institute of Physics and the Institute of Electrical and Electronics Engineers. Thirty-one papers were presented and the attendance was 145.

The Conference on 'Instrumentation in Oceanography' at the University College of North Wales, Bangor, also in September 1975 was the third IERE venture on this general theme. Thirty-six papers were presented and 165 delegates attended. Co-sponsors were the Institution of Electrical Engineers, the Institute of Physics, the Institute of Acoustics, the Institute of Electrical and Electronics Engineers, the Royal Institute of Navigation and the Society for Underwater Technology.

The fourth Conference during 1975 was 'Civil Land Mobile Radio', held at the National Physical Laboratory, Teddington, in November 1975. This, too, was very successful and attracted 174 delegates—more than double the expected attendance. Thirty-two papers were presented and co-sponsors were the Institution of Electrical Engineers and the Institute of Electrical and Electronics Engineers.

The full texts of the papers presented at the four Conferences are published in IERE Conference Proceedings nos. 30, 31, 32 and 33. These are currently on sale from the Institution's Publications Department. Because Conference Proceedings are produced much more rapidly than standard text books the volumes represent the most up-to-date treatises available on their respective subjects. They are, therefore, very useful in their own right as well as being an essential part of the conferences.

Joint Conferences. In addition to the Conferences organized by the IERE, the Institution was co-sponsor for a number of other conferences. Many invitations are received by the Institution to be associated with Conferences, Vacation Schools and Exhibitions and the Professional Activities Committee examines each of these and makes recommendations to Council on whether any particular invitation should be accepted or declined. In some instances the invitations are for events which are not directly associated with the 'advancement of the science and practice of radio and electronic engineering' and are, in consequence, declined.

Local Committees of CEI. The Institution is represented on the local committees of the CEI which now operate in 12 centres throughout the UK and on five joint committees of graduates and students. These local associations arrange meetings with as wide an appeal to the different engineering disciplines as possible. Symposia on careers and participation in student recruitment together with similar ventures are important activities of these local committees.

Representation on BSI Committees. The Institution has supported the work of standardization for many years and a number of Institution members serve on Technical Committees of the British Standards Institution (see Appendix 7). With the United Kingdom's entry into the European Economic Community in 1974 the work on standardization has increasingly tended to be of an international character and a number of IERE representatives on BSI committees are active in this enterprise.

Representation on Other Organizations. The Institution is also represented on a number of outside technical committees and organizations; details of these appointments are given in Appendix 6.

Programme Booklet. It was reported last year that Council had approved a recommendation that the IERE should produce its own programme booklet for meetings in London and the South East of England twice a year and notice was given to the Institution of Electrical Engineers of the Institution's intention to withdraw from the arrangement for future productions of a joint programme booklet. Discussions have now taken place with the Institution of Electrical Engineers over the feasibility of improving the format of the joint booklet in order to make it more attractive to the members of both Institutions. Already members will have noticed some change to the format insofar as meetings of the local sections in the South East have been separated from the main body of meetings. The Professional Activities Committee believe that to withdraw from the joint programme booklet would be wrong now that a more satisfactory format has been accepted, and the original arrangement will therefore continue. It is regarded as most important that publicity for all meetings should be as cost-effective as possible.

Golden Jubilee Year. Much of the learned society activity during 1975-76 has been identified with celebrating the 50th anniversary of the foundation of the Institution. The success of the meetings has been achieved by the enthusiasm of members of organizing committees, including those of the local sections and the attendance of members which together has helped to overcome the economic stringencies imposed in the last two years. The fact that similar economic conditions prevailed at the time that the Institution was formed was commented upon at the Jubilee Banquet held in the Guildhall on 23rd October 1975.

Although not within the purview of 'Professional Activities' the Service of Thanksgiving for the Institution's Golden Jubilee—held in St. Clement Danes in the Strand, London—was organized by a committee of three, including Professor Gosling, Chairman of the Professional Activities Committee. The occasion, reported in the Journal (December 1975, pp.761–763), was welcomed and supported by many members including a considerable number who made long journeys in order to be present.

Acknowledgments. The Council especially wishes to thank Universities, Technical Colleges and other organizations for providing accommodation for meetings; the Editors of technical periodicals for publicizing details of Institution meetings and other activities in Great Britain and overseas; the many Institution members who contribute to the success of learned society activities by serving on various Institution committees both national and local, and also the many members who represent the Institution on BSI and other, similar organizations.

EDUCATION AND TRAINING COMMITTEE

The CEI Examination. The Committee has made a critical review of the results achieved by IERE-sponsored entrants in the May 1975 CEI examinations; currently the Institution sponsors upwards of 450 entrants annually, approximately two-thirds of whom are from overseas. There are very few UK entrants for Part 1 of the examination because most candidates in the British Isles qualify for exemption from that part by means of an H.N.D. or its equivalent.

The percentage of passes in Part 2 was considerably lower than that achieved in previous years, and there was also a very high failure rate in some subjects. Although the Committee did not consider the question papers in those subjects to be of unduly high standard, it thought a substantial number of the questions were too long for the time available for answering and communicated this view to CEI. In consequence it was agreed that in future CEI Standing Committee A, which oversees educational matters, will investigate criticisms of the CEI examinations made by constituent Institutions.

Whilst the IERE Education and Training Committee felt that it was justified in criticizing some features of the May 1975 examination papers, it also has recommended that the IERE should investigate possible deficiencies both in the quality of the candidates and in the adequacy of the courses of preparation. The investigation is still in progress, but it is becoming increasingly evident that the percentage of H.N.D. holders who can reach the standard of the CEI Part 2 examination *in one academic year* is small, and that this is probably the principal cause of the high failure rate.

In the related field of assessment of exempting qualifications, the Committee welcomed the decision by the CEI Exemptions Sub-Committee to produce a statement of the criteria it applies in giving recognition to alternative examinations. It is understood that the statement may be approved for publication by the CEI Board at the end of 1976. Regrettably, it seems unlikely that any degree awarded by the Open University will be considered to meet the requirements for exemption from the CEI examinations. Although the matter is under active consideration both within the Institution and by CEI, complete exemption cannot be recommended at present because it is not yet possible to construct a satisfactory degree in electronic engineering from any combination of modules offered by the Faculty of Technology. Possible means of remedying this situation are to be discussed with a senior member of the Faculty.

In view of the ever-increasing complexity of electronic technology and the problems of producing a degree syllabus which is neither overloaded nor out of touch with new developments, the Council has approved the establishment of a Working Group which will attempt to identify the essential features of a good degree in electronic engineering. It is intended that this Working Group should have wide powers of co-option and that industry especially should be well represented. An announcement will be made in *The Radio and Electronic Engineer* shortly inviting the co-operation of members interested. It is also hoped that the Working Group will be a fruitful source of advice regarding revision of the syllabus of electronic engineering subjects in the CEI Part 2 examinations, which CEI plans for 1978–79.

Technician Engineer Training. Since the IERE Council requires its Education and Training Committee, *inter alia*, to consider the training requirements of the Technician Engineer and Technician in relation to the needs of the professional electronic and radio engineer, notice is being taken of the progress being made by the Technician Education Council (TEC) in the development of courses leading to the award of the new Technician Certificates in electronic subjects. While entirely in sympathy with the declared objectives of TEC, the Committee has felt some uneasiness regarding the extent of their fulfilment in practice, and will observe with interest the first courses to commence operation. It will also anxiously await developments in respect of the 'follow-on' Higher Technician Certificate and Diploma, since there are widespread fears that the Diploma in particular may not be an adequate replacement for the present H.N.D. It is intended to make this a topic for discussion at a future Education and Training Group Colloquium so as to draw wide attention to the problem of recruiting and training technicians.

In this latter connection, the Committee has discussed two draft documents produced by the Engineers' Registration Board—one dealing with the Training Requirements for Technician Engineers and Technicians, and the other with the Academic Requirements. In both cases it was felt that the documents did not adequately specify the type of work which the ERB envisaged as being undertaken by the persons whose studies and training it was attempting to prescribe. While it appreciates that because of the wide range of disciplines involved, it may not be possible to produce all-embracing definitions, the Committee believes that an attempt should at least be made to produce meaningful 'group' definitions, and intends to organize a Colloquium at which employers in the electronics industry will be able to pool ideas on this subject.

Recruitment to the Profession. Many changes have taken place since the Institution produced its first 'careers' booklet for young people, and it was agreed that there were now two needs to be met: an authoritative information booklet to assist Careers Officers and young people already interested in electronic engineering to choose the most suitable means of study in any given circumstances, and a colourful leaflet designed to awaken an interest in electronics on the part of young people still undecided about their future careers. It is recommended that the IERE should produce the information booklet; the National Electronics Council, following its initiative in promoting the 'Link Scheme' between Schools and Industry might persuade major companies in the electronics industry to participate in the production of the second.

Council takes this opportunity to thank the National Electronics Council for its enterprise in proving the viability of introducing 'Electronic Systems' as an examination subject at 'A' Level. The scheme and course work has been designed by a team under the direction of Professor G. B. B. Chaplin (Fellow) of Essex University. If approved by the Schools Council the scheme could have a nation-wide effect in improving basic ability for admission to degree courses in electronics, and better understanding—eventually at managerial level—of the commercial and industrial potential of electronics.

Acknowledgment. The IERE Committee is both an advisory committee of Council and the organizing committee for Education and Training Group activities. In formulating revised terms of reference, the Council agreed to incorporate in the new Committee the functions of the former Academic Standards Committee as it was anxious that those members who have served the Institution as expert advisers on examination matters should still help in education matters. It is gratifying to be able to record the fact that all the former members of the Academic Standards Committee accepted the invitation to become members of the Education and Training Committee.

The work of the Committee is not only important in defining the quality of membership but also in promoting adequate standards of training and education. For the future of the profession as well as the Institution, the Committee welcomes the interest of members who have succeeded in their professional career.

MEMBERSHIP COMMITTEE

Continued growth in corporate membership is the salient feature of this year's report.

For the second year running the combined total of Fellows and Members is now greater than the total of all other grades; whilst this fact is evidence of the Institution's maturity and its attraction for the senior engineer, the Council is concerned about the overall drop of just over 1% in total membership which has been wholly caused by the decline in graduate membership. This is especially regretted as happening during the Institution's Golden Jubilee Year when so much thought and effort is being directed toward the future of the Institution and the essential part that adequately trained engineers must play in realizing the potential economic benefits arising from developments in electronics in both public and private sectors*.

This problem has been acknowledged by the pioneer work of the National Electronics Council in promoting both the industry/schools link scheme and the 'A' level examination in electronic systems which aim to stimulate at 5th and 6th form level an understanding of the use of electronics in commerce, industry and other applications as well as providing basic preparation for the able student who wishes, by university, or other training, to qualify as a professional radio and electronic engineer. This move toward promoting better understanding of technology† is welcomed by the Institution, but still cannot help those graduate members who have given as their reasons for resigning the fact that they cannot qualify for corporate membership without undertaking the further examinations laid down by CEI. A considerable number of graduate members are in this position having been elected on pre-1973 academic qualifications, i.e. before the mandatory decision of CEI in regard to C.Eng. registration.

The IERE Council feels that there will be a continuing annual loss in membership for this reason and also because many potential applicants who are highly suitable for admission as graduate members are discouraged from seeking election with so little prospect of ultimately obtaining full and recognized professional status.

Table 1 shows the overall position in comparison with the the previous year. Not evident is the encouraging fact that the number of removals from the Register, for all reasons, is less than half compared with the previous year. This stability —evidenced over several years— has prompted the Council to invite the Membership Committee to report on their prognosis on future growth in membership notwithstanding the revised Charter and Bye-Laws of CEI.

The Council believes that all members will appreciate the diligence of the Membership Committee at a time of great change in serving the needs of private and public enterprise in developing radio and electronics, the minimum requirements of the Institution for membership and the super-

* Since this report was drafted *The Times* (10th August 1976) reported 'In association with the Manpower Services Commission, the National Economic Development Office will shortly be reporting on averting shortages of trained engineers as economic activity improves. Although the report will be considered by the main Neddy Council, many of the Government's working parties on industrial strategy are being asked in the interim to examine the issue of skilled manpower resources and what action can be taken to improve the supply of professionally qualified engineers.' The importance of electronics to the national economy will, presumably, largely feature in the final report.

† See also '*Nat. Electronics Rev.*', Vol. 12, No. 3, p. 45, May–June 1976.

Table 1. Institution Membership April 1975 to March 1976

	Membership at 31.3.75	ADDITIONS			Total Additions	DEDUCTIONS		Total Deductions	Nett Gain (+) or Loss (−)	Membership at 31.3.76
		Direct Election	Reinstatement	Transfers		Deaths Resignations Removals	Transfers			
Honorary Fellows	10	2	—	—	2	1	—	1	+ 1	11
Fellows	709	4	1	16	21	17	—	17	+ 4	713
Members	7291	131	28	73	232	145	16	161	+ 71	7362
Total Corporate Membership	**8010**	**137**	29	**89**	**255**	**163**	16	**179**	+ **76**	**8086**
Graduates	4052	47	4	27	78	401	80	481	−403	3649
Companions	19	—	—	—	—	—	—	—	—	19
Associates	435	13	3	10	26	67	3	70	−44	391
Associate Members	578	92	1	26	119	6	1	7	+112	690
Students	1313	287	1	—	288	136	52	188	+100	1413
Total Non-Corporate Membership	**6397**	439	9	**63**	**511**	**610**	**136**	**746**	**−235**	**6162**
Grand Total	**14407**	**576**	**38**	**152**	**766**	**773**	**152**	**925**	**−159**	**14248**

numerary edicts of the older branches of engineering as reflected in the rules of CEI.

Award of Prizes. With the cessation of the Institution's own Graduateship examination, the Executive Committee has been considering suggestions for the award of prizes to candidates for membership who have achieved an outstanding academic record.

One decision which has been approved by Council is to award an Institution prize annually to the best student passing out of the Royal Naval Engineering College at Manadon, in membership or who had applied for membership of the Institution. Negotiations are also taking place with the Royal Corps of Electrical and Mechanical Engineers and with the Royal Air Force on similar awards for Army and R.A.F. candidates.

PAPERS COMMITTEE

The Golden Jubilee. Considerable thought was given by the Committee during 1974/75 to the most appropriate way of commemorating the Institution's Golden Jubilee in the Journal. For the great majority of members who would not be able to participate in the special events organized to mark this anniversary, a special issue of the Journal seemed to be the ideal way of marking the event. It was decided that rather than assemble a series of lengthy review papers which could well duplicate to some extent reviews published earlier in our own Journal and elsewhere, senior members of the Institution would be asked to prepare contributions which would be more in the nature of essays and which would give personal views of developments in particular fields. So swift has been the expansion of electronic engineering into new fields that the whole history of many of the special areas selected for coverage could reasonably be expected to fall comfortably within the professional working life of the writers. Such instances are semiconductor devices, lasers, fibre optics, many aspects of radio navigation, as well as radar, computer engineering and nucleonics. Applications of electronics in space, in ocean exploration, and in medicine have all burgeoned within two or three decades, and indeed a similar period has transformed radio, television and communications generally.

The Golden Jubilee issue was published in October 1975 as near as possible to the actual anniversary date, and the nineteen contributions have formed a commemorative publication which has attracted considerable interest and favourable comment.

Feature Issues. The Golden Jubilee issue may be regarded as a rather special type of 'feature issue' and during 1975 several other issues were prepared which dealt extensively and effectively with particular subject areas. Just before the period covered by this Annual Report the January/February issue was published devoted to Ionospheric Radio Wave Propagation; in May 1975 papers were published on Leaky Feeder Radio Communication Systems; the 25th Anniversary of the Stored Programme Computer was marked by nine papers contributed by pioneers in computer engineering and published in the July and August issues; while three papers in December dealt in some depth with the subject of Epitaxial Magnetic Garnets, a materials development likely to have very considerable influence on several areas of electronics in the near future. Another forward-looking theme was Surface Acoustic Wave Electronics, which appeared in May 1976.

The Committee, in planning future subject areas to be dealt with in this special manner, has set guidelines that each issue should be as broad in interest to members as possible, or should endeavour to set the scene for a new development expected to be of considerable significance within a fairly short period.

Encouragement of Papers. The task of the Committee in trying to satisfy the reasonable requirements which every member regards as the function of his professional journal is clearly impossible within the practicable limits of time and space, manpower and publishing expenditure. Ways of coming as close as possible to the ideal are continually being reviewed by the Committee, who find themselves faced with the truly enormous coverage of present-day electronic and radio engineering, not to mention the need to include more general aspects of engineering and non-technical aspects which affect all engineers. Within the bounds of an economically sound Journal the Committee is thus encouraging the submission of general-interest papers of high standard. A new venture which it is hoped will start during the coming year, will be the publication of papers by students describing final-year projects from degree and diploma courses that are both novel and of fairly wide interest.

An extension of the Committee's links having the aim of widening its range of expertise is being forged by closer contact with the Specialized Group Committees and Local Sections, and, a new development, the appointing of 'corresponding members' who are knowledgeable in particular areas of electronics within the British Isles or are familiar with the extent of activity in important countries overseas, for instance Canada, the United States, India and New Zealand and in European countries.

While these measures reflect the Committee's desire to broaden its awareness, it sees itself as having also an important role in enabling engineers to extend their professional capabilities by publishing papers on their work. To this end a leaflet, 'Guidance for Inexperienced Authors' is proposed which will be complementary to the well established booklet 'Guidance for Authors', now in its fourth edition.

Assessment. The maintenance of high standards does not mean that the Committee selects only papers comprehensible only to those who are themselves working in a particular field at a degree of erudition comparable with the writer's. Going to the opposite extreme, a too rigid adherence to a policy of popularization would necessarily exclude the adequate presentation of the new work of today which may well be the commonplace of tomorrow. Twenty years ago many aspects of semiconductor technology which are now part of everyday design work would have been condemned as of little interest to the broad majority of members, and therefore inappropriate in a members' Journal.

In its task of assessment, therefore, the Committee has to tread a difficult path between apparently conflicting aims, and the year's work in assessing papers may perhaps indicate the strictness with which it has discharged its task. The details of papers considered by the Committee are as follows (1974–75 figures in parentheses):

Number of papers considered ..	151	(148)
Accepted for publication ..	62	(71)
Returned for revision	21	(19)
Rejected	68	(58)

These figures include the consideration of some 30 papers presented at Institution Conferences; in the event 9 of these were accepted for re-publication in the Journal, representing quite a small proportion of the total of 130 papers given at the four Conferences held during the year. Conference papers are brought to the attention of engineers through lists in the Journal and by inclusion in Abstracts publications. It is for these reasons, and the need to devote as much of the Journal as possible to new papers, rather than any fall in standard of Conference papers, that the number republished is smaller than in previous years.

Premiums. The award of Premiums for papers published in the 1975 volume was the second occasion on which the new scheme of awards covering nearly all relevant subject areas has operated. It is interesting to note that even though more Premiums are now available for award than previously, the number of awards actually made has changed little over recent years. It is believed that this is as it should be—the prestige value of an Institution Premium is every bit as important as its monetary value, and the presentation of Premiums with little reference to the relative standard of prize-winning papers of previous years would detract from this prestige. Details of the prize-winning papers were announced in the July issue of the Journal and are reproduced in Appendix 8 of this Report.

INSTITUTION PUBLICATIONS

The Radio and Electronic Engineer. The bite of rising costs both in production and in distribution of the Journal has continued but nevertheless the overall size of the Journal has risen by a modest amount as the following figures show. The greater part of the increase has been in the space devoted to papers and nearly all of this accounted for by the increased size over the average Journal of the Golden Jubilee Commemorative Issue published in October 1975. Details are (last year's in parentheses):

Papers 604 (535) pages

General 164 (161) pages

The space devoted to general matters, i.e. under the heading 'IERE News and Commentary', may however be expected to increase in the future because, as mentioned in the Report of the Papers Committee, more material is to be included here to broaden the general appeal of the Journal.

The issues for 1975, which number eleven because the January and February issues were combined to contain a feature issue, comprised a total of 80 papers, short contributions and addresses, 11 more than last year and accounted for by the increased size of the October issue referred to above.

Publishing costs. Inevitably increased expenditure on all factors governing production and distribution of the Journal has been necessary during the year and in the first half of 1976 several of these costs have risen still further. It is difficult to envisage any economy which would offset such increases by more than a trivial amount without seriously reducing the standard in service to members of the Institution. Indeed the Council believes that the interests of members would be served by the Journal increasing in size.

There are obviously various fundamental changes which could be made, one of which, occasionally suggested by members, is to divide the papers and the 'News and Commentary' sections into two separate publications, the former being sent optionally to members at a special rate. Overall savings on producing two such publications are illusory, as was found during the years 1963–70 when *Proceedings of the IERE* was produced. The point made in 1970 still applies, namely that a single monthly publication is more convenient and that members have a right and a need to know about the latest developments at an authoritative level.

The offsetting of the publishing costs of the Journal by means of advertisements continues to be disappointingly small. All areas of the electronics industry which might be expected to give such support are restricting their expenditure and only a considerable change in the economic climate seems likely to effect much improvement.

Although most advertising of appointments vacant for radio and electronic engineers is placed in daily or weekly publications, the more discerning employers realize that for many positions the main sources of potential applicants must be from within the ranks of the Institution's membership. The cost-effectiveness of such advertisements thus is a significant factor outweighing the slight limitation of monthly publication.

Circulation. The circulation of the Journal has fallen very slightly for 1975 compared with the 1974 figure, a change attributable almost entirely to the removal of members from the Institution's registers. The trend over recent years is shown in the accompanying bar graph which is based on figures certified by the Audit Bureau of Circulations: the exact figure for average monthly circulation from January to December 1975 was 15,209. The subscriptions to the Journal by libraries and other organizations are not indicated separately but these continue to show a steady increase.

ALPSP. Useful exchanges of information on publishing matters continued to be derived from the Institution's membership of the Association of Learned and Professional Society Publishers. The Association has been especially active in initiating discussions with the Post Office, and rises, particularly in overseas postage rates, could well have been greater had not ALPSP, supported by other periodical publisher's organizations, explicitly presented the disadvantages which its members would experience if postal rates were not held in check.

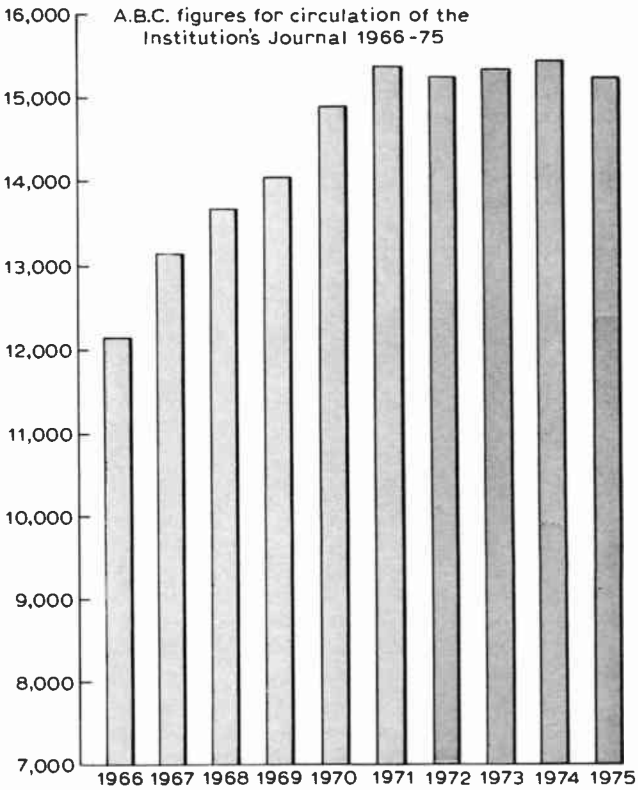
Conference Proceedings. The year 1975 was one of considerable activity for IERE Conferences: Conference Proceedings were produced for each of the four Conferences, representing a total of 130 papers and 1260 pages.

The series of IERE Conference Proceedings is widely regarded for its timeliness in presenting the latest developments in radio and electronics and their applications, and some idea of the demand which they attract can be gained from the number of out-of-print volumes, even for quite recent Conferences.

National Electronics Review. The *National Electronics Review* has continued its bi-monthly publication during the year and is another instance of the services which the Institution renders, in this case through its function as publisher.

A diverse range of subjects has been covered during 1975, ranging from an article on *Skynet II* to the use of computers by the Armed Services and the National Electronics Council's report on telecommunications and electronics in broadcasting. The now well-established series of reports on Electronics Research in British Commonwealth Universities and the Company Profiles have been joined by a new series on 'Electronic Engineering in British Commonwealth Polytechnics'.

The *National Electronics Review* may be obtained on subscription by members of the IERE and other Institutions



at a reduced rate, details of which may be obtained from the Institution. Back numbers in bound volume form may be obtained on application to the Secretary of NEC, Mr D. Dibsdall, O.B.E., C.Eng., M.I.E.R.E., Abell House, John Islip Street, London SW1P 4LN.

Indian Proceedings. This bi-monthly publication, which is sent to members of the IERE and of the IEE in India, has continued to publish papers and news items, primarily originating from within India. Now in its 14th year of publication, the 1975 volume comprises a total of 22 papers and 236 pages, only a little below the level for 1974. Editing and production are entirely the responsibility of the Administrative Office in Bangalore.

First IERE Historical Monograph. In January 1976 the Institution published a monograph written by Mr. Maurice Exwood (Fellow) and entitled 'John Logie Baird—50 Years of Television'. Its publication coincided with the 50th anniversary of Baird's first demonstration of true television and it contained much painstaking research by the author into some little known aspects of Baird's entrepreneurial activities in the 'twenties. There has been great interest during the past year or two in the role of this controversial figure in television history, and the monograph's publication was timely.

LIBRARY AND INFORMATION SERVICE

One of the most important services which a professional Institution can provide for its members and Committees is effective access to information, whether by direct loan of published work in journals or books, or by providing information from other, less specialized sources.

Over the years the IERE Library has built up holdings of back volumes of the leading radio and electronics journals on a world wide basis and while its shelves of text books manifestly could not physically accommodate every title likely to be called for, many requests can be met straight away and inter-library loans fulfil the remainder usually with only small delay.

It is thus almost an article of faith that with the impending move of the Institution's headquarters from Central London, the facilities which members can obtain from their present library must not be lessened by the effects of that move. Because the majority of loans are executed by post rather than by personal call, and information is usually sought and provided by telephone or letter, the existence of a reading room and physical access to library material can be regarded as of secondary importance. Nevertheless the views of members on the implications of an out-of-London information service will be welcomed. For instance, how many believe a reading room to be essential—by reason of their own past, present and anticipated future use of it? Many telephone enquiries understandably originate from within the London area and access to the library through a London number might be desirable. These are some of the matters on which suggestions would be helpful.

Short-term difficulties have arisen over the pressure on storage space at 9 Bedford Square and have necessitated appraisal of the material to be kept and that to be disposed of. Some contraction is wise in any case, for with a fast developing field such as electronics there is a stage beyond which retention of old information is not justified. This operation does call for careful assessment of the really significant books in particular so that the researcher into the history of our discipline can find out how things began and discover the abandoned projects and theories.

The day-to-day activity of the library has been maintained at last year's level and growing use is made of photocopying from journals as this is generally more satisfactory to the enquirer and the library than the loan of a complete issue.

FINANCE COMMITTEE AND ADMINISTRATION

As first suggested in the 46th Annual Report* the Institution auditors continue to be consulted on ways of providing more easily understood accounts. As shown on pages 441–42 the accounts for the year ended 31st March 1976 are shown in columnar style so that the final position on income and expenditure is summarized to show the year end result and similarly the Balance Sheet records the deficiency—as in this year—or surplus of assets.

Short-term borrowing was extended ahead of the improvement in revenue budgeted for by the increase in subscriptions called for in the Council notice given in the November 1975 issue of *The Radio and Electronic Engineer*. With hindsight it would have been prudent to call for these increases a year or two earlier; in the event the Council wishes to anticipate next year's report by thanking the members who have so quickly responded to the reminder for the 1976/7 subscription and thus helped to reduce the period of short-term borrowing. An increasing number of members now use the Direct Debit system of payment of subscriptions and thereby considerably help to reduce costs—a much appreciated effort.

As can be seen from the comparative figures given in the accounts, last year saw a continuing saga of inflation in the cost of those services and materials which are indispensable to the operations of the Institution. Everyone and all Institutions continue to face these problems and members will not wish to see repeated again those details given in the last two Annual Reports of advances in rent and rates and yet again further increases in the charges for telephones, postage and printing.

Against such adversity, however, the Council is resolved to protect the future of the Institution by at least stabilizing the cost of accommodation—in accordance with the approval given by members to the last Annual Report in which it was proposed that the Institution should acquire freehold premises outside London and if achieved the success of this enterprise will be of paramount importance to future generations of members. There can, for example, be an immediate improvement in administrative facilities and services to all members by better use of the income derived from subscriptions.

To be successful this project will be wholly dependent on the support of members, especially if help is also to be sought from sources outside the membership. The Council is heartened in undertaking this enterprise by the experience of sister Institutions as in, most recently, the case of the Institution of Chemical Engineers—founded in 1922 and granted a Royal Charter in 1957—whose Building Appeal has had such a magnificent response.

Future Housing. Following his selection as Secretary-designate, Air Vice-Marshal Davidson was appointed Chairman of a 'House Committee' which will report to Council on the suitability of available sites.

Meanwhile the attached accounts show the customary pattern of increased revenue from all sources; regrettably the rate of increase has been much lower than the unprecedented rate of inflation which has for the second consecutive year resulted in an adverse balance. This result has been brought into the Balance Sheet which shows the cumulative financial position of the Institution.

Appreciation. The Council is sure that it is joined by all members in expressing appreciation of the voluntary work of those members who serve on committees and who otherwise represent the Institution. The appendices indicates the scope of their activities.

In the Golden Jubilee Year there has been an increase in the volume of work. This has been handled without any major changes in the small secretariat and the Council pays tribute to the loyalty and enthusiasm of the staff who have played a great part in a year of economic difficulty.

* See *The Radio and Electronic Engineer*, 42, No. 11, p. 172, November 1972.

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31 MARCH 1976

	1976 £	1976 £	1975 £	1975 £
INCOME				
Subscriptions Received including arrears		175,548		170,439
Entrance, Transfer and Exemption Fees		2,344		2,025
Sales—Institution Journal . .	28,543		25,198	
Other Publications . .	10,185	38,728	6,114	31,312
Fees Received—Symposia and Colloquia		37,436		—
Dividends and Interest Received		1,936		1,992
Total Income		255,992		205,768
Deduct:				
EXPENDITURE				
Cost of Publishing Journal				
Printing Costs	54,174		50,123	
Less: Advertising Receipts . .	8,731		4,618	
	45,443		45,505	
Postage	24,656		15,744	
Envelopes and Wrappers . .	462		1,055	
	70,561		62,304	
Direct Expenses relating to Symposia and Colloquia				
Printing of Papers	8,801			
Accommodation and Travel	16,526			
	25,327		—	
		95,888		62,304
		160,104		143,464
Deduct:				
Administration Expenses				
Salaries and National Insurance	86,553		76,249	
Superannuation Scheme . .	4,852		4,381	
Postage and Telephone . .	14,669		8,521	
Printing and Stationery . .	6,156		5,195	
Computer Service	6,076		5,965	
Travelling Expenses . .	5,430		2,581	
Council and Committee Expenses	4,460		3,785	
Delegates Expenses . .	1,284		1,454	
Bank Charges and Differences on Exchange . .	3,623		1,913	
Audit Fees	850		650	
Miscellaneous Expenses . .	1,903		2,709	
	135,856		113,403	
Establishment				
Rent, Rates and Insurance . .	36,513		10,931	
Lighting and Heating . .	1,763		1,445	
Office Expenses and Cleaning	5,606		3,903	
Repairs and Maintenance . .	5,280		3,820	
	49,162		20,099	
Carried forward	185,018	160,104	133,502	143,464

	1976 £	1976 £	1975 £	1975 £
Brought forward	185,018	160,104	133,502	143,464
Meetings and Golden Jubilee Celebrations	5,693		1,572	
Divisions and Sections Operating Expenses				
Salaries, Printing, Stationery, Postage and Office Expenses	7,383		4,494	
Hire of Accommodation, Lectures and Meeting Expenses	2,914		4,971	
Travelling Expenses . .	1,578		2,588	
Indian Proceedings . .	1,435		1,150	
	13,310		13,203	
Subscriptions to the Council of Engineering Institutions . .	5,832		4,525	
Awards and Contributions to Other Institutions	754		723	
Depreciation				
Amortization of Leasehold Premises	2,267		2,268	
Furniture and Equipment . .	1,218		1,490	
Library	765		718	
	4,250		4,476	
		214,857		158,001
Excess of Expenditure over Income for the year		54,753		14,537
Adverse Balance 1 April 1975 . .	7,717		(6,820)	(Credit)
Add:				
Prior Year adjustments (Note 1)	9,875		—	
		17,592		(6,820)
Adverse Balance 31 March 1976		£72,345		£7,717

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

BALANCE SHEET AS AT 31 MARCH 1976

	1976 £	1976 £	1975 £	1975 £
Fixed Assets (Note 2) ..		36,366		38,765
Quoted Investments at Cost .. (Note 3)	27,540			
Less: Surplus on Sales .. (Market Value £22,375– 1975 £24,268)	4,182	23,358		32,007
Current Assets				
Stock of Institution's Publications (Note 4)	18,146		17,969	
Income Tax repayment claim	649		225	
Sundry Debtors and Prepayments	21,719		10,085	
Balances at Bankers and in Hand	13,186	53,700	9,039	37,318
		113,424		108,090
Less:				
Current Liabilities				
Sundry Creditors		78,719		53,091
		34,705		54,999
Add:				
General Fund Account				
Adverse Balance		72,345		7,717
		£107,050		£62,716

Financed by:

	1976 £	1976 £	1975 £	1975 £
Premises Improvement Reserve				
Balance 1 April 1975 ..	2,838		2,617	
Add: Donations received during year ..	246	3,084	221	2,838
Deferred Revenue				
Subscriptions and Receipts in Advance		33,576		23,746
Short Term Borrowings				
Bank Overdraft		70,390		36,132
		£107,050		£62,716

Signed

P. A. ALLAWAY (*President Elect*)
F. N. G. LEEVERS (*Chairman Finance Committee*)
S. R. WILKINS (*Honorary Treasurer*)
G. D. CLIFFORD (*Secretary*)

Notes forming part of the Accounts for the year ended 31 March 1976

1. Prior Year Adjustments

	£
Addition to Reserve relating to Advance Journal Sales	4,975
Additional Provision relating to Examination Fees payable to CEI	4,900
	£9,875

2. Fixed Assets

	Improvements to Leasehold Premises 8/9, Bedford Square, London £	*Furniture and Equipment* £	*Library* £	*Total* £
Cost				
At 31 March 1975 ..	24,940	26,388	13,286	64,614
Additions	—	658	1,193	1,851
At 31 March 1976 ..	£24,940	£27,046	£14,479	£66,465
Depreciation				
At 31 March 1975 ..	2,268	16,746	6,835	25,849
Provided during Year	2,267	1,218	765	4,250
At 31 March 1976 ..	£4,435	£17,964	£7,600	£30,099
Net Book Values				
At 31 March 1975 ..	£22,672	£9,642	£6,451	£38,765
At 31 March 1976 ..	£20,405	£9,082	£6,879	£36,366

3. Quoted Investments

Nominal		*Cost* £
500	Allied Textile Co. Ltd. 25p Ordinary Shares ..	511
£1,000	7¾% Barnet Corporation Loan 1982/84	982
1,500	B.B.A. Group Ltd. 25p Ordinary Shares	1,115
700	Boots Pure Drug Co. Ltd. 25p Ordinary Shares ..	988
1,250	British Oxygen Co. Ltd. 25p Ordinary Shares ..	768
£500	British Petroleum Co. Ltd. 8% Cumulative First Preference Stock	685
500	Decca Ltd. 25p Ordinary Shares	1,422
125	Decca Ltd. 25p 'A' Ordinary Shares	424
200	Distillers Co. Ltd. 50p Ordinary Shares	342
1,000	Dunlop Co. Ltd. 50p Ordinary Shares	1,181
1,000	E.M.I. Ltd. 50p Ordinary Shares	2,654
600	English China Clays Ltd. 25p Ordinary Shares ..	779
374	Grattan Warehouses Ltd. 25p Ordinary Shares ..	802
500	Hartle Machinery International Ltd. 25p Ordinary Shares	205
500	I.C.I. Ltd. £1 Ordinary Shares	2,042
£270	Inchcape & Co. Ltd. 12½% Unsecured Loan Stock 1993/98	99
£1,000	Islington Corporation. 10% Redeemable Stock 1982/83	995
732	Lonrho Ltd. 25p Ordinary Shares	1,088
1,600	Marks & Spencer Ltd. 25p Ordinary Shares ..	2,187
£1,000	Middlesex County Council 6¼% Redeemable Stock 1975/77	973
500	Muirhead Ltd. 25p Ordinary Shares	557
£2,000	New Zealand 7¼% Stock 1977	1,987
625	Plessey Co. Ltd. 50p Ordinary Shares	1,149
250	Racal Electronics 25p Ordinary Shares	680
£1,000	Slough Corporation 8¾% Redeemable Stock 1979/80	990
£521.20	Southern Rhodesia 6% Stock 1978/81	515
£500	Stock Exchange 7¼% Mortgage Debenture Stock 1990/95	485
£500	Thorn Electrical Industries Ltd. 5% Convertible Unsecured Loan Stock 1990/94	522
500	United Gas Industries Ltd. 25p Ordinary Shares	413
	Total	£27,540

4. Stock of the Institution's publications is stated at the lower of cost or net realizable value.

5. Rates of Exchange

Overseas remittances and receipts during the year have been converted into sterling at the current rates then ruling and bank and cash balances held overseas at 31 March at the rate of exchange ruling at that date. Any resulting exchange differences have been included with bank charges in the Income and Expenditure Account.

AUDITORS REPORT TO THE MEMBERS OF THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

In our opinion the annexed Accounts give a true and fair view of the Institution's affairs at 31 March 1976 and of the deficit for the year ended on that date and comply with the Royal Charter and Bye-Laws of the Institution.

50 Bloomsbury Street, London WC1B 3QT
7 September 1976

GLADSTONE, JENKINS & CO.
Chartered Accountants

Appendix 1

Membership of the Council and its Committees as at 31st March 1976

The Council of the Institution

President:

H.R.H. The Duke of Kent, G.C.M.G., G.C.V.O. (*Fellow*)

Past Presidents:

Sir Ieuan Maddock, C.B., O.B.E., D.Sc., F.R.S. (*Fellow*)
Harvey F. Schwarz, C.B.E., B.Sc., (*Fellow*)
A. A. Dyson, O.B.E. (*Fellow*)

Vice Presidents:

P. A. Allaway, C.B.E., D.Tech. (*Fellow*)
Air Vice-Marshal S. M. Davidson, C.B.E. (*Fellow*)
Professor D. E. N. Davies, D.Sc., Ph.D. (*Fellow*)
Professor W. A. Gambling, Ph.D., D.Sc. (*Fellow*)
D. W. Heightman (*Fellow*)
J. R. James, Ph.D. (*Fellow*)
J. Powell, T.D., B.Sc., M.Sc. (*Fellow*)

Ordinary and ex-officio Members:

J. T. Attridge (*Member*)*
J. B. Bennett (*Member*)*
M. S. Birkin (*Member*)
H. Blackburn (*Member*)
C. S. den Brinker (*Fellow*)*
Professor D. S. Campbell, B.Sc., D.Sc., D.I.C. (*Fellow*)
R. G. Christian, M.Eng. (*Member*)*
W. H. Clark (*Member*)*
P. L. Dalgliesh (*Member*)*
C. R. Fox (*Associate Member*)
P. J. Gallagher, M.Sc., Ph.D. (*Member*)*
D. J. Henman, V.R.D., B.Sc. (*Member*)*
R. C. Hills, B.Sc. (*Fellow*)
I. D. Jefferies (*Member*)*
C. T. Lamping (*Member*)*
G. Lauder, B.Sc. (*Member*)*
Professor D. W. Lewin, M.Sc. (*Fellow*)
Brigadier R. W. A. Lonsdale, B.Sc. (*Fellow*)
J. D. G. Marshall (*Member*)*
E. R. Middlemiss (*Member*)*
P. L. Mothersole (*Fellow*)
Professor K. G. Nichols, B.Sc., M.Sc. (*Fellow*)
G. Phillips (*Associate*)
V. J. Phillips, Ph.D., B.Sc. (*Member*)
W. L. Price, O.B.E., Ph.D. (*Fellow*)*
J. E. Read, F.C.A. (*Companion*)
S. J. H. Stevens, B.Sc. (Eng.) (*Fellow*)
K. G. M. Tippett, B.Sc.(Eng.) (*Member*)*
L. A. Trinogga, M.Sc. (*Member*)*
M. M. Zepler, M.A., Dip.El. (*Member*)

Honorary Treasurer:

S. R. Wilkins (*Fellow*)

Director and Secretary:

Graham D. Clifford, C.M.G. (*Fellow*)

**Chairman of a Local Section in the UK*

Standing Committees of the Council

Executive Committee

Chairman:
The President

P. A. Allaway, C.B.E., D.Tech. (*Fellow*)
Major-General Sir Leonard Atkinson, K.B.E., B.Sc. (*Fellow*)
Air Vice-Marshal S. M. Davidson, C.B.E. (*Fellow*)
A. A. Dyson, O.B.E. (*Fellow*)
Professor W. A. Gambling, Ph.D., D.Sc. (*Fellow*)
Professor W. Gosling, B.Sc. (*Fellow*)
D. W. Heightman (*Fellow*)
J. R. James, Ph.D. (*Fellow*)
Sir Ieuan Maddock, C.B., O.B.E., D.Sc., F.R.S. (*Fellow*)
J. Powell, T.D., B.Sc., M.Sc. (*Fellow*)

Finance Committee

Chairman:
F. N. G. Leevers, B.Sc. (Eng.) (*Fellow*)

D. W. Heightman (*Fellow*)
G. Phillips (*Associate*)
S. R. Wilkins (*Fellow*)

Education and Training Committee

Chairman:
D. L. A. Smith, B.Sc.(Eng.) (*Fellow*)

Air Vice-Marshal S. M. Davidson, C.B.E. (*Fellow*)
D. Dick (*Fellow*)
K. E. Everett, Ph.D., M.Sc. (Eng.) (*Fellow*)*
Cdr. A. H. Fraser, RN, B.Sc.(Eng.) (*Member*)
B. F. Gray, B.Sc.(Eng.) (*Fellow*)
G. P. Heywood, B.Sc. (*Graduate*)
J. J. Jarrett (*Member*)
C. H. G. Jones (*Member*)
A. J. Kenward, B.Sc. (*Member*)
Professor K. G. Nichols, B.Sc., M.Sc. (*Fellow*)
W. L. Price, O.B.E., Ph.D., M.Sc. (*Fellow*)*
A. C. Shotton, B.Sc. (*Fellow*)
Col. F. R. Spragg, B.Sc. (*Fellow*)
A. Tranter, B.Sc.(Eng.) (*Member*)*
Col. J. Vevers, O.B.E. (*Fellow*)*

Membership Committee

Chairman:
Brigadier R. W. A. Lonsdale, B.Sc. (*Fellow*)

C. W. Brown, M.A. (*Member*)
R. F. C. Butler, M.A. (*Member*)
R. M. Clark (*Member*)
D. N. J. Cudlip (*Member*)
Wing Cdr. P. J. Dunlop, RAF (Ret.) (*Fellow*)
N. L. Garlick, M.Sc.(Eng.) (*Fellow*)
R. C. Hills, B.Sc.(Eng.) (*Fellow*)
H. Hudson (*Member*)
G. H. Pegler (*Fellow*)
S. H. Perry (*Fellow*)
J. Powell, T.D., B.Sc., M.Sc. (*Fellow*)
R. S. Roberts (*Fellow*)
Group Capt. J. M. Walker, RAF (*Member*)
M. M. Zepler, M.A. (*Member*)

Professional Activities Committee

Chairman:
Professor W. Gosling, B.Sc. (*Fellow*) (*to* 31.12.75)
Professor D. S. Campbell, B.Sc., D.Sc., D.I.C. (*Fellow*) (*from* 1.1.76)

Lt. Col. F. G. Barnes, M.A., R Sigs (Ret.) (*Member*)
A. F. Dyson, Dip.El. (*Member*)
M. H. W. Gall, M.A. (*Fellow*)
J. R. Halsall, Dip.El. (*Member*)
A. Hann, B.Sc. (*Fellow*)
Brigadier R. Knowles, C.B.E. (*Fellow*)
R. Larry (*Fellow*)
D. L. A. Smith, B.Sc.(Eng.) (*Fellow*)
W. E. Willison (*Member*)

Papers Committee

Chairman:
J. R. James, Ph.D., B.Sc. (*Fellow*)

L. W. Barclay, B.Sc. (*Fellow*)
J. Bilbrough (*Fellow*)
L. A. Bonvini (*Fellow*)
W. G. Burrows, Ph.D. (*Member*)
R. J. Cox, B.Sc. (*Member*)
Professor E. A. Faulkner, Ph.D. (*Fellow*)
K. G. Freeman, B.Sc. (*Member*)
Professor D. W. Lewin, M.Sc. (*Fellow*)
T. B. McCrirrick (*Fellow*)
J. R. Parks, Ph.D. (*Member*)
E. Robinson, Ph.D. (*Fellow*)
L. A. Smulian, B.Sc. (*Fellow*)
A. G. Wray, M.A. (*Fellow*)

Trustees of the Institution Benevolent Fund

Colonel G. W. Raby, C.B.E. (*Fellow*)
The President (*ex-officio*)
S. R. Wilkins (*Fellow*) *Hon. Treasurer*
Graham D. Clifford, C.M.G. (*Fellow*) *Hon. Secretary*

**Member of the Academic Standards Committee up to its amalgamation with the Education and Training Committee on 1st January 1976.*

Specialized Group Committees

Aerospace, Maritime and Military Systems

Chairman:
T. W. Welch (*Fellow*)

N. G. V. Anslow (*Member*)
Col. W. Barker (*Member*)
Wing Cdr. F. S. Cocker, D.F.C., RAF (*Member*)
Professor J. W. R. Griffiths, Ph.D. (*Fellow*)*
A. Hann, B.Sc. (*Fellow*)
A. Harrison, B.Sc. (*Fellow*)
J. A. C. Kinnear (*Fellow*)
R. N. Lord, M.A. (*Member*)
C. H. Nicholson (*Fellow*)
D. M. O'Hanlon (*Fellow*)
C. Powell (*Fellow*)
J. S. Shayler, B.Sc. (*Fellow*)
R. M. Trim, B.E. (*Fellow*)

Automation and Control Systems

Chairman:
Professor D. R. Towill, M.Sc. (*Fellow*) (*to* 4.12.75)
M. S. Birkin (*Member*) (*from* 4.12.75)

P. Atkinson, B.Sc.(Eng.) (*Member*)
M. T. Challenger (*Member*)
A. E. Crawford (*Fellow*)
J. R. Halsall, Dip.El. (*Member*)
W. F. Hilton, D.Sc. (*Fellow*)
Inst. Cdr. D. J. Kenner, B.Sc., M.Sc., RN (Ret.) (*Member*)
Brigadier R. Knowles, C.B.E. (*Fellow*)
J. L. Paterson (*Member*)
D. E. O'N. Waddington (*Member*)

Communications

Chairman:
Professor J. W. R. Griffiths, Ph.D. (*Fellow*)

A. R. Bailey, M.Sc., Ph.D. (*Fellow*)
L. W. Barclay, B.Sc. (*Fellow*)
Professor D. E. N. Davies, D.Sc., Ph.D. (*Fellow*)
L. W. Germany (*Fellow*)
A. N. Heightman (*Fellow*)
R. C. Hills, B.Sc.(Eng.) (*Fellow*)
Cdr. D. W. Jackson, RN (*Member*)
J. J. Jarrett (*Member*)
G. R. Jessop (*Member*)
A. A. Kay (*Fellow*)
R. Larry (*Fellow*)
P. L. Mothersole (*Fellow*)
R. S. Roberts (*Fellow*)
R. E. C. B. Smith (*Member*)
K. R. Thrower (*Member*)
K. E. Ward (*Member*)
M. M. Zepler, M.A., Dip.El. (*Member*)

Components and Circuits

Chairman:
Professor D. S. Campbell, B.Sc., D.Sc., D.I.C. (*Fellow*)

C. S. den Brinker (*Fellow*)
P. W. Boyce (*Member*)
J. S. Brothers (*Member*)
A. F. Dyson, Dip.El. (*Member*)
J. B. Lock (*Member*)
B. V. Northall, C.G.I.A. (*Member*)
D. R. Ollington (*Fellow*)
A. Pugh, B.Sc., Ph.D. (*Fellow*)

Computer

Chairman:
Professor D. W. Lewin, M.Sc. (*Fellow*)

Col. W. Barker (*Member*)
K. D. F. Chisholm (*Fellow*)
P. L. Hawkes, B.Sc. (*Member*)
D. T. Law (*Member*)
D. M. MacLean, B.Sc. (*Fellow*)
Wing Cdr. D. G. L. Packer, B.Sc., DUS RAF, (*Member*)
T. J. Stakemire (*Member*)
E. R. Tomlinson (*Member*)
S. E. Williamson, B.Sc., Ph.D. (*Member*)

Electronics Production Technology

Chairman:
A. F. Dyson, Dip.El. (*Member*)

J. W. Anstead (*Member*)
J. F. Burns (*Member*)
D. S. Girling (*Fellow*)
L. Hale (*Member*)
R. W. Hill (*Member*)
D. G. Horan (*Member*)
R. P. Marie (*Member*)
B. Pike (*Member*)

Measurements and Instruments

Chairman:
Professor P. B. Fellgett, M.A., Ph.D. (*Fellow*)

M. H. W. Gall, M.A. (*Fellow*)
P. A. Payne, Ph.D. (*Graduate*)
R. W. A. Siddle (*Member*)
G. W. Taylor (*Member*)
D. E. O'N. Waddington (*Member*)

Medical and Biological Electronics

Chairman:
R. Brennand (*Member*)

K. Copeland (*Member*)
R. E. George (*Member*)
W. G. Gore (*Member*)
A. J. Huelin (*Member*)
P. A. Payne, Ph.D. (*Graduate*)
L. W. Price, M.A. (*Member*)
J. R. Roberts, B.Sc., Ph.D. (*Graduate*)
H. J. Terry, B.A., Ph.D. (*Member*)

Appendix 2

Representatives of the Institution on the Board and Committees of the Council of Engineering Institutions

Board

Professor W. A. Gambling, Ph.D., D.Sc. (*Fellow*)
Professor W. Gosling, B.Sc. (*Fellow*) (ALTERNATE)

Executive Committee

P. A. Allaway, C.B.E., D.Tech. (*Fellow*)

Standing Committee A

D. L. A. Smith, B.Sc.(Eng.) (*Fellow*)

Standing Committee B

J. Powell, T.D., B.Sc., M.Sc. (*Fellow*)

Standing Committee C

Air Vice-Marshal S. M. Davidson, C.B.E. (*Fellow*)

CEI-CSTI Joint Affairs Committee

To be appointed

Council for Environmental Science and Engineering

Professor H. M. Barlow, Ph.D., F.R.S. (*Honorary Fellow*)

British National Committee on Ocean Engineering

P. W. Warden (*Member*)
M. J. Tucker, B.Sc. (*Member*) (ALTERNATE)

Committee on Health and Safety

Colonel F. R. Spragg, B.Sc. (*Fellow*)

Engineers Registration Board

Technician Engineer Section Board, Supervisory Committee and Joint Membership Committee
K. J. Coppin, B.Sc. (*Member*)

Joint Qualifications Committee
Brigadier R. W. A. Lonsdale, B.Sc. (*Fellow*): *Chairman*

Appendix 3

Institution Representation at Universities, Polytechnics and Colleges

University of Aston in Birmingham
Convocation
Professor D. G. Tucker, D.Sc., Ph.D. (*Fellow*)

Barnsley College of Technology
Engineering Advisory Committee
D. Shaw, B.Sc. (*Fellow*)

University of Bradford
Court
P. J. Gallagher, M.Sc., Ph.D. (*Member*)

Darlington College of Technology
Electrical Engineering and Science Advisory Committee
R. W. Blouet (*Member*)

East Ham Technical College
Electrical Engineering Advisory Committee
D. W. Bradfield, B.Sc. (*Member*)

Glasgow College of Technology
Advisory Board
R. D. Pittilo, B.Sc. (*Member*)

City of Gloucester College of Technology
Electrical Engineering Advisory Committee
H. V. Sims (*Fellow*)

Huddersfield Technical College
Engineering Advisory Committee
R. Barnes (*Member*)

Merton Technical College
Board of Governors
A. A. Kay (*Fellow*)

City of Nottingham Education Committee
Electrical Engineering Advisory Committee
F. W. Hopwood (*Member*)

University of Nottingham
Court
Air Vice-Marshal S. M. Davidson, C.B.E. (*Fellow*)

Reading College of Technology
Board of Governors
Major-General Sir Leonard Atkinson, K.B.E., B.Sc. (*Past President*)

Southall College of Technology
Governing Body
B. S. Pover (*Member*)
Administrative Committee
A. G. Wray, M.A. (*Fellow*)

South East London College
Engineering Consultative Committee
J. I. Collings (*Fellow*)

Stannington College of Further Education, Sheffield
Electrical and Telecommunications Consultative Committee
P. A. Bennett (*Fellow*)

University of Surrey
Court
Sir Ieuan Maddock, C.B., O.B.E., D.Sc., F.R.S. (*Past President*)

Wakefield College of Art and Technology
Engineering Advisory Committee
G. F. Lane-Fox (*Member*)

University of Wales Institute of Science and Technology
Court
Professor W. Gosling, B.Sc. (*Fellow*)

Watford College of Technology
Engineering Advisory Committee
F. P. Thomson, O.B.E. (*Member*)

Widnes Technical College
Electrical and Instrument Engineering Advisory Committee
D. Chalmers (*Fellow*)

Appendix 4

Representatives on Joint Committees for the Awards of National Certificates and Diplomas in Engineering

England and Wales

Higher National Certificates and Diplomas in Electrical and Electronic Engineering

B. F. Gray, B.Sc.(Eng.) (*Fellow*): *Chairman*
D. L. A. Smith, B.Sc.(Eng.) (*Fellow*)
A. Tranter, B.Sc.(Eng.) (*Member*)

Ordinary National Certificates and Diplomas in Engineering

B. F. Gray, B.Sc.(Eng.) (*Fellow*)

Scotland

National Certificates in Electrical and Electronic Engineering

D. S. Gordon, Ph.D., B.Sc. (*Member*)
D. Dick, D.I.C. (*Fellow*)

Northern Ireland

Higher National Certificates in Electrical and Electronic Engineering

Captain A. W. Allen, RN (Ret.) (*Member*)
J. A. C. Craig, B.Sc. (*Member*)

Ordinary National Certificates and Diplomas in Engineering

J. A. C. Craig, B.Sc. (*Member*)

Appendix 5

Institution Representation on Other Educational Bodies

City and Guilds of London Institute

Telecommunications Advisory Committee
B. F. Gray, B.Sc.(Eng.) (*Fellow*)

Joint Advisory Committee for Radio, Television and Electronics
W. B. K. Ellis, B.Sc. (*Member*)

Radio Amateurs' Examination Advisory Committee
R. G. D. Holmes (*Fellow*)

Advisory Committee on Communication of Technical Information
F. P. Thomson, O.B.E. (*Member*)

Council for National Academic Awards

Electrical and Electronic Engineering Board
B. F. Gray, B.Sc.(Eng.) (*Fellow*) (*to* 13.8.75)
A. G. Wray, M.A. (*Fellow*)

Technical Education Council (TEC)

Programme Committee A2
K. R. Thrower (*Member*)

London and Home Counties Regional Advisory Council for Technological Education

Advisory Committee on Electrical and Electronic Engineering
K. J. Coppin, B.Sc. (*Member*)

North Western Regional Advisory Council for Further Education

Specialist Advisory Committee for Nautical Education
A. G. Brown (*Member*)

Radio Television and Electronics Examination Board

F. O. M. Bennewitz (*Member*) (*from* 28.11.75)
W. B. K. Ellis, B.Sc. (*Member*)
J. W. Graham, B.Sc. (*Fellow*) (*to* 27.11.75)
N. G. Green (*Member*)

Scottish Technical Education Council (ScoTEC.)

Course Committee A2
P. G. Wilks, B.Sc. (*Member*)

Yorkshire Council for Further Education

Engineering County Advisory Committee
F. O. M. Bennewitz, M.Sc. (*Member*)

Welsh Joint Education Committee

Advisory Panel for Electrical Engineering
I. D. Dodd, B.Sc. (*Member*)

Appendix 6

Members Appointed to Represent the Institution on External Bodies

Royal Society

Committee on Scientific Information
Admiral of the Fleet the Earl Mountbatten of Burma, K.G., F. R. S. (*Honorary Fellow*)
Panel on Mechanized Information Retrieval
Graham D. Clifford, C.M.G. (*Fellow*)

EUREL (Convention of National Societies of Electrical Engineers of Western Europe)

Professor W. Gosling, B.Sc. (*Fellow*)
F. W. Sharp (*Fellow*)

British National Council for Non-Destructive Testing

A. Nemet, Dr. Ing. (*Fellow*)

British Nuclear Energy Society

R. J. Cox, B.Sc. (*Member*)

International Broadcasting Convention

Management Committee and Programme Committee
P. L. Mothersole (*Fellow*)
R. S. Roberts (*Fellow*)

National Council for Quality and Reliability

Brigadier R. Knowles, C.B.E. (*Fellow*)

National Electronics Council

Sir Ieuan Maddock, C.B., O.B.E., D.Sc., F.R.S. (*Past President*)
Graham D. Clifford, C.M.G. (*Fellow*)

Parliamentary and Scientific Committee

Executive Committee
J. Langham Thompson (*Fellow*)
Graham D. Clifford, C.M.G. (*Fellow*)

British Electrotechnical Approvals Board

R. S. Roberts (*Fellow*)

Economic Development Committee for the Electronics Industry

Working Group on Scientific and Technological Manpower
Graham D. Clifford, C.M.G. (*Fellow*)

Association of Learned and Professional Society Publishers

F. W. Sharp (*Fellow*)

UK Automation Council

Professor D. W. Lewin, M.Sc. (*Fellow*)
M. S. Birkin (*Member*)

UK Liaison Committee for Sciences Allied to Medicine and Biology

R. E. George, B.Sc. (*Member*)

Standing Committee of Kindred Societies

Major-General Sir Leonard Atkinson, K.B.E., B.Sc. (*Past President*)
Graham D. Clifford, C.M.G. (*Fellow*)

Appendix 7

Members representing the IERE on Technical Committees of the British Standards Institution

EEL/– **Electronic Equipment**
Brigadier R. Knowles, C.B.E. (*Fellow*)

ECL/– **Electronic Components**
Brigadier R. Knowles, C.B.E. (*Fellow*)

E/–/12 **Maintenance/Terotechnology**
L. A. Bonvini (*Fellow*)
Brigadier R. W. A. Lonsdale, B.Sc. (*Fellow*)

EPC/1 **Acoustics**
W. V. Richings (*Fellow*)

ELE/103 **Medical Electrical and Radiological Equipment**
R. Brennand (*Member*)

ELE/103/2 **Electro-Medical Equipment**
A. J. Huelin (*Member*)

ELE/103/–/4 **Safety—Medical Electrical and Radiological Equipment**
A. J. Huelin (*Member*)

ELE/103/–/5 **Installations—Medical Electrical and Radiological Equipment**
A. J. Huelin (*Member*)

ELE/TLE/1 **Terminology Common to Power and Telecommunications**
E. H. Jones, B.Sc.(Eng.) (*Fellow*)

ELE/TLE/1/1 **Fundamental Terminology**
E. H. Jones, B.Sc.(Eng.) (*Fellow*)

ELE/TLE/1/10 **General Heavy Electrical Terminology**
E. H. Jones, B.Sc.(Eng.) (*Fellow*)

ELE/TLE/1/20 **Magnetism Terminology**
E. H. Jones, B.Sc.(Eng.) (*Fellow*)

NSS/5/6 **Audio Aids (School Music)**
M. H. Evans (*Member*)

TLE/5 **Electronic Tubes and Valves**
G. R. Jessop (*Member*)

TLE/5/8 **Tube and Valve Performance—Light Conversion**
(*vacant*)

TLE/8/8 **Oscilloscopes**
D. Styles (*Member*)

TLE/12/5 **Microwave Semiconductor Devices**
R. R. Harman (*Member*)

TLE/16 **Electronic Reliability**
Brigadier R. Knowles, C.B.E. (*Fellow*)

TLE/17 **Integrated Electronic Circuits**
(*vacant*)

TLE/17/1 **Performance of Integrated Electronic Circuits**
(*vacant*)

TLE/23 **Safety of Telecommunication and Electronic Components and Equipment**
Col. F. R. Spragg, B.Sc. (*Fellow*)

TLE/24/–/1 **Radiation-induced Ignition and Detonation (Research and Development Co-ordination)**
Col. F. R. Spragg, B.Sc. (*Fellow*)

TLE/24 **Electro-Acoustics**
S. Kelly (*Fellow*)

TLE/24/1 **Audio Engineering**
S. Kelly (*Fellow*)

TLE/25 **Radio Communication**
R. Larry (*Fellow*)

TLE/25/4 **Aerials**
C. Hale (*Member*)

TLE/26 **Performance of Household High Fidelity Audio Equipment**
R. S. Roberts (*Fellow*)

MEE/41 **Code of Practice on the Safe Use of Cranes**
W. P. Rowley, M.B.E. (*Fellow*)

Appendix 8

Award of Institution Premiums for 1975

Main Premiums

HEINRICH HERTZ PREMIUM *Value £50*
(Physical or mathematical aspects of electronics or radio)
'Solar-terrestrial relations and short-term ionospheric forecasting'
by F. E. Cook and C. G. McCue (Ionospheric Prediction Service, Department of Science, Australia)
(Published in the January/February issue of the Journal)

MARCONI PREMIUM *Value £50*
(Engineering)
'Microwave device applications of epitaxial magnetic garnets'
by Dr J. D. Adam, Professor J. H. Collins and Dr J. M. Owens (University of Edinburgh)
(December)

Specialized Technical Premiums

CHARLES BABBAGE PREMIUM *Value £25*
(Computers)
'Magnetic bubble domain memories in epitaxial garnet films'
by Dr J. L. Tomlinson (State Polytechnic University, Pomona, California) and Dr H. H. Wieder (Naval Electronics Laboratory Centre, San Diego, California)
(December)

LORD BRABAZON PREMIUM *Value £25*
(Aerospace, maritime or military systems)
'Limitations of radar techniques for the detection of small surface targets in clutter'
by P. D. L. Williams (Decca Radar) (August)

A. F. BULGIN PREMIUM *Value £25*
(Components)
'The importance of water purity in the successful operation of vapour-cooled television klystrons'
by Dr R. Heppinstall and G. T. Clayworth (English Electric Valve Co.)
(August)

REDIFFUSION TELEVISION PREMIUM *Value £50*
(Communications or broadcasting engineering)
'Long-term h.f. propagation predictions for radio-circuit planning'
by P. A. Bradley (Appleton Laboratory)
(January/February)

SIR CHARLES WHEATSTONE PREMIUM *Value £25*
(Instrumentation and measurement)
'Digital waveform synthesis'
by W. A. Evans, W. A. Grey and E. M. Davies (University College of Swansea)
(June)

General Premiums

ARTHUR GAY PREMIUM *Value £25*
(Production techniques)
'Evaluation methods for the examination of thick film materials'
by M. V. Coleman (Standard Telecommunication Laboratories)
(March)

SIR HENRY JACKSON PREMIUM *Value £25*
(History of electronics or radio)
'Electronics and nuclear power'
by R. J. Cox (Atomic Energy Establishment, Winfrith)
(October)

Papers of sufficiently high standard were not published within the terms of the following Premiums and they are withheld:

CLERK MAXWELL PREMIUM *Value £75*
(Most outstanding paper of the year)

LORD RUTHERFORD PREMIUM *Value £25*
(Atomic or nuclear physics)

J. LANGHAM THOMPSON PREMIUM *Value £50*
(Control engineering)

P. PERRING THOMS PREMIUM *Value £50*
(Radio or television reception)

DR NORMAN PARTRIDGE PREMIUM *Value £25*
(Audio frequency engineering)

DR V. K. ZWORYKIN PREMIUM *Value £40*
(Medical or biological electronics)

LESLIE MCMICHAEL PREMIUM *Value £25*
(Management techniques)

ERIC ZEPLER PREMIUM *Value £25*
(Education)

HUGH BRENNAN PREMIUM *Value £25*
(North Eastern Section paper)

SIR J. C. BOSE PREMIUM *Value £25*
(Outstanding paper by an Indian author)

LOCAL SECTIONS PREMIUM *Value £25*
(Outstanding paper first read at a Local Section meeting and subsequently published in the Journal)

NOMINATIONS FOR ELECTION TO COUNCIL

Brief Biographical Notes

In accordance with Bye-Law 43 the Council's nominations for election to the 1976–77 Council were notified to Corporate Members in the June issue of the Institution's Journal.

FOR ELECTION AS PRESIDENT OF THE INSTITUTION

Dr. Percy Albert Allaway, C.B.E., D.Tech. (Fellow 1971), age 61, is Chairman of EMI Electronics Ltd.

Dr. Allaway's first appointment during his technical training was with The Gramophone Company between 1930 and 1933, when he was concerned with electro-mechanical engineering and the early developments in television. He subsequently moved to the Submarine Signal Corporation and then the Philco Radio and Television Corporation, returning to EMI in 1939 as a design engineer to work on military radar systems. He held progressively more senior posts and was in 1954 appointed to the Board as Director, Designs and Development, becoming Managing Director of EMI Electronics in 1961. He is also on the Main Board of EMI Ltd. and is Chairman or a Director of many companies within EMI Electronics and Industrial Operations. He was appointed C.B.E. in the 1973 New Year Honours List.

Dr. Allaway has been an active member of numerous industrial associations and government committees, including the Electronic Engineering Association, of which he was President and Chairman from 1970 to 1971. He represents the Department of Industry on the National Electronics Council and he was a member of the Ministry of Technology Electronics Research Council and of the 'Raby' Committee on defence equipment policy. He is Chairman of the Defence Industries Quality Assurance Panel and in 1972 was Chairman of the National Council for Quality and Reliability. Dr. Allaway has been closely associated with Brunel University since its formation and is a member of its Court; the University conferred its Honorary Degree of Doctor of Technology on him in 1973. Dr. Allaway has served on the Institution's Council since 1972 and was first elected a Vice-President in 1973. He has been the Institution's representative on the Board of CEI and is a member of its Executive Committee.

FOR RE-ELECTION AS VICE-PRESIDENTS

Professor David Evan Naunton Davies, D.Sc., Ph.D., B.Sc., F.I.E.E., Fellow 1974, Member 1962, age 40, has held a Chair in Electrical Engineering at University College London since 1971.

Professor William Alexander Gambling, D.Sc., Ph.D., F.I.E.E. Fellow 1964, Member 1958, age 49, is head of the Department of Electronics at University of Southampton.

Denis William Heightman, Fellow 1968, Member 1942, age 64, is Group Technical Director of Thorn Television Rentals Ltd.

Professor James Roderick James, Ph.D., B.Sc., F.I.E.E., Fellow 1975, Member 1960, Graduate 1956, age 43, has recently been appointed to a Chair in Electronics at the Royal Military College of Science, Shrivenham.

John Powell, T.D., M.Sc., Fellow 1965, Member 1957, Graduate 1953, age 52, is Head of Corporate Planning, Cable & Wireless Ltd.

(Fuller biographies of the above Vice-Presidents were given in the August 1975 issue of the Journal.)

D. E. N. Davies

W. A. Gambling

D. W. Heightman

J. R. James

J. Powell

W. Gosling

R. C. Hills

S. R. Wilkins

L. A. Bonvini

Sir Raymond Brown

FOR ELECTION AS VICE-PRESIDENTS

Professor William Gosling, B.Sc., F.I.E.E., M.Inst.P., Fellow 1968, age 44, is a graduate of Imperial College, London. Professor Gosling has been Head of the Electronics Group at the School of Engineering at the University of Bath since 1974. He was previously at the University College of Swansea for some 16 years and was Professor of Electrical Engineering and Head of the Department of Electronic and Electrical Engineering from 1966 until 1973. He has contributed numerous papers to the Journal on a variety of subjects including instrumentation, semiconductor devices and circuits, and radio receiver techniques. Professor Gosling was Chairman of the Professional Activities Committee from 1971 to 1976 and he serves currently on the Executive Committee; he chaired the Golden Jubilee Convention Committee. He was first elected a member of the Council in 1970, and served as a Vice-President from 1972 to 1975. He has served on various CEI Committees and is now an alternate representative of the Institution on the Board.

Raymond Clement Hills, B.Sc.(Eng.), F.I.E.E., Fellow 1972, Member 1961, age 43, has been Chief Engineer, Transmitters of the Independent Broadcasting Authority since 1973. He went to the Authority in 1966, following twelve years with the B.B.C., which he joined as a Graduate Apprentice after leaving the University of Bristol; during this period he was concerned with aerial design and installation for radio and television. First appointed Head of Mast and Aerials Section with the ITA, in 1969 Mr. Hills became Head of the Station Design and Construction Department. A member of the Communications Group Committee since 1968, he has served on the Council from 1968 to 1971 and from 1973. He has been a member of the Golden Jubilee Convention Committee and of conference organizing committees.

FOR RE-ELECTION AS HONORARY TREASURER

Sydney Rutherford Wilkins (Fellow 1942, Member 1935, Associate 1934) has been Managing Director of Fleming Instruments Ltd. since 1970. He was first elected Honorary Treasurer in 1973. (A fuller note on his professional career was published in the Journal for September 1972.)

FOR ELECTION AS ORDINARY MEMBERS OF COUNCIL

From the Class of Fellows

Leonard Alfred Bonvini, Fellow 1969, Member 1963, Graduate 1958, age 44, has been with the Government Communications Headquarters since 1965, initially as a Project Engineer and since 1968 as Head of Station Engineering Branch of the Composite Signals Organization. After completing National Service in the Royal Signals, Mr. Bonvini joined the Scientific Civil Service and from 1953 to 1965 was an Experimental Officer at the Radio Research Station, Slough. He worked on the development of special purpose instruments and from 1960 to 1962 was in charge of the ionospheric group of the RRS in Singapore. Mr. Bonvini served on the Institution's Technical Committee from 1965 to 1971 and on the Communications Group Committee from 1968 to 1972; since 1971 he has been a member of the Papers Committee.

Sir Raymond Frederick Brown, O.B.E., Fellow 1974, Companion 1969, age 56, has been Managing Director of Muirhead Ltd. for the past six years and Chairman since 1972. He was joint founder of Racal Electronics Ltd. in 1950 and Chairman and Managing Director until 1966 when he was appointed Head of Defence Sales, Ministry of Defence. He has been Chairman of Racecourse Technical Services Ltd. since 1970 and he is a Director of British Aircraft Corporation (Holdings) Ltd. He was appointed O.B.E. in 1966 and knighted in 1969. Sir Raymond entered the electronics industry in 1934 joining Rediffusion Ltd. (later Redifon Ltd.) with whom he remained until 1949 when he was appointed Sales Manager of the Communications and Electronics Division of the Plessey Company Ltd. He is a past Vice-Chairman of the Council of the Electronics Engineering Association and was its President in 1975.

Leonard Frederick Mathews, C.B.E., Fellow 1957, Member 1951, Associate 1948, Student 1946, age 59, is at present Senior Resident Director of ATV Network Ltd. in Birmingham. He has held successively more responsible positions with Associated Television Ltd. since he joined the Company as Head of Communications Department on the inception of independent television in 1955. Following war service with the Fleet Air Arm, from 1946 to 1955 he was a Senior Maintenance Engineer with the BBC. In 1970 Mr. Mathews received the O.B.E. for services to broadcasting. An examiner in television for the IERE Graduateship Examination from 1958 to 1965, he has also given papers at Institution conferences and meetings. He has been particularly concerned with the international television links, including the use of satellites which was the subject of his paper in the 1969 Convention on 'Radio Techniques and Space Research'.


L. F. Mathews


N. G. V. Anslow


K. Copeland


C. J. Lilly


J. M. Walker

From the Class of Members

Nigel George Victor Anslow, Member 1948, Associate 1943, age 55, was appointed Group General Manager Communications of British Airways in 1972. Prior to the merger with BEA he had been Controller of Communications for BOAC since 1966; he joined the Corporation in 1946 as a Signals Officer following war service in the RAF as a Signals Officer and subsequently with the Air Ministry. Mr. Anslow has been a member of the Aerospace, Maritime and Military Systems Group since 1972.

Keith Copeland, M.I.E.E., Member 1955, Student 1942, age 55, is a Research Assistant in the Department of Biophysics at University College London, where he has worked with Professor Sir Bernard Katz since 1951. He joined the UCL Biophysics Research Unit under Professor A. V. Hill in 1947 following service as a radar mechanic in the RAF, and has been active in devising electronic instrumentation for physiological research ever since. He also has an interest in aids for the severely handicapped and is editor of a recent book on this subject. Mr. Copeland has served on the Medical and Biological Electronics Group Committee since its formation in 1959 and was its chairman for four years. He is a founder member and served as honorary secretary of the Biological Engineering Society and he was honorary treasurer of the International Federation for Medical and Biological Engineering.

Christopher John Lilly, Member 1973, Graduate 1969, age 30, is an Executive Engineer in the Development Department of the Post Office Telecommunications Headquarters. He received his technical education at South East London Technical College and the Polytechnic of the South Bank and started his career in the Reactor Control Division of Elliott Automation Ltd. In 1967 he joined the Line and Radio Transmission Systems Division of the Post Office Development Department as an Assistant Executive Engineer in the Audio Equipment Development Group. On promotion to Executive Engineer in 1970 Mr. Lilly became responsible for the development of high capacity 4, 12 and 60 MHz frequency division multiplex coaxial line transmission systems. He is currently involved in the development of optical fibre transmission systems and their application in telecommunications networks.

Note.—Mr. Lilly has been nominated by thirteen Corporate Members: W. D. Brown, J. D. Buffin, D. Denman, J. F. S. Forster, F. A. Franks, M. G. Hansen, C. Jelly, J. G. Jenkins, A. R. Lawrence, R. K. LeGood, J. G. Pain, M. Russell and G. G. Stephens.

Group Captain James Martin Walker, RAF, M.R.Ae.S., Member 1966, Graduate 1957, Student 1956, age 41, took up the appointment of Officer Commanding RAF Locking and Commandant, No. 1 Radio School, in March of this year.


J. Domican


T. D. Ibbotson

Before joining the RAF as a National Serviceman in 1956, he was a student apprentice with EMI Engineering Development Ltd. He continued studies at the RAF Technical College and he has served overseas in the Middle East and East Africa, and in the United States as a Special Assistant to the Director of Communications-Electronics at HQ Strategic Air Command. Other postings include two years at RAE Farnborough on R & D duties and to the RAF Staff College and the RAF College, Cranwell, where from 1974 to 1976 he was Chief Instructor of the Electrical Engineering Wing. Group Captain Walker has served on the Institution's Membership Committee for the past year.

From the Class of Associate Members

Lieutenant Commander Joseph Domican RN, Associate Member 1974, Graduate 1962, age 41, has been for the past two years, an Instructor Officer at the Royal Naval Detention Quarters, Portsmouth. Following National Service in the RAF as a Radar Mechanic he was for six years with the Central Electricity Generating Board and in 1962 successfully completed the Higher National Diploma. He then was commissioned in the Royal Navy in the Instructor Branch and after appointments at HMS *Collingwood* and at sea he was loaned for $4\frac{1}{2}$ years as Training Officer to the Kenya Navy. Prior to taking up his present post, Lt.-Cdr. Domican was Head of Electrical Engineering Science at the Artificer Apprentice Training School, HMS *Fisgard*, at Plymouth.

From the Class of Associates

Thomas Denis Ibbotson, Associate 1966, age 61, who was recently appointed Technical Director of S. G. Brown Communications Ltd., joined the parent company S. G. Brown Ltd. in 1932 as an Acoustic Test Engineer. During the war he moved to the production side, first as Chief Inspector, then as a Production Engineer and, from 1944 to 1946, as Assistant Works Manager. Mr. Ibbotson then became a gyro development engineer with the marine navigation division and later was Superintendent of the Electrical and Experimental Laboratories before being appointed Chief Engineer of the Communications Division.

IERE News and Commentary

The Winston Churchill Memorial Trust

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

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

The categories for which grants are to be specially allotted in 1977 include 'Communication between Management and Employers', 'Women in Industry', 'Sport and Adventure' and 'Prevention of Vandalism'. A limited number of awards will be made for outstanding or unusual projects not covered by this list.

The grants cover all Fellowship expenses; the average length of which is three months. Interviews will be held in London in January 1977 and successful candidates will be expected to start their travels during that year.

To apply, send your name and address only on a postcard as soon as possible to the Winston Churchill Memorial Trust, 15 Queen's Gate Terrace, London SW7 5PR. You will receive an explanatory leaflet and a form to complete which must be returned before 1st November 1976.

The Marconi International Fellowship

Nominations are now being invited for the award of the Third Marconi International Fellowship. Established in 1974 on the 100th anniversary of the birth of Guglielmo Marconi by 22 international communications and electronics corporations, the Council which makes the award is chaired by Marconi's daughter, Mrs. Gioia Marconi Braga, and administered by the Aspen Institute for Humanistic Studies, Boulder, Colorado; Lord Nelson of Stafford, Chairman of the General Electric Company Limited, is the British member of the Council.

The Fellowship has as its primary purpose to recognize and inspire accomplishments by creative men and women who come from the fields of science, engineering and the humanities and whose work is characterized by the desire that their achievements and discoveries shall help to better the human condition. The Fellowship and the work commissioned by its award form an integral part of the Programme of Science Technology and Humanism of the Aspen Institute.

The first Marconi International Fellowship was awarded in 1974 to Dr. James R. Killian Jr., Honorary Chairman of the Massachusetts Institute of Technology and a former special assistant to President Lyndon B. Johnson for Science and Technology. Dr. Killian used his award to commission Professor Asa Briggs, Vice-Chancellor of the University of Sussex, to extend his work on the history of broadcasting. (Professor Briggs is the author of the three-volume work, 'The History of Broadcasting in the United Kingdom.')

In May, H.R.H. The Duke of Edinburgh presented the 1975 Fellowship to Dr. Hiroshi Inose, Professor of Engineering at the University of Tokyo, who is a leading authority on the application of electronic computers and has led the research and development of time division switching systems for integrated digital computer communication systems. This latter subject will form the basis of the work he will write as his commission under the Fellowship.

The third Fellowship will be awarded early in 1977; the closing date for nominations is 15th November 1976. All inquiries should be addressed to: Marconi International Fellowship Council, Aspen Institute for Humanistic Studies, 1919 Fourteenth Street, Boulder, Colorado 80302, USA.

Royal Society's Clifford Paterson Lecture

The Council of The Royal Society has appointed Sir Eric Eastwood, C.B.E., C.Eng., F.I.E.E., F.R.S., Consultant with GEC-Marconi Electronics Limited, to deliver the first Clifford Paterson Lecture. The lecture, to be given annually, is being established by means of a gift from The General Electric Company Limited to The Royal Society. The lecture is to be on a subject within the field of electrical science and technology, including the science and technology of electronic materials, components and systems.

Sir Eric will deliver his lecture, entitled 'Radar engineering: new techniques and applications', at the Royal Society on Thursday, 11th November 1976, at 4.30 p.m. All interested in the subject will be welcome to attend but are requested to give prior notice to this effect to the Executive Secretary, The Royal Society, 6 Carlton House Terrace, London SW1Y 5AG. (Telephone enquiries to: 01–839 5561, extension 278.)

The 1976–77 programme of the Royal Society also includes a two-day discussion meeting on 28th and 29th October on 'The use of operational research and systems analysis in decision making'. It is being organized by Professor J. F. Coales, F.R.S. and Mr. R. C. Tomlinson.

On 10th and 11th March there is to be a discussion meeting on 'Telecommunications in the 1980s and after', organized by Sir James Lighthill, F.R.S., Sir Eric Eastwood, F.R.S., Mr. C. A. May and Professor K. W. Cattermole. Participation in these meetings is on the same basis as the November meeting.

Institution Meetings in the South East

The joint programme booklet for the first half session (September 1976—January 1977) has been published containing IERE meetings held in London and by the East Anglian, Kent, Thames Valley and Beds. and Herts. Sections, as well as IEE meetings in London and environs, and details of joint conferences. Copies are being sent to all members living in those areas: Non-Corporate Members will receive their booklet with this issue of the Journal, and Corporate Members have already been sent theirs separately.

Members in other parts of the British Isles may obtain a copy of the booklet from the Institution by sending a stamped addressed envelope (not smaller than 11 cm × 15 cm —4 in × 6 in).

Electronics in Society

Some highlights of the Golden Jubilee Convention

CAMBRIDGE, 28th JUNE—1st JULY 1976

The culmination of the Institution's Golden Jubilee Year was the Convention held at Cambridge at which the theme of 'Electronics in Society' was elaborated upon in addresses, lectures and papers. Some of these will be published in the Journal in the normal way and the following pages give excerpts from a few of the items which went to make an exceptionally useful four days.

Sir Leonard Atkinson (Past President) opens the Convention

Many people these days ask what is the value of an Institution—is it just an expensive way of getting some letters after your name and getting recognized by CEI as a chartered engineer? No, the very first and probably the most important function of an Institution and particularly our Institution dealing as it does with fast-moving electronics, is to keep our members and particularly our young members up-to-date with developments in their technology.

For far too many people the first degree is the beginning and the end of their technical education. Many never read or even glance at the headings of the Journal. They don't even know what new inventions and developments there are—let alone anything about them.

I graduated with a degree in electrical engineering in 1932. Just think of the inventions that have been made since, which are now common place and taken for granted, but which were unheard of and largely unsuspected 40 years ago. If one had not tried to keep up-to-date by looking at new ideas, attending conventions, listening to people talk and reading, we as electronic engineers would be still way back in the three-electrode thermionic valve era, with unwieldly high loss coils, bulky batteries, chunks of ebonite and huge aerials!

Truly a good first degree is essential both as a mind trainer and in order to learn one's chosen discipline—to date! Equally important is to up-date that knowledge, otherwise a degree becomes just another attainment gained many years ago. This up-dating or continued education, undertaken by the individual, is probably the most important role of the Institution. The Armed Forces with their staff colleges and technical courses have done this for years, but industry has rather lagged behind.

Another purpose of an institution is to enable members to meet, irrespective of commercial or government employment, so that they may exchange ideas. This applies to electronic engineers going abroad, not only to create business but to study consumer needs of other countries and also to see what engineers abroad are doing in our field. This is why our oversea branches and members overseas are so important and valuable to our Institution.

Of course being up-to-date technically is one thing—very important indeed is being abreast of modern production methods. However clever the invention, it is no good unless it is developed for the production of goods to sell at home and abroad for the creation of wealth.

All this means that we in our several capacities must know something of R. & D, production, selling and finance, not forgetting man management. As electronic engineers we must see and understand not only what electronics is doing now but where it can be used in the future. As a director of an investment banking firm I would say there are no real problems, just opportunities; it is just the way you look at it.

In truth the creation of wealth is akin to the rainbow, it takes many colours and new developments before we reach the crock of gold. But first we must make our rainfall—and what a watershed the radio and electronic engineer has created in the fifty years life of this Institution!

The wide range of subjects covered in this Convention is symptomatic of the growth and use of electronics—communications in every form, data processing, medical electronics, micro-electronics, control, automation and the Clerk Maxwell Memorial Lecture. Many of you listening to your personal subject will learn something; others listening to other people's pet subject will learn something of adjacent disciplines and will be alerted and learn what is going on in 1976 and a bit about the way ahead. To us older engineers 1925 was still a miracle of communication without wires. Today half a century later, electronics is used everywhere and its future seems as limitless as that crock of gold.

Sciences and the Schools—the views of Sir Hermann Bondi

An appeal for an imaginative approach to draw more of Britain's school leavers into scientific careers was made by Sir Hermann Bondi, F.R.S., the Chief Scientific Adviser to the Ministry of Defence, when he gave the first Keynote Address of the Convention.

Sir Hermann claimed that the sciences, from maths to engineering were 'under a cloud' so far as school leavers were concerned. Would-be students, he said, viewed many of the scientific disciplines as being 'not very human' and far too much concerned with inanimate objects.

It was a prejudice and misconception, which had to be ended by those already in the profession. One of the most 'human' of all the science subjects was development engineering in which human performance had to be very accurately gauged.

He pointed out that none of the scientific disciplines should be 'sold as a soft option or easy subject'. 'Every subject has its irregular verbs, which are a bore, but I am not a believer in soft options,' said Sir Hermann.

He spoke of the overcrowded timetable in schools which could produce scientists who were so bored with the learning process they would not continue to keep abreast of developments after their initial qualification. And it had to be remembered, he said, that for a scientist much of what he initially learned would be obsolete after a third of his working career.

The President's Speech at the Convention Banquet

H.R.H. the Duke of Kent began by expressing the hope that at such an ancient college, so securely founded on faith and divine inspiration, it would not be thought sacrilegious to mention the 'miracle' of radio and electronics—for so swift and dramatic had been the advent of this science that to many it still seemed little short of miraculous. The President continued:

'In Cambridge, we members of the Institution of Electronic and Radio Engineers follow in the footsteps of our mentor, James Clerk Maxwell. Although I have never attempted to wrangle with them myself I think any student will testify that his mathematical equations are the very devil to master! The technology has moved a long way since his days although some of the papers in our Journal seem to indicate that all progress in electronics must first be proved by an extension of the Maxwell theorem!

'Indeed, one of the constant problems faced by the Council is the need for the Institution to strike a happy balance of service, both to the members engaged in research or development and those members concerned with production and its attendant problems. The Institution has to try and cater for the needs of all its members although it is doubtless hard to please all of them all the time! What we can do, however, and this Jubilee Convention presents an excellent opportunity for this, is to bring the specialists together in order to take stock of the present stage of our art, to try to see the ways in which our technology is developing, and the effect that our products are having on society.

'Our meetings this week have therefore been based around a series of review papers on six of the most important branches of electronics. It is in these areas that I believe future developments will have the greatest social impact and also incidentally the greatest significance for the advancement of our science.

'One excellent reason why I believe an occasional pause for reflection like this is salutary is that not only does it enable engineers and managers to keep abreast of progress in spheres other than their own; it also gives all of us a chance to keep check on advancing technologies which not infrequently throw up surprises whose significance may well be overlooked at the time. For instance, I wonder what would have happened if the semiconductor effect, which had been noticed long before the valve ever came into existence, had been closely examined rather than merely observed as a passing curiosity. Could the seeds of similarly exciting developments be lurking in any of today's laboratories? It is a tantalizing thought.

'A useful vehicle for our members to keep in touch with what the other half is thinking is our Journal and the Golden Jubilee issue provided a wide-ranging review not only of past achievements but of ground gained in the past fifty years. Nor have we neglected the other aspects of our learned society activities. To take just one Conference, that on 'Civil Land Mobile Radio' showed progress in a very exciting field and one which is currently presenting great challenges in view of the shortage of wavelengths available. I find it amusing that throughout the whole history of radio we have constantly been told by experts that there are insufficient frequencies available but somehow or other we have always managed to extend our horizons just in time to open up yet another waveband. The Conference last November showed how scientists and engineers are meeting the constant new demands for extending the spectrum—though presumably a limit has to be reached eventually.

'An important feature of our Conventions is the opportunity given to members to visit those Universities whose research work and faculties provide much of the background and members necessary for the progress of our Institution. For these reasons we have a special affection for the University of Cambridge and I must express our warmest thanks to all the Departments concerned and to King's College in particular for the facilities provided during this past week. All those who have taken part in these four days of our Golden Jubilee Convention will surely remember it as the highlight of this anniversary year as well as a landmark in the progress of the young, vital and dynamic science which this Institution represents.'

An amusing informal response on behalf of authors and guests to the President's speech was made by Dr. H. B. G. Casimir, who had given his Clerk Maxwell Memorial Lecture on the previous evening in the Lecture Theatre of that name in the Cavendish Laboratory. Dr. Casimir's lecture is printed in full in this issue.

The Electronic Engineer in the European Economic Community

Keynote Address: **LEON SMULIAN**, C.Eng., F.I.E.R.E.*

I have spent the last 2½ years in Brussels assisting various representatives of the member states to formulate and co-ordinate policies aimed at strengthening Community activity in the fields of telecommunications, computer communications and supporting technologies. I believe that there is no significant technological barrier to providing Europe with all the tools and infrastructure needed to enter the new industrial era in which human beings can use their brains instead of brawn and can rely on the effective acquisition and application of knowledge and information to control their destiny—natural disasters sometimes excluded.

Nevertheless the Community has not yet succeeded in co-ordinating its operational requirements or educational and applications programmes. Furthermore, the industries that have the technical capability have failed to create in many key areas either a market or technology base of the size and coherence needed to support the critical level of product development and application expenditure found to be necessary, by IBM for example, to ensure that products are available having the right performance at the right time to take advantage of new world wide growth markets that promise continual and apparently indefinite expansion for the application of electronic technology.

Our job in the Commission is to find ways and means and to propose Community policies and actions that will assist the people that live in the Member States to develop this market-sector by sector. The obvious actions are laid down in the Treaty of Rome. The removal of tariff barriers for example† and also of non-tariff barriers such as one-sided protective technical restrictions and government aids.

In the field of consumer products—radio, television, hi-fi, white goods, motor vehicles, etc., little or no public education was necessary to create a vigorous demand, and foreign suppliers with strong marketing and reliable after sales support were able to achieve rapid penetration of Community markets. The future of the European electronics industry in so far as its application to consumer products of

**Telecommunications Division, Directorate-General for Industrial and Technological Affairs, Commission of the European Communities.*

† In the absence of a common currency a unilateral devaluation or float of 10% could create the equivalent tariff change.

all kinds is concerned has no reason to be any less bright than that of any other trading entity. However, this is not the case for some other applications, in particular the data processing sector together with closely allied aspects of telecommunications and advanced electronic components such as integrated circuits for digital applications.

It has been said that it is more important to possess and use data processing and associated telecommunications and computer communications facilities than it is to build and sell them, since it is increasingly on these facilities that the rest of our manufacturing, distributing and information based industries and services depend. It could possibly be true—if we had a sufficient range of alternative activities and resources that could be applied to creating the wealth necessary to support the living standards we believe we have the right to expect. This is clearly not the case in Europe where it is precisely in these very fields of advanced technology industry and information based systems that we increasingly rely to achieve high-added-value products and services.

Not only are these the largest fastest growing industries, but, since the development of all other sectors of industry and services are dependant on the electronic information telecommunication complex, their impact on the overall productivity and social organization of Europe is immense.

What are we doing about it? Well, to start off we have to help industry to establish European standards with which to structure a homogeneous market for these facilities. The reason that this is not already the case as it is with consumer products is, of course, that the applications and software content of consumer products are virtually identical over the whole world. In the case of this new electronic infrastructure however, facilities have been developed based on national market structures. *Similar needs* in different Community countries are being met by *different solutions*. Only a company with the Europe-wide market power of IBM is able to sell *European* solutions.

This is beginning to change in the field of data networks where a Community project for dissemination of scientific and technical information—called EURONET* provided us with the opportunity to bring together the Community Telecommunication Administrations in order to devise a European solution to the data transmission requirement and thus to speed up the preparation of a CCITT, and hence international, standard terminal interface specification for public packet switching networks.

These have been also missed opportunities. One that was significant was proposed by Germany in 1973 for a four-year programme of work in the field of semiconductor technologies and was concerned with integrated circuits, optoelectronic and r.f. devices. The cost to German government and industry, shared, was of the order of \$200 M. The proposal stated that this programme was essential to establish the technology base from which to support their telecommunication data processing and certain space and defence industries and that it was an important factor in the long-term survival of German industry which was ultimately bound up with the health of its electronics industry for which this programme was a key. It further stated that to realize its full potential the programme should be extended to and carried out in co-operation with the other member states with similar industrial concerns. The good sense of this proposal was not recognized at the time and Germany went ahead alone. It is interesting to note that the programme implementation was resource-limited to the extent that Siemens has now negotiated a full manufacturing and software support licence with Intel for current and future microprocessor and peripheral modules. This must have represented a very substantial additional financial outlay to the four-year programme.

Just imagine what might have been achieved if a fully co-operative programme embracing c.a.d. for l.s.i. development and test had been undertaken as a Community effort. It might even have been possible that Europe would have succeeded where the US effort had failed in automating the design and test process with advantages in cost and performance such that the general microprocessor solution to system architecture could have been more selectively applied.

It is estimated that over 50% of Europe's integrated circuits needs will be imported this year. The forecast ahead worsens from the present situation in which Europe produces 14% of world consumption and consumes 23% to the 1980 prediction of producing 10% and consuming 26%, increasing the \$200 M deficit in 1974 to \$740 M in 1980 at current prices.

Community industry has expressed the will and determination to prevent this deterioration and to create a microelectronics capability in all areas of R & D and production including the manufacture of production and test equipment. The Commission has proposed a number of actions that could be supported by Community funds as also have national delegations. We are also proposing similar actions for supporting co-operative programmes in the fields of software engineering and both near-in and far-out computer peripherals.

On the broad front of electronic engineering, and in particular integrated circuit technology, it is absolutely essential that equipment and device manufacturers work together in close association for a common future. At a recent meeting held with device manufacturers the principle was agreed of putting together the resources on the scale required to compete with the USA and Japan with the next generation of v.l.s.i. and microprocessor technology.

Such a basic programme for long-term stability can only succeed if equipment suppliers in all sectors of the device user industries, support and participate in all phases and this must include the new users referred to by Bernard Asher of NEDO during his keynote address on Tuesday. Quite apart from the technical and operational benefits of such co-operation a further very important result will be that the European integrated circuit industry will achieve the degree of credibility and desireability in the eyes of the equipment industries that is necessary to generate a European scale of activity displacing US suppliers as the automatic first choice and capable of supplying the majority of European requirements.

To conclude this brief description of some of our present plans and actions to bring about an E.E.C. policy for the European electronics industry I would like to draw your most serious attention to that sector of the market that has a most important effect on the development and health of your industry. I refer to defence electronics, a subject generally considered outside the scope of E.E.C. policies but probably the key to a successful industrial policy for the broader subsequent application of electronic technology to other sectors.

In a successful market economy the initiative will always be taken by industry and supported appropriately by government, not the other way round. The present situation demands such initiatives by the leaders of the European electronics industry who, by seeking out and proposing the joint actions that will overcome the handicaps caused by a fragmented Community home market, will command the support of national and Community policies, and could also draw defence electronics into the common market place as it is in the United States of America.

* 'Go-ahead for Euronet'. *The Radio and Electronic Engineer*, 46, No. 5, p. 264, May 1976.

CEI News for Members

REORGANIZATION: OUTSTANDING ISSUES AGREED BY CEI BOARD

A major step forward in the protracted discussions on CEI reorganization was taken by the Council's Board on 22nd July when it reached agreement on all the outstanding issues on which decisions were required. Resolutions affecting the name of the Council—which it was decided should remain as 'The Council of Engineering Institutions'—the composition of the Board and its method of election and of determining subscriptions, and the procedure for setting up committees, were all passed at the meeting.

'The agreements reached today', said Mr. Tony Dummett, the Council's Chairman, speaking at a Press Conference, 'pave the way for CEI to implement its newly defined objective, to promote and maintain in the public interest the unity, integrity and quality of the engineering profession'. In particular they will lead to some fundamental changes sought by those involved in the complex discussions on reorganization that have taken place over the last months. One of these will result in a membership of CEI comprising individual chartered engineers on the one hand and corporate bodies—including non-chartered ones as Affiliates—on the other.

'The settling of our organizational problems on which so much time has already been spent', continued Mr. Dummett, 'will enable us to pursue our proper task of representing the profession on other vital matters of concern to it, for example, in consultation with Government, the status of the engineer and in standards of training'.

The agreements reached provide for free national elections of individual chartered engineers to the Board under the single transferable vote system but with a limit of not more than two elected members from any one institution. At the same time the Board's composition will be representative of all the chartered engineering institutions by the nomination of one representative from each of the Constituent Members.

The final resolution passed unanimously by the Board was that the Council approved the draft Petition and the draft Supplemental Charter and By-Laws as submitted to, and amended by the meeting, 'for submission for ratification by Special Resolution at a meeting of the Council to be called for the purpose on 22nd September 1976'.

After the Special Resolution is passed CEI will then be in a position to submit its new Charter and By-Laws to the Privy Council for consideration. If all goes according to the Chairman's unofficial expectations, the way should be clear for elections to be held at the beginning of 1978. Until then CEI will continue to operate under the Interim Board consisting basically of one nominated representative of each Institution, which took office in February of this year. A major task facing the Interim Board will be to draw up Regulations to cover the complicated election procedure (such as the implications of multiple membership) and other features of the new Charter.

The position of the IEE, which last year gave notice of its intention to withdraw from CEI in December 1976 because of dissatisfaction with the earlier proposed constitutional changes, notably the decision not to have nationally-elected individual engineers on the Board, had not been made clear at the time of writing.

The composition of the new Board will be as follows:

Ex officio: Chairman, Vice-Chairman and Immediate Past Chairman	3
One member nominated by each Corporation Member (i.e. Chartered Institution)	15
Elected members (equal to the number of nominated members above)	15
Chairman of the Regional Affairs Committee (if not already a Board Member)	1
The Chairman of each of the 3 Sections of the ERB	3
Total:	37

Annual Report of CEI

In a Foreword to CEI's Annual Report for 1975—the Council's (then) Chairman, Professor J. F. Coales, says that the tenth year of CEI has without doubt been the most active and controversial of its relatively short history. Reviewing the progress of the reorganization proposals, Professor Coales says: To begin with it appeared that the views of the smaller institutions were diametrically opposed to those of the large institutions as formulated in the three Presidents' paper but thanks to the good sense of all concerned a compromise was reached by the Board in July (1975) and a start could be made on drafting a Supplemental Charter and new By-laws for submission to the Privy Council.

Professor Coales points out that if CEI is to speak and act for the profession it can only be effective if the profession itself is seen to be united. The preoccupation of the national press with disagreements between the institutions has been most damaging to the profession. It has been grossly exaggerated since the most notable aspect of the discussions between the Presidents of the member institutions and the meeting of the Board has been the determination of all concerned to find a solution to CEI's problems which would best meet the needs both of institutions and of individual engineers.

Professor Coales says that some seemed to think that a strong, highly regarded CEI would in some way detract from the prestige and influence of the member institutions, a view which he regards as quite erroneous 'because CEI will only be highly regarded and effective if each part of the profession is itself held in high esteem, and this can only be the case if each and every constituent member is itself strong and respected.'

The 40-page Report covers the complete range of CEI and of ERB activities during the year and lists the various committees and sub-committees involved in its work. Copies are obtainable from CEI at 20p a copy, including postage.

The Professions and Industrial Democracy

In a submission of evidence to the Bullock Industrial Democracy Committee, the Council of Engineering Institutions recommends that, in addition to employers and trade unions, the professions should be recognized as 'a third force' with vital interest in, and responsibility for, the performance of industry, as well as an added responsibility to the public at large. It further recommends that if directors are appointed to the supervisory boards of industry from the representatives of trade unions, then trade unions appropriate to the professional man should be included.

Earlier in its 2,000-word submission CEI says that 'while the principle of industrial democracy as set out in Acts and consultative documents is accepted, it causes grave concern to the Council that in formal consultations only trade unions are specifically mentioned, and no provision is made for consultation with professional engineers, whose views, it might be expected, would be of major importance and who are anxious to contribute as much as possible to the industries they serve'.

The role of the professional engineer in highly technological industries, CEI points out, is a key one 'as he is not only responsible for design and development—without which such industries cannot thrive—but is playing an increasingly important part in controlling operations on the shop floor, in marketing and in management. The innovative role of the engineer is essential to the improvement of industrial performance and to the further creation of wealth. . . .'

The Council, says the submission, considers that industrial democracy implies that all who are engaged in an industry are consulted, and that their views are taken into account in the management and organization of it. 'For this to be effective', it continues, 'there must be adequate disclosure of information on the company's affairs to enable the views expressed through consultative machinery to be objective and constructive. . . .'

In its conclusions CEI says that it is concerned that the general debate polarizes industry into the employers on the one hand and trade unions on the other, as this will reduce the role of the professional in industry at a time when his support is needed in contributing towards the country's future industrial prosperity.

Third General Assembly of the ERB

It was reported at the third General Assembly of the Engineers Registration Board—held at the Institution of Civil Engineers on 2nd June—that the total number of member institutions is unchanged at 48 and a small number of applications for membership is currently being processed. The number of institutions in the respective sections is: Chartered Engineer Section 15; Technician Engineer Section 43; Technician Section 30: with ten of CEI's constituent institutions now being also members of one or both of the other two sections.

The gross total of corporate members nominated to the Chartered Engineer Register by CEI's 15 Institutions was 210,842 as at 1st July last year. This figure makes no allowance for multiple membership, and the net number of individuals is likely to be about 170,000. At 30th April 1976 the number of Technician Engineers registered was 42,569, and of Technicians 15,093.

Speaking to the assembly, CEI's President, Lord Hinton, expressed his concern about the training of those engineers who set out to follow the normal course of study which leads to chartered status. Too little practical training is given to them, he felt, although he conceded that in recent years there had been a greater willingness to use the thick sandwich course which at one time many heads of university engineering faculties had opposed. 'Several of the new technological universities', said Lord Hinton, 'use the thin sandwich course. But I do not believe that either of these courses in themselves give the depth of practical training which makes a complete engineer. I think that too often industry takes on university trained engineers and keeps them on specialized work until they are so narrowly specialized that they can be nothing but specialists.'

Dr. D. F. Galloway, Chairman of the General Assembly (who was later re-elected in this capacity for 1976/77) said that the increasing recognition of the interdependence of engineers in different institutions as they faced the complex problems of modern industry was reflected in the growing support of industry and government for the ERB concept of a single Register embracing all parts of the engineering profession. 'A major commitment of the ERB', he continued, 'is to ensure sound standards of training, experience and academic qualifications for all kinds of engineers and technicians admitted to the register . . . . An ERB statement on the training and experience requirements for registration as a Technician Engineer or Technician has now been considered by the respective Boards, and it is hoped that this can be finalised and published during the current year.' This would be followed by a statement on academic requirements so that the ERB would have its own objective criteria against which academic awards could be judged.

Professor J. F. Coales, Dr. J. Cowley and Mr. W. Wetton, Chairmen of the respective Boards (Chartered Engineer, Technician Engineer, and Technician) spoke of the work of these during the past year.

Standard Frequency Transmissions—June 1976

(Communication from the National Physical Laboratory)

June 1976	Deviation from nominal frequency in parts in 10^{10} (24-hour mean centred on 0300 UT)	Relative phase readings in microseconds NPL—Station (Readings at 1500 UT)	
	Droitwich 200 kHz	*GBR 16 kHz	†MSF 60 kHz
1	−0·1	697·6	612·2
2	−0·1	697·7	612·2
3	−0·1	697·8	612·4
4	−0·1	697·5	612·1
5	−0·1	697·7	612·2
6	−0·1	697·9	612·3
7	−0·1	697·7	611·7
8	−0·2	697·5	611·3
9	−0·2	697·3	611·1
10	−0·2	697·0	611·1
11	−0·2	697·0	611·1
12	−0·2	697·1	611·5
13	−0·2	697·1	611·6
14	−0·2	697·5	611·6
15	−0·1	697·1	611·7
16	−0·2	697·3	611·8
17	−0·1	697·3	611·7
18	−0·1	698·0	611·7
19	−0·2	697·4	611·9
20	−0·2	697·4	611·9
21	0	697·6	611·8
22	0	697·6	612·3
23	0	697·5	611·8
24	0	697·4	611·6
25	−0·1	697·4	611·4
26	−0·1	697·3	611·5
27	−0·2	697·3	611·4
28	−0·2	697·2	611·5
29	−0·2	697·2	611·7
30	−0·2	697·2	611·6

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

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

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

Applicants for Election and Transfer

THE MEMBERSHIP COMMITTEE at its meeting on 17th August 1976 recommended to the Council the election and transfer of the following candidates. In accordance with Bye-law 23, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communication from Corporate Members concerning the proposed elections must be addressed by letter to the Secretary within twenty-eight days after publication of these details.

Meeting: 17th August 1976 (Membership Approval List No. 224)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Member to Fellow

DAVIES, Thomas William. *Penarth, Glamorgan.*
DENBY, Peter. *London.*
ELLIS, Richard John Godwin. *Milton, Cambridge*

Direct Election to Member

ARNOLD, Vaughan. *Winchester, Hampshire.*
GLENNIE-SMITH, Stephen Paul. *Ledbury, Herefordshire.*
SEYMOUR, William Roy. *Worcester Park, Surrey.*
WOODING, George William Henry. *Chatham, Kent.*
WYATT, Trevor George. *Plymouth, Devon.*

Transfer from Graduate to Member

BAKER, Barry Thomas. *Dartford, Kent.*
CROSSE, Robin Julius. *Newbury, Berkshire.*
LINDSEY, Peter Edward. *Ipswich, Suffolk.*

Transfer from Associate to Member

GURNEY, Joseph Benjamin. *Twickenham, Middlesex.*

Transfer from Student to Member

HICKMAN, Peter John. *Hitchin, Hertfordshire.*
PAGE, Colin James. *Stone, Staffs.*

NON-CORPORATE MEMBERS

Direct Election to Companion

CORFIELD, Kenneth George. *London.*

Direct Election to Associate Member

NETHERTON, John. *Leighton Buzzard, Bedfordshire.*

Transfer from Student to Associate Member

LAZENBURY, Michael Philip Andrew. *London.*

OVERSEAS

CORPORATE MEMBERS

Direct Election to Member

CARRUTHERS, Hugh Allan. *Cape Town.*
NEVILLE, Graham Charles. *West Hill, Ontario.*
YUEN, Heng Seng. *Singapore.*

NON-CORPORATE MEMBERS

Direct Election to Graduate

CHEUNG, Tze Ming. *Hong Kong.*

Direct Election to Associate Member

HO, Juh Nam Thomas. *Hong Kong.*
TAY, Boon Hwee. *Singapore.*
WARREN, Walter Simon. *Gimli, Manitoba.*

Transfer from Associate to Associate Member

ELUGBAIYE, Johnson Akande. *Lagos, Nigeria.*

Transfer from Student to Associate Member

WONG, Chi Fun. *Hong Kong.*

STUDENTS REGISTERED

CHNG, Lay Beng. *Singapore.*
CHOW, Chin Fatt. *Kuala Lumpur, Malaysia.*
GUNAWARDANE, G. W. D. Nihal. *Moratuwa, Sri Lanka.*
HO, Kok Hay. *Hong Kong.*
HO, Weng Kwong. *Singapore.*
LIM, Cheng Hwa. *Singapore.*
NG, Cheuk-Yin Joseph. *Hong Kong.*
ONG, Hong Chuan. *Singapore.*
PNG, Bee Beng. *Singapore.*
POON, Wai Kwong. *Hong Kong.*
TAN, Bee Hoon (Miss) *Singapore.*
TAN, Chin Huat. *Singapore.*
TAN, Hoon Juay. *Singapore.*
TANG, Ming-Sin. *Hong Kong.*

Conference on 'Electromagnetic Compatibility'

The compatibility of electromagnetic and electronic equipment of various kinds, especially when units of such equipment are assembled into complete systems, is a matter of increasing concern to both electronic and radio engineers and to those who use the systems. Examples of malfunctions in ships, aircraft and land installations have been quoted and, whilst there is evidence of an increasing awareness of the problem, there seems still to be an extensive desire for opportunities to discuss solutions to be applied at the design stage and later. The Institution, with the association of the Institution of Electrical Engineers, the Institute of Electrical and Electronics Engineers, the Institute of Quality Assurance, the Institute of Marine Engineers and the Royal Aeronautical Society, has therefore arranged this conference which is to be held at the University of Surrey from 4th to 7th April 1978.

Under the chairmanship of Mr. T. W. Welch and with a wide representation from Industry, Government Departments and Research Establishments, the Organizing Committee now invites the submission of synopses of papers for the conference. It will be the aim of the Organizing Committee to select from the synopses offered a range of papers suited to each of several 'session themes' at the conference itself.

Systems to be considered include those in civil use in ships, aircraft and other transport vehicles and in control, computing and communication centres. Subjects in the mainly military field are not to be excluded, particularly where they have a counterpart civil application.

Methods for preventing the generation of potentially interfering signals and for reducing the susceptibility of equipment to interference, both within systems and between systems, will represent the main theme of the conference. All types of man-made interference, including radiated, induced and conducted interference, whether from electronic equipment or from electrical plant, are to be included in the range of subjects covered. Contributions will be considered regarding protection from natural sources of interference. The position relating to domestic equipment, both as to its protection from external interference and its own potential for generating it, will be a welcome topic.

The points of view of those concerned with national and international planning, and regulations, standards and specifications, systems and equipment design, tests and measurements criteria, purchase and procurement, operation and installation will, it is hoped, be represented.

Papers covering economic aspects of design for the avoidance of incompatibility and analytical contributions regarding the necessary balance between 'designed in' protection and 'post installation' remedies are also invited.

It is intended that the conference should be primarily a discussion meeting and it is proposed to publish the selected papers in a pre-conference document and to provide for their presentation only (rather than their reading) with the authors then available as a group for the following discussion.

A synopsis, typically about 200 words and detailed enough to enable the Committee to assess the scope of the proposed paper, should be sent to the Secretary, Organizing Committee for the Conference on Electromagnetic Compatibility, Institution of Electronic and Radio Engineers, 8–9 Bedford Square, London WC1B 3RG. Synopses should be submitted as soon as possible but not later than 12th November 1976. Final papers may be either in short form or full length, i.e. containing either 2000 words or 4000 words approximately. Papers will be pre-printed, and are therefore required in final form by 29th June 1977.

Further information and registration forms for the Conference will be available in due course from the Conference Registrar at the IERE.

Forthcoming Institution Meetings

London Meetings

Wednesday, 6th October

ANNUAL GENERAL MEETING OF THE INSTITUTION

To be followed at 6.45 by **The Presidential Address of**

Dr. P. A. Allaway, C.B.E.

London School of Hygiene and Tropical Medicine, 6 p.m. (Tea 5.30 p.m.)

Tuesday, 12th October

JOINT IERE/IEE MEDICAL AND BIOLOGICAL ELECTRONICS GROUP

Physiology for engineers—1

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

Thursday, 21st October

COMMUNICATIONS GROUP

The London radio paging system

By I. H. Beck and N. W. Brown (*Post Office*)

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

Thursday, 28th October

AUTOMATION AND CONTROL SYSTEMS GROUP

Introduction to microprocessors

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

Further details to be announced.

Wednesday, 3rd November

JOINT IERE/IEE COMPUTER GROUP AND AUTOMATION AND CONTROL SYSTEMS GROUP

Design philosophy of pocket calculators

By Clive Sinclair (*Sinclair Radionics*)

London School of Hygiene and Tropical Medicine, 6 p.m. (Tea 5.30 p.m.)

Tuesday, 9th November

JOINT IEE/IERE MEDICAL AND BIOLOGICAL ELECTRONICS GROUP

Physiology for engineers—2

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

Further details to be announced.

Wednesday, 17th November

EDUCATION AND TRAINING GROUP

Colloquium on TECHNICIANS IN THE ELECTRONICS INDUSTRY

Royal Institution, Albemarle Street, London W1, 2 p.m. Advance registration necessary. For further details and registration forms, apply to Meetings Officer, IERE

Thursday, 18th November

COMMUNICATIONS GROUP

Compatible noise reduction in stereo broadcast systems

By Dr. A. R. Bailey (*University of Bradford*)

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

Thames Valley Section

Wednesday, 13th October

Evolution of facilities provided by modern message switching systems

By L. Rutherford (*ITT, Potters Bar*)

Caversham Bridge Hotel, Reading, 7.30 p.m.

Thursday, 11th November

Facsimile—a review

By M. S. Bowden and M. J. Malster (*Rank Xerox*)

Caversham Bridge Hotel, Reading, 7.30 p.m

South Western Section

Monday, 4th October

JOINT MEETING WITH IEE

The history of the telephone

By J. Sunderland (*Post Office*)

Students' Refectory, University of Bristol, 6 p.m. (Tea 5.30 p.m.)

Tuesday, 2nd November

JOINT MEETING WITH IEE

Microprocessors and applications

By Dr. E. L. Dalgless (*University of Wales*)

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

Wednesday, 3rd November

Electronic aids for medical and biological studies

By P. J. Best and Dr. E. J. Powner (*UMIST*)

Room 4E3.10, University of Bath, 7 p.m. (Tea 6.30 p.m.)

Wednesday, 24th November

CEI MEETING

Department of Chemistry, University of Bristol, 7 p.m.

Further details to be announced.

Southern Section

Wednesday, 6th October

JOINT MEETING WITH IEE

Chairman's Address: **Megawatt experimental research**

Dr. M. J. Little (*Marchwood Engineering Laboratories*)

Southampton University, 6.30 p.m. (Tea 5.45 p.m.)

Thursday, 21st October

TV for British Forces in Germany

By Major N. A. Walter (*School of Signals, Blandford Camp*)

Synopsis: Providing a British Television Service to the scattered military communities in Germany has posed some unusual problems. Examples from the planning and installation of the first phase of the project will be used to illustrate how they have been overcome.

South Dorset Technical College, Weymouth 6.30 p.m.

Thursday, 4th November

Loudspeaker enclosures

By A. Dyke.

Farnborough College of Technology, 7 p.m. (Tea 6.30 p.m.)

Wednesday, 10th November

The Dolby noise reduction system

By P. Plunkett (*Dolby Laboratories*)

Synopsis: The Dolby A and Dolby B systems will be demonstrated and described, explaining how the classical problems associated with audio noise reduction systems are overcome. Advances in tape recording techniques coupled with higher standards demanded by audiophiles have created the need for audio noise reduction. The requirements for a hi-fi noise reduction system will be laid down and conventional static and dynamic noise reduction systems are described along with their advantages and disadvantages. The professional Dolby A and simpler Dolby B systems will be demonstrated and described explaining how the problems associated with more conventional approaches are overcome.

Lanchester Theatre, Southampton University, 7 p.m.

Friday, 12th November

Electronic ignition

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

Isle of Wight College of Arts and Technology, 7 p.m.

Wednesday, 17th November

JOINT MEETING WITH IEE

Universal adaptor for computer peripherals

By D. M. Taub (*IBM*)

Southampton University, 6.30 p.m. (Tea 5.45 p.m.)

Wednesday, 24th November

Helium speech

By Dr. N. G. Kingsbury (*Marconi Space and Defence Systems*)

Room ABO-11, Portsmouth Polytechnic, 7.30 p.m.

Kent Section

Thursday, 14th October

The advanced passenger train

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

Further details to be announced.

Thursday, 11th November

Microprocessors

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

Further details to be announced.

Beds & Herts Section

Wednesday, 13th October

The influence of l.s.i. on logic system design

By Professor D. W. Lewin (*Brunel University*)

Synopsis: The availability of complex m.s.i. and l.s.i. components such as r.o.m.s p.l.a.s, microprocessors etc. has radically changed the technique of logic system design. Established switching theoretic methods such as Boolean minimization, optimal state-assignment etc. are no longer strictly relevant when designing at the sub-system level and new methods must be devised. The lecture will consider some of the difficulties associated with implementation using r.o.m., multiplexer and p.l.a. modules and will conclude with the use of hardware descriptive languages and other techniques which are being investigated as a means of designing at the sub-system level.

St. Albans College of Further Education, 7.45 p.m.

Tuesday, 9th November

New semiconductor devices

By C. S. den Brinker (*Mackintosh Consultants Co.*)

Synopsis: In spite of the rather prolonged world recession, several new approaches to integrated circuit manufacture have recently become established. This is complemented by a series of new circuit technologies. If history does repeat itself, then at this moment we appear to be at the verge of another major innovative cycle, similar to that of the early sixties when the integrated circuit was introduced. These new technologies will be discussed, and it will be shown that some of the sharp divisions that were prevalent at one time are now rapidly beginning to disappear. Technologies to be described include integrated injection logic, d-mos, v-mos, the latest results in bipolar processes, as well as some of the recent advances in linear professional designs.

Luton College of Technology, 7.45 p.m.

West Midlands Section

Tuesday, 19th October

JOINT MEETING WITH R.Ae.S.

The maintenance of the Tornado/MRCA in the Royal Air Force

By Sqn. Ldr. E. C. Graham and Sqn. Ldr. E. W. Poynter (*Tornado Project Team, RAF Swanton Morley*)

Astra Cinema, RAF Cosford, 7.15 p.m. (Tea 6.30 p.m.)

Tuesday, 16th November

JOINT MEETING WITH IEE

Area traffic control in Coventry

By D. J. Clowes (*West Midlands Traffic Authority*)

To be followed by a visit to the Traffic Control Centre

Lanchester Polytechnic, Coventry, 6.30 p.m. (Tea 5.45 p.m.)

East Midlands Section

Tuesday, 26th October

Hybrid applications of the Membrain Computer

By M. J. Morse (*Leicester Polytechnic*)

Hawthorn Building, Room H.08, Leicester Polytechnic, 7 p.m. (Tea 6.30 p.m.)

Tuesday, 9th November

JOINT MEETING WITH IEE

Ceefax—a new form of broadcasting

By D. T. Wright (*BBC Research Department*)

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

South Midlands Section

Wednesday, 6th October

Teletext decoding—an ideal application for l.s.i.

By G. A. Garrard (*Texas Instruments*)

Foley Arms Hotel, Malvern, 7.30 p.m.

East Anglian Section

Wednesday, 13th October

ANNUAL GENERAL MEETING

Saracen's Head Hotel, High Street, Chelmsford, 7 p.m.

Wednesday, 20th October

JOINT MEETING WITH IEE AND THE CHELMSFORD ENGINEERING SOCIETY

Telecommunications: the side you rarely see

By M. Payne (*Post Office*)

County Hotel, Rainsford Road, Chelmsford 6.30 p.m. (Tea 6 p.m.)

Thursday, 28th October

JOINT MEETING WITH IEE

Electronics in the study of blood flow in man

By Dr. V. C. Roberts (*King's College Hospital Medical School*)

University Engineering Laboratories, Trumpington Street, Cambridge, 6 p.m. (Tea 5.30 p.m.)

Thursday, 18th November

Golay triple error correction code

By Alan Croft (*Plessey*)

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

Thursday, 25th November

Viewdata—a Post Office interactive information medium for the general public

By S. Fedida (*Post Office Research Establishment, Martlesham*)

University Engineering Laboratories, Trumpington Street, Cambridge, 6 p.m. (Tea 5.30 p.m.)

North Eastern Section

Tuesday, 5th October

Air Traffic Control

By S. Ratcliffe (*RSRE*)

Discusses the implications of forecast developments in air traffic for the traffic control system and, less directly, for the designers of the electronic tools need for ATC. Present-day airports tend to have a relatively rigid strategy for the use of runways and other congested facilities, mainly because a more flexible approach would involve a prohibitive amount of co-ordination between a large 'committee' of very busy controllers. In theory, at least, such flexible strategies can be devised by an automated decision-taking process which can offer an appreciable pay-off in reduced traffic delays. The lecture will be illustrated by films and recordings taken in London to illustrate some of the problems which controllers face. An account will be given of an automated system, still in the experimental stage, which may suggest a solution to some of the problems.

YMCA, Ellison Place, Newcastle-upon-Tyne, 6 p.m. (Tea 5.30 p.m.)

Tuesday, 2nd November

Optoelectronic theory

By M. Miller (*Texas Instruments*)

A presentation of basic optoelectronic theory tailored for the designer/engineer to help him understand the principle of operation will include a discussion of photoresistor, photodiodes, phototransistors and the various solid state light emitting diodes. Emphasis will be on the practical aspects rather than the theoretical with a brief discussion of recent product developments. A review of actual applications for opto electronic devices will give insight into their uses and solution to varied circuit/design problems.

YMCA, Ellison Place, Newcastle-upon-Tyne, 6 p.m. (Tea 5.30 p.m.)

North Western Section

Thursday, 21st October

Electronic equipment for air traffic control

By a speaker from *BAC, Warton*

Bolton Institute of Technology, 6.15 p.m. Light refreshments available before the meeting.

Thursday, 18th November

Integrated circuits in the modern world

By a speaker from *Ferranti, Hollinwood*

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