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Technology at Childhood's End

By **Professor W. GOSLING,** B.Sc., C.Eng., F.I.E.R.E.
(*Vice-President of the Institution*)

This abridgement of a Public Lecture given by Professor Gosling on 24th October 1974 to mark his inauguration into the Chair of Electronics at the University of Bath is published in place of the customary editorial article because of its considerable relevance to many of the wider problems which today concern all engineers.

IN this particular epoch of world history my task is complicated because I feel that to give a lecture which narrowly concerns my own specialism would seem to many to be a rather ostrich-like activity at a time when our leaders are apt to present us with very gloomy forebodings of our national future. Indeed on the world scale optimism takes a very particular kind of talent, just at the moment. We seem to have passed into an epoch in which foreboding is the dominant sensation. Over the last decade a growing conviction has come to be very generally held, that human society faces a multiple crisis.

Perhaps it was the uncontrolled growth of world population which first gave cause for alarm, and many still see this as the most fundamental of all the factors driving world economics to a point of irretrievable disequilibrium. In an attempt to provide a rising standard of living for an ever larger population, the resources of technology have been exploited quite ruthlessly. Although largely successful in its main purpose, that exploitation has now been found to give rise to crises of raw materials exhaustion and environmental pollution. Current political problems, such as worldwide inflation, may be seen as symptoms of the increasing difficulty of further expansion of the scale of economic activity. The sudden emergence of an acute energy crisis, more accurately an oil crisis, in the winter of 1973 produced a discontinuity in public opinion leading to much more universal awareness of the acute nature of these problems than hitherto. Hand in hand with material changes profound psychological and sociological changes also seem to be in train. The decline of established religious beliefs as the foundation of the State is a universal phenomenon. Throughout the world the triumph of liberal philosophical ideas, born in the Enlightenment, is virtually complete and has led to a general abandonment of moral standards which were considered unquestionable only a generation or two ago.

Another unrecognized source of tension in contemporary social life is the technical obsolescence of warfare between major nations. A customary means of resolving international conflicts has always been warfare. It has also to some extent functioned as a means of resolving and clarifying tensions within states, whether due to class or political conflicts, which often fade away in the face of a foreign threat. The escalation of military technology has rendered the material and human cost of a global war so large now that nation states seem increasingly unwilling to embark upon it. We are in a situation where we have had to live for thirty years without a major recourse to arms in western Europe. It is not at all clear as yet that the nations can forever endure the grinding pressure of peace.

We find ourselves, then, in an over-populated world which is running short of resources and which is becoming rapidly more congested and polluted. It has abandoned its religious ideals and is in a cynical frame of mind. It has been deprived of war as a solvent of social problems.

The curve which describes the growth of human population is of a type which grows ever more steeply, doubling about every forty years. This exponential characteristic rises steeply without limit, and obviously if it is assumed that this rate of growth will continue for ever some of the consequences are quite bizarre. Within a few hundred years there would be only one square metre for every man, woman or child, and all life would in fact become quite impossible.

Thus the exponential curve may be an adequate model of the early stages of the growth of world population but cannot represent it for all time. A similar situation applies in many other fields, for example, the growth of scientific research. The number of scientific journals publishing research papers is one measure of the growth of science and here too the curves are of an exponential type. For science, as for world population, the same arguments hold, namely that such a rate of growth cannot for ever endure. However during this period of exponential growth some very curious consequences result. It is true, for example, to say that 90% of the scientists who have ever lived in the history of the world are alive today, and more than half of all the people who have lived in the history of the world are also alive today.

Other natural phenomena demonstrate exponential growth in the early stages but change later to a more limited rate of development. An example is the natural curves of growth measured for ordinary garden plants. In its beginning the rate of growth of a plant is extraordinarily rapid and follows the same exponential curve but later slows down considerably. The same is true for the human being, who begins as a single fertilized cell. This cell doubles and the two cells so formed then each double again and then another doubling occurs. Because the rate of growth increases so rapidly it cannot continue indefinitely but must always lead to a phase when the processes slacken, the curve turns over, and a stable state is approached. All the exponential growth processes that we see at the present time, and in particular the growth of population, of science, of energy consumption, and of all the parameters that determine the scale and style of our present civilized way of life, must themselves be subject to this law.

The deceleration point on the curve is crucial, since it divides two different and contrasted epochs. The first is the age of infancy in which exponential growth is the rule. The second is the epoch of maturity in which growth slows and draws to an end. It is difficult, looking at the data that we have, to determine where these crucial deceleration points occur for the growth curves that are of most importance to us today. It has been estimated that the turn-over point for science occurred about 1940 and perhaps the deceleration point for technology was a little later.

So far as world population is concerned, growth is simply not homogeneous. A number of developed countries are already showing greatly reduced rates of growth of their population: by contrast there are countries in the world, where the growth of population continues and already the social consequences for them are painful in the extreme. Unfortunately, population control measures work best in a prosperous society and are less effective in the poor societies where they are most needed. Contrary to popular belief, warfare can make only a negligible contribution to population control. All deaths which occurred in World War II correspond to only about three months' increase in world population at present rates. In the same way epidemics do not have much impact on population, but endemic diseases, which carry off the undernourished and will continue to do so year after year, are the main regulating factor. Although the situation is very variable, the world as a whole must be near to the point of population growth deceleration which in developed parts of the world is already some years into history.

If any of the parameters measuring the development of our society are observed it will be found that they are approaching or have passed their turn-over point. Again and again the apparently exponential curves are showing themselves to be in fact sigmoidal, the curve of natural growth. Again and again the turn-over points of the curves appear to fall in the last half of the twentieth century. As a consequence, in all these areas at once we are faced with a radical change in our style of life from what we have been used to for the past three hundred years. Population growth, science, energy use, technology, all have come to childhood's end.

Let us be clear that we are not facing a cataclysm, nor is civilization doomed to collapse. Through our own folly we could destroy ourselves at any time, but there is nothing inevitable about such an end. We face not the demise of civilization but only its coming of age. This is no end, but a beginning. The transition from childhood to maturity may be painful and may contain many risks and hazards, but it is not to be confused with senility.

It is important too, to understand precisely what we can expect from this slackening of growth curves. Science and technology will not disappear, any more than the world's population will suddenly fall. We shall not abandon the artefacts that our lives depend upon. All that will happen is that the level of our activity, as it relates to human numbers, consumption of energy, or demands on irreplaceable natural resources, will be stabilized. A slow transition will be made to a self-sustaining economy that can live indefinitely within the naturally regenerating resources of our planet. There will not be less technology than now, in fact there will be more, but it will have to be a new technology which pays better attention both to the nature of man and to the environment in which he must live. This is the technology of childhood's end and it is to this technology that we must direct our thoughts.

It needs to be understood that by technology we have risen from the animal condition. But we do have the option of adapting our technology in ways which will make it nearer to the instrument we need when our civilization is mature. In the infancy of the race our powers were so feeble that we were able to do violence both to ourselves and to the world we lived in without too dreadful a consequent calamity. The awful scars wrought on the face of England by the Industrial Revolution are quickly reclaimed by the natural world, and the ruins of yesterday's factories become tomorrow's wildlife sanctuaries. The technology of the twentieth century is so much more powerful in its sweep, unleashes much greater forces, and is on so much larger a scale, that we can now no longer take a careless view. Wrongly managed technology could deplete irreplaceable resources and pollute this planet to an extent not recoverable in thousands of years. At last we are aware of these possibilities and begin to take them seriously. We are perhaps coming to realize that the purpose of technology is the service of human needs, and are less willing to sacrifice some part of our population in order to operate a technological economy for the benefit of the rest. The kind of social cannibalism which consumed England's poor in the nineteenth century, obliging them to serve an imperfectly constructed industrial society in ways profoundly destructive of life and dignity, is now seen as what it had always been—an inhumanity and a disaster. Thus technology at childhood's end must be technology with a human face.

I am an engineer, and therefore I feel that it would be particularly fruitful for me to consider what dominant features in technology I can discern which are likely to be significant over the next generation.

Technology at childhood's end will be a technology of management, communication and control. It will be a taming technology, not a technology of exploration, and it will require machines that adapt themselves to people rather than people who adapt themselves to machines. Already we see signs of this trend. A modern car is adapted to the driver in a way that a nineteenth-century locomotive never was. It does not demand prodigies of strength or skill, nor does it oblige human beings to undertake hard and repugnant tasks. Our computers are every day adapted more and more to interact with human beings on human terms, no longer requiring men to learn the language of machines. The media of communication enable us to relate to each other more effectively as social animals. However, if this trend has begun, it has as yet gone but a little way and we must look for a great extension in the future.

A technological development of the last ten or fifteen years will, in my opinion, be our principal resource for solving these difficult problems. We have now entered the age of microelectronics.

Wherever information is to be collected, conveyed or stored, wherever processes or machines are to be controlled, wherever decisions are to be taken or calculations are to be made, in all those skills which are most distinctly human and most remote from the beasts, electronics is the means by which the faculties of Man can be stretched to equal their task.

Why does electronics play this central role? The reason is not hard to see. All artefacts depend upon matter, but the electron is the smallest and lightest of the fundamental particles of matter which carries a charge. That electrical charge makes it possible to move the electron about at will, yet the lightness and smallness of the electron means that it can be moved with almost inconceivable rapidity, so that electronic equipment can work even hundreds of millions of times in a second without the inertia of the electron introducing any insurmountable handicap. Thus the electron is the only possible particle for our needs, and it is upon electronics that we have come to depend.

[*Professor Gosling then surveyed the development of electronics from the thermionic valve through to microcircuits, referring to the growing complexity of the radio receiver as an illustration.*]

The economy and reliability of microcircuits can be exploited to build machines of a complexity and power as yet unimaginable.

Some years ago the famous automata theorist A. M. Turing asked, in a memorable paper, how complex a computer would have to be in order to simulate a human being, to the point where its behaviour would be indistinguishable from human behaviour over a lengthy period. He thought that a thousand million bits of store would be needed to simulate human behaviour. In our most important electronics companies design studies are now being pursued for a machine which would automate the directory enquiry function of the telephone system. Design of such a system is under way and is entirely practicable in terms of modern microcircuits. The interesting design parameter is the size of store that this machine will need. It is in fact ten thousand million bits, or ten times the size that Turing thought necessary to enable it to simulate human behaviour so well that none of us could tell that it was only a machine. This human-like machine is thus within the bounds of possibility.

At the other extreme of the computing range, the pocket calculator, which is now becoming so familiar to us all, is an example of something that was impossible before the microcircuit revolution. An electronic calculator typically contains some twenty-five thousand transistors, in the form of microcircuits. The first electronic computer that was ever built, ENIAC, contained some six thousand valves, filled a very large room and consumed fourteen kilowatts of power whereas the modern calculator fits into the pocket and consumes only about one watt.

Modern microcircuit engineering is above all things the engineering of complexity. It enables us to build structures of an intricacy unparalleled by anything that man has previously created, rivalling the complexity of living things themselves. It is a technology which uses negligible amounts of materials, for silicon is one of the commonest constituents of the earth's crust and yet the amount used in a microcircuit can be measured in milligrams. Little energy is used in creating a microcircuit and less in operating it. Thus microelectronic technology, which achieves formidable complexity and sophistication of function, yet absorbs practically no materials and little energy. It is a technology viable into the farthest foreseeable future, no matter what our materials and energy crises may be.

It is difficult to gain an impression of the probable consequence of microcircuits for our future. They permit an increase in the complexity of electronics systems by about one thousand times or, in scientific language, by three orders of magnitude. Such a big single jump in technology has rarely—perhaps never—been seen before in the history of mankind.

Perhaps the most striking of all technological developments and the most significant was the invention of the wheel. But a wheeled vehicle reduces the tractive power needed to drag a load along smooth ground by a factor of only about one hundred. Thus it is a two, not a three, order of magnitude revolution. The speed achieved by a running man is perhaps five or six miles an hour whereas a jet aircraft for passengers typically goes about a hundred times faster. Again this is a two order of magnitude revolution all the way from a man on foot to a jet aircraft. A manual worker using his own unaided effort can exert, over a prolonged period of time, about a third of a horse power, whereas the worker in modern mechanised industry can call upon substantially larger sources of power. Even so, only the driver of a juggernaut-sized lorry is continually using an energy source as large as three hundred horse power and therefore only for this small group among industrial workers is there a three order of magnitude increase in their rate of power.

It is probably better to think in quite different terms, to think perhaps in terms of the invention of fire and the consequent discovery of metallurgy although even here metals rarely achieve three orders of magnitude improvement in their properties over other naturally occurring materials. With a revolution so large and so dramatic in its impact it is very hard to say what the outcome will be. It gives us an instrument of immense power and the right kind of instrument for the problems which face us, because it can be used to give advances in communication, information processing and control which are going to be the dominant technological problems of our society in its maturity. If we are to appreciate the nature of the world we live in we must understand microelectronics as not merely one technology among others, but as something unique, comparable with the great turning points in industrial history, which has potentialities far beyond all the other technologies, important though they be, with which we may at present be concerned.

[Professor Gosling mentioned at this point some applications of microelectronics of especial interest and significance.]

Most significant of all, this new generation of machines can be human-like. Without in any way threatening their creators, the machines can be made to have such a complexity of behaviour, deriving from the intricacy of their structures, that they are able to respond far more adequately to the complexities of the human being. Until now technological societies have often featured an undesirable level of regimentation, treating all human beings in a standardized way because there are so many of them. This approach to the management and government of mankind is now obsolescent and it is possible, as it has always been desirable, to value the individual human being for his individuality and not for his adherence to the standards of the mass. Thus the individualism so highly prized in our culture need now no longer be incompatible with the machines that we use. Their complexities can mirror ours and they can respond as they should to the variety of our needs.

Armed as we are with the power to engineer a biological order of complexity, we can create artefacts with a sufficient subtlety of response in behaviour that we need no longer be a threat to the world in which we live and, still more, to ourselves. This technological resource does not excuse us from facing and solving our social, psychological, and ethical problems. There is no god in the machine.

In the end no real thing can be done in the world without engineers play their part in it. What the microcircuit revolution does for us is to give us a technological instrument of such subtlety, power and range that the strategies open to us are immensely augmented and the apparently insoluble problems that now fright us can at last be laid to rest if we have but the will.

In this age of the Earth optimism has become unfashionable, but it remains necessary. There is a task yet for us to do, dimly though we may perceive it, and the instrument for carrying it through is in our hands. We are not at the end of the world but only at the end of an age. We are at childhood's end.

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Optimizing non-recursive digital filters to non-linear phase characteristics

L. G. CUTHBERT, B.Sc.(Eng.)*

SUMMARY

Various methods based on optimization have been used to design linear phase filters. One such method has been to use a general-purpose optimization program to minimize some error criterion, a function of the filter coefficients and of the error between the specified and achieved gain responses. However, if this were to be used with arbitrary phase designs, the error criterion would have to be formulated as a function that combines the gain and phase errors in a meaningful way. It is shown here that this particular difficulty can be avoided by regarding the phase specification as a deviation from the linear phase and splitting the characteristic into real and imaginary components, rather than gain and phase, and optimizing separately.

* *Department of Electrical and Electronic Engineering, Queen Mary College, University of London, Mile End Road, London E1 4NS.*

1 Introduction

One of the big advantages of finite duration impulse response (f.i.r.) digital filters is that they can have a truly linear phase characteristic and the vast majority of previous work on designing such filters naturally concentrates on this application. However, there are instances where a non-linear phase response can be useful; in particular the compensation of other non-linearities in a system so that the overall system phase response is linear. In these cases the f.i.r. filter can still have advantages as it is very easy to realize and the repetitive structure of the direct non-recursive realization (Fig. 1) lends itself to large scale integration, especially when each product is calculated sequentially and added into an accumulator.

Optimization, in various forms,[1-4] has proved to be a useful tool for designing f.i.r. filters. With filters requiring both the phase response, as well as the gain response, to meet some arbitrary specification it would be quite possible to use a general-purpose non-linear optimization program to adjust the filter coefficients, minimizing some objective function. This would have to be a function of both the gain and phase errors (for instance a sum-of-squares criterion taking both the gain and the phase errors at each specified frequency) and weighting would be necessary so that neither was incorrectly emphasized. However, weighting is a problem in itself, as discussed in a previous paper,[5] and an alternative approach is presented here.

2 Theory

The frequency response of a f.i.r. digital filter is:

$$G(\omega) = \sum_{k=0}^{N-1} p_k \exp(-jk\omega T) \tag{1}$$

where p_k are the tap coefficients and T the sampling period.

Considering a filter where N is even (the corresponding results for N odd will be discussed later), it is well known[6] that for a linear phase response the p_k must be symmetric, i.e. $p_k = p_{N-1-k}$. ($k = 0$, to $\frac{1}{2}N-1$).

However, for an arbitrary phase response this symmetry does not apply but the coefficients can be treated as being the sum of two symmetric sets, one exhibiting even symmetry and the other odd:

$$p_k = a_k + b_k$$

and $$p_{N-1-k} = a_k - b_k$$

for $$k = 0 \text{ to } \tfrac{1}{2}N-1 \tag{2}$$

Substituting these symmetry relations into the expression for the frequency response gives:

$$G(\omega) = \sum_{k=0}^{\frac{1}{2}N-1} \{a_k \exp(-jk\omega T) + a_k \exp(-j\omega T[N-1-k])\}$$
$$+ \sum_{k=0}^{\frac{1}{2}N-1} \{b_k \exp(-jk\omega T) - b_k \exp(-j\omega T[N-1-k])\} \tag{3}$$

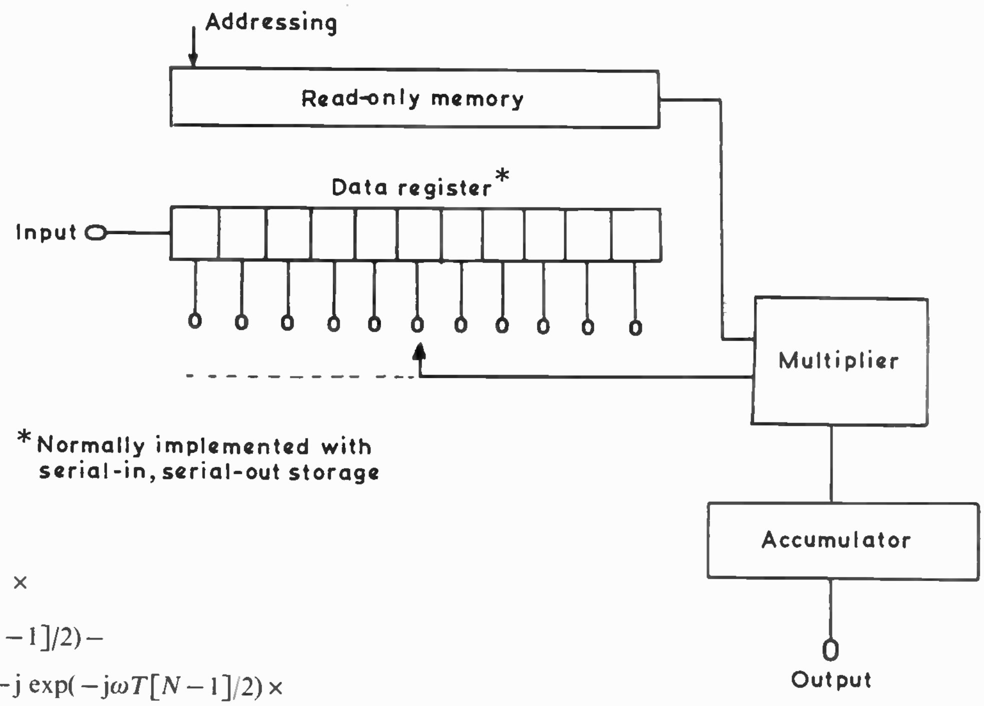

Fig. 1. Schematic of a hardware realization of an f.i.r. filter.

and simplifying

$$G(\omega) = \exp(-j\omega T[N-1]/2) \times \sum_{k=0}^{\frac{1}{2}N-1} 2a_k \cos \omega T(k-[N-1]/2) - -j \exp(-j\omega T[N-1]/2) \times \sum_{k=0}^{\frac{1}{2}N-1} 2b_k \sin \omega T(k-[N-1]/2) \quad (4)$$

or

$$G(\omega) = 2 \exp(-j\omega T[N-1]/2) \times \sum_{k=0}^{\frac{1}{2}N-1} \{a_k \cos \omega T(k-[N-1]/2) - -jb_k \sin \omega T(k-[N-1]/2)\} \quad (5)$$

The important feature that equation (5) shows is that the overall phase response takes the form of a linear function with a superimposed deviation. Since it is the deviation only that depends on the filter coefficients, it is convenient to specify filters in terms of this, rather than the total phase angle.

It is worth noting that if all the b_k are zero, the coefficients are a symmetric set (since the a_k are by definition symmetric) and the response reverts back to the linear phase case.

A similar result holds for N odd:

$$G(\omega) = \exp(-j\omega T[N-1]/2)\{a_{\frac{1}{2}[N-1]} + 2 \times \sum_{k=0}^{\frac{1}{2}[N-3]} a_k \cos \omega T(k-[N-1]/2) - j2 \times \sum_{k=0}^{\frac{1}{2}[N-3]} b_k \sin \omega T(k-[N-1]/2)\} \quad (6)$$

If the design is considered only in terms of the deviation from linear phase, it can be seen that the a_k depend only on the real part and the b_k only on the imaginary part of the characteristic and the real and imaginary parts can be optimized *separately* and then the a_k and b_k combined to give the resultant coefficients.

3 Filter Specification

3.1 Passband

Having specified the filter in terms of its gain and deviation from linear phase (g_n and Φ_{Dn}) it is straightforward to convert this to the real and imaginary components suitable for optimizing a_k and b_k.

The nth specified point of the filter is obviously given as

$$r_n = g_n \cos \Phi_{Dn} \quad (7)$$

$$q_n = g_n \sin \Phi_{Dn} \quad (8)$$

where r_n is the nth point in the real specification and q_n the corresponding point in the quadrature part.

The optimization method described in an earlier paper[2] is used here to separately optimize the a_k and the b_k to the real and quadrature components of the specification. Part of this approach is the technique of using tolerances in the specification to form a series of 'dynamic weights'. These weights have a value of 0 or 1 so that if the response is within the specified limits at that frequency the error is counted as zero.

Unfortunately, tolerances in gain and phase deviation do not transform directly into limits for the real and quadrature components, a situation illustrated in Fig. 2.

If the outer corners of the tolerance area (shaded) are used to define the limits of the acceptable real and quadrature values, a much wider tolerance area will be produced (Fig. 2(b)) and although a point may be inside the limits for r and q it could be outside those for g and Φ_D.

There are, of course, an infinite number of rectangles parallel to the r and q axes that will fit within the gain and phase deviation limits. The best would obviously be that which gives the biggest allowable tolerances for r and q, but the determination of this would need a fair amount of calculation.

However, with the filters designed at Queen Mary College, a compromise approach was used for simplicity. A tolerance was allowed on the filter gain but not in the

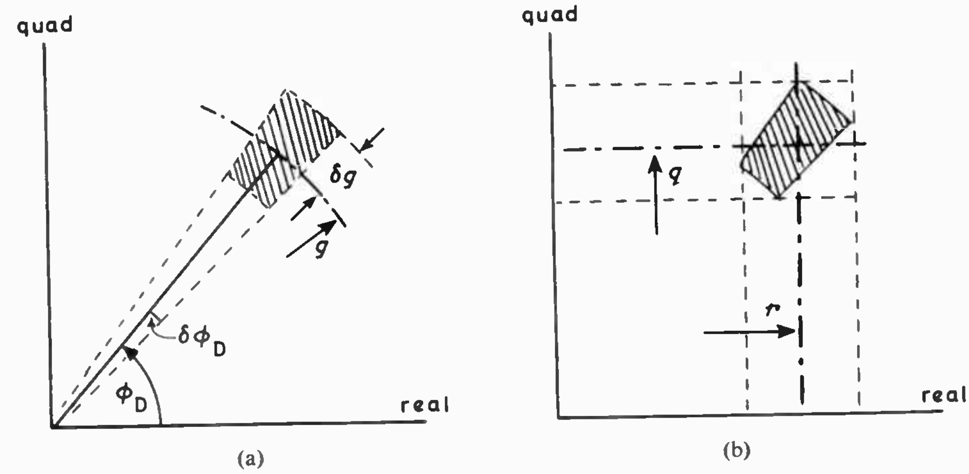

Fig. 2. Translation of tolerances from polar to cartesian co-ordinates.

phase deviation (Fig. 3) which ensured that a point within the limits for r and q would also satisfy the tolerance on the gain. However, from the diagram, it can clearly be seen that some phase error is likely to result from a solution within these limits. However, it must be remembered that the allowable limits for gain in the pass band are generally very small so that the tolerance produced for the phase would also be small. Figure 3 has deliberately been exaggerated for the sake of clarity.

The efect of this approach on the phase can be illustrated by considering a filter required to have a 45° deviation from the linear phase value with unity gain, within 5% (just under 0·5 dB, quite a large tolerance). The maximum possible phase error, with the solution still being inside the limits for the real and quadrature components, would be 3° (6%). Naturally, if this were excessive, the tolerance on the gain could be reduced.

An alternative, but similar, system would be to define limits for the phase deviation and accept whatever gain tolerance resulted. The choice of which set of limits to specify would depend on which were the more tightly defined in the particular application.

3.2 Stopband

In the stopband the phase is, of course, irrelevant and the requirement is simply that $r^2+q^2 < \varepsilon^2$ where ε is the maximum allowed value for the stopband gain. In order to ensure that the overall gain limit will be less than this, the tolerance used for both the real and quadrature specifications is $\pm\varepsilon/\sqrt{2}$.

3.3 Weighting

Some earlier papers have discussed the technique of weighting[5,7] various regions of the characteristic to ensure a better fit to these parts when optimizing. One way of weighting implicitly is to optimize in dB rather than in terms of the linear gain function, and this has been used by the writer successfully on linear phase filters.

However, with the approach described in this paper it must be realized that both the real and quadrature components of the passband can be negative and this sign (unlike that in the stopband) is important as it is used to define the phase. Optimization in dB cannot therefore be used to emphasize the stopband error and another approach has to be used.

One alternative would be to use a heavy multiplying factor but the choice of this multiplier (10, 50, 100, 1000?) would be a problem in its own right. A very simple technique used by the author for both linear phase and non-linear phase filters is to optimize in the linear domain, firstly to the complete specification, then, starting from the first result, to optimize again, but this time to the stopband specification only. At first sight it may be thought that the result of this second optimization would be to make all coefficients zero since the stopband requirements would obviously then be satisfied. However, after using this approach extensively, this has not happened at all and the technique has been found to be useful. Some slight deterioration of the passband does occur in the second run but is usually not too serious and can be controlled, if necessary, by a further run using weighting.

An illustration of the result using two optimization runs (to the whole specification and then continuing to the stopband only) is shown in Fig. 4. The sum of squares

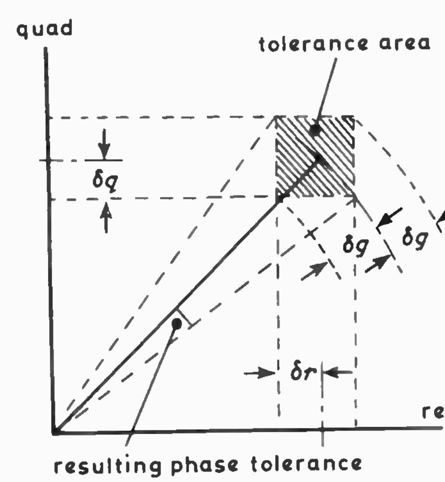

Fig. 3. Compromise tolerancing used at Queen Mary College.

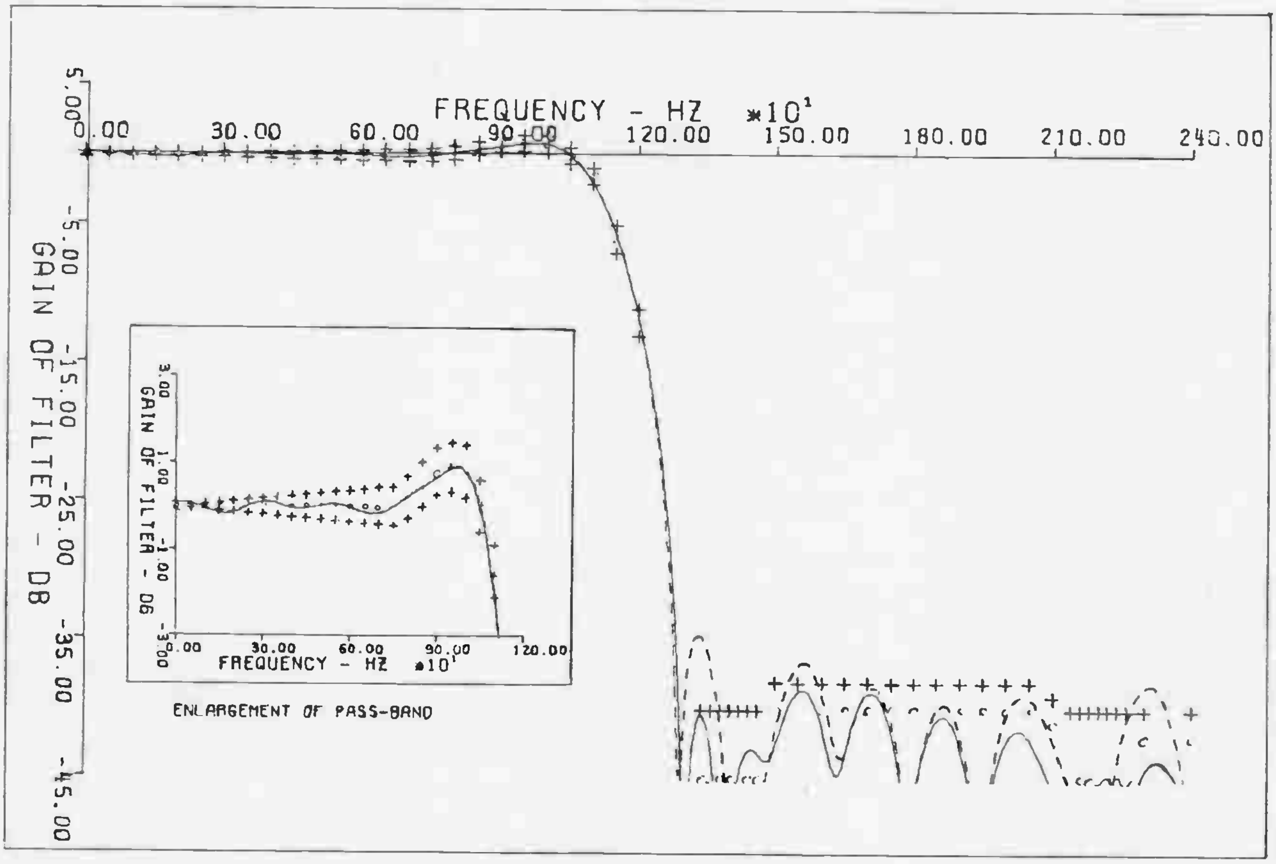

Fig. 4. Design example 1 (32 coefficients). Gain Response.

error for each region after each run is tabulated below for the real component.

	PASSBAND	STOPBAND
Starting (Discrete Fourier Transform)	0·012	0·004
Optimizing to complete specification	0·0025	0·0012
Continuation to stopband requirements	0·0033	0·00007

It can be seen that relatively slight deterioration of the passband occurred during the second run although the stopband was improved considerably.

4 Design Examples

The results presented in this Section were all obtained using a sum of squares criterion with a program based on standard optimization algorithms (steepest descent[8] and Fletcher-Powell[9]), as used previously with linear phase filters.[2] About one minute of processor time on the QMC ICL 1904S computer was taken for each run.

4.1 Example 1

Figure 4 shows the result of using the approach described in this paper to design a 32-tap low-pass filter and it can be seen that a good fit is obtained.

The gain specification has a defined transition region, although the stopband limits are not unduly stringent, but the phase deviation (Fig. 5) is required to be nearly 90° in the middle of the passband and the effect of this on the real component is especially drastic, as shown in

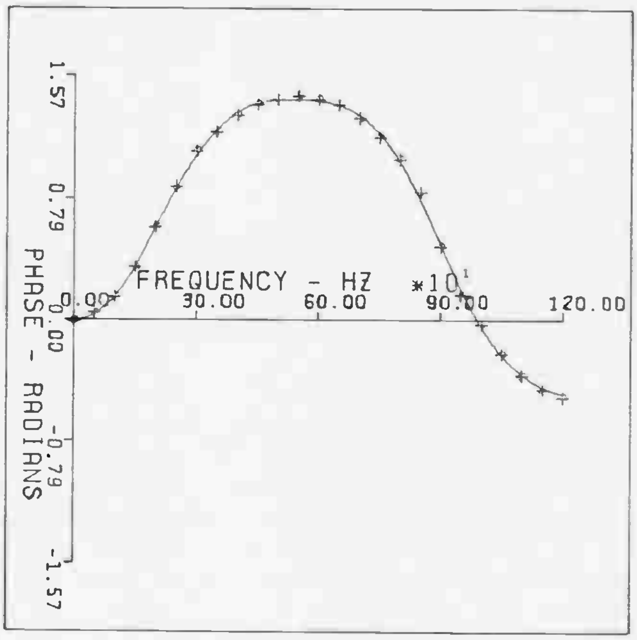

Fig. 5. Design example 1.
Phase deviation from linear (only the passband is relevant)

Fig. 6. The significance of the dip in the real component can be appreciated when it is remembered that fitting the a_k to the real part is *exactly* the same as fitting the coefficients of a linear phase filter to the same shape gain function. Thus, in this particular example, it is like designing a response which has 3 transition regions. Although the 32-coefficient filter copes with this difficulty, a 24-tap design with the same deviation requirement (Fig. 8) does not manage so well. The design was optimized according to the technique of Section 3.3 and it is one of the cases where the passband deterioration may be unacceptable, in which case weighting would have to be used to achieve a reasonable compromise between passband and stopband. The insert showing the real component clearly illustrates where the trouble is occurring.

A further important point when considering the number of coefficients to use is that the *total* phase depends on N:

$$\Phi(\omega) = \Phi_D(\omega) - \tfrac{1}{2}\omega T[N-1]$$

4.2 Example 2

In Fig. 9 a filter response is shown that was designed to meet the same gain requirements as in the previous example, but with the specification for the phase deviation being changed. Although this was a more complicated shape, the shift from the linear phase value was much less and a 24-coefficient filter met the requirements quite well. The main errors in the phase deviation are around 600 Hz and over the range 900–1200 Hz where the shape of the specified characteristic is changing sharply.

When optimizing linear phase filters, it was sometimes found that the program would be stuck in a local minimum. The method adopted to enable the program to continue was to change the error criterion so that the error surface would be changed, the 'hole' hopefully disappearing.[2] With linear phase filters a switch could always be made between a criterion calculated in dB and one in terms of the linear gain but, with the technique described here for arbitrary phase designs, this is not possible. The alternative used is again to optimize to the whole specification or to the stopband only.

In this example it was found that the coefficients of the real component obtained from the Discrete Fourier Transform were in a local minimum when using an error figure calculated from the whole specification. One run of the program, with the stopband error only, enabled the coefficients to be shifted from this minimum and the approach of Section 3 was then used to get the results of Fig. 9.

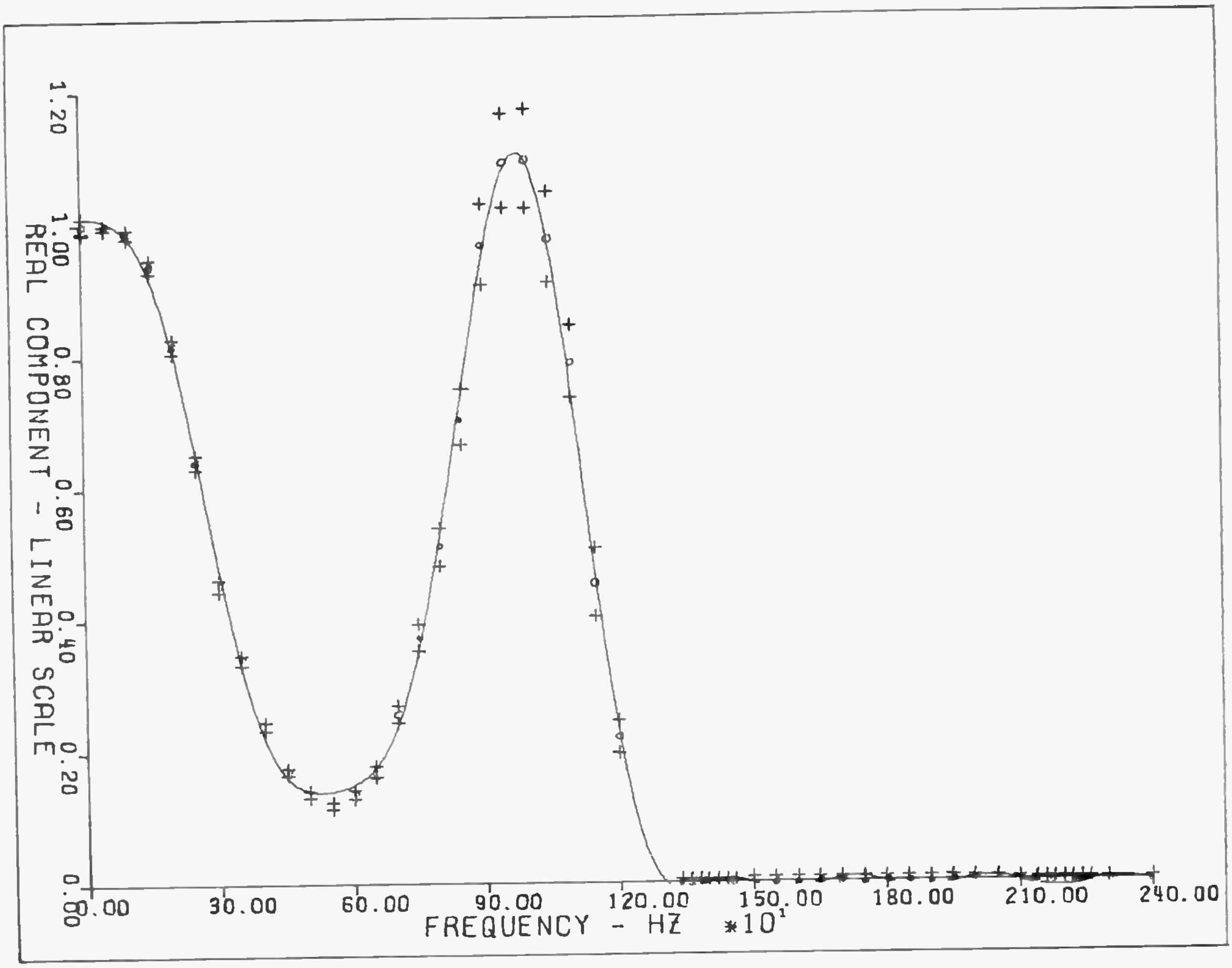

Fig. 6. Design example 1. Result of optimizing real component.

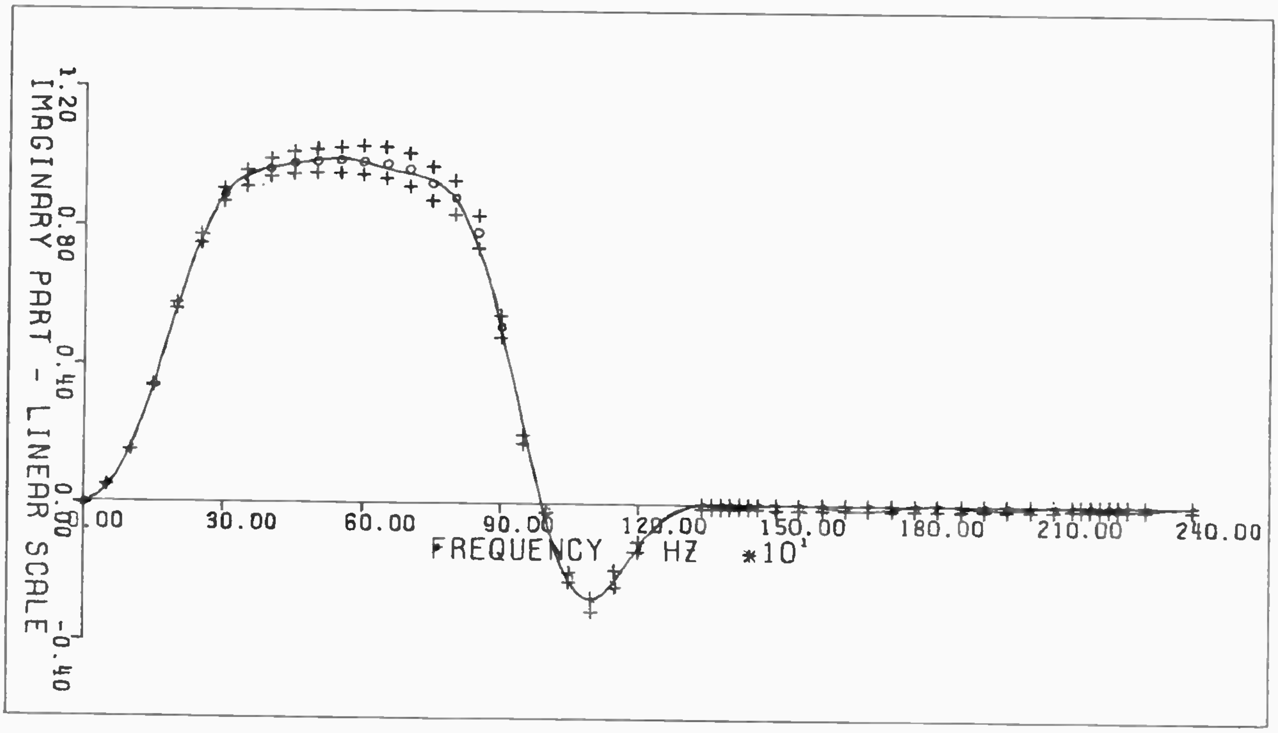

Fig. 7. Design example 1. Result of optimizing quadrature component.

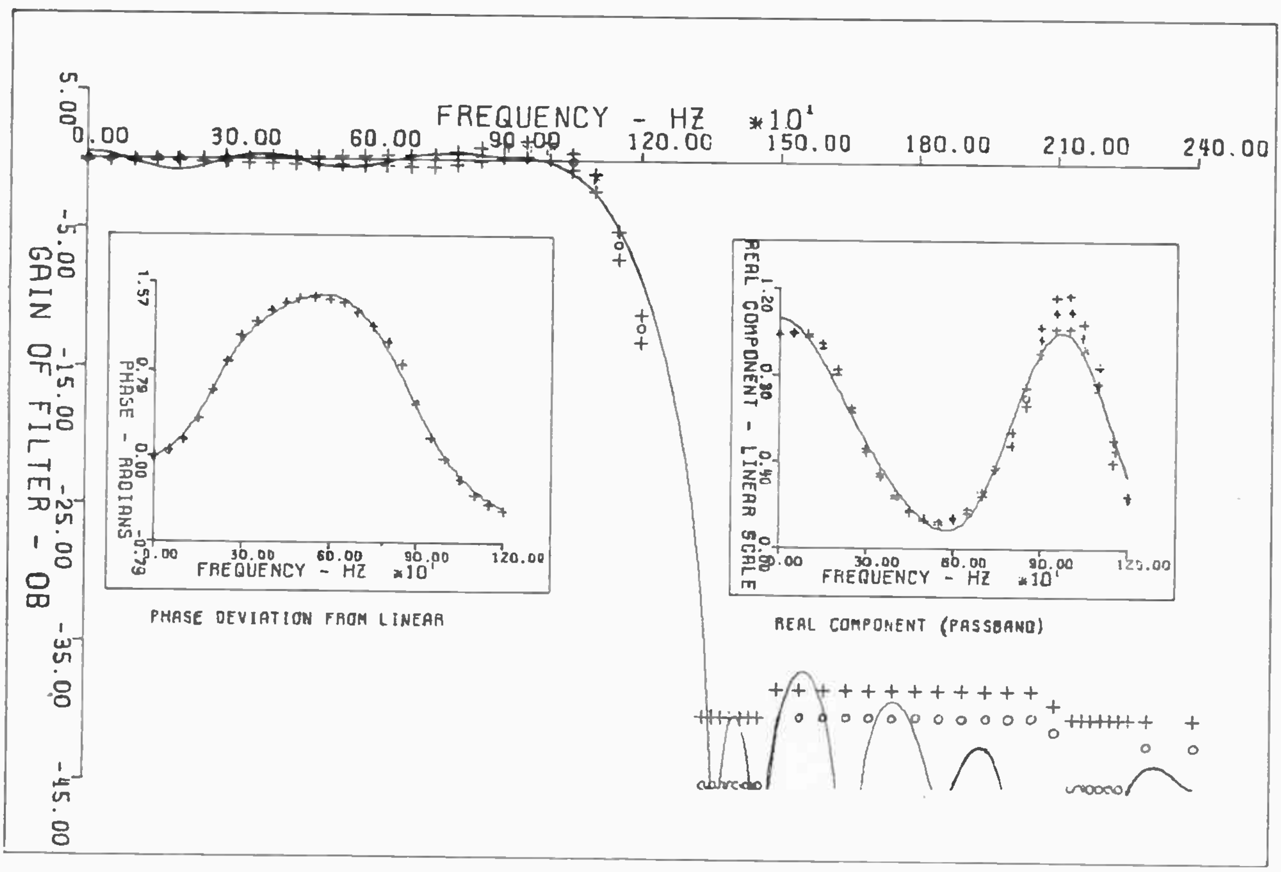

Fig. 8. Design example 1 but 24 coefficients. Gain response.

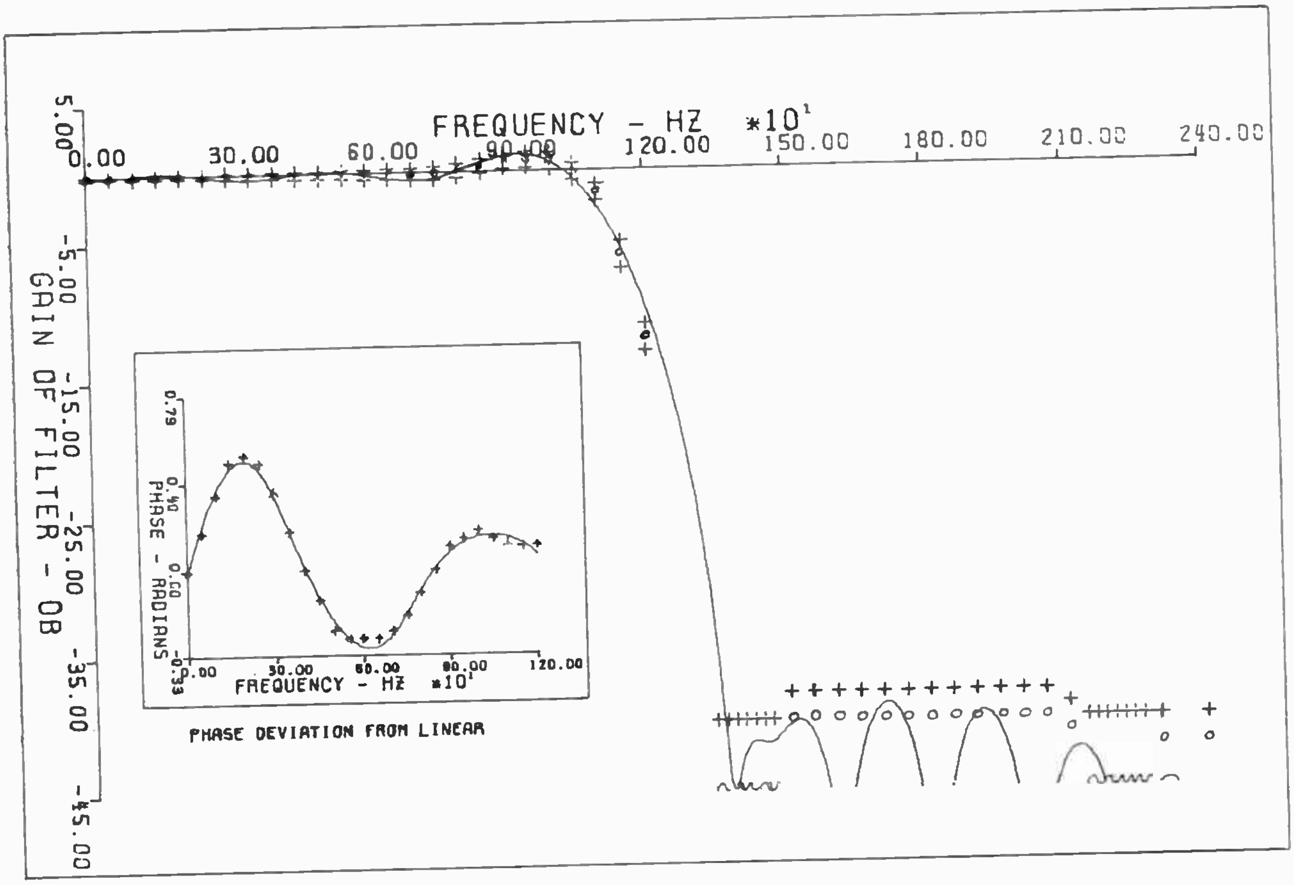

Fig. 9. Design example 2. 24 coefficients. Gain response.

5 Conclusions

The approach presented in this paper gives a viable method for designing f.i.r. digital filters required to have a non-linear phase characteristic. Treating the phase as a deviation from the linear enables the problem to be separated into real and imaginary components and the designer can immediately see if there are likely to be any problems caused by either component having a too sharply changing form, in a similar way to the design in Fig. 6.

Furthermore, there is no difficulty with trying to construct an error criterion containing some weighted combination of gain and phase errors, and the real and quadrature parts can be fitted separately, using optimization techniques similar to those already used for designing linear phase filters.

Although the stopband error cannot be accentuated by converting to dB, the same effect is achieved by using two optimization runs, the second to the stopband specification only. This has proved to be a simple and useful technique. Furthermore, use of the stopband error only is often helpful when trying to shift a set of coefficients from a local minimum.

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A solution for component values of radio frequency interference filters for phase-controlled switching systems

D. H. J. BAERT, Dr. Ir.*

SUMMARY

When applied to phase-controlled switching systems, the performance of simple radio-frequency interference filters is limited by circuit operating considerations. More complex filters can readily be designed using curves given in the paper. Their derivation and typical performance are described.

* Laboratory for Electronics and Metrology, State University of Ghent, Sint-Pietersnieuwstraat 41, B-9000 Ghent, Belgium.

1 Introduction

It is known that phase-controlled systems (p.c.s.) with thyristors or triacs and with resistive loads generate a considerable amount of radio frequency interference (r.f.i.) in the power lines.[1,2] In order to suppress the r.f.i. voltage, it is customary to apply a filter F between the load resistance R, the line generator $e = E \sin \omega_N t$ and the switching element T. Often F is a second-order LC filter as shown in Fig. 1(a). Figure 2 gives the resulting current through T, with F (Fig. 2, curve b) and without F (Fig. 2, curve a) when the p.c.s. works with a control angle θ. Without F the initial current shows a steep edge which is responsible for the generated r.f.i. The r.f.i. consists of a directly-radiated component which is in general not very important and a conducted component that propagates along the transmission lines and can influence other sensitive circuits. The rise-time of the edge is determined in this case by the parasitic inductance of R, the line generator impedance and the power line impedance. With F, the initial current is mainly determined by L, C and R.

It is also known[1] that the current i tries to reverse when the quality factor

$$Q = R\sqrt{\frac{C}{L}} \tag{1}$$

of the circuit becomes greater than about 2·5 (Fig. 2,

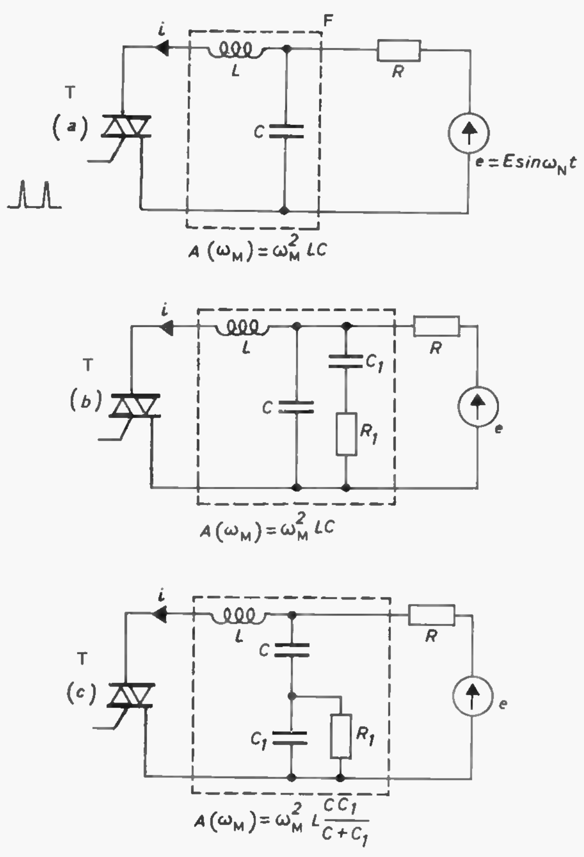

Fig. 1. Phase controlled system with a switch T, load resistance R, line generator $e = E \sin \omega_N t$ and a second order r.f.i. suppression filter F. The gate circuit of T has been omitted. (a) Second order LC-filter, (b) and (c) third-order filter resulting from (a).

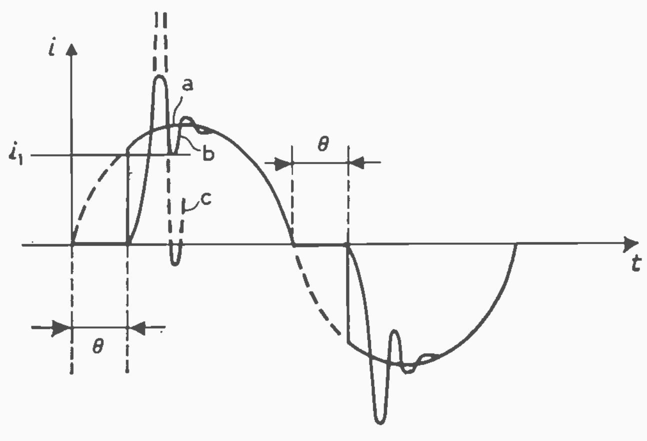

Fig. 2. Current i through the switch T. The first minimum of i is i_1. (a) Without filter. (b) With the LC-filter, but with a relatively small value of R. (c) With LC-filter and a large value of R.

curve c). Since the switch T in this case becomes non-conducting, this gives an irregular and spurious action of the p.c.s. On the other hand, the value of C and L depends upon the required filter attenuation

$$A(\omega_M) = \omega_M^2 LC, \qquad R > \frac{1}{\omega_M C} \tag{2}$$

at the lowest cyclic frequency ω_M of interest. The inequality $R > 1/\omega_M C$ expresses the fact that ω_M lies in the range where the magnitude of the transfer function of the filter falls steadily at a rate of 20 dB/decade.

From (1) and (2) we see that the only way to increase $A(\omega_M)$ at high values of R is to increase L, but this is not very economical. On the other hand, if the highest value of the load resistor R of the p.c.s. is not fixed, as in the case of light dimmers, it is difficult to obtain the required $A(\omega_M)$ without violating the condition $Q \leqslant 2{\cdot}5$.

Figures 1(b) and 1(c) give a known possible way to increase the circuit damping during the transient: it suffices to extend F with the elements R_1 and C_1. This does not alter $A(\omega_M)$. The filter thus becomes a third-order filter. A general design method for this type of filter has not so far been known. By an original method, we have derived curves that permit the design of the circuits of Fig. 1(b) and (c).

2 Results

We shall investigate first the circuit of Fig. 1(b). It is clear that the product LC follows from the given $A(\omega_M)$. The capacitor C has to be chosen so that $1/\omega_M C < R_m$, with R_m the smallest value of R that can be expected, and this gives a lowest limit for C. Since inductances are rather costly, one will try to use a large value for C, e.g. $0{\cdot}1 < C < 1$ µF. The physical dimensions of the system can also influence the final choice of C. The choice of C determines the value of L, but it is possible that the condition $Q \leqslant 2{\cdot}5$ is not met. So we have to determine the C_1 and R_1 that give a transient current that never crosses the time axis in Fig. 2.

On the assumption that we want a practical and simple parameter set for solving the problem we can derive, e.g. from the Buckingham theorem,[3] a necessary set of parameters that determines completely the behaviour of the circuit:

$$\frac{R_1}{R}, \quad \frac{C_1}{C}, \quad Q = R\sqrt{\frac{C}{L}}. \tag{3}$$

We have determined the values of Q and R_1/R, with C_1/C as a parameter, that give a transient current with a first minimum i_1 that is tangent to the time axis. Figure 3 gives the resulting curves. In this figure, all points that lie under the curve for a given value of C_1/C represent parameter combinations that correspond with $i_1 > 0$ for the positive half-period and $i_1 < 0$ for the negative half-period.

To complete the design of the third-order filter we calculate $Q = R\sqrt{(C/L)}$ and draw a horizontal line on Fig. 3 at this value, and so we find immediately the minimum value of C_1/C that is required (e.g. for $Q = 10$, $C_1/C = 2{\cdot}5$ suffices). This gives C_1 and also two intersection points $[R_1/R]_{min}$ and $[R_1/R]_{max}$ of the Q-line with the curve for the already determined C_1/C value. The value of R_1 can thus be taken within the range $R[R_1/R]_{min}$ and $R[R_1/R]_{max}$. It is preferable to take a value of R_1/R halfway between the range so that the tolerances on C, C_1 and R_1 do not move the parameter set outside the limit curve for C_1/C.

Figure 4 gives an analogous set of curves for the filter of Fig. 1(c). Since the filter attenuation is

$$A(\omega_M) = \omega_M^2 L \frac{CC_1}{C+C_1}$$

in this case, it is more appropriate to have the quantity

$$Q = R\sqrt{\frac{1}{L}\frac{CC_1}{C+C_1}}$$

in ordinate; the other quantities R_1/R and C_1/C remain as the abscissa and the parameter. The choice of $A(\omega_M)$ determines as before $CC_1/(C+C_1)$ and thus Q. The values of R_1 and C_1 can be found as in the case of the Fig. 1(c). From the expressions of $A(\omega_M)$ for both circuits it follows that the circuit of Fig. 1(b) is more advantageous than the circuit of Fig. 1(c).

3 Method for the Calculation of the Curves

From the differential equations of both circuits, Fig. 1(b) and 1(c), it is easy to see that there is no simple connexion between the parameters Q, R_1/R, C_1/C and the coefficients of the differential equation. This means that digital or analogue computer simulation of the system will be unnecessarily complicated. However, since the problem is to be realized practically, it is not necessary to have the ultimate precision that can be obtained from digital computation. Thus, a direct simulation of both circuits can be adequate if one uses adjustable precision components for R, R_1, C, C_1 and L. This requires however that L can easily be varied.

For L we have therefore used an original gyrator circuit[4] designed by the author, that permits adjustment of L by means of a variable precision decade capacitor C_i.

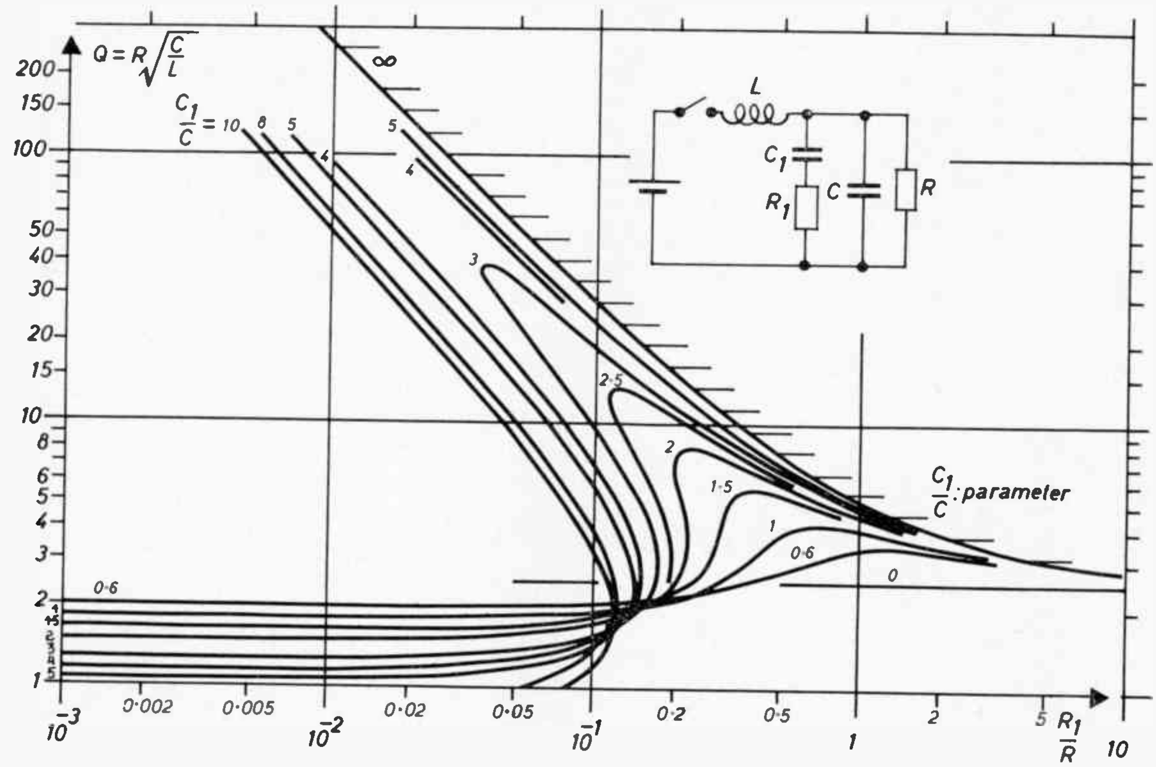

Fig. 3. Design curves for third-order filter of Fig. 1(b).

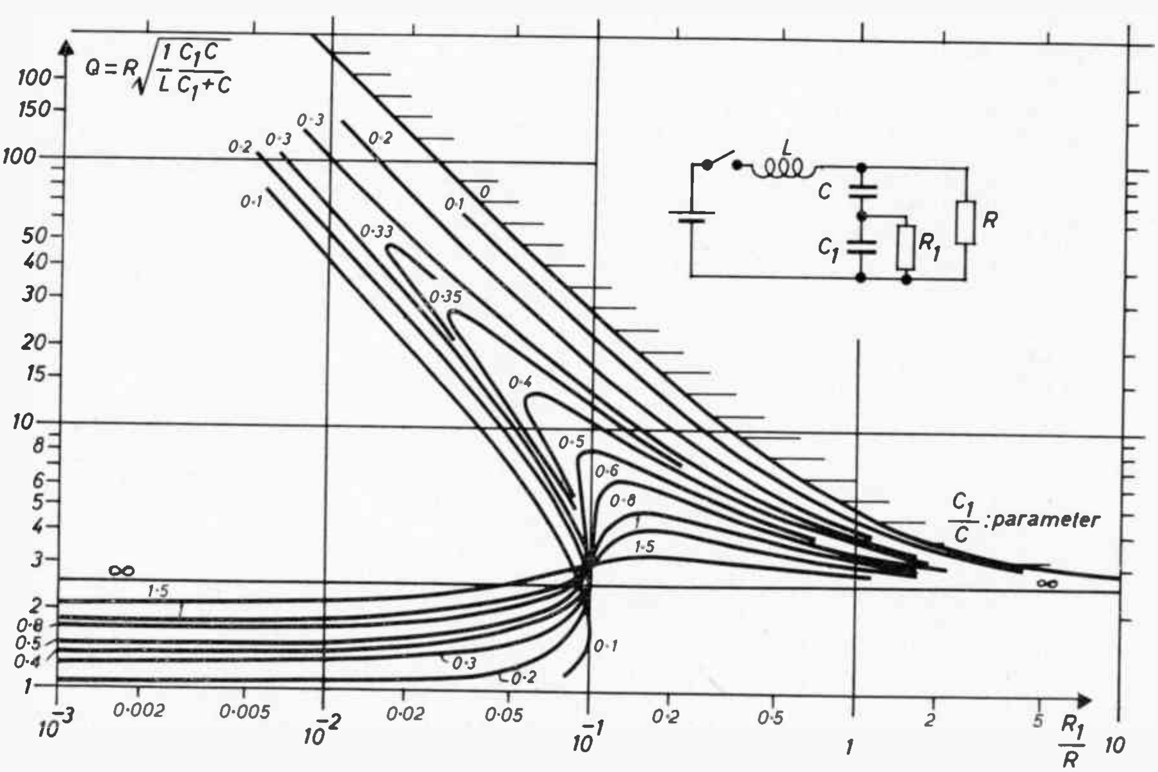

Fig. 4. Design curves for third-order filter of Fig. 1(c).

Besides, the current i in L can be directly measured as a voltage at a point of this circuit. Since we only have to determine the points where i_1 touches the time axis we can use an oscilloscope as detector.

The simplest way to obtain the curves of Figs. 3 and 4 is to fix C_1/C, R and Q and to determine the two points on the horizontal Q-line at $[R_1/R]_{min}$ and $[R_1/R]_{max}$ by varying R_1. The value of Q is adjusted by means of the gyrator capacitance C_i.

The behaviour of the curves for limit cases ($C_1/C \to 0$, $C_1/C \to \infty$, $R_1/R \to \infty \ldots$) can be predicted from the simple LC-filter of Fig. 1(a). It turns out that the predicted and measured limit curves coincide almost completely and this confirms the value and reliability of the method.

We have also investigated the influence of series losses in L and C_1; it appears that with these losses the curves open more rapidly than the curves of Figs. 3 and 4. As a consequence, if we implement the filter, calculated with the curves of the Figs. 3 or 4, with practical components that have in general rather high losses, even greater values of the load resistance can be tolerated before i_1 crosses the time axis.

4 An Example

In order to give the reader an idea of the improvement that can be obtained in the design of the r.f.i. filters we give an example of a typical calculation.

Figure 5 gives the admissible limits of the r.f.i. content of a p.c.s. as proposed by the CISPR and the VDE authorities. In this Figure, 60 dB corresponds with a noise meter indication of 1 mV according to a spectral density of 0·16 μVs at the input of the noise meter. For domestic applications the curve N is commonly used.

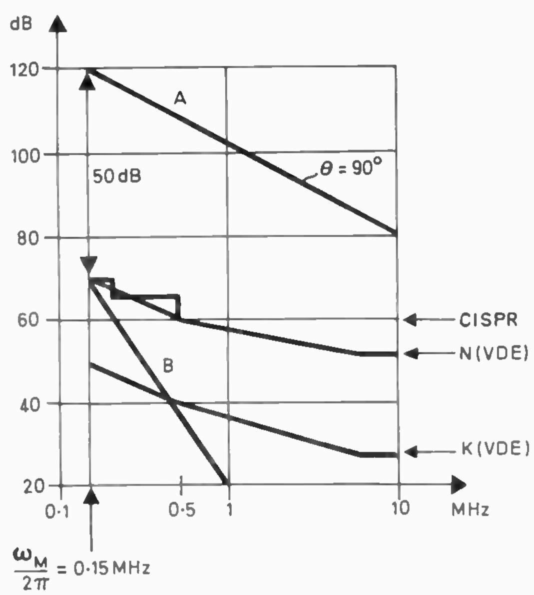

Fig. 5. CISPR and VDE regulations for the r.f.i. generated in phase-controlled systems. The curve A gives the noise meter reading for a p.c.s. working with an effective voltage of 220V and a control angle of $\theta = 90°$. The curve B shows the noise spectrum of the p.c.s. with a second-order filter. The lowest frequency of interest is

$$f_M = \frac{\omega_M}{2\pi} = 150 \text{ kHz}.$$

As a consequence of the steep edge of the load current, the noise meter indication falls off with ω for a p.c.s. without filter. The curve A of Fig. 5 shows the r.f.i. spectrum in this case for a p.c.s. working at 220 V. It can be seen that an attenuation of about 50 dB, i.e. 315, at 150 kHz is required in order to suppress the r.f.i. of the p.c.s. below the curve N. Corresponding to this 50 dB attenuation, the curve B in Fig. 5 gives the noise meter reading that can be expected from the p.c.s. with a second-order filter: the reading falls off with ω^3, i.e. 60 dB/decade, in view of the expression (2).

In order to design the LC filter we first choose a trial value for C in the range 0·1 μF to 1 μF, e.g. 0·22μF. This determines the value of L from equation (2) and we find $L = 1{\cdot}6$ mH at the condition that

$$R > 1/\omega_M C = 4{\cdot}8\ \Omega.$$

From $Q \leqslant 2{\cdot}5$ it then follows that the maximum admissible value of the load R is

$$R_M = 2{\cdot}5\left(\frac{L}{C}\right)^{1/2} = 214\ \Omega$$

and this corresponds with a power P_L at the load of about 227 W. This value considerably exceeds the smallest P_L that are generally used in light dimmer applications. Light dimmers have to work well with loads of, e.g., 50 W or $R = 970\ \Omega$. Of course, for other types of varying loads the same considerations will hold.

On the other hand, we can directly calculate from a given R_M and $A(\omega_M)$ the values of L and C:

$$C = \frac{2{\cdot}5}{R_M\omega_M}\,[A(\omega_M)]^{1/2} \tag{4}$$

$$L = \frac{R_M}{2{\cdot}5\omega_M}\,[A(\omega_M)]^{1/2} \tag{5}$$

With $R_M = 970\ \Omega$, $\omega_M = 2\pi \times 150 \times 10^3\ \text{s}^{-1}$ and $A/(\omega_M) = 315$ we obtain the results $C = 0{\cdot}048$ μF and $L = 7{\cdot}3$ mH. This large value of L requires an expensive inductor, especially when large powers have also to be handled by the p.c.s. Indeed, the volume of the core of the coil is proportional to LI^2, with I the peak current that occurs in L.

We therefore try to improve the transient behaviour of the filter with $L = 1{\cdot}6$ mH and $C = 0{\cdot}22$ μF by means of the circuit of Fig. 1(b) in such a way that loads of 970 Ω can be handled. We now find

$$Q = R_M\left(\frac{C}{L}\right)^{1/2} = 11{\cdot}4$$

and Fig. 3 then shows that $C_1/C = 2{\cdot}5$ or $C_1 = 0{\cdot}55$ μF suffices to obtain the required result. The range of R_1/R goes from $[R_1/R]_{min} = 0{\cdot}12$ to $[R_1/R]_{max} = 0{\cdot}17$ or $(R_1)_{min} = 116\ \Omega$ and $(R_1)_{max} = 165\ \Omega$; a suitable value of R_1 is therefore 140 Ω.

It is clear that the addition of C_1 and R_1 permits the use of a filter coil that is about 4·5 times smaller than the coil of the simple LC-filter, and so a considerable cost reduction is obtained.

Of course, other considerations can influence the determination of L and C. If, for example, one makes use of commercially-available filter coils it is in general not possible to obtain the calculated inductance value. In this case the curves of Figs. 3 and 4 once more permit a quick and economical design if one uses the nearest nominal value of the commercial series and determines the new values of C, C_1 and R_1.

5 Conclusion

The transient behaviour of the simple LC filter can be improved by the addition of a resistor R_1 and a capacitor C_1. The curves of Figs. 3 and 4 determine the useful parameter ranges that correspond with a switch current i that does not change its sign during the transient. They are universally valid for the circuit shown on Figs. 1(b) and 1(c).

We have determined the curves of Figs. 3 and 4 by means of a direct simulation of the filter circuit with precision components (0·2% for resistors and 0·5% or better for the capacitors). The inductor however is simulated with an original precision gyrator circuit and can easily be varied.

From the example it follows that the filters of Figs. 1(b) and 1(c) can be designed very quickly and accurately using the curves of Figs. 3 and 4. It also becomes possible to investigate very easily the influence of a change of one of the parameters without being obliged to make use of a computer or to execute elaborate calculations.

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STANDARD FREQUENCY TRANSMISSIONS—October 1974

(Communication from the National Physical Laboratory)

Oct. 1974	Deviation from nominal frequency in parts in 10^{10} (24-hour mean centred on 0300 UT)			Relative phase readings in microseconds NPL—Station (Readings at 1500 UT)	
	GBR 16 kHz	MSF 60 kHz	Droitwich 200 kHz	*GBR 16 kHz	†MSF 60 kHz
1	−0·1	0	−0·2	702	603·0
2	0	0	−0·2	702	602·9
3	0	0	−0·2	702	603·0
4	+0·1	0	−0·2	701	603·0
5	0	0	−0·2	701	602·9
6	0	0	−0·2	701	602·9
7	0	0	−0·2	701	602·9
8	0	0	−0·2	701	602·8
9	0	0	−0·2	701	602·8
10	+0·1	0	−0·2	700	602·8
11	−0·1	0	−0·2	701	602·9
12	+0·1	0	−0·2	700	603·0
13	0	0	−0·2	700	603·0
14	0	0	−0·2	700	602·7
15	0	0	−0·2	700	603·0
16	+0·2	0	−0·2	698	603·1
17	0	0	−0·2	698	603·0
18	−0·1	0	−0·2	699	603·0
19	−0·1	0	−0·2	700	603·0
20	+0·1	0	−0·2	699	603·0
21	−0·1	0	−0·2	700	603·0
22	+0·2	0	−0·1	698	603·0
23	−0·2	0	−0·1	700	603·0
24	0	0	−0·1	700	603·1
25	0	0	−0·1	700	603·0
26	0	0	−0·1	700	603·0
27	0	0	−0·1	700	603·1
28	−0·1	0	−0·1	701	603·1
29	0	0	−0·1	701	603·3
30	−0·1	0	−0·1	700	603·4
31	0	0	−0·1	700	603·4

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

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

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

UDC 621.371

A new mathematical model to describe the physics of propagation

PETER B. JOHNS, Ph.D., B.Sc.(Eng.)*

SUMMARY

While Green's functions provide a powerful analytical means of solving the wave equation, they do not give a very realistic description of the mechanism of propagation. Also the adaptation of Green's function techniques to numerical methods of solution is not easy. This paper introduces the assumption that propagation takes place in discrete steps, and it is shown that Huygens's principle then becomes physically much more realistic. The basis for a very simple numerical procedure for the solution of the wave equation is also provided.

* Department of Electrical and Electronic Engineering, University of Nottingham, University Park, Nottingham NG7 2RD.

1 Introduction

In 1690 Huygens[1] proposed a new mechanism for the propagation of light waves. This basic model is extended in this paper and used to examine the fundamentals of wave propagation. The new model introduced is very simple in conception and yet produces a mathematically correct description of the wave equation. From an engineering point of view the important feature is that the model is particularly suitable for the numerical solution of wave problems.

According to Huygens, a wave-front may be considered to consist of a number of secondary radiators which give rise to spherical wavelets as shown in Fig. 1. At a later instant a new wave-front is formed by the envelope of these wavelets and this in turn gives rise to a new generation of spherical wavelets. So the wave-front advances.

At first sight it is not obvious how rectilinear propagation occurs when wave-fronts are emitting secondary wavelets isotropically, particularly if the wave is considered as an impulsive disturbance. In fact, Huygens himself was led to suppose that the secondary wavelets had little effect except at the points at which their envelope touches the next wave-front. 'Similarly the other particles of the sphere DCF (the next wave-front, Figure 1), such as bb, dd, etc., will each make its own

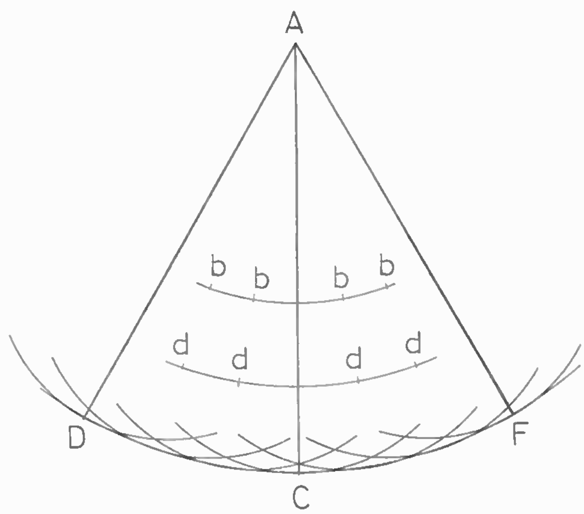

Fig. 1. Huygens's principle and secondary wavelets.

wave. But each of these waves can be infinitely feeble only as compared with the wave DCF, to the composition of which all the others contribute by the part of their surface which is most distant from the centre A.'—'Treatise on Light' (Ref. 1, translation by Silvanus P. Thompson).

The following explanation for the propagation of rays was given by Fresnel in 1818[2] and won the Paris Academy's prize for him. Basically, Fresnel postulated that if the wave propagation is a continuous process varying sinusoidally with time then the secondary wavelets will mutually interfere with each other. Figure 2 shows a wave-front with secondary radiators at A_1, A_2, A_3, etc. The combined effect of all the

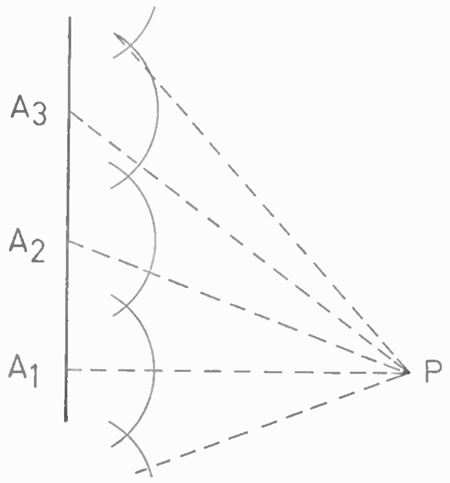

Fig. 2. Secondary wavelets contributing to the field at P.

wavelets at point P is to be considered. The shortest distance from the wave-front to P is along the line A_1P and this will give rise to a certain phase delay at P for the wavelet A_1. The wavelet at A_2 will have an additional delay at P since the distance A_2P is longer. The delay increases as secondary wavelets further away from A_1 are considered. If the wavelength of the propagation is small compared with the dimensions of the wave-front, the contributions from the secondary wavelets situated well away from A_1 will tend to cancel. Thus it is only that portion in the vicinity of A_1 that contributes to the field at P and the rectilinear nature of propagation is explained. Actually, if a quantitative analysis (Ref. 3, Sect. 8.2) is performed it can be shown that two additional assumptions must be made:

(i) The amplitudes of the secondary vibrations are to the amplitudes of the primary vibrations in the ratio 1 : wavelength of propagation.

(ii) The secondary waves oscillate a quarter of a period in advance of the primary wave.

These assumptions (which were also made by Fresnel) will be discussed further in the next section.

If the wave-front is partially obscured as shown in Fig. 3, a point such as P which is geometrically in a shadow is in fact illuminated by secondary wavelets A_1, A_2, etc., which are not obscured. Thus the rectilinear propagation conditions break down and a diffraction process takes place. The natural way to proceed to calculate the effect of this diffraction process is to summate the effects of secondary wavelets A_1, A_2, etc., and to ignore the effect of the obscured wavelets. In very elementary terms, this is the basis of the Green's function approach. However, it is hoped to show that the model for the physical mechanism of propagation as presented by the use of Green's functions is not very satisfactory.

Green's functions yield analytically correct solutions of the differential equations of propagation and therefore the results obtained are accurate. However, if the techniques involved are related to Huygens's principle it will be shown that the mathematical juggling required of 'nature' is quite extensive. It may be that the natural processes of propagation are complicated and that the operations described by the mathematics do take place, but it is proposed that this is unlikely.

2 Green's Functions and Huygens's Principle

The problem of wave propagation lies in obtaining solutions to the wave equation

$$\nabla^2\psi - \frac{1}{c^2}\frac{\partial^2\psi}{\partial t^2} = -4\pi q(r, t) \tag{1}$$

where ψ is a scalar field amplitude and $q(r, t)$ describes a source density distribution in space and time.

The technique for using Green's functions for the solution of this equation at first sight seems to be obvious. To obtain the field caused by the distributed sources, the effect of an elementary portion of the source is first calculated and then the contributions by all such elementary portions are added up to give the whole field.

Thus, if the elementary source is written in the form of a delta function, the Green's function $g(\mathbf{r}, t|\mathbf{r}_0, t_0)$, giving the effect of sources in the region $\mathbf{r}_0$ at a time t_0 at an observation point in the region $\mathbf{r}$ and at time t, is given by

$$\nabla^2 g - \frac{1}{c^2}\frac{\partial^2 g}{\partial t^2} = -4\pi\delta(\mathbf{r}-\mathbf{r}_0)\delta(t-t_0) \tag{2}$$

In three-dimensional space, a solution for this equation

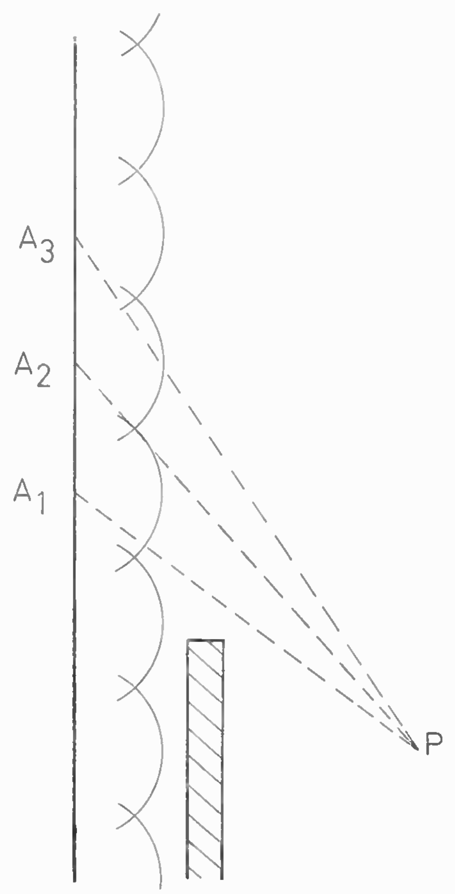

Fig. 3. A partially obscured wave-front.

is the expanding impulsive spherical wave

$$g = \frac{\delta[(R/c)-\tau]}{R} \tag{3}$$

where $R = |\mathbf{r}-\mathbf{r}_0|$, and $\tau = t-t_0$. Using the reciprocity relation,

$$g(\mathbf{r}, t|\mathbf{r}_0, t_0) = g(\mathbf{r}_0, -t_0|\mathbf{r}, -t)$$

and Green's theorem, the general solution of equation (1) may be written as (Ref. 4, Sect. 7.3):

$$4\pi\psi(\mathbf{r}, t) = 4\pi \int_0^t \mathrm{d}t_0 \iiint_V g(\mathbf{r}, t|\mathbf{r}_0, t_0)q(\mathbf{r}_0, t_0)\,\mathrm{d}V_0 + \\ + \int_0^t \mathrm{d}t_0 \iint_S (g \operatorname{grad}_0 \psi - \psi \operatorname{grad}_0 g).\mathrm{d}\mathbf{S} - \\ - \frac{1}{c^2}\iiint_V \left[\left(\frac{\partial q}{\partial t_0}\right)_{t_0=0}\psi_0(\mathbf{r}_0) - g_{t_0=0}v_0(\mathbf{r}_0)\right]\mathrm{d}V_0 \tag{4}$$

The 'sub-zeros' refer again to the region of the sources and ψ_0 and v_0 are the initial values of ψ and $\partial\psi/\partial t$.

The first integral in equation (4) represents the contribution to the field amplitude $\psi(\mathbf{r}, t)$ of the sources q, and is a straightforward superposition integral. The final integral concerns the initial conditions of the field ψ and is closely related to the source integral because it stipulates the nature of sources needed to set the field up in the manner required. The second integral is concerned with boundary conditions of the propagating wave on the surface S.

To study the representation of Huygens's principle, concentration is first focused on this second integral since it describes the effect of wave-front surfaces at $\mathbf{r}_0$ and t_0 on the field ψ at $\mathbf{r}$ and t. Inserting the expression for the Green's function given by equation (3) into the second integral of equation (4),

$$\psi(\mathbf{r}, t) = \frac{1}{4\pi}\int_0^t \mathrm{d}t_0 \iint_S \left\{\left[\frac{\delta(R/c-\tau)}{R}\right]\operatorname{grad}_0 \psi - \\ - \psi \operatorname{grad}_0\left[\frac{\delta(R/c-\tau)}{R}\right]\right\}.\mathrm{d}\mathbf{S}_0$$

After some manipulation (Ref. 4, Sect. 7.3) this expression becomes.

$$\psi(\mathbf{r}, t) = \frac{1}{4\pi}\iint_S \left[\left(\frac{1}{R}\right)\operatorname{grad}_0 \psi(\mathbf{r}_0, t_0) + \left(\frac{\mathbf{R}}{R^3}\right)\psi(\mathbf{r}_0, t_0) - \\ - \left(\frac{\mathbf{R}}{cR^2}\right)\frac{\partial}{\partial t_0}\psi(\mathbf{r}_0, t_0)\right].\mathrm{d}\mathbf{S}_0 \tag{5}$$

where $\tau = t-t_0 = R/c$.

The first term in this equation may be regarded as the contribution of an isotropically radiating source of strength $1/4\pi.\partial/\partial n.\psi(\mathbf{r}_0, t)$, where $\mathbf{n}$ is the outward normal to the surface S_0. The next two terms are contributions (one of strength proportional to ψ and the other proportional to $\partial\psi/\partial t$) whose radiation is weighted by the cosine of the angle between the direction of $(\mathbf{r}-\mathbf{r}_0) = \mathbf{R}$ and the normal $\mathbf{n}$ to the surface S_0. It may be shown (Ref. 5, Sect. 5.4) that these last two terms are in effect the contribution from a double source (a positive and a negative source close together) of strength $\psi/4\pi$ directed normally to S_0.

Thus, if a wave-front is going to be considered as a collection of secondary radiators each contributing to the field ahead of the wave-front, equation (5) shows that these must be quite complicated. It would seem that the natural mechanisms of propagation require processes equivalent to finding the space differential of the field normal to a wave-front and a process equivalent to taking the time differential. The mechanism requires knowledge of the direction of the wave-front at a point in order to take the space differential and also of the set-up of the double source. This last requirement presents considerable difficulties since a field function ψ which is continuous in space and time has, presumably, sources distributed throughout the entire space. The concept of a wave-front or equi-phase surface under these conditions is very much a man-made mathematical construction. Many authors cast a dubious eye on the physical interpretation of equation (5). Born and Wolf say (Ref. 3, Sect. 8.3.1): 'Naturally these sources and doublets are fictitious, there being no deep physical significance behind such an interpretation'; Morse and Feshbach (Ref. 4, Sect. 7.3) refer to the sources as 'a curious sheet'; Baker and Copson (Ref. 5, Sect. 5.4) refer to the sources as 'fictitious'.

Even if the expressions are simplified by making approximations, the secondary sources described are physically unrealistic. For example, Fig. 4 shows an expanding spherical steady-state scalar wave centred on O, the problem is to find the fields at P due to the field on the spherical surface S_0. The field on the wave-surface is therefore

$$\psi(\mathbf{r}_0, t_0) = \exp(\mathrm{j}kR_1).\exp(-\mathrm{j}\omega t_0)/R_1 \tag{6}$$

where R_1 is the radius of the wave surface under consideration and $k = \omega/c$.

Equation (6) is now substituted into equation (5):

$$\psi(\mathbf{r}, t) = \psi(P, t) \\ = \frac{\exp(-\mathrm{j}\omega t_0)}{4\pi}\iint_S \left[\frac{1}{R}\frac{\partial}{\partial R_1}\frac{\exp(\mathrm{j}kR_1)}{R_1} + \\ + \frac{\cos\alpha}{R^2}\frac{\exp(\mathrm{j}kR_1)}{R_1} + \\ + \frac{\cos\alpha}{cR}\mathrm{j}\omega\frac{\exp(\mathrm{j}kR_1)}{R_1}\right]\mathrm{d}S_0 \tag{7}$$

where $\mathbf{R}.\mathrm{d}\mathbf{S}_0 = \cos\alpha$, and α is the angle between the outward normal to the surface S_0 and the direction of $(\mathbf{r}-\mathbf{r}_0)$.

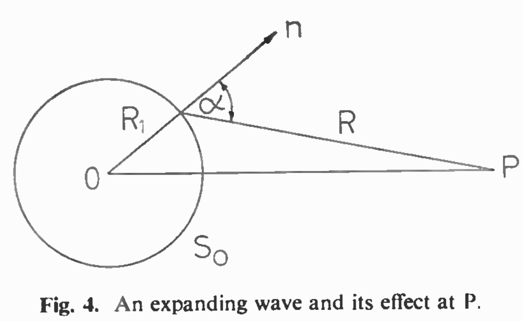

Fig. 4. An expanding wave and its effect at P.

Thus,

$$\psi(P,t)=\frac{1}{4\pi}\iint_S \frac{\exp(-j\omega t_0)+jkR_1}{R_1R}\times$$

$$\times\left[jk(1+\cos\alpha)-\frac{1}{R_1}+\frac{\cos\alpha}{R}\right]dS_0 \quad (8)$$

If now, it is assumed that the wavelength $2\pi/k$ is small compared with R and R_1, then $1/R$ and $1/R_1$ are small compared to k. This gives the approximate formula

$$\psi(P,t)=\frac{1}{4\pi}\iint_S\left[\frac{\exp(-j\omega t_0)+jkR_1}{R_1R}jk(1+\cos\alpha)\right]dS_0 \quad (9)$$

Equation (9) shows that the field at P is due to the total contribution of secondary sources of the form

$$\frac{1}{2\lambda}\frac{\exp(jkR_1)}{R_1}(1+\cos\alpha)\exp j(\pi/2-\omega t_0) \quad (10)$$

In demonstrating the principle of stationary phase, Silver (Ref. 6, Sect. 4.6) arrives at an identical formula. It may be further argued (as Silver does for example) that phase cancellation occurs as α gets larger, and the higher the frequency, the more quickly this occurs. (Note: this is also the qualitative argument used in the Introduction.) Thus, for high frequencies, expression (10) may be written as,

$$\frac{1}{\lambda}\frac{\exp(jkR_1)}{R_1}\exp j(\pi/2-\omega t_0) \quad (11)$$

Here the requirement that the secondary source has 'knowledge' of the wave-front is lifted. However, the secondary sources are required to be a quarter of a period in phase advance of the primary source and the amplitude of the secondary source is required to be proportional to $1/\lambda$. These are the two assumptions also made by Fresnel (see the Introduction). Baker and Copson say (Ref. 5, Sect. 1.4.1): 'The necessity for these two additional assumptions led many to regard Fresnel's theory merely as a convenient means of calculation which lacked any sound physical basis.'

The necessity for these two assumptions may be avoided by recognizing that,

$$\frac{\partial}{\partial R_1}\frac{\exp(jkR_1)}{R_1}=\frac{\exp(jkR_1)}{R_1}\left(jk-\frac{1}{R_1}\right) \quad (12)$$

Also remembering that $1/R_1 \ll k$, expression (10) may be written as

$$\frac{\partial}{\partial R_1}\frac{\exp(jkR_1)}{R_1}(1+\cos\alpha)\exp(-j\omega t_0) \quad (13)$$

Even allowing α to be small, the propagation mechanism still requires recognition of the wave-front direction and the performance of a space differential. Thus, even with the approximation that $k \ll (R \text{ or } R_1)$, a satisfactory physical explanation is difficult. As a demonstration of the principle of stationary phase the approximation presents the difficulty of restricting the values of R and R_1 which in nature must be quite arbitrary.

3 Green's Functions and Initial Conditions

The previous Section has attempted to show that it is difficult to attach physical meaning to the generation of one propagating wave-front from another as demonstrated by the use of Green's functions.

One of the complications not mentioned as yet is that a propagating wave-front only produces a field ahead of the wave-front and not behind it. The mathematical description must include, therefore, some mechanism for cancellation in the backward direction. This basic property of waves immediately presents difficulties for the Huygens's model of propagation because it again requires the individual secondary wave sources to have detailed 'knowledge' about the wave-front as a whole.

In order to remove this difficulty, and thereby obtain a better insight into the physical meaning, the propagation of a wave set up by the initial conditions of the field is considered. If, for example, the initial conditions are set up by sources in a plane in three-dimensional space then propagation will take place both in front of the plane and behind it.

One way of analysing such a plane is to find the Green's function in one-dimensional space from a knowledge of the Green's function in three-dimensional space. It should be noted that the choice of three dimensions for the starting point is quite arbitrary, the process of descending (Hadamard's method) can take place from the $(n+1)$th dimension to the nth where n is any positive integer (see Ref. 7, Chap. 6, Sect. 12.3).

The Green's function for three-dimensional space has already been written as

$$g(x,y,z,t)=\frac{\delta(R/c-\tau)}{R} \quad (14)$$

Hadamard's method of descent requires the setting up of the source of equation (14) in three-dimensional space along the z-axis from $z=-\infty$ to $z=+\infty$. In this way a geometry independent of z is achieved, and the effect at any point (x, y) in a z = constant plane is found by superposition. This technique is particularly interesting here because this is precisely the mechanism that would be employed using Huygens's principle as a model. The argument used, of course, is that if equation (14) is a solution of the three-dimensional wave equation then the linear superposition of solutions like equation (14) must also be a solution. Thus the two-dimensional Green's function is

$$g(x,y,t)=\int_{-\infty}^{+\infty}\frac{\delta(R/c-\tau)}{R}\,dz \quad (15)$$

In Fig. 5 a point $(x, 0)$ is chosen for the solution point, in which case

$$R^2=x^2+z^2$$

and equation (15) becomes

$$g(x,y,t)=\begin{cases}\dfrac{2c}{\sqrt{(c^2\tau^2-x^2)}} & x<c\tau\\ 0 & x>c\tau\end{cases} \quad (16)$$

Similarly by integration of $g(x, y, t)$ along the y-axis it may be shown (Ref. 4, Sect. 7.5) that the one-dimen-

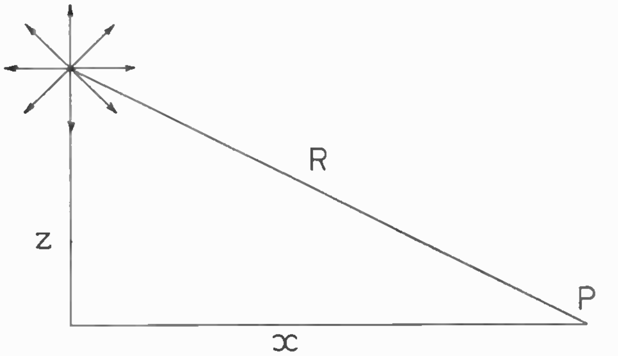

Fig. 5. Superposition of isotropic sources to form a two-dimensional solution.

sional Green's function is

$$g(x, t) = 2c\pi\left[1 - u\left(\frac{x}{c} - \tau\right)\right] \qquad (17)$$

where u is the unit step function.

Consider now the infinite plane $x = 0$ filled with sources which are impulsed at time $t_0 = 0$ with a delta function, and each of which radiates isotropically in three-dimensional space. There is no field at the point P distance x away from the plane until a time x/c has elapsed. Thereafter, from equation (17), the field is of constant value $2c\pi$. If now the initial field points (rather than the sources) in the plane are delta functions at time $t_0 = 0$, then by the common sense of one-dimensional propagation the effect at P must also be a delta function passing through at time $t = \tau = x/c$.

To obtain this result analytically the initial conditions given by the last integral in equation (4) must be applied. If $v_0 = 0$, this last integral becomes (in one-dimensional space)

$$\psi(x, t) = -\frac{1}{4\pi c^2}\int\left[-\left(\frac{\partial q}{\partial t_0}\right)_{t_0=0}\psi_0(x_0)\right]\mathrm{d}x_0$$

Substituting for g from equation (17)

$$\psi(x, t) = \tfrac{1}{2}[\psi_0(x+c\tau)+\psi_0(x-c\tau)] \qquad (18)$$

This is the expected result for one-dimensional propagation and in the case of an impulsive field $\psi_0(x) = \delta(x)$,

$$\psi(P, t) = \tfrac{1}{2}\delta(x-c\tau) \qquad (19)$$

Thus, if a plane impulsive wave-front is considered to consist of simple isotropic radiators all superposing to give the field at P, then the wrong answer is obtained as demonstrated by equation (17). However, if the Green's function of equation (17) is modified according to the initial conditions formulation of equation (4) then the correct answer is obtained. Again the physical process is only explained after some mathematical processing, though in this case the processing only amounts to a time differential of the Green's function.

If this time differential is assumed to occur on the plane of the source before the propagation takes place, then the one-dimensional solution, including the principle of stationary phase, may be explained as follows. Figure 6 shows the plane S_0 at $x = 0$ on which there are assumed to be isotropic impulsive radiators differentiated in time. Representing the differentiated delta function as

$$\delta'(t_0) = \lim_{\varepsilon\to 0}\left[\frac{\delta(t_0)-\delta(t_0-\varepsilon)}{\varepsilon}\right] \qquad (20)$$

it can be seen that if this function radiates isotropically in three dimensions the first effect at P is a positive delta function of strength $1/\varepsilon R$ after a time R/c.

It is now assumed that the strength of $\delta'(t_0)$ at the point A is $\varepsilon R/2$ and further that the contribution at P from point B is delayed by the time increment $(R/c+\varepsilon)$, due to the longer distance travelled, and that its strength at P is $\varepsilon R_1/2$. Similarly, it is assumed that the source at C is delayed by $(R/c+2\varepsilon)$ and its strength is $\varepsilon R_2/2$, and so on. The total field at P due to these isotropic radiators is then

$$\psi(P) = \lim_{\varepsilon\to 0}\frac{\varepsilon}{2}\left\{\left[\frac{\delta(t_0-R/c)-\delta(t_0-R/c-\varepsilon)}{\varepsilon} + \frac{\delta(t_0-R/c-\varepsilon)-\delta(t_0-R/c-2\varepsilon)}{\varepsilon} + \ldots\right]\right\}$$

Thus

$$\psi(P) = \tfrac{1}{2}\delta(t_0-R/c) \qquad (21)$$

These assumptions are summarized in the solution of the initial value problem (Cauchy's problem) for the wave equation in three-dimensions (see Ref. 7, Chap. 3, Sect. 4.2),

$$\psi(P, t) = tM_t(v_0) + \frac{\partial}{\partial t}\,tM_t(\psi_0) \qquad (22)$$

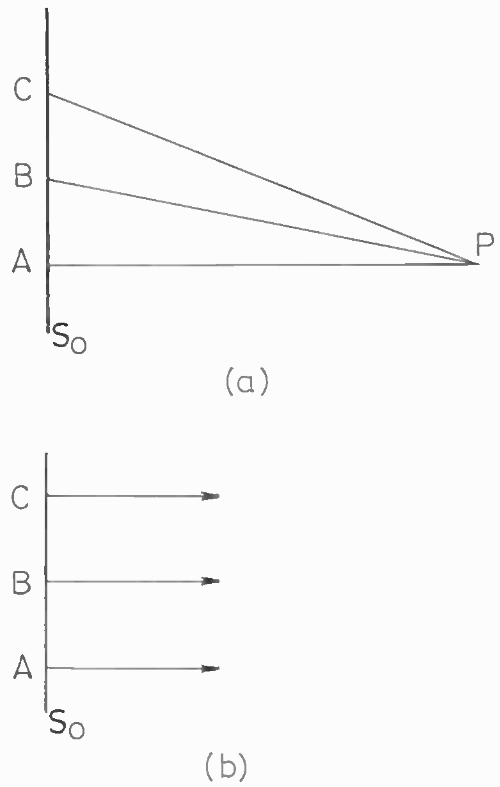

Fig. 6. One-dimensional propagation of the wave-front S_0.

where M_t denotes the mean value of the function v_0 or ψ_0 over the surface of the sphere of radius t centred on P.

Equation (21) is, of course, the correct solution for impulsive plane wave propagation and it has been derived by recognizing that the contributions from sources in the plane cancel, except for the one perpendicularly behind P at point A in Fig. 6(a).

At this point the property of a new propagation model can be proposed. From the one-dimensional solutions of the wave equation it would seem more natural that the plane S_0 in Fig. 6 moves as a whole in the directions perpendicular to itself. Thus if the idea of superposing fields is abandoned, the concept of points like A, B and C only contributing in the direction perpendicular to the plane may be introduced as shown in Fig. 6(b). The advantage of considering the propagation to take place in this way is that the requirement of taking a time differential is removed and the sources are not required to radiate according to the direction and distance of P with respect to the source. The disadvantage is that the radiation property of the individual sources is modified according to the wave-front, a difficulty that has been encountered throughout. In the next Section it will be shown how this final difficulty may be overcome. For the moment, therefore, it is assumed that the collection of sources in a plane causes the individual sources to move along lines perpendicular to the plane and that the sources do not superpose.

Moving back to two-dimensional propagation, the equivalent assumption is that the collection of sources along the line of the z-axis causes the individual sources in that line to radiate outwards in disks perpendicular to the line (in planes of z = a constant). However, many texts explain the tail or wake in two-dimensional propagation (see equation (16)) as being due to the contributions from other sources on the z-axis above and below the plane containing the observation point. This explanation is given for example by Morse and Feshbach (Ref. 4, Sect. 7.3); Baker and Copson (Ref. 5, Sect. 6.1); and Courant and Hilbert (Ref. 7, Chap. 3, Sect. 4.6) and would seem to defeat the assumption proposed here. After all, equation (16) was derived by superposing all the sources along the z-axis.

However, equation (16) may be derived in an alternate way in which propagation solely in two dimensions is considered.

The wave equation in cylindrical co-ordinates is

$$\frac{\partial^2\psi}{\partial R^2}+\frac{1}{R}\frac{\partial\psi}{\partial r}+\frac{1}{R^2}\frac{\partial^2\psi}{\partial\theta^2}+\frac{\partial^2\psi}{\partial z^2}=-\omega^2\mu\varepsilon\psi$$

In two dimensions and assuming circular symmetry, this equation becomes

$$\frac{\partial^2\psi}{\partial R^2}+\frac{1}{R}\frac{\partial\psi}{\partial r}+\omega^2\mu\varepsilon\psi=0$$

This is Bessel's equation and a solution is

$$\psi=\mathrm{j}\pi H_0\left(\frac{\omega R}{c}\right)$$

where H_0 is the Hankel function of the second **kind** (outgoing waves) and order zero.

Now the Hankel function may be expressed as a definite integral as follows (Ref. 4, p. 1323):

$$\mathrm{j}H_0\left(\frac{\omega R}{c}\right)=2\int_1^\infty\frac{\exp(-\mathrm{j}\omega Ru/c)}{\sqrt{(u^2-1)}}\,\mathrm{d}u$$
$$=2\int_{r/c}^\infty\frac{\exp(-\mathrm{j}\omega t)}{\sqrt{t^2-(R/c)^2}}\,\mathrm{d}t$$

This last integral is in a highly convenient form since its Fourier transform may be written down by inspection as

$$g(R,t)=\begin{cases}0 & t<R/c\\ \dfrac{2}{\sqrt{t^2-(R/c)^2}} & t>R/c\end{cases}\tag{23}$$

where $g(R, t)$ is the impulse response for unit impulsive source in two dimensions, i.e. the Green's function.

Equation (23) is the same as equation (16) but the derivation has not required the use of superposition of sources. If the tail does not arise from superposition, what is the physical explanation? This may be seen by recognizing that two-dimensional cylindrical propagation may be simulated by a one-dimensional constant velocity transmission-line but with a linearly increasing characteristic impedance along its length. For example, in electromagnetic terms, Maxwell's equations for E-modes may be written as,

$$\begin{aligned}\frac{\partial(rH_\theta)}{\partial r}&=r\varepsilon\frac{\partial E_z}{\partial t}\\ -\frac{\partial E_z}{\partial r}&=-\frac{\mu}{r}\frac{\partial(rH_\theta)}{\partial t}\end{aligned}\tag{24}$$

where

$$\frac{\partial}{\partial z}=\frac{\partial}{\partial\theta}=0$$

The standard relationships between voltage V and current I on a transmission-line with inductance L and capacitance C per unit length are

$$\begin{aligned}\frac{\partial V}{\partial x}&=-L\frac{\partial I}{\partial t}\\ \frac{\partial I}{\partial x}&=-C\frac{\partial V}{\partial t}\end{aligned}\tag{25}$$

The equivalence between equations (24) and equations (25) can be seen, and in particular $L\equiv r\varepsilon$ and $C\equiv\mu/r$. Physically this condition is met by a diverging pair of wires which conforms with the concept of an outwardly expanding cylindrical wave. Thus the tail in cylindrical propagation may be thought of as due to the non-uniform nature of the transmission as the wave expands its shape. A purely two-dimensional concept.

4 The Propagation Model

The first step in forming a new model for propagation is to consider the possible physical mechanism of propagation. Suppose an aerial launches a small loop or vortex of **E** field into space. If the amplitude of the vortex changes with time, then one of Maxwell's equations states:

$$\text{curl } \mathbf{H} = \varepsilon \frac{\partial \mathbf{E}}{\partial t} \tag{26}$$

(Note that the conduction current has been neglected since it is assumed that the propagation is taking place in ideal free space.)

Stokes's theorem may be used to expand equation (26) as follows:

$$\iint_S \text{curl } \mathbf{H}.\mathrm{d}\mathbf{S} = \oint \mathbf{H}.\mathrm{d}\mathbf{l} = \iint_S \varepsilon \frac{\partial \mathbf{E}}{\partial t}.\mathrm{d}\mathbf{S} \tag{27}$$

Equation (27) says that if an **E** field changes in time then an **H** field is set up which tends to form loops around the **E** field. Thus, the **E** field becomes 'linked' with the **H** field as shown in Fig. 7(a).

Also, from Maxwell's equations,

$$\text{curl } \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$

i.e.

$$\iint_S \text{curl } \mathbf{E}.\mathrm{d}\mathbf{S} = \oint \mathbf{E}.\mathrm{d}\mathbf{l} = \iint_S -\frac{\partial \mathbf{B}}{\partial t}.\mathrm{d}\mathbf{S} \tag{28}$$

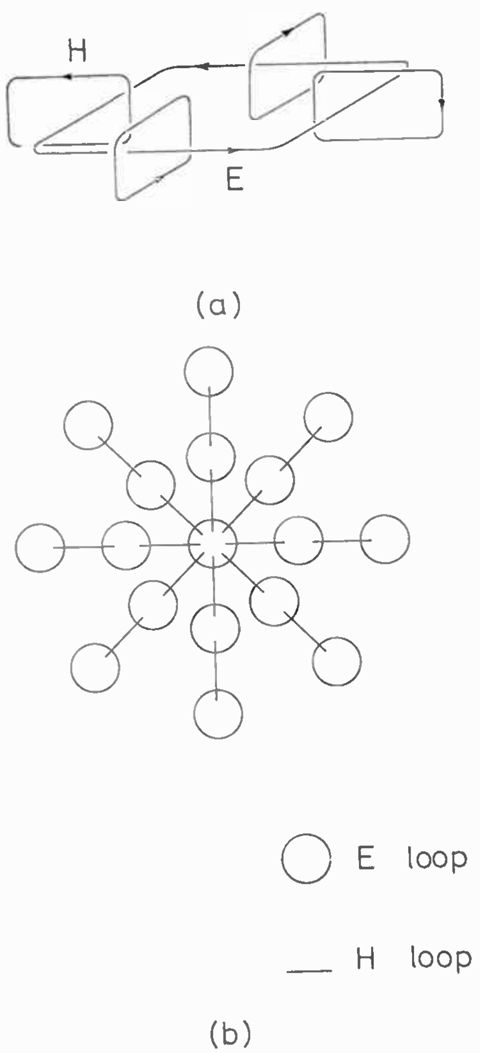

Fig. 7. Propagation of loops of E and H fields.

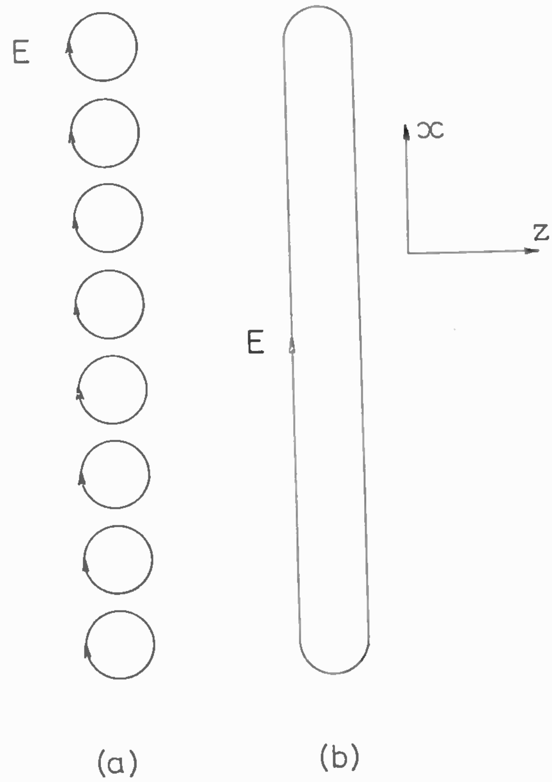

Fig. 8. Formation of an elongated loop of E field.

So, in a similar way, a changing **H** field induces loops of **E** field, and so the energy is propagated outwards (see Fig. 7(b)). Notice also that if, for example, an **E** field creates a loop of **H** field then the **H** field in turn creates a loop of **E** field which tends to oppose the original **E** field setting it up. In this way a new generation of **H** loops cancels the **E** loops creating them and prevents propagation in the backward direction.

Thus, in a qualitative way, the physical mechanism of Huygens's principle can be seen. A system of sources creates a new system of sources in such a way that cancellation occurs in the reverse direction and propagation continues in the forward direction. The main difference so far between this model and the Green's function model is that the secondary wavelets are very close to the primary ones. There is not an arbitrary large distance between them.

Imagine now a plane wave-front consisting of a number of **E** loops side-by-side as shown in Fig. 8(a). These will not exist as separate loops but will immediately combine to form an elongated loop as shown in Fig. 8(b). The induced **H** loops will now only be oriented in a direction perpendicular to the original wave-front. These **H** loops in turn will generate another elongated loop of **E** field and so the process continues. Notice that the loops of **E** field are taken long enough to allow the effects at the ends to be neglected.

A physical explanation of how individual sources in a wave-front are affected by other sources has now been given. In this example of plane wave propagation it becomes apparent that propagation only proceeds in a

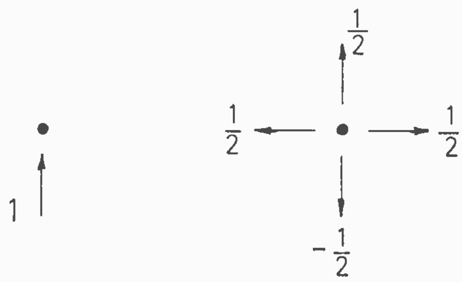

Fig. 9. Incident and radiated pulses at a node.

direction perpendicular to the plane. Precisely the same arguments can also be applied to two-dimensional propagation.

There are however many short-comings in the picture built up so far. While it is possible that the physical mechanism of propagation has been qualitatively explained, the model certainly does not lend itself to a mathematical and quantitative treatment. In the simple impulsive plane-wave example it is easy to see how elementary sources combine to form large loops but in the case of diffraction over a knife-edge, for example, the effects of the ends of loops would have to be taken into consideration together with deformation of the shapes of the loops. Also in a steady-state wave situation, where the field is distributed throughout space, it is not clear how the individual vortices of field combine to form the larger loops. Certainly there is no reason why they should combine on an equi-phase surface only. Finally, the model as described requires the abandonment of Huygens's principle in the sense that a wave-front no longer consists of individual elementary sources. While a scientist should be prepared to abandon a principle if it does not fit the physical situation, Huygens's principle is a cause-and-effect type of model which crops up a lot in nature (heat flow for example).

In the following paragraphs the concept of space being discretized is introduced. By taking this step it will be shown that Huygens's principle in its most simple form can explain the phenomenon of propagation.

In the discrete-space model propagation is considered to take place from isolated points in space and in order to simplify the approach the points or nodes are considered to be situated on a two-dimensional Cartesian matrix.

Assume that a node is excited from the negative x direction by a delta function travelling in the positive x direction towards the node. Suppose that the node re-radiates the energy isotropically which is the simplest and most natural way it could radiate it, and is certainly in agreement with ideas presented in Fig. 7(a). If the power strength or energy (power $\times$ time) of the delta function at the input to the node is unity, the power strength of each of the four delta functions leaving the node (one in each co-ordinate direction) must be 1/4. The amplitude strength (amplitude $\times$ time—hereafter loosely termed amplitude) of the four delta functions must be $\pm 1/2$.

Consider now the case where a single node has delta functions of unity amplitude incident from all four co-ordinate directions. In order to conserve energy and also by consideration of the symmetry of the problem, the amplitude of the delta functions leaving in each of the four directions must also be unity. Since, individually, each delta function must contribute an amplitude of $\pm 1/2$, it follows that on each direction there must be amplitude of $+1/2$, $+1/2$, $+1/2$ and $-1/2$. Summarizing, it may be concluded that a single delta function entering a node produces delta functions leaving in the four co-ordinate directions of magnitude 1/2. The sign of these is positive in three of the directions and negative in the fourth.

Intuitively (and this is the only reason at this stage) it seems 'nice' to have the negative pulse leaving in the direction from which the incident pulse arrived, as shown in Fig. 9. This gives the impression of cancellation of waves in the backward direction.

In the rectangular array of nodes shown in Fig. 10, the distance between nodes is Δl and the time taken for a delta function to travel from one node to the next is taken as $t_0 = \Delta l/c$. If at time $t = 0$ a point source radiates unit amplitude delta functions in the four co-ordinate directions, then propagation progresses as shown in Fig. 10. Here it can be seen that the pulse shape is not preserved but 'breaks-up' into many pulses which eventually fill the whole matrix of nodes. This lack of preservation of pulse shape is not only due to the two-dimensional nature of the propagation, but also due to the discreteness of the model which causes dispersion. This aspect of the model is dealt with in detail in reference 8, but a further qualitative picture can be given by considering one-dimensional propagation. In Fig. 11 a rectangular array of nodes is excited along a line and a wave-front propagates to left and to right. The form of the propagation of the right-hand wave-front is shown in the Figure.

The first point to note is that whatever pulse leaves a node in the $+x$ or $-x$ direction there is a similar pulse travelling towards the node from the $+x$ or $-x$ directions respectively. This means that open circuit reflecting points could be inserted at the mid-points between vertical nodes. Thus, each source in effect only propagates in the $\pm z$ direction. Although each node radiates in all four co-ordinate directions the proximity of neighbouring nodes means that propagation from each node is in the $\pm z$ direction. This, of course, is in agreement with the original physical model for one-dimensional propagation (see Fig. 8).

The second point to note is that after time $t = 2\Delta l/c$ the bulk of the energy is leaving nodes at a distance one node away from the source. Similarly, at time $t = 4\Delta l/c$ the maximum value of the wave-front is approximately two nodes away. This suggests that the array of nodes is acting as a slow-wave structure which is not surprising in view of its periodic nature.

Finally, it should be noted that this model has a network analogue in the form of a mesh of transmission-lines,[8] the junctions of which also obey the nodal properties illustrated in Fig. 9. As shown in references 8

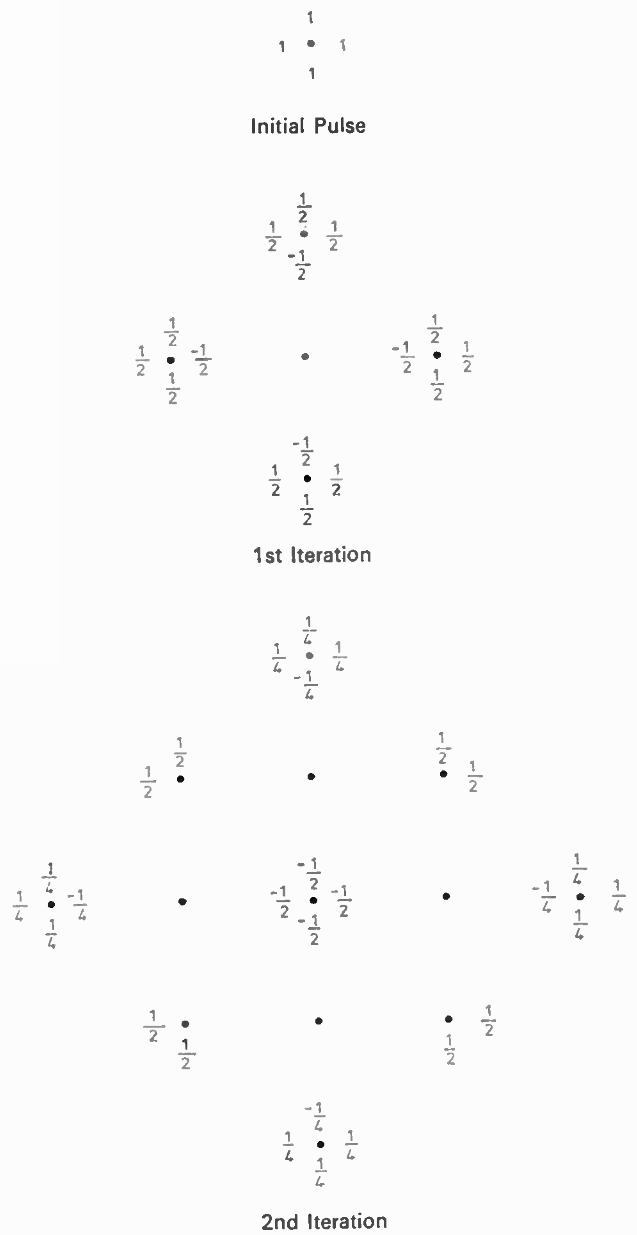

Fig. 10. Propagation of a point source of a two-dimensional array.

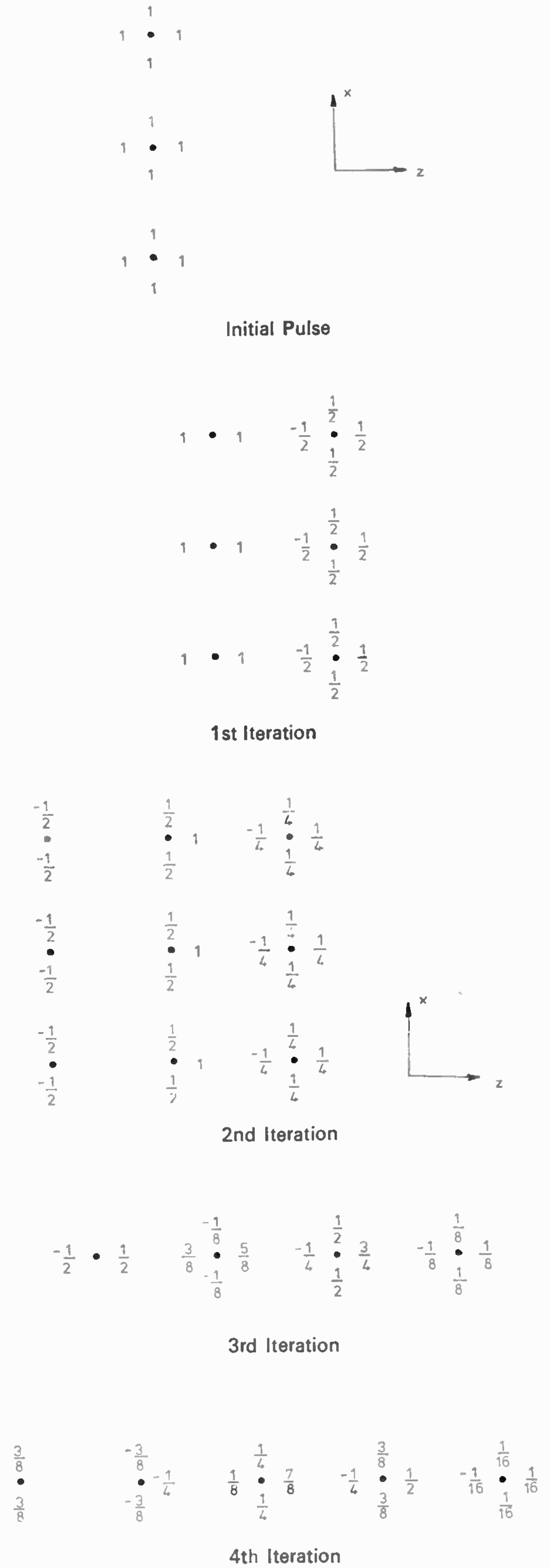

Fig. 11. Propagation of a one-dimensional wave on a two-dimensional array.

and 9 there is a direct equivalence between the voltages and currents on the mesh of lines and the **E** and **H** fields in Maxwell's equations. In this way it is shown that the model gives an exact solution (if the internodal distance Δl is small enough) to the wave equation. This is the basis of the transmission-line matrix method of numerical analysis of waves. The method has been applied to the solution of scattering problems,[8] cut-off conditions of homogeneous waveguides[9] and inhomogeneous waveguides,[10] and to losses in waveguides.[11]

5 Discussion and Conclusion

It has been shown that the expression of Huygens's principle using Green's functions (i.e. straightforward superposition) makes the physical mechanism of propagation unrealistic. Perhaps the most interesting revelation of the difficulties involved is given by Courant and Hilbert (Ref. 7, Chap. 7, Sect. 12.7) when they say: 'Huygens's principle is valid for the radiation problem with odd space dimensions. Huygens's principle does not, however, hold for radiation in an even number of space dimensions.' The simple continuous model introduced in this paper removed many of the difficulties, and the concept of discretized space produced a model which only relied on Huygens's principle in its simplest form.

However, the concept of discretized space does introduce the idea that space is a slow-wave structure whose cut-off depends on the closeness of the nodes (the magnitude of Δl). It may be that the nodes are infinitely close together in real space, in which case the cut-off frequency will tend to infinity. This does not alter the validity of the transmission-line matrix model. It has been found in reference 8 that low frequency waves or the mass-action in the form of a dispersed pulse, travels at $1/\sqrt{2}$ of the speed of the individual elementary pulses contributing to the wave as a whole. (It should be noted that the factor $1/\sqrt{2}$ applies only to the two-dimensional space considered here and that a different factor would apply to three-dimensional space.)

In the case of impulsive propagation the main difficulty in the Green's function analysis arises because it relies on the superposition of the mass-action impulsive wave. Green's function analysis gives the correct answers, it is its reality as a physical model that is being questioned. On the discrete space model the individual pulses obey the principle of superposition. This must be so, of course, because the network analogue is linear, passive and 'well-behaved' in the network theorems' sense. However, the mass-action effect, i.e. the dispersed impulse travelling at $1/\sqrt{2}$ of the speed of the individual pulses, does not obey the principle of superposition. The mass-action effect is the envelope of the individual pulses and it is changing its shape as it propagates because it is being dispersed. While the individual components obey superposition, the envelope does not.

For example, if a single pulse is injected into the transmission-line matrix at the point (x_0, y_0), the combined effect of the individual pulses on the lines (travelling at velocity c) will be to give a cylindrically expanding wave travelling at the velocity $c/\sqrt{2}$ (see Fig. 10). However, a line of sources on the line $x = x_0$ injected into the matrix will give rise to a linear wave-front travelling at $c/\sqrt{2}$ as shown in reference 8 (see also Fig. 11). Although the individual pulses on the lines obey the principle of superposition, the linear wave-front is not the superposition of many cylindrical wave-fronts.

By far the most interesting question raised by a discrete model of free-space is: 'Is free space itself discretized?' In other words, 'If the model described here is truly representative of what really happens, what is the value of Δl for free-space? Does Δl have a small average value or is it infinitely small?'

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Characterization methods of Gunn oscillators

K. TOMIZAWA, B.Sc., M.Sc., Ph.D.*

and

Professor H. HARTNAGEL, Ph.D., C.Eng., F.I.E.E., F.I.E.R.E.*

SUMMARY

Three measurement techniques for determining the large-signal characteristics of Gunn-diode oscillator networks are described and compared. These are the reflexion method, the transient method and the steady state oscillation method. It is shown that the technique adopted should depend on the type of device to be tested.

* *Department of Electrical and Electronic Engineering, The Merz Laboratories, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU.*

1 Introduction

For an optimum design of Gunn-oscillator networks, it is necessary to know the large-signal characteristic of the Gunn diodes to be used. The determination of the equivalent-circuit parameters of such diodes versus microwave voltage amplitude often presents great difficulties as a high proportion of them cannot be stabilized by heavy loading. Simple reflexion-type measurements cannot be employed then and more sophisticated methods are required. Several of these methods have been reported,[1-3] but a comparison and an assessment of their merits has not yet been undertaken.

We have used extensively the three most important measurement methods, namely (a) the reflexion-type method with those Gunn-diodes which can be stabilized, (b) the transient method[2] and (c) the steady-state oscillation method with changing load conductance.[3] We are therefore able to undertake a comparative assessment of their features. Regarding the last method we developed a new experimental system which permits one to determine the equivalent-circuit of the semiconductor chip directly without having to transform the impedance through the equivalent circuit of the encapsulation. This work is therefore also suitable for a realistic assessment of the effect of the package on the performance of the semiconductor device. The operating large-signal admittance of Gunn diodes is obtained here by using the principle that the steady-state of an oscillator is established under the condition of equal circuit and diode admittance magnitude with opposite sign. The transient method, however, is in principle identical to this steady-state measurement as it employs quasi-steady-state transient oscillations of the oscillator.[2]

2 Harmonic Content

As the characterization methods generally employed impose the assumption of single frequency operation, it is important to estimate the error caused by harmonics. Steady-state Gunn-diode oscillations are produced by a non-linear admittance of the active device. Therefore a purely sinusoidal alternating voltage and current of the diode are unlikely and one can expect higher-harmonics to occur.

In order to estimate the harmonic content of a Gunn oscillator, we simulated it numerically. The cavity in the computation is either a lumped circuit model or a one-dimensional distributed line with a finite length. The behaviour of the diode is treated by finite-difference formulae of Poisson's equation and the current continuity equation. The details of the calculation are given in the Appendix. The oscillatory waveform of the distributed-line circuit was found to be mainly different from the one for the lumped circuit model during the oscillation transient after the application of a voltage step.

The normalized amplitudes of the harmonics are shown in Fig. 1 by continuous lines as a function of the loaded Q factor Q_L of the cavity. The harmonic content of a non-stabilizeable diode in a coaxial resonator (diode A of Section 3) as a function of Q_L is determined by Fourier-analysing the output waveshape as recorded by a fast sampling oscilloscope together with an x-y plotter.

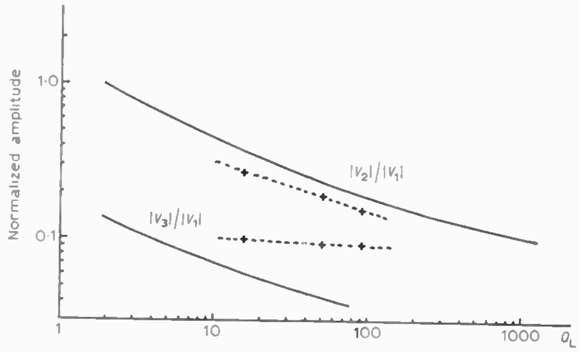

Fig. 1. Normalized amplitude of the second (V_2) and the third harmonics (V_3) versus the loaded Q factor of the cavity (V_1 is amplitude of the fundamental)
—— theoretical; - - - - - experimental.

These results are obtained by using an adjustable capacitive coupling probe for the setting of the Q_L values. The findings are inserted in Fig. 1 as crosses. They exhibit relatively good agreement between theory and experiment for the second haronic, whereas the agreement for the third harmonic is moderate only.

The presence of this harmonic power distorts the measurement results of diode conductances, and the error can be expected to be more than 10% for Q_L values smaller than 10, whereas for $Q_L = 1000$, the error can be as low as 1%.

3 C.W.-Oscillation Method

The cavity for the c.w. measurement of the large-signal diode admittance by variable load conductance is of coaxial type as shown in Fig. 2. One end of the inner conductor of the cavity is connected to a low-pass filter for the application of the bias voltage to the diode. The other end of the conductor has an arrangement for mounting the diode to be measured. The inner conductor end has a hole there into which the heat sinking end of an S4 housing is inserted. A very small 50 Ω coaxial line of 1·6 mm outer diameter, attached to the cavity end is terminated on the heat-sinking pedestal as shown by Fig. 3. This coaxial line permits one to measure the microwave impedance inside the S4 package when it is inserted into the coaxial cavity. A thin bronze wire is bonded to the heat sinking pedestal and connected by pressure contact to the inner conductor of the coaxial probing line to simulate the effect of the bonding wire of ecapsulated diode chips. The circuit for the measurement of the cavity has two main differences as compared with the one with the oscillating diode. Firstly the equivalent positions of the diode chip and the gold wire are reversed. Then the cavity has a 50 Ω line at one end when the cavity is measured, but this end is short-circuited when the diode is mounted. These differences may give some error. The coupling between cavity and load, and the resonant frequency are mechanically adjustable. It is possible to obtain a tuning range covering X-band, and the coupling covers Q_L from 10 to 100.

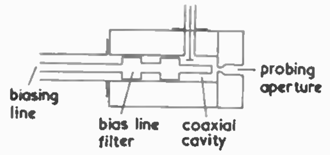

Fig. 2. The structure of the cavity used for the diode-admittance measurements under c.w. conditions.

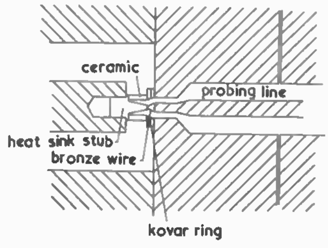

Fig. 3. Details of the cavity of Fig. 2 with an open S4 package mounted together with a miniature coaxial line to measure the circuit impedance applied to the active semiconductor chip.

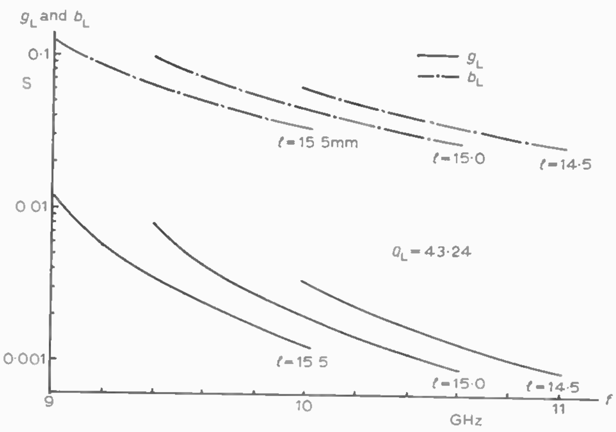

Fig. 4. The characteristic of the cavity measured with the miniature coaxial line of Fig. 3 as a function of frequency for $Q_L = 43{\cdot}24$. l is the cavity length.

Some of the measured frequency characteristics g_L+jb_L of the cavity alone at the position of the diode chip are shown in Figs. 4 and 5. The diode admittance g_D+jb_D can then be evaluated by using the characteristic of the cavity for the oscillation frequency obtained when a diode is mounted and a bias voltage applied. The a.c. voltage V_{ac} across the diode is estimated roughly by using the following formula:

$$V_{ac} = \sqrt{\frac{2P_0}{g_D}(1+Q_{ex}/Q_0)} \tag{1}$$

where P_0 is the output power of the cavity, and Q_{ex} and Q_0 are the external and unloaded quality factors of the cavity respectively.

It is in connexion with this equation that the V_{ac} values are inaccurate as the power of higher-harmonic waves is neglected when P_0 is measured. If for example $|V_2|/|V_1| = 0{\cdot}4$ for $Q_L = 15$ (see Fig. 1) the second harmonic power would be roughly 16% of P_0. Correspondingly, the error of V_{ac} would be 8%.

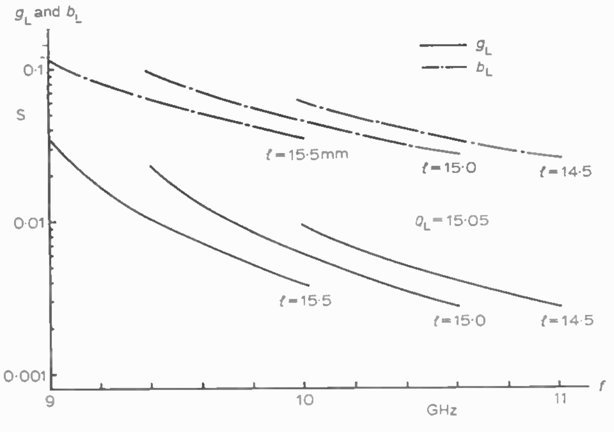

Fig. 5. The characteristic of the cavity measured from the diode position as a function of frequency for $Q_L = 15{\cdot}05$. l is the cavity length.

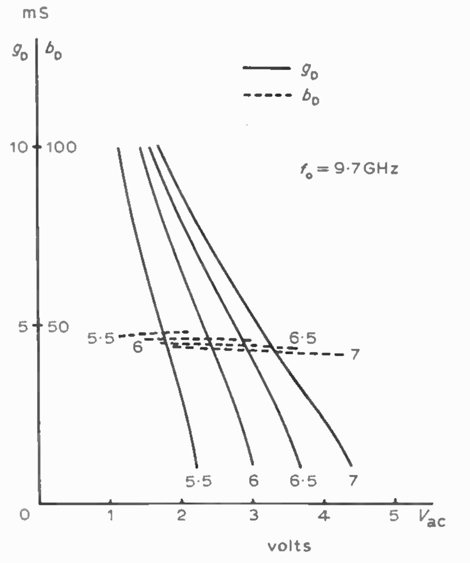

Fig. 7. The V_{ac} dependence of the admittance $g_D + jb_D$ of diode A, for various bias voltages as parameters.

Two kinds of X-band diodes are measured (types A and B). They have an active layer of 10 µm thickness, an average ionized donor density of around 1×10^{15} cm^{-3} and a cross-sectional area of a 100 µm diameter circle. Diode type A cannot be stabilized by a high load conductance. Therefore a reflexion-type measurement is not possible with diode Type A. Diode type B on the other hand can be stabilized by the use of a high load conductance. A reflexion type measurement is, therefore, possible with this diode; moreover this type of diode is useful as a reflexion type amplifier.

The a.c. voltage waveform of the microwave output is shown in Fig. 6 for diode A. The strong second harmonic distortion is noticeable as given by the crosses of Fig. 1. The measured a.c. voltage dependence of the conductance and susceptance of diode A is shown in Fig. 7. The diode susceptance is almost constant over the V_{ac} range considered here.

The output waveform for diode B is shown in Fig. 8. In contrast to the results of diode A a relatively pure sinusoidal waveform is observed. This diode gives the characteristics as shown in Fig. 9. The major difference between diodes B and A are the a.c. voltage dependence of the diode conductance. The conductance of diode B is finite when the a.c. voltage becomes zero. This diode is stabilized when the diode is presented with a high load conductance of the cavity. The experimental result shows that the maximum conductance is 2·5 mS.

4 Amplifier Method

As diode B has a finite conductance, as shown in the previous Section, when the a.c. voltage across the diode becomes zero, it is possible to stabilize the diode by a high load conductance and to obtain the operation of a reflexion type amplifier. The power reflexion coefficient for such an amplifier is given as

$$\frac{P_0}{P_{in}} = \Gamma^2 = \left\{\frac{g_L - g_D}{g_L + g_D}\right\}^2 \qquad (2)$$

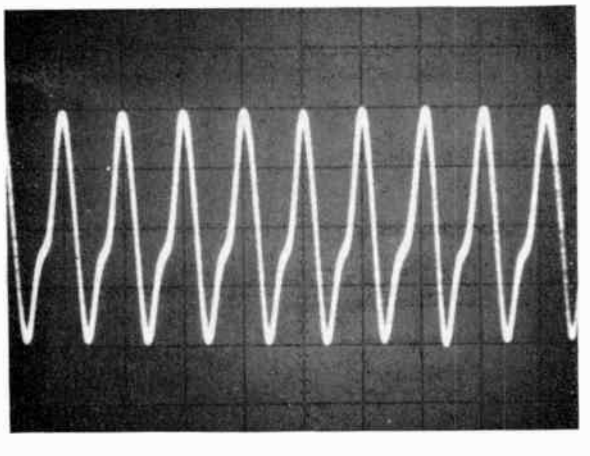

Fig. 6. The waveform of the microwave oscillation when diode A is mounted. The distortion by the second harmonic is clearly observed when Q_L is low (= 15·05).

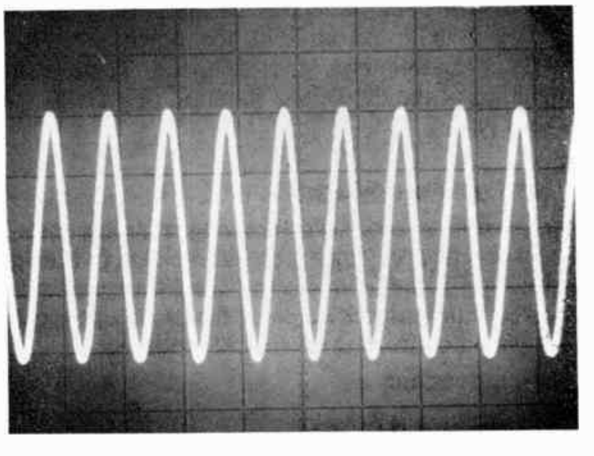

Fig. 8. The waveform of the microwave oscillation when diode B is mounted in the circuit.
$Q_L = 43{\cdot}24$. $V_B = 8{\cdot}5$ V.

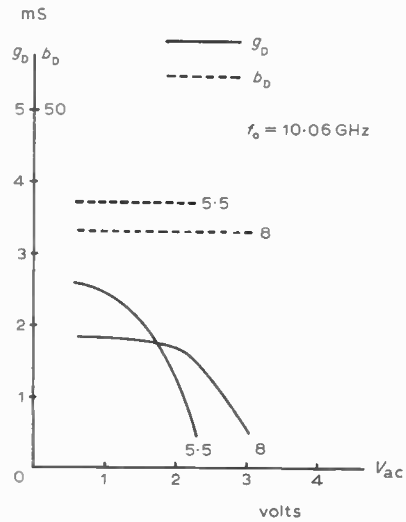

Fig. 9. The V_{ac} dependence of the admittance $g_D + jb_D$ of diode B, for two bias voltages.

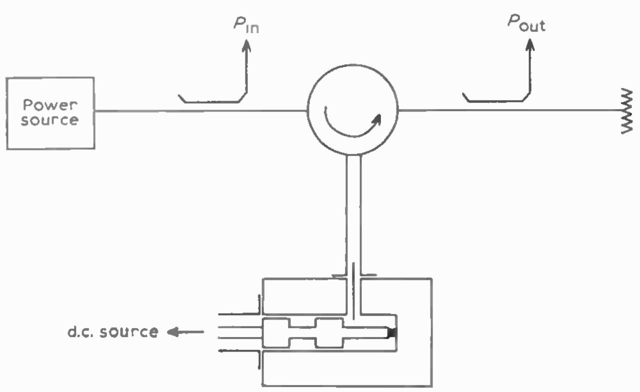

Fig. 10. The circuit used for the amplifier method.

The evaluation of the diode conductance using the measured input and reflected power is possible after we determine the load conductance g_L. The circuit diagram for this measurement is shown in Fig. 10. The cavity is employed with strong coupling to the load. Tuning of the cavity is adjusted so that the maximum gain is available at the frequency of 10·25 GHz. The measured conductance of the diode as a function of a.c. voltage is given in Fig. 11.

5 The Transient Method

It is possible to record the growing transient envelope of oscillation by applying a step bias voltage to the diode in the cavity.[2] If the following two conditions are satisfied during the transient, the value of the diode conductance can be evaluated from the transient envelope:

(a) ω_0 is constant

(b) $V_{ac}/V_0 = n$ is constant

where ω_0 is the oscillating frequency and V_{ac} and V_0 are the a.c. diode voltage and the voltage of the 50 Ω ouput line respectively.

The above two conditions are satisfied when during the experiment:[4]

(a) $g_D \ll b_D$ or $g_D \ll Y_0$

(b) b_D = constant

where g_D and b_D are the diode conductance and susceptance respectively. Y_0 is the characteristic admittance of the coaxial line used for the cavity. For diode B, $g_D \ll b_D$ and $b_D \simeq$ constant so that the transient method is justified.

The circuit diagram for this measurement is shown in Fig. 12. A positive d.c. voltage is provided via the bias T connector and a negative square pulse of equal amplitude with 20 ns duration and 2 ms repetition rate is simultaneously applied via a 50 Ω coaxial cable. In this way the negative conductance function is determined for the normal d.c. operating temperature of the device. The frequency of the c.w. oscillation is adjusted to be 10·25 GHz. The evaluated transient envelope is shown in Fig. 13.

The diode conductance as a function of a.c. voltage is calculated by using eqn. (7) of reference 2 with the following measured circuit constants:

$$n = 0{\cdot}0975 \qquad g_L = 0{\cdot}02\text{S}$$
$$Q_{ex} = 342{\cdot}0 \qquad Q_0 = 51{\cdot}25$$
$$f_0 = 10{\cdot}25\ \text{GHz} \qquad \omega_0 = 2\pi f_0$$

The diode conductance measured with this technique is shown by Fig. 11.

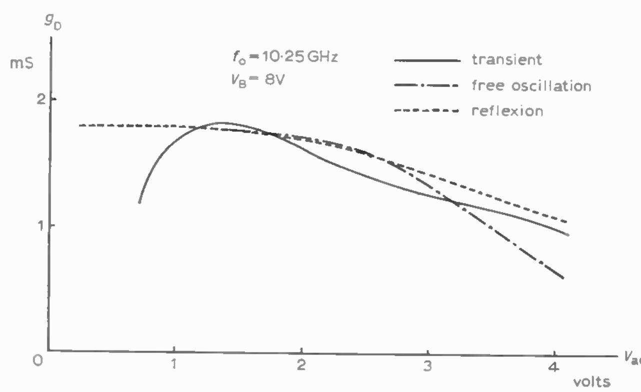

Fig. 11. The diode conductance as a function of a.c. voltage V_{ac} evaluated by the three different techniques.

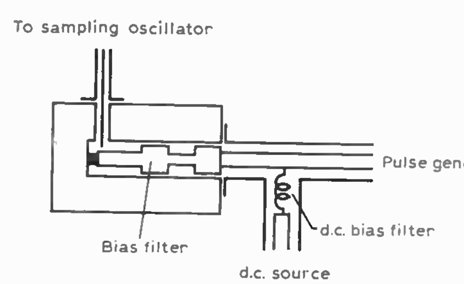

Fig. 12. The circuit for the transient method. A positive d.c. voltage and negative square pulse of equal amplitude are applied, in order to establish the same operating temperatures as for the c.w. method.

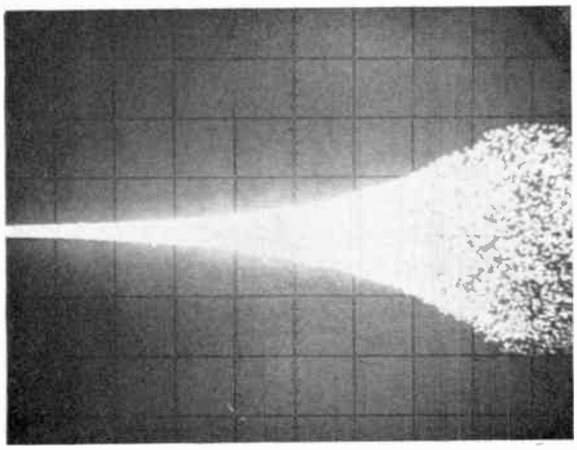

Fig. 13. A growing transient envelope of oscillation.
Horizontal scale: 2 ns/div
Vertical scale: 200 mV/dv.

6 Conclusion

By comparing the conductance results obtained by each of the three methods (see Fig. 11), it can be seen that basic agreement exists for the higher V_{ac} ranges. The difference in g_D decreases for high V_{ac} values for the reflexion and c.w. oscillation methods. Differences between reflexion and transient methods for small V_{ac} ranges might be caused by the effect of the load conductance presented to the diode on the space charge mode and thus on the negative—conductance behaviour. However, for low V_{ac} values this difference could also be caused by the high degree of inaccuracy there of the transient method. The conditions which have to be satisfied for the transient method do not make it as attractive as one might assume for quick production-line assessment of Gunn devices by routine evaluation of the conductance functions. The free-oscillation method is always applicable, and can be used relatively easily after a full assessment of the cavity-circuit impedance has been performed. The reflexion-type measurements are only possible with those types of diodes which can be stabilized by a high load conductance.

The measurement method has to be selected therefore in accordance with the type of devices available.

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9 Appendix: The numerical analysis of a Gunn-diode in a cavity

The cavity is assumed to be a one-dimensional distributed line with finite length. A purely resistive load Z_L is connected at one end of the line, and a Gunn-diode is connected at the other end.

The voltage and current distribution on the line have the following relations according to the transmission-line equations:

$$\left.\begin{aligned} \frac{\delta v(x,t)}{\delta x} &= -L_0\frac{\delta i(x,t)}{\delta t} \\ \frac{\delta i(x,t)}{\delta x} &= C_0\frac{\delta v(x,t)}{\delta t} \end{aligned}\right\} \tag{3}$$

where L_0 and C_0 are the inductance and the capacitance for the unit length of the line. The characteristic impedance of the line is given as $Z_0 = \sqrt{(L_0/C_0)}$.

The boundary conditions at both ends ($x = 0$ and $x = l$) of the line are given as follows.

$$\left.\begin{aligned} v(0,t) &= Z_l\,.\,i(0,t) \\ i(l,t) &= -i_D \\ v(l,t) &= V_B - V_{ac} \end{aligned}\right\} \tag{4}$$

V_B is the bias voltage of the diode and V_{ac} is its r.f. voltage.

The total current i_D through the diode is expressed as the sum of the drift current, the diffusion current and the displacement current, i.e.

$$\begin{aligned} i_D &= -A\left(qnv_e - qD\frac{\delta n}{\delta z} + \varepsilon_0\varepsilon\frac{\delta E}{\delta t}\right) \\ &= i_0 + C_D\frac{dV_{ac}}{dt} \end{aligned} \tag{5}$$

where A is the cross-sectional area of the diode $i_0 = -A\int en.v_e\,dz$, and the other symbols are the same as commonly employed.

The initial condition of eqn. (3) is given as follows when a step voltage is applied at $t = 0$:

$$\left.\begin{aligned} t < 0,\ v(l,t) &= i(l,t) = 0 \\ t = 0,\ v(l,t) &= V_B \end{aligned}\right\} \tag{6}$$

$v(x, t)$ and $i(x, t)$ of eqn. (3) are expressed by a linear combination of two functions that propagate on the line in opposite directions. At $x = 0$, their ratio is given by the reflexion at Z_l.

The equations for the diode are Poisson's and the current continuity equations. The electron drift velocity v_e as a function of electric field E is approximated by the following formula:

$$v_e = \frac{0{\cdot}8E + 8{\cdot}0\times10^4\times(E/4{\cdot}0\times10^5)^4}{1+(E/4{\cdot}0\times10^5)^4} \tag{7}$$

The boundary conditions at both ends of the model are:

$$\left.\begin{aligned} V_{ac} &= -\int_0^L E\,dz \\ \left.\frac{\partial E}{\partial z}\right|_{z=0} &= \left.\frac{\partial E}{\partial z}\right|_{z=L} = 0 \end{aligned}\right\} \quad (8)$$

where L is the interelectrode length of the diode.

The initial conditions are:

$$\left.\begin{aligned} V_{ac} &= 0 \\ n(z) &= n_0(z) \text{ for } z = 0 \text{ and } z = L \end{aligned}\right\} \quad (9)$$

The finite difference equation for Poisson's equation is

$$E_i = E_{i-1} + \frac{hq}{\varepsilon_0 \varepsilon}(n_i - n_{0i}) \quad (10)$$

where h is the spatial mesh interval.

The first boundary condition of eqn. (8) must be satisfied when eqn. (10) is solved. The following procedures are useful for this boundary condition:

If E_0 is temporarily fixed as zero, then every E_i is sequentially evaluated using eqn. (10). The voltage V'_{ac} is evaluated by the integration of E_i for the whole length of the model, i.e.

$$V'_{ac} = -\int_0^L E_i\,dz \quad (11)$$

As the actual diode voltage V_{ac} is known, it is necessary to correct the value of the electric field by the term

$$\Delta E = -\frac{V_{ac} - V'_{ac}}{L} \quad (12)$$

The finite difference formula for the current continuity equation is:

$$n_i = \frac{k}{2h}\left\{(n_i + n_{i-1})V_{e(i-1)} - (n_{i+1} + n_i)V_{e(i)} + \right. \\ \left. + \frac{kD}{h^2}(n_{i-1} - 2n_i + n_{i+1}) \right. \quad (13)$$

where k is the time interval of the calculation. h and k must be smaller then the Debye length and the dielectric relaxation time respectively in order to give a physical reality in the computation, as expressed by the following inequalities:

$$\left.\begin{aligned} h &< \sqrt{\frac{D\varepsilon_0\varepsilon}{qn\mu}} \\ k &< \frac{\varepsilon_0\varepsilon}{qn\mu} \end{aligned}\right\} \quad (14)$$

Additionally, the following relation must be satisfied for the convergence of the numerical calculation.

$$\left.\begin{aligned} v_e\frac{k}{h} &< 1 \\ D\frac{k}{h^2} &< \tfrac{1}{2} \end{aligned}\right\} \quad (15)$$

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Transitional Butterworth-Legendre filters

Professor B. D. RAKOVICH,
Dipl. Eng., Ph.D.*

SUMMARY

A new class of monotonic passband low-pass filters, referred to as transitional Butterworth-Legendre (TBL) filters, is introduced. The closed form expressions of the characteristic functions of these filters depending on one variable parameter q are derived by generalization of the results previously obtained for Legendre sharp cut-off monotonic filters. The parameter q, the values of which are restricted to non-negative integer values ($q \leqslant n$) controls the number of flatness conditions in the magnitude response at the origin and enables a trade-off between the passband loss and the stopband attenuation of the resulting filters. The Legendre, Halpern and Butterworth filters are shown to be special cases of TBL filters. Only all-pole filter functions are discussed although the results can easily be extended so as to include low-pass filters with finite real frequency transmission zeros.

* *Faculty of Electrical Engineering, University of Belgrade, Belgrade, Yugoslavia.*

1 Introduction

Monotonic passband low-pass filters with all transmission zeros at infinity and with finite real frequency zeros have received a renewed attention in recent years. Budak and Aronhime,[1] Dutta Roy[2] and Chang[3] have discussed the rational transfer functions of the maximally flat type with one or more pairs of imaginary axis zeros determined so that the Chebyshev stopband attenuation is obtained. Some other monotonic passband filters functions belonging to the same class as the well-known Legendre filters have been introduced. Examples of these are the class H or Halpern filters[4] having the maximum asymptotic cut-off rate and the least-squares monotonic low-pass filters[5,6] which have been derived by minimizing the passband loss in terms of a least squares norm.

The Legendre or class L filters, first derived by Papoulis[7,8] by use of Legendre polynomials provide the greatest slope of the magnitude response at the cut-off frequency. Their stopband attenuation is much higher than that for the Butterworth maximally flat type characteristic and is only slightly smaller than in the case of class H filters which yield the smallest transition bandwidth region among all filters whose magnitude passband response is bounded to be monotonic. On the other hand, the passband magnitude responses of the class L and particularly of the class H filters are inferior to that for the Butterworth filter. As shown by Jovanović and Rabrenović[9] both class L and class H filters show a rounded step magnitude passband response of the staircase pattern with $(n-1)/2$ and $(n-2)/2$ inflexion points with horizontal tangents.

The least-squares monotonic passband filters, referred to as the l.s.m. filters, are the best where minimum passband loss is of overriding importance. These filters have also better stopband magnitude performance than the Butterworth filter and if the transfer function is augmented by adding real frequency transmission zeros their magnitude characteristic can be made comparable even with Cauer elliptic filters.[6] Unfortunately, the l.s.m. filter functions have not been obtained in closed form. More recently[10] it has been shown that the class L and class H filters are, in fact, special cases of least-squares approximation technique.

In this paper a unified and more general approach is presented to determine the closed form expressions of the transfer functions of monotonic passband filters. A variable parameter q, restricted to non-negative integral values in the range $1 \leqslant q \leqslant n$, is introduced which determines the number of the flatness conditions at the origin. If $q = n$, where n is the order of the filter, the maximally flat solution is obtained, while for $q = 1$ the non-maximally flat magnitude response corresponding to either class L or class H filter results. Hence, assigning different values for the parameter q a trade-off between the passband magnitude distortion and the stopband performance of the filter is made possible. These filter functions, which will be referred to as transitional Butterworth–Legendre or TBL filters, are also shown to include as a special case the optimum monotonic passband response which is very similar to least-squares monotonic filters.

2 Monotonic Magnitude Characteristic

The magnitude squared characteristic of a filter with no finite transmission zeros can be written in the form

$$A_n^2 = \frac{1}{1+f_n(\omega^2)} \tag{1}$$

where in order to make the $\omega_{3\mathrm{dB}}$ bandwidth equal to unity, we normalize $f_n(\omega^2)$ so that $f_n(1) = 1$.

If $f_n(\omega^2) = \omega^{2n}$ is chosen, the first $n-1$ derivatives with respect to ω^2 at the origin are equal to zero and the Butterworth maximally flat magnitude response is obtained. Reducing the number of flatness conditions at the origin to $q-1$, where $q < n$, we can write

$$f_n(\omega^2) = \int_0^\omega x^{2q-1}\phi(x)\,\mathrm{d}x \tag{2}$$

where $\phi(x)$ is an even function in x which has no zero at the origin. In order that the magnitude response be monotonic in the passband all zeros of $\phi(x)$ in the interval $0 < x < 1$ must be of even multiplicity and assuming that $\phi(x)$ is a perfect square $\phi(x) = u_k^2(x^2)$ we have

$$f_n(\omega^2) = \int_0^\omega x^{2q-1}u_k^2(x^2)\,\mathrm{d}x \tag{3}$$

To determine the polynomial $u_k(x^2)$ whose degree k is such that $2k+q = n$ we expand it into a series of the shifted Jacobi polynomials $G_i(p, q, x)$

$$u_K(x^2) = \sum_{i=0}^{K} a_i G_i(p, q, x^2) \tag{4}$$

The shifted Jacobi polynomials $G_i(p, q, y)$ are orthogonal on the interval $0 \leqslant y \leqslant 1$ with respect to the weight function $w(y) = (1-y)^{p-q}y^{q-1}$ with $p-q > -1$, $q > 0$ so that

$$\int_0^1 (1-y)^{p-q}y^{q-1}G_m(p, q, y)G_n(p, q, y)\,\mathrm{d}y = 0 \qquad (m \neq n) \tag{5}$$

Let $p = q$ and $y = x^2$ in (5) and we have

$$\int_0^1 x^{2q-1}G_m(q, q, x^2)G_n(q, q, x^2)\,\mathrm{d}x = 0 \tag{6}$$

and from tables [11] for orthogonal polynomials

$$G_n(p, q, x) = \frac{(n+q-1)!}{(2n+p-1)!}\sum_{m=0}^{n}(-1)^m\binom{n}{m}\times \frac{(2n+p-1-m)!}{(n+q-1-m)!}\,x^{n-m} \tag{7}$$

From (3) and (4) and normalizing to $f_n(1) = 1$,

$$f_n(\omega^2) = \frac{\int_0^\omega x^{2q-1}\left(\sum_{i=0}^{K} a_iG_i(q, q, x^2)\right)^2 \mathrm{d}x}{\int_0^1 x^{2q-1}\left(\sum_{i=0}^{K} a_iG_i(q, q, x^2)\right)^2 \mathrm{d}x} \tag{8}$$

or, since,[11]

$$\int_0^1 x^{2q-1}G_i^2(q, q, x^2)\,\mathrm{d}x = \frac{1}{2}\,\frac{1}{(2i+q)\binom{2i+q-1}{i+q-1}^2} \tag{9}$$

$$f_n(\omega^2) = \frac{\int_0^\omega x^{2q-1}\left(\sum_{i=0}^{K} a_iG_i(q, q, x^2)\right)^2 \mathrm{d}x}{\frac{1}{2}\sum_{i=0}^{K}\frac{a_i^2}{(2i+q)\binom{2i+q-1}{i+q-1}^2}} \tag{10}$$

The constants a_i will be determined from the condition that the slope of the magnitude characteristic at the cut-off frequency $\omega_c = 1$ is maximum, and, hence,

$$\left.\frac{\mathrm{d}\,f_n(\omega^2)}{\mathrm{d}\,\omega}\right|_{\omega=1} = \frac{\left(\sum_{i=0}^{K} a_iG_i(q, q, 1)\right)^2}{\frac{1}{2}\sum_{i=0}^{K}\frac{a_i^2}{(2i+q)\binom{2i+q-1}{i+q-1}^2}} \tag{11}$$

where the right-side must be a maximum. Since $G_i(q, q, 1) > 0$ the constants a_i are all positive and in order to find their values we use the following theorem recently derived by Mitrinović and Vasić:[12]

Theorem 1. If $\alpha_0, \alpha_1 \ldots \alpha_n > 0$, $\beta_0, \beta_1 \ldots, \beta_n > 0$ and $a_0, a_1 \ldots\ldots a_n > 0$ then for $r > s > 0$ the following inequality holds

$$\frac{\left(\sum_{i=0}^{n} a_i^r\alpha_i\right)^{1/r}}{\left(\sum_{i=0}^{n} a_i^s\beta_i\right)^{1/s}} \geqslant \left(\frac{\alpha_0^{s/(s-r)}}{\beta_0^{r/(s-r)}} + \ldots + \frac{\alpha_n^{s/(s-r)}}{\beta_n^{r/(s-r)}}\right)^{(s-r)/rs} \tag{12}$$

with the equality sign if and only if,

$$a_0\left(\frac{\alpha_0}{\beta_0}\right)^{1/(r-s)} = \ldots = a_i\left(\frac{\alpha_i}{\beta_i}\right)^{1/(r-s)} = \ldots = a_n\left(\frac{\alpha_n}{\beta_n}\right)^{1/(r-s)} \tag{13}$$

For $r = 2$, $s = 1$ (12) and (13) become

$$\frac{\left(\sum_{i=0}^{n} a_i\beta_i\right)^2}{\sum_{i=0}^{n} a_i^2\alpha_i} \leqslant \sum_{i=0}^{n}\frac{\beta_i^2}{\alpha_i} \tag{14}$$

$$a_i\left(\frac{\alpha_i}{\beta_i}\right) = C \qquad i = 0, 1, 2 \ldots n \tag{15}$$

where C is a constant.

Substituting

$$\alpha_i = \frac{1}{2(2i+q)\binom{2i+q-1}{i+q-1}^2}; \qquad \beta_i = G_i(q, q, 1) \tag{16}$$

in (14) and (15) we find

$$\frac{\left(\sum_{i=0}^{K} a_iG_i(q, q, 1)\right)^2}{\frac{1}{2}\sum_{i=0}^{K}\frac{a_i^2}{(2i+q)\binom{2i+q-1}{i+q-1}^2}} \leqslant 2\sum_{i=0}^{K}(2i+q)\binom{2i+q-1}{i+q-1}^2 G_i^2(q, q, 1) \tag{17}$$

$$a_i = C\frac{\beta_i}{\alpha_i} = 2C(2i+q)\binom{2i+q-1}{i+q-1}^2 G_i(q, q, 1) \qquad (18)$$

But[11]

$$G_i(q, q, 1) = \frac{1}{\binom{2i+q-1}{i+q-1}} \qquad (19)$$

and from (17) and (19) we have

$$\max \frac{\left(\sum_{i=0}^{K} a_i G_i(q, q, 1)\right)^2}{\frac{1}{2}\sum_{i=0}^{K} \frac{a_i^2}{(2i+q)\binom{2i+q-1}{i+q-1}^2}} = 2\sum_{i=0}^{K}(2i+q) = 2(K+1)(K+q) \qquad (20)$$

which is the maximum slope of the characteristic function at the cut-off frequency $\omega_c = 1$.

Substituting (18) in (10) and taking into account (19) we obtain

$$f_n(\omega^2) = \frac{2}{(K+1)(K+q)}\int_0^{\omega} x^{2q-1} \times \left(\sum_{i=0}^{K} \frac{(2i+q)!}{i!(i+q-1)!} G_i(q, q, x^2)\right)^2 \mathrm{d}x \qquad (21)$$

Most recently, however, the following relationship for Jacobi polynomials has been proved[13]

$$\sum_{i=0}^{K} \frac{(2i+q)!}{i!(i+q-1)!} G_i(q, q, x) = \frac{(2K+q)!}{K!(K+q-1)!} G_K(q+1, q, x) \qquad (22)$$

so that from (22) and (21) we have finally

$$f_n(\omega^2) = 2\binom{2K+q}{K+q}\binom{2K+q}{K+q-1} \times \int_0^{\omega} x^{2q-1} G_K^2(q+1, q, x^2)\,\mathrm{d}x \qquad (23)$$

where, as before, $n = 2K+q$. Equation (23) represents the most general expression for monotonic passband filters having maximum attenuation slope at the cut-off frequency. Of course, eqn. (23) includes the Legendre filter as a special case for $q = 1$ or $q = 2$ depending on whether n is odd or even.

If, instead of the slope at the cut-off frequency $\omega_c = 1$, the asymptotic growth of $f_n(\omega^2)$ is optimized the general solution is obtained by substituting $a_0 = a_1 = \ldots a_{k-1} = 0$ and $a_k = 1$ in (10),

$$f_n(\omega^2) = 2(2K+q)\binom{2K+q-1}{K+q-1}^2 \times \int_0^{\omega} x^{2q-1} G_K^2(q, q, x^2)\,\mathrm{d}x \qquad (24)$$

Again the Halpern class H filters are obtained from (24) for $q = 1$ and $q = 2$ for n odd and n even respectively.

From (19) and (24) the slope of the characteristic function at the cut-off frequency $\omega_c = 1$ can easily be found

$$\left.\frac{\mathrm{d} f_n(\omega^2)}{\mathrm{d}\,\omega}\right|_{\omega=1} = 2(2K+q) = 2n \qquad (25)$$

As can be seen the attenuation slope at the bandedge is independent of q and is equal to that for the Butterworth filter.

Another important case is obtained by substituting

$$a_i = \sqrt{2i+q}\binom{2i+q-1}{i+q-1} \qquad (26)$$

in (10), so that, we have

$$f_n(\omega^2) = \frac{2}{K+1}\int_0^{\omega} x^{2q-1} \times \left(\sum_{i=0}^{K} \sqrt{2i+q}\binom{2i+q-1}{i+q-1} G_i(q, q, x^2)\right)^2 \mathrm{d}x \qquad (27)$$

For $q = 1$, and having in mind that[11]

$$P_n(x) = \binom{2n}{n} G_n\left(1, 1, \frac{1+x}{2}\right) \qquad (28)$$

where $P_n(x)$ is the Legendre polynomial, eqn. (25) becomes

$$f_n(\omega^2) = \frac{1}{n+1}\int_{-1}^{2\omega^2-1} \left(\sum_{i=0}^{(n-1)/2} [\sqrt{2i+1}] P_i(x)\right)^2 \mathrm{d}x \quad (n \text{ odd}) \qquad (29)$$

The explicit expression for the Legendre polynomial is

$$P_n(x) = \frac{1}{2^n}\sum_{m=0}^{n} (-1)^m \binom{n}{m}\binom{2n-2m}{n} x^{n-2m} \qquad (30)$$

3 Discussion of Results

From the foregoing analysis it follows that eqn. (23) represents the most general expression for the characteristic function of all-pole filters with optimum slope of the magnitude response at the cut-off frequency. For all n this slope is maximum for minimum value of q, i.e., $q = 1$ and $q = 2$ for n odd and even respectively, in which case the well-known Legendre filters are recovered. Since all zeros of the orthogonal polynomials are simple, real and located in the orthogonality interval corresponding to the passband of the filter, in this case the magnitude response has $k = (n-1)/2$ or $k = (n/2)-1$ inflexion points with horizontal tangents depending on whether n is odd or even. For example, if $n = 9$, $q = 1$, there are four inflexion points in the passband as can be seen in Fig. 1. For $q = 3$ one flatness condition at the origin substitutes for one inflexion point; for $q = 5$ two inflexion points are replaced by two flatness conditions at the origin and so on. Finally, if $q = n$ and $k = 0$ in (23) the Butterworth maximally flat magnitude response is obtained. Hence, increasing q decreases the passband loss at lower frequencies at the expense of the stopband attenuation and a trade-off between the passband distortion and the stopband performance of the filter is obtained. For convenience in Table 1 the pole locations of the transfer functions derived from eqn. (23) for $n = 3$–10 are tabulated.

The same holds good if instead of (23), eqn. (24) is used to define the characteristic function of the filter as

Table 1. Transfer functions derived from equation (23)

n	q	$\sigma_1 \pm j\omega_1$	$\sigma_2 \pm j\omega_2$	$\sigma_3 \pm j\omega_3$	$\sigma_3 \pm j\omega_4$	$\sigma_5 \pm j\omega_5$
3	1	-0.3451856 ±j0.9008656	-0.6203318 ±j0.0			
3	3	-0.5 ±j0.8660254	-1.0 ±j0.0			
4	2	-0.2316887 ±j0.9455106	-0.5497434 ±j0.3585718			
4	4	-0.3826834 ±j0.9238795	-0.9238795 ±j0.3826834			
5	1	-0.1535867 ±j0.9681464	-0.3881398 ±j0.5886323	-0.4680898 ±j0.0		
5	3	-0.1746414 ±j0.9636588	-0.4754142 ±j0.5343752	-0.6444795 ±j0.0		
5	5	-0.3090169 ±j0.9510565	-0.8090169 ±j0.5877852	-1.0 ±j0.0		
6	2	-0.1151926 ±j0.9779222	-0.3089608 ±j0.6981674	-0.4389015 ±j0.2399813		
6	4	-0.1401930 ±j0.9731563	-0.4133846 ±j0.6377991	-0.6425126 ±j0.2225816		
6	6	-0.2588190 ±j0.9659258	-0.7071067 ±j0.7071067	-0.9659258 ±j0.2588190		
7	1	-0.0862085 ±j0.9843698	-0.2374397 ±j0.7783008	-0.3492317 ±j0.4289961	-0.3821033 ±j0.0	
7	3	-0.0922308 ±j0.9832442	-0.2576674 ±j0.7618325	-0.4070740 ±j0.3849931	-0.4928206 ±j0.0	
7	5	-0.1171125 ±j0.9788911	-0.3637705 ±j0.7052035	-0.6102706 ±j0.3730511	-0.6969923 ±j0.0	
7	7	-0.2225209 ±j0.9749279	-0.6234898 ±j0.7818314	-0.9009688 ±j0.4338837	-1.0 ±j0.0	
8	2	-0.0689421 ±j0.9879709	-0.1942758 ±j0.8247667	-0.3002840 ±j0.5410422	-0.3671763 ±j0.1808791	
8	4	-0.0769263 ±j0.9865539	-0.2212024 ±j0.8034638	-0.3747938 ±j0.4838512	-0.5047133 ±j0.1602205	
8	6	-0.1005637 ±j0.9826889	-0.3239797 ±j0.7522729	-0.5704073 ±j0.4798203	-0.7013671 ±j0.1663710	
8	8	-0.1950903 ±j0.9807852	-0.5555702 ±j0.8314696	-0.8314696 ±j0.5555702	-0.9807852 ±j0.1950903	
9	1	-0.0550969 ±j0.9906602	-0.1572837 ±j0.8613429	-0.2485529 ±j0.6338196	-0.3093854 ±j0.3365432	-0.3256878 ±j0.0
9	3	-0.0574594 ±j0.9902502	-0.1647940 ±j0.8551293	-0.2647227 ±j0.6154404	-0.3522376 ±j0.3016066	-0.4048879 ±j0.0
9	5	-0.0659881 ±j0.9887974	-0.1938436 ±j0.8327955	-0.3450493 ±j0.5558002	-0.4962073 ±j0.2783002	-0.5484945 ±j0.0
9	7	-0.0881155 ±j0.9853713	-0.2916424 ±j0.7868347	-0.5307209 ±j0.5585444	-0.6836818 ±j0.2930790	-0.7362438 ±j0.0
9	9	-0.1736481 ±j0.9848077	-0.5 ±j0.8660254	-0.7660444 ±j0.6427876	-0.9396926 ±j0.3420201	-1.0 ±j0.0
10	2	-0.0459000 ±j0.9923824	-0.1325185 ±j0.8852624	-0.2141730 ±j0.6945376	-0.2774054 ±j0.4396461	-0.3172064 ±j0.1454302
10	4	-0.0492644 ±j0.9918155	-0.1432287 ±j0.8765332	-0.2369371 ±j0.6688095	-0.3345799 ±j0.3902159	-0.4201676 ±j0.1264191
10	6	-0.0577780 ±j0.9904124	-0.1725303 ±j0.8545625	-0.3185733 ±j0.6104938	-0.4789969 ±j0.3691116	-0.5622695 ±j0.1248780
10	8	-0.0784110 ±j0.9873580	-0.2549648 ±j0.8132009	-0.4938282 ±j0.6184557	-0.6566981 ±j0.3913825	-0.7412654 ±j0.1341538
10	10	-0.1564344 ±j0.9876883	-0.4539904 ±j0.8910065	-0.7071067 ±j0.7071067	-0.8910065 ±j0.4539905	-0.9876883 ±j0.1564344

illustrated by Fig. 2 in which the magnitude responses for $n = 10$ and different values of the parameter q are presented. Again, for $q = n$ the Butterworth filter is obtained. On the other side, if q has minimum value ($q = 2$ for n even) the Halpern magnitude function with four inflexion points in the passband is recovered. For $q = 8, 6, 4$, the transitional magnitude responses having one, two and three inflexion points respectively are obtained. The poles of the corresponding transfer functions for $n = 3$–10 are given in Table 2 except for $q = n$ in which case the Butterworth filter functions are obtained.

Table 3 contains the pole locations which were computed from the characteristic function (27), while in Fig. 3 the magnitude response of this filter for $n = 7$, $q = 1$, is compared with the corresponding Butterworth and Halpern filters. Finally, in order to complete the comparison the element values for an equally terminated lossless-coupling ladder realization of these filters are given in Table 4. It can be seen from an inspection of (23), (24) and (27) that the realization of the TBL filters is neither symmetrical nor antimetrical except for the Butterworth case $q = n$. Also, for $q = 1$ the reflexion coefficient has only one $j\omega$ axis zero meaning

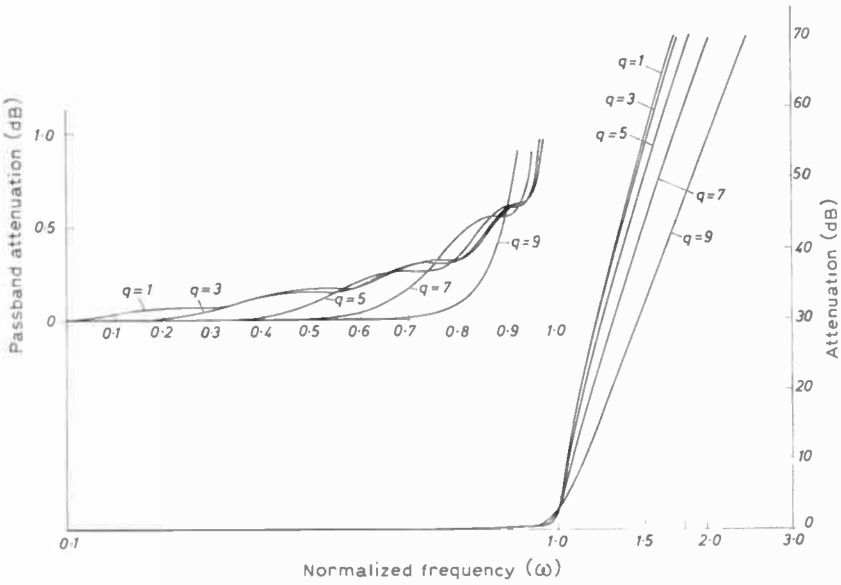


Fig. 1. Magnitude responses of TBL filters for $n = 9$ obtained from eqn. (23)

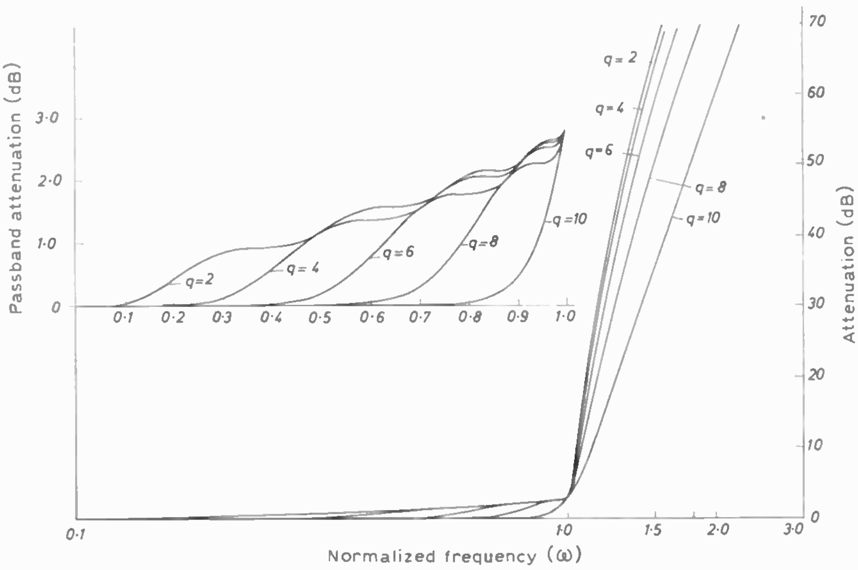


Fig. 2. Magnitude responses of TBL filters for $n = 10$ obtained from eqn. (24)

Fig. 3. Magnitude response of TBL filter for $n = 7$ obtained from eqn. (29) compared with the seventh-order Butterworth (B) and Halpern (H) filters.

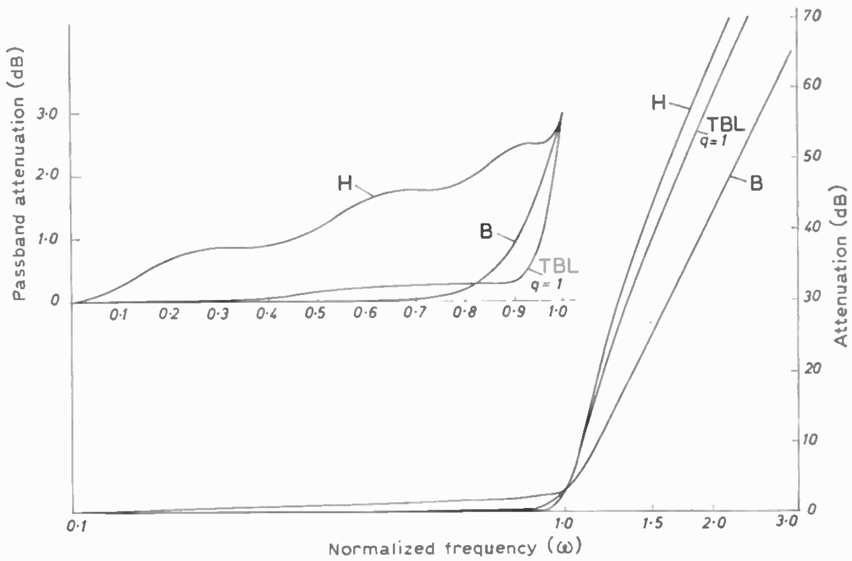


Table 2. Transfer functions derived from equation (24)

n	q	$\sigma_1 \pm j\omega_1$	$\sigma_2 \pm j\omega_2$	$\sigma_3 \pm j\omega_3$	$\sigma_4 \pm j\omega_4$	$\sigma_5 \pm j\omega_5$
3	1	-0.3183759 ±j0.9807780	-0.4702390 ±j0.0			
4	2	-0.2069521 ±j1.0086690	-0.4472631 ±j0.3381555			
5	1	-0.1342938 ±j1.0193778	-0.3142166 ±j0.6176714	-0.3282751 ±j0.0		
5	3	-0.1531901 ±j1.0141954	-0.3947570 ±j0.5052403	-0.5780310 ±j0.0		
6	2	-0.0996370 ±j1.0196751	-0.2498758 ±j0.7287007	-0.3308413 ±j0.2260071		
6	4	-0.1215555 ±j1.0149901	-0.3471720 ±j0.6062534	-0.5893136 ±j0.2117702		
7	1	-0.0741657 ±j1.0188072	-0.1929154 ±j0.8112946	-0.2626181 ±j0.4457142	-0.2574614 ±j0.0	
7	3	-0.0792508 ±j1.0182660	-0.2077517 ±j0.7899384	-0.3140732 ±j0.3609751	-0.4184079 ±j0.0	
7	5	-0.1007312 ±j1.0144955	-0.3078725 ±j0.6737161	-0.5660401 ±j0.3569606	-0.6526249 ±j0.0	
8	2	-0.0591536 ±j1.0171048	-0.1580599 ±j0.8554935	-0.2269514 ±j0.5603180	-0.2652055 ±j0.1708181	
8	4	-0.0658069 ±j1.0166555	-0.1778184 ±j0.8288211	-0.2927798 ±j0.4549581	-0.4423395 ±j0.1498916	
8	6	-0.0859895 ±j1.0136468	-0.2757693 ±j0.7218198	-0.5329055 ±j0.4612212	-0.6631986 ±j0.1600832	
9	1	-0.0472895 ±j1.0154607	-0.1286180 ±j0.8900369	-0.1896105 ±j0.6577382	-0.2222906 ±j0.3479756	-0.2139642 ±j0.0
9	3	-0.0492279 ±j1.0154526	-0.1341141 ±j0.8830871	-0.2002232 ±j0.6341878	-0.2607382 ±j0.2822454	-0.3316177 ±j0.0
9	5	-0.0562696 ±j1.0151699	-0.1554266 ±j0.8556791	-0.2717866 ±j0.5247259	-0.4417702 ±j0.2620469	-0.4958022 ±j0.0
9	7	-0.0750073 ±j1.0127410	-0.2493517 ±j0.7577745	-0.4984342 ±j0.5388938	-0.6504964 ±j0.2830620	-0.7023358 ±j0.0
10	2	-0.0394259 ±j1.0139388	-0.1087135 ±j0.9114163	-0.1640957 ±j0.7184539	-0.2006311 ±j0.4532195	-0.2227347 ±j0.1377084
10	4	-0.0421679 ±j1.0140065	-0.1165566 ±j0.9019373	-0.1791109 ±j0.6864015	-0.2508278 ±j0.3655000	-0.3571957 ±j0.1171817
10	6	-0.0491503 ±j1.0138690	-0.1380410 ±j0.8753238	-0.2524800 ±j0.5786789	-0.4307089 ±j0.3494199	-0.5157351 ±j0.1184030
10	8	-0.0665102 ±j1.0118777	-0.2273545 ±j0.7856247	-0.4656658 ±j0.5985436	-0.6276158 ±j0.3791632	-0.7109928 ±j0.1300116

that several reflexion coefficient zeros choices are possible and, hence, the element values are not unique. The element values given in Table 4 were computed by selecting reflexion coefficient zero locations in the left-half plane of the complex frequency. As is well known from the so-called gain-bandwidth theorem of Bode this choice leads to the largest input capacitance for a given bandwidth and impedance level.

From the point of view of the stopband magnitude performance the filter derived from (27) is much superior to Butterworth filter and is only slightly inferior to the Halpern filter. Its passband loss, however, is much smaller than that of the Halpern filter and is less than 0·3 dB up to the normalized frequency 0·92. This result is comparable even with the l.s.m. filter which is known to yield the minimum passband loss[5]. The general expression for the attenuation slope of this class of filters (valid for both n even and n odd and different values of q) as obtained from (27) and (19) is

$$\left.\frac{\mathrm{d}\, f_n(\omega^2)}{\mathrm{d}\,\omega}\right|_{\omega=1} = \frac{2}{K+1}\left(\sum_{i=0}^{K}\sqrt{2i+q}\right)^2 \tag{31}$$

Since

$$\frac{2}{K+1}\left(\sum_{i=o}^{K}\sqrt{2i+q}\right)^2 > \frac{2}{K+1}\left(\sum_{i=o}^{K}(2i+q)\right) = 4(K+q) \tag{32}$$

an interesting conclusion can be drawn from (20), (25) and (31). Namely, among all monotonic passband magnitude filters under consideration, Butterworth and Halpern filters have the least attenuation slope at the bandedge. Yet, Halpern filters provide more stopband attenuation than any other monotonic passband magnitude filters.

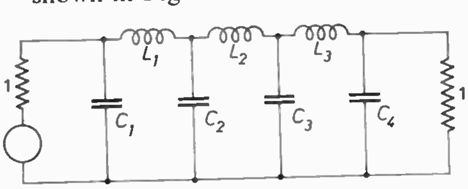
In many applications all-pole filters discussed previously are not suitable since their magnitude response do not provide enough stopband attenuation unless the order of the filter is rather high. The stopband performance of the filter can be greatly improved by adding one pair or more pairs of real frequency transmission zeros so that the magnitude squared function takes the following form

$$A_n^2(\omega^2) = \frac{(\omega^2-\omega_1^2)^2(\omega^2-\omega_2^2)^2\ldots(\omega^2-\omega_m^2)^2}{(\omega^2-\omega_1^2)^2(\omega^2-\omega_2^2)^2\ldots(\omega^2-\omega_m^2)^2+\alpha_m f_n(\omega^2)} \tag{33}$$

Table 3. Transfer functions derived from equation (27)

n	q	$\sigma_1 \pm j\omega_1$	$\sigma_2 \pm j\omega_2$	$\sigma_3 \pm j\omega_3$	$\sigma_4 \pm j\omega_4$	$\sigma_5 \pm j\omega_5$
3	1	-0.3949695 ±j0.8755897	-0.7663799 ±j0.0			
4	2	-0.2519625 ±j0.9340296	-0.6074537 ±j0.3670054			
5	1	-0.1801306 ±j0.9606708	-0.4533684 ±j0.6139384	-0.5187819 ±j0.0		
5	3	-0.1857232 ±j0.9573207	-0.5064890 ±j0.5442525	-0.6726234 ±j0.0		
6	2	-0.1291127 ±j0.9721542	-0.3466977 ±j0.7096611	-0.4766899 ±j0.2479136		
6	4	-0.1471915 ±j0.9691687	-0.4327083 ±j0.6464039	-0.6597834 ±j0.2261212		
7	1	-0.1017928 ±j0.9811868	-0.2742844 ±j0.7969752	-0.3832255 ±j0.4291985	-0.4369373 ±j0.0	
7	3	-0.1007694 ±j0.9792143	-0.2820964 ±j0.7684843	-0.4340485 ±j0.3939747	-0.5174850 ±j0.0	
7	5	-0.1219364 ±j0.9761589	-0.3768786 ±j0.7123180	-0.6218439 ±j0.3773656	-0.7088095 ±j0.0	
8	2	-0.0784547 ±j0.9847344	-0.2188202 ±j0.8346764	-0.3263049 ±j0.5454866	-0.4010496 ±j0.1838765	
8	4	-0.0826956 ±j0.9836465	-0.2383012 ±j0.8078675	-0.3947042 ±j0.4923382	-0.5224133 ±j0.1634798	
8	6	-0.1040910 ±j0.9807025	-0.3334192 ±j0.7581262	-0.5786040 ±j0.4840248	-0.7099245 ±j0.1678266	
9	1	-0.0652284 ±j0.9889746	-0.1808884 ±j0.8745314	-0.2725249 ±j0.6346897	-0.3477335 ±j0.3425254	-0.3587215 ±j0.0
9	3	-0.0638199 ±j0.9876471	-0.1821797 ±j0.8610023	-0.2850948 ±j0.6200116	-0.3770061 ±j0.3072741	-0.4273405 ±j0.0
9	5	-0.0701470 ±j0.9866171	-0.2064842 ±j0.8359563	-0.3602497 ±j0.5634042	-0.5094815 ±j0.2826714	-0.5617139 ±j0.0
9	7	-0.0908074 ±j0.9838631	-0.2987453 ±j0.7916875	-0.5367704 ±j0.5623777	-0.6900870 ±j0.2950820	-0.7428395 ±j0.0
10	2	-0.0527086 ±j0.9903721	-0.1495598 ±j0.8931534	-0.2326540 ±j0.6975284	-0.3045000 ±j0.4433759	-0.3444313 ±j0.1483810
10	4	-0.0538075 ±j0.9897631	-0.1561421 ±j0.8803298	-0.2531450 ±j0.6728510	-0.3538455 ±j0.3866313	-0.4370044 ±j0.1290403
10	6	-0.0609189 ±j0.9887222	-0.1822577 ±j0.8569556	-0.3305148 ±j0.6171898	-0.4892569 ±j0.3737162	-0.5725562 ±j0.1264309
10	8	-0.0805330 ±j0.9861743	-0.2704927 ±j0.8172688	-0.4984408 ±j0.6218690	-0.6616179 ±j0.3935296	-0.7464480 ±j0.1348868

Table 4. Element values for filters whose magnitude responses are shown in Fig. 3



Type	C_1	L_1	C_2	L_2	C_3	L_3	C_4
BUTTERWORTH $n = q; n = 7$	0·44504	1·24697	1·80193	1·99999	1·80193	1·24697	0·44504
HALPERN $n = 7; q = 1$ (eqn. 24)	3·56144	1·12277	2·54875	1·42875	2·11397	1·34631	0·96518
$n = 7; q = 1$ (eqn. 29)	1·55381	1·73383	1·96605	1·85618	1·87390	1·42423	0·76221

where $\omega_1, \omega_2 \ldots \omega_m$ $(2m < n)$ are the transmission zeros, $f_n(\omega^2)$ is the characteristic function given by (23), (24) or (27), and $\alpha_m = (\omega_1^2-1)^2(\omega_2^2-1)^2 \ldots (\omega_m^2-1)^2$ in order that the ω_{3dB} bandwidth is equal to unity. For any prescribed minimum stopband attenuation the zero locations can be determined so that the Chebyshev stopband attenuation is obtained. A simple computer program which can be preferably used for this purpose is described elsewhere[10] and need not be repeated here.

4 Conclusion

In this paper general expressions for monotonic passband low-pass filters have been derived in closed form. The results previously obtained by Papoulis and Halpern have first been generalized by introducing a new variable parameter, restricted to nonnegative integer values, which entails a tradeoff between the number of flatness conditions at the origin and the number of inflexion points in the passband magnitude response. Then the conditions for optimizing the attenuation slope at the cut-off frequency have been obtained simultaneously for both n even and n odd and for different values of the variable parameter q. These filters, which can be referred to as transitional Butterworth-Legendre filters, include as special cases the Butterworth, Legendre, and Halpern monotonic magnitude filters. Also, the close form expression for the characteristic functions of a special type of monotonic magnitude functions is presented which give small passband loss and have similar magnitude response to that for the least-squares-monotonic filters. The pole locations of the new filter functions are tabulated for n = 3–10.

5 Acknowledgments

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He also wishes to express his thanks to his friend and colleague Professor P. Vasić for bringing Theorem 1 to his attention.

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Contributors to this issue

Mr. L. G. Cuthbert graduated in 1969 from Queen Mary College, University of London, with a B.Sc.(Eng.) degree in electrical engineering. He then worked on digital systems as a research engineer at Standard Telecommunication Laboratories, Harlow, from 1969 to 1970, when he returned to Queen Mary College as a research student supported by S.T.L. as well as by the Science Research Council. In October 1972 he was appointed to a lectureship in the Electrical Engineering Department at the College and he is currently working for a Ph.D. on the design of digital filters.

Dr. Daniel Baert received his engineer's degree from the University of Ghent in 1963, and after completing his studies became an assistant in the Laboratory of Electronics and Metrology at the University. For the next two years he was mainly involved in lecturing and in electronic circuit design. In 1965 he went into the army for a year and worked on the determination of the speed of projectiles.

After his military service he returned to the University and was appointed a research assistant and later a lecturer in industrial electricity. He was mainly concerned with such industrial problems as the reduction of radio frequency interference of dielectric furnaces, and the measurement of magnetic properties of materials. As a result of this work he became interested in the problem of r.f.i. of thyristor controlled systems and in October 1973 obtained his doctor's degree with a study on the r.f.i. suppression of linear and non-linear filters on which the paper in this issue is based.

Dr. Baert has a number of papers to his credit in both national and international publications, including a joint paper in this *Journal* on baluns in 1968

Dr. K. Tomizawa received his undergraduate and postgraduate training at the University of Meiji, Tokyo, where he obtained a B.Sc. degree in 1967, an M.Sc. in 1969, and a Ph.D. in 1972 for work on transferred electron effect. Since October 1972 he has been in the United Kingdom as a Research Associate at the University of Newcastle upon Tyne.

Dr. Peter B. Johns studied at Regent Street Polytechnic (now Polytechnic of Central London) and Battersea College of Technology (now University of Surrey) from 1961 to 1966, obtaining external London University degrees in electrical engineering and physics. From 1964 to 1967 he was an Executive Engineer with the British Post Office and worked on modulation methods associated with satellite communications. In 1967 he was appointed lecturer in the Department of Electrical and Electronic Engineering at the University of Nottingham and he was recently granted his Doctorate by the University. Dr. Johns is co-author of a book on communication systems analysis.

Professor H. L. Hartnagel (Fellow 1972) who graduated Dipl. Ing. in electronics from the Technical University of Aachen, Germany, in 1959 worked for Telefunken for a short period and then joined the Institut National des Sciences Appliquées, Lyons, France. In 1961 he took up an appointment as a research fellow in the Department of Electronic and Electrical Engineering at the University of Sheffield, subsequently becoming a lecturer, in 1968 a senior lecturer, and a reader in 1970. He received his Ph.D. from the University of Sheffield in 1964 for a thesis on electron beam behaviour and the D.Eng. degree in 1971. Two years ago Professor Hartnagel was appointed to the new chair in electronic engineering at the University of Newcastle upon Tyne. He is author of a book 'Semiconductor Plasma Instabilities' and of numerous papers for one of which, on Gunn diode ultra-fast logic, he received the Institution's Charles Babbage Award.

Professor Branko D. Rakovich is Head of the Department of Electronics in the Faculty of Electrical Engineering, University of Belgrade. He has contributed several papers to the *Journal* and a biography was published in October 1974.

IERE News and Commentary

IERE Representative on UWIST Court

The Council has appointed Professor William Gosling (Fellow) as the representative of the Institution on the Court of the University of Wales Institute of Science and Technology, Cardiff, in succession to Professor Emrys Williams who died last February. Professor Gosling, who is at the University of Bath and is a Vice President of the Institution, will serve for a term of three years from 1st August 1974.

IEE—IERE Proceedings—India

The principal contents of recent issues include the following:

Volume 12, No. 3, May-June 1974

'Dielectric coated metal spherical antennas excited in the symmetric TM mode at microwave frequencies'.
Professor Mrs. R. Chatterjee, T. S. Vedavathy, Parveen Wahid and B. K. Nagesh.

'Some aspects of the origin and instrumentation of bio-electric phenomena'.
J. K. Choudhury.

'The use of junction diodes, photo-resistors and thyrite as a.g.c. losser elements in an analogue seismic amplifier'.
S. L. Sah.

Volume 12, No. 4, July-August 1974

'Parasitic bulk resistances of junction field effect transistors'.
T. Siva Ram and Professor B. Ramachandra Rao.

'Biquadratic pulse transmission networks'.
R. Hariharan and S. N. Rao.

Volume 12, No. 5, September-October 1974

'Technology transfer for large systems'.
R. P. Shenoy.

'The effect of dislocations on the capacitance vs. bias voltage characteristic of m.o.s. capacitors'.
Dr. S. M. Goklaney and Dr. W. A. Porter.

Among the news items in this issue is a report that Indian television set manufacturers hope to export 30 000 sets this year, the major markets being Arab countries and, surprisingly, Japan. A brief note is also given of the testing of the first Indian scientific satellite which is due to be launched into a near Earth orbit from a Russian rocket at the end of this year.

Malaysian Government Recognition of IERE

The Permanent Committee for the Evaluation and Recognition of Foreign Qualifications in the Public Services Department of the Malaysian Government has decided to recognize Graduate Membership of the IERE for the purpose of enabling the holder to be accepted as an Engineer in the Managerial and Professional Group in the Public Service. It is a condition that Graduate Membership of the Institution was obtained after having sat and passed the examinations required by the Council of Engineering Institutions, (CEI Part 2 examination or CEI Part 2 Academic Test).

Learned Journals and the Far East

A Far East Trade Mission organized by the Association of Learned and Professional Society Publishers with the support of the Ministry of Trade visited Japan, Hong Kong, Malaysia and Singapore during May-June 1974. A Report on trading conditions and prospects for technical publications in these countries has been prepared and represents a unique collection of marketing information. In particular it analyses the nature of the market in each of the four countries and draws attention to the special needs of universities and their libraries, general libraries, government libraries and industrial libraries. Names of book importers and periodical wholesalers are also given. The Report has now been made available for sale to non-members of ALPSP at a price of £20 per copy. Orders with remittances should be sent to Mr. R. J. Millson, C.Eng., Hon. Sec. ALPSP, c/o The Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1H 9JJ.

1974 Nobel Prize for Physics

For the first time astronomers have been awarded the Nobel Prize for physics and, a point of particular interest to radio engineers, those so honoured are British radio astronomers who have played a leading part in establishing the high standing of this branch of science in this country. The prize is awarded jointly to Professor Sir Martin Ryle, F.R.S., Head of the Mullard Radio Astronomy Observatory, Cambridge University and Astronomer Royal and Professor Antony Hewish, F.R.S., who is also in the Department of Physics at Cambridge.

Work on radio astronomy at the Cavendish Laboratory was initiated by Professor Ryle in 1946 and he has been especially concerned with the development of radio telescopes of ever greater resolution. These operate on the principle of the interferometer which by aperture synthesis provides results having detail as fine as that of an optical astronomical photograph. It is this continuing programme of work that has gained the award for Professor Ryle.

Professor Hewish has been concerned with rather different techniques using multi-element arrays which enable the scintillation of radio objects to be observed—aperture synthesis obtains its results over a lengthy period since it depends on the Earth's rotation. As a result of these investigations, Professor Hewish and his fellow workers discovered and made highly significant observations of pulsars, the so-called neutron stars which emit regularly spaced pulses, and whose periodic time is more reliable than any man-made clock.

Both Professor Ryle and Professor Hewish have given lectures to the IERE on various aspects of radio astronomy on several occasions during the past 15 years.

Radio Astronomer to be Director of the Royal Greenwich Observatory

The Science Research Council has announced that Professor F. Graham Smith, F.R.S., Professor of Radio Astronomy at the University of Manchester, is to be appointed Director of the Royal Greenwich Observatory, Herstmonceux Castle, Sussex. He will succeed Dr. A. Hunter who retires at the end of 1975 after 38 years at RGO. In the meantime Professor Smith will take up appointment at RGO at Deputy Director level.

CEI News

FEANI Meets in Barcelona

The 6th International Congress of Engineers (FEANI) was held in Barcelona from 6th to 12th October. Having the theme of Creativity and Innovation, the Congress was attended by some 250 persons from twenty countries, 61 papers being presented of which eight were by UK authors.

Coincident with the Congress was the triennial General Assembly of FEANI. The business meetings, that is, meetings of the Bureau (Committee of Officers), Direction Committee, Formation Committee (Education and Training), and General Assembly itself were all attended by representatives of the British National Committee for FEANI.

The newly-elected President is Professor C. Piguet of Switzerland. Mr. M. W. Leonard, Secretary of CEI—who has just completed a term as Treasurer—was elected Vice-President. A policy of FEANI is that, wherever practicable, committees are serviced by the country of which the chairman of the committee is a national. The current Chairman of the Formation Committee is Professor W. E. J. Farvis (Edinburgh University) and this committee is therefore serviced by CEI.

'Design and the Engineer'—A New Careers Film

'Design and the Engineer', one of a series of films about engineering and technology for those about to leave school, shows the approach of engineering design teams in two different sized firms and in a university. The main link in the film is the design process in each organization, and the film is not concerned with the products in themselves, but with the identification of a number of needs which the design teams are required to meet. Copies of the film are available on free loan from the Central Film Library, Government Buildings, Bromyard Avenue, Acton, London W3 7JB, or from its affiliated libraries in Scotland and Wales.

Believed to be the first film of any kind to be devoted specifically to design work in engineering, 'Design and the Engineer', was launched on 15th October by the Department of Industry, for the Interdepartmental Committee on Publicity for Engineering and Technology (IDC). The fundamental objects of the Committee, on which CEI is represented, are to ensure that young people, when making career choices, have the right information on individual opportunity and on the challenge of engineering and technology, and that science teachers are aware of technical change and its effect on everyday life. Films are a primary activity for this purpose.

Health and Safety at Work Bill

When the Health and Safety at Work etc Bill was considered in the House of Lords on 4th July Lord Avebury, on behalf of CEI, put forward amendments which would have extended the protection accorded to employed engineers, ensured that relevant professional bodies were consulted before appointments were made to the new Health and Safety Commission, and extended the safeguards to ensure that Inspectors were properly and professionally qualified.

The amendment concerning consultation was accepted and valuable undertakings were given over the professional qualifications that will be required of Inspectors.

National Electronics Review

A report on industry based degrees was given in the May/June issue of *National Electronics Review*, the Journal of the National Electronics Council. This had been prepared by a working party set up by NEC under the Chairmanship of Sir James Tait and as well as urging that more information should be available on facilities for higher degrees, it advocated that there should be greater opportunities provided to enable graduates in industry to improve their careers.

An authoritative account was given by Rear Admiral Sir Peter Anson, lately Assistant Chief of the Defence Staff (Signals) on the consequences and causes of the failure of the *Skynet II* defence communications satellite in January of this year. It reveals that the conclusion of the Board which investigated the failure was that the most likely cause was a loose washer!

Regular features of the *Review* are profiles of companies and reports of electronics research in Commonwealth universities. In this issue, the organization and activities of the Plessey Company are described and also the work of the Department of Electrical Engineering at the University of Edinburgh. The brief report is also given of the New Zealand Electronics Industry during 1973 against the activities of the National Electronics Development Association.

A notable feature in the July/August issue is an article on 'Telecommunications and Electronics in Japan' based on reports prepared by Professor H. M. Barlow and Professor F. E. Jones who visited Japan in October/November 1973 under the scientific exchange arrangements between the Royal Society and the Japan Academy. It describes scientific and technological developments by Government Laboratories, including the telecommunications organization in the universities and in industry. A brief account is also given of the teaching facilities—only 4 of the 7 Imperial Universities were visited but it is a characteristic of Japanese higher education that there are many hundreds of universities based on private funds and where income comes primarily from student fees. The article stresses the desirability of British technologists working in Japan under reciprocal exchange arrangements.

NEC has set up a working party on satellites for navigation and communication with aircraft and ships, and a brief report on marine communications satellites is contained in this issue. It urges that Government and industry should jointly examine the proposals for developing an experimental ship-borne terminal based on MARISAT, the first satellite of which is scheduled to be launched before the end of this year. The Decca Navigator Company is the subject of the 'Company Profile' and the School of Engineering Science of the University College of North Wales, Bangor gives details of its main research activities.

Chartered Engineers and the 'Closed Shop'

The implications of proposed Government legislation to repeal certain provisions relating to the 'closed shop' are currently being closely examined by CEI. A memorandum has been prepared and sent to the Department of Employment which puts forward the profession's misgivings on a particular proposal in the DOE Consultative Document. In view of the importance of this subject to all engineers, the CEI memorandum is printed here in full.

Memorandum on the Department of Employment Consultative Document in the Matter of the Proposed Protection of Employment Bill.

1. The Council of Engineering Institutions welcomes the publication of the Consultative Document on the proposed Protection of Employment Bill.
2. It is taking the advice of its Constituent Members, the fifteen Chartered Engineering Institutions, on a number of issues raised in that Document, and may wish, in due course, to submit representations on some of them.
3. Immediately, however, the Council is concerned with only one matter to which reference is made in the Consultative Document, and which it views with great concern.
4. That is the proposal that the Employment Protection Bill shall be the vehicle for repealing those provisions in the Trade Union and Labour Relations Act 1974, which extend the rights of workers, in a closed shop situation, to opt out of Trade Union membership, by allowing them to opt out not only on religious grounds, but also on any other reasonable grounds.
5. The Department will be aware, from representations made in the past, when this and related issues have been under consideration that Chartered Engineers who have a professional code of conduct under which they have an obligation at all times to safeguard public health and safety could find themselves in acute difficulties if, after having to join a Trade Union because of the operation of the closed shop principle, they were to find that the subsequent obligations of that membership were in conflict with that obligation in their professional code, at all times to safeguard public health and safety.
6. The Council is aware of the arguments put forward to justify the principle of the closed shop, and it is not anxious to become involved in any controversy with political overtones. The Council is a-political and has within its Constituent Membership, individuals of all and every political complexion. The Council does not regard this question as a political issue, but entirely as a question which could lead to serious and dangerous professional difficulties.
7. In the Consultative Document the view is expressed that the wider basis for individual choice in the matter of Trade Union membership which the 1974 Act, as amended, provided, 'will harm rather than improve industrial relations.'
8. The Council cannot too strongly emphasize that if the new proposals are embodied in legislation without any due account being taken of this potential area of conflict, very serious harm may well be done to industrial relations in the future.
9. It is unlikely that any professional engineer would be prepared to accede to a union request for the withdrawal of labour, in an industrial dispute if, by doing so in his opinion, public health and safety would be prejudiced. To do otherwise would be a negation of his professional standing. Thus a highly emotive conflict could be precipitated on an issue where the presence of the question of public safety could excite much public sympathy.
10. To design legislation that might allow such a conflict to arise would not, in the view of the Council be in the best interests of the future of indistrial relations, or of the country. It would, moreover, be a reflection of a singular lack of appreciation of the status of professional engineers, and their crucial role in industrial and public life.
11. The Council earnestly hopes that the force of its views will be recognized and some provision embodied in the Bill, which, while in no way detracting from the rights of Trade Unions, will, at the same time, extend the right protection to professional engineers and their obligation to observe their professional code, in relation to public health and safety.

M. W. LEONARD
Secretary

16th October 1974

Members' Appointments

CORPORATE MEMBERS

Dr. Ieuan Maddock, C.B., O.B.E., F.R.S. (President) has been elected to the Council of the Royal Society. Members will recall that at the Annual General Meeting, at which his re-election as President of the Institution was approved, it was announced that Dr. Maddock had been appointed a Foreign Member of the Royal Swedish Academy of Engineering Sciences.

Mr. J. E. Betteridge (Fellow 1972, Member 1970, Graduate 1954) whose appointment as Director and General Manager of Steering Systems Inc., of Covington, Louisiana, was announced in the September 1974 Journal, takes up the post of Vice President of the company on January 1st 1975.

Mr. R. Schild (Fellow 1965, Member 1957, Graduate 1950) is now Joint Chief Executive of the Huntleigh Group with particular responsibilities for development of trading activities in the area of precision engineering. He was co-founder and later Chairman and Joint Managing Director of SE Laboratories, formed in 1963 and subsequently acquired by EMI Limited. He continued as Joint Managing Director until 1973 when he joined the Board of Hymatic Engineering, one of the companies within the Huntleigh Group.

Mr. H. O. J. Cline-Cole (Member 1972, Graduate 1966) has been appointed Assistant Registrar for Technical Examinations with the West African Examinations Council, Lagos. Following industrial and technical teachers' training in England, he joined the Post and Telecommunications Department of Sierra Leone and was latterly a Telecommunications Engineer in charge of an engineering district.

Mr. R. Collis (Member 1973, Graduate 1969) has been appointed Area Traffic Engineer with the Oxford County Council. Previously he was Senior Assistant Engineer with the London Borough of Brent concerned with traffic signals and associated electronic equipment.

Mr. A. L. Cotcher, M.Sc. (Member 1962) has joined Satra Consultants (UK) Ltd, London as a Project Manager and will be attached to the company's office in Moscow where he will be primarily concerned with technical trade negotiations on behalf of the Plessey Company. Mr. Cotcher was previously with Cutler-Hammer Europa and its predecessor, Brookhirst Igranic, in Bedford.

Mr. R. Downton (Member 1966, Graduate 1962) who has been with the Science Research Council since 1963 and was from 1970 at the Daresbury Nuclear Physics Laboratory, has now moved to the Appleton Laboratory at Slough.

Sqn. Ldr. M. J. Gregory, M.Sc., RAF (Member 1969) has been posted to RAF Cosford as Officer Commanding Navigation Systems Squadron. Since 1971 he has been on the Electrical Engineering staff of the Ministry of Defence (Air).

Mr. A. F. Harrison (Member 1959) has been appointed Director of Communications, Home and Health Department, at the Scottish Office in Edinburgh. For the past two years he was Head of Traffic Control, Radio, Data and Television Groups in the Electrical Services Division of the Greater London Council.

Mr. J. Hockley (Member 1972) who has been with the Government Communications Headquarters since 1964 and was promoted Senior Scientific Officer in 1973, has joined the Ionospheric Studies Group at the Weapons Research Establishment, Salisbury, South Australia on a two years' attachment. In August 1973 Mr. Hockley contributed a paper to the Journal on 'A goniometer for use with high frequency circularly disposed aerial arrays'.

Mr. T. E. Hyde (Member 1974, Graduate 1967) has joined Plessey Telecommunications Ltd as Head of the Quality Engineering Department in the Electronic Switching Division at Huyton. From 1971 to September of this year he was a Senior Quality Engineer on the TXE4 exchange with Standard Telephones and Cables.

Flt. Lt. R. Leach RAF (Member 1972, Graduate 1968) takes up an appointment with British Aircraft Corporation in Saudi Arabia next year. He retired from the Service at the end of 1974, his last appointment being Engineering Officer on 55 Squadron, RAF Marham.

Mr. K. A. Wells (Member 1968, Graduate 1963) who joined the Central Electricity Generating Board in 1965 is now First Engineer, Control and Instrumentation with the Board at Barnwood, Gloucester.

NON-CORPORATE MEMBERS

Mr. J. E. Brooke-Stewart (Graduate 1963) has been appointed Technical Manager with Philips Electronic Industries, Toronto. His previous post was that of Product Sales Manager with the Automation Division of Westinghouse Brake & Signal Co., Ltd. Chippenham.

Mr. A. B. Chattopadhyay (Graduate 1965) is now Engineer in charge at the Orissa Cluster Headquarters of the Office of the Satellite Instructional Television Experiment. Mr. Chattopadhyay, who served in the Indian Air Force, joined the Indian Space Research Organization in 1970.

Obituary

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

Desmond Reginald Sherley-Price (Member 1948, Associate 1945) died on 30th June 1974, aged 57 years. He leaves a widow.

Born in Devon, Mr. Sherley-Price was educated in Hampshire and Berkshire and on the outbreak of the war, received his early technical training at the London Telegraph Training College. He joined the British Broadcasting Corporation as an engineer and later moved to the Valve Laboratory of the Mullard Radio Valve Company as a Research Assistant. During this period he completed City and Guilds of London qualifications to gain the then Associateship of the Institution. In 1945 he joined Beethoven Electric Equipment Ltd., as Development Engineer, subsequently being appointed Assistant Chief Engineer. He remained with the company for two years, then went to the British Overseas Airways Corporation as a Signals Research Engineer. In 1948 he received an appointment with A. C. Cossor as a Radar Development Engineer and in 1951 he went to Fairey Aviation. In 1956 he joined the UK Atomic Energy Authority and for the remainder of his professional career was a Senior Experimental Officer at the Atomic Weapons Research Establishment, Aldermaston. Because of family committments, Mr. Sherley-Price retired early from the Authority in 1969.

Gordon Thomas Vale (Graduate 1958) died on 13th January 1974, aged 49 years. He leaves a widow, a son and two daughters.

Gordon Vale was born and educated in Coventry and served with the RAF as a Wireless Mechanic during the war. Following demobilization in 1947 he joined the Ministry of Supply as an Examiner concerned with inspection of electronic plotting and computing equipment. In 1951 he was appointed Engineering Technical Grade III with the Directorate of the Inspection of Armaments. In 1963 he transferred to the Professional Engineering Grade as Engineer III and was posted to the Electronic Design and Development Section of the Royal Ordnance Factory, Blackburn.

Mr. Vale resigned from government service in 1965 and emigrated to New Zealand where he joined the Pye Manufacturing Division of Akrad Radio Corporation Ltd, Waihi. For the next 4½ years he was engaged in the development of telecommunications equipment and in 1970 moved to the company's Purchasing Department. At the time of his death he held a senior position in this Department.

Energy Conservation

Government Energy Appointments

An Advisory Council on Energy Conservation to help the Government in promoting the more efficient use of energy has been set up by Mr. Eric Varley, Secretary for Energy. The Council's functions will include identifying areas in private, public, industrial or commercial consumption where improvements in energy use can be made, and advising on how the improvements can be achieved. Its chairman will be Professor Sir William Hawthorne, C.B.E., Master of Churchill College, Cambridge.

Chartered Engineers are well represented on the Advisory Council. Apart from Sir William Hawthorne, who is a Fellow of the IMechE and of the RAeS there are six other Chartered Engineers among its eighteen members:

Mr. Ronald Richardson, CBE, Electricity Council Deputy Chairman;

Mr. Denis Rooke, CBE, British Gas Corporation Deputy Chairman;

Mr. Wilson Campbell, a consulting engineer;

Mr. J. R. S. Morris, a director of the Board of British Nuclear Fuels Ltd;

Dr. Leonard Rotherham, CBE, Vice Chancellor of Bath University;

Sir Frederick Warner, Member of the Royal Commission on Environmental Pollution.

The Council's terms of reference are: To advise and assist the Secretary of State for Energy in carrying out his duty of promoting economy and efficiency in the use and consumption of energy, in particular by:

(a) identifying fields in which improvements in energy use can be achieved;
(b) advising on the means of realising such improvements;
(c) stimulating and maintaining public interest in energy conservation with a view to the widespread adoption of more efficient practices; and
(d) reviewing progress made.

Members will be acting in a personal capacity.

Shortly after the announcement concerning Sir William, Mr. Varley announced that Dr. Walter Marshall, Board member for research of the UK Atomic Energy Authority and director of the Atomic Energy Research Establishment at Harwell, had been appointed chief scientist in the Department of Energy with effect from 1st July. It is on a part-time basis and Dr. Marshall remains director at Harwell.

These appointments are seen as of particular relevance to CEI's offer (reported in the May Journal) to the Government of the engineering profession's co-operation in dealing with energy problems.

Energy Research and the Research Councils

At the end of 1973 the Advisory Board for the Research Councils set up a committee of representatives of Government departments and Research Councils to find out whether the energy research effort sponsored or carried out by the Research Councils was of the right size and kind. A report has now been issued which presents a broad picture of responsibilities for R and D connected with energy issues and the current work of the Research Councils. As well as being a useful reference to activity in this important area, the report will be useful to research workers in university and elsewhere who are considering submitting research grant proposals to Research Councils. Copies may be obtained free of charge from either the ABRC Secretariat, Department of Education and Science, Elizabeth House, York Road, London SE1 7PH, or from the Secretary, Energy Round Table, Engineering Division, Science Research Council, State House, High Holborn, London WC1R 14A.

Electronics and Energy

The continuing oil crisis and the coal strike at the end of last year led the National Electronics Council to consider how electronics could contribute towards the ways and means of improving the economy, conservation and control of energy. A Working Party was set up in January 1974 under the chairmanship of H.R.H. The Duke of Kent (Deputy Chairman of NEC) and has just reported back to the Council. Copies of the Report have been sent to the Chairmen of the Advisory Council on Energy Conservation and of the Electronics EDC.

In the view of the Working Party, there is a paramount need for the nation to become more energy conscious. Rising prices will be a major factor in this process but people will have to be convinced of the importance of conserving energy. They expect electronics to have a wide application both in prompting this attitude of mind and in meeting the subsequent demand for means of saving fuel and power.

The role of electronics will be secondary, rather than primary, in providing answers to the energy problems. Nevertheless, both in the supply of energy and in its most economic use electronics will have a very significant part to play in monitoring, measurement, control and communication.

The NEC Working Party suggests that in the present and immediate future electronic techniques can most profitably be used in two ways—

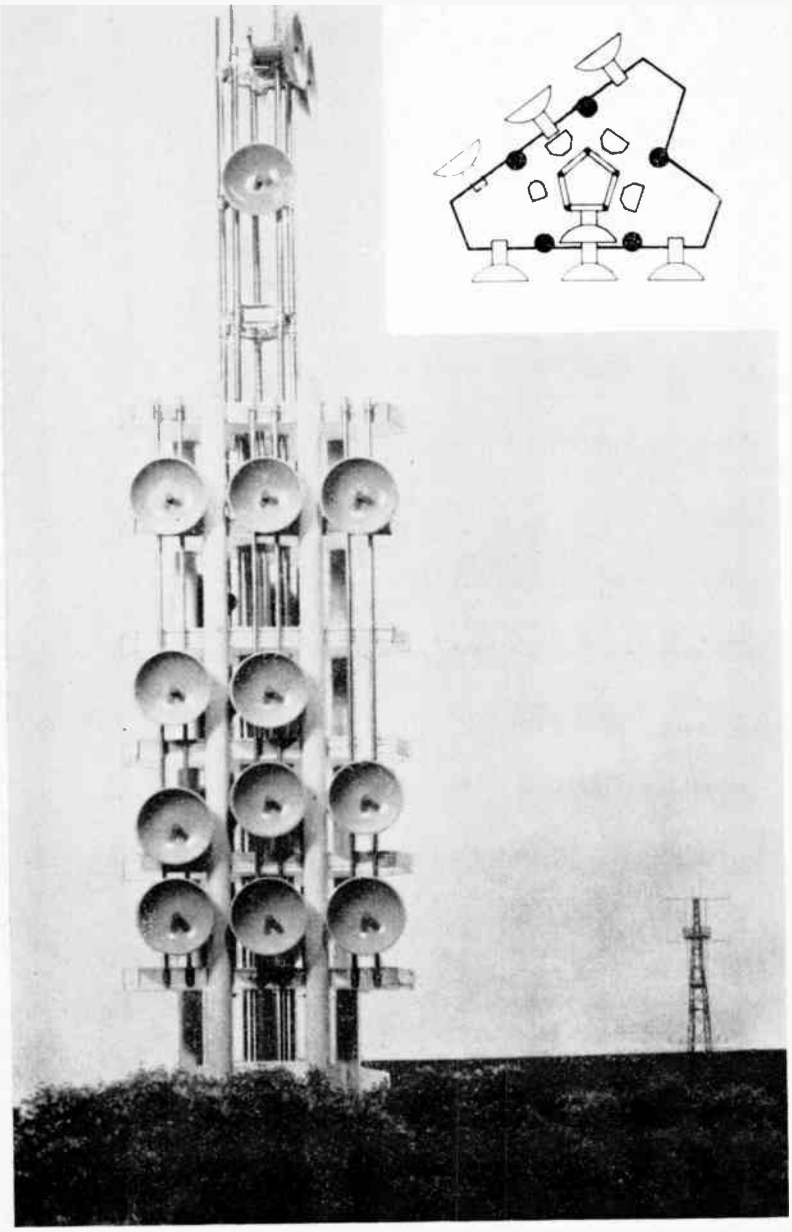
To assist the rapid development and exploitation of North Sea Oil and Gas, the greater use of nuclear energy and the further development of the coal industry.

By means of automation, recording and instrumentation, to help make the most efficient use of all forms of energy in manufacturing, transportation and for domestic purposes.

In the longer term there will be new opportunities and a new challenge for technology. The need for more efficient use of energy will continue and more ambitious methods of avoiding waste such as district heating or more precise controls will become necessary. In this time span it is probable that novel sources of energy, which have not been practicable or viable to date, will become significant, e.g. geothermal, tidal, wave motion and thermonuclear. Electronics will play a role in all of these.

The electronics industry should be urged to develop instrumentation and devices aimed at enabling economies in the use of energy to be attained at reasonable cost. As a major research objective, the application of electronics towards improving the efficiency of energy conversion and to reducing energy wastage as a result of inherently 'spend-thrift' processes should be encouraged. It is also recommended that consideration be given to using computer modelling techniques in any study of future national power requirements.

New Cross-Channel Telephone Link in Service



Model and plan (inset) of the Post Office's new microwave radio relay tower at Tolsford Hill, near Folkestone, Kent. The tower will be 64 m high, with six galleries, triangular in plan, spaced at 6 m intervals. The top gallery, 42 m above ground level, is surmounted by a 22 m tubular steel tower. The galleries are supported on five circular reinforced concrete columns, arranged as a regular pentagon; the vertical members of the steel tower also form a pentagon Dish antennae will be clamped to tubular steel risers fixed to the outside faces of the galleries; some antennae will also be mounted on the upper tower. This arrangement gives flexibility in positioning and spacing of aerials for the cross-Channel route, for which space diversity reception is necessary to combat fading due to sea reflexions. It is being built for the Post Office by the Property Services Agency of the Department of the Environment.

Expansion of Britain's busiest single international route—the 38-mile radio 'hop' across the English Channel—has taken a further step forward. Under the Post Office's plan to double the route's call-carrying capacity, the first sixty telephone circuits of a new microwave link are now carrying calls to France. The new link, which will eventually be handling up to 1800 calls simultaneously, is the first of two to be provided in the Post Office's drive to expand telephone and telex services with Europe.

The route, from the Post Office's microwave station on Tolsford Hill near Folkestone in Kent to its French counterpart at Fiennes near Loos, can at present carry 2160 telephone calls simultaneously. The new microwave links will boost this to 5760. Under present plans, the Post Office expects to add 1000 circuits of the extra capacity in the next six months. Further groups of circuits will be progressively brought into service during the following year.

The paraboloidal aerials for the new link—one for transmission and two for receiving the reverse-direction signal from France—have been mounted on the existing lattice-steel radio tower, which has been strengthened to take them. Those for the second link—due to come into service next summer—are likely to be mounted on the new ferro-concrete tower now being built next to the existing structure. When the new tower has been completed, all the microwave links on the route will be transferred to it and the old tower dismantled.

The new radio equipment operates in the lower 6 GHz band, whereas the existing links are at 4 GHz. The British equipment, supplied and installed by GEC, conforms to CCIR recommendations. The French authority has installed Thomson CSF radio equipment conforming to the same recommendations. Following close liaison, the two equipments are fully compatible and the calculated performances have been achieved.

In both directions, there is a working bearer channel and standby channel, to which the telephony traffic is switched automatically if the need arises. Both main and standby may be operated as two independent bearer channels each of 1800 circuit capacity.

Height diversity has been adopted to combat the tendency for microwave signals on an overwater path to fade—due to variation in grazing-incidence reflexion from the water surface and to changes in refractive index of the air in still conditions. The two receiving dishes are mounted in the same vertical plane 15 m and 21 m (49 ft and 69 ft) above tower base. Their outputs are continuously monitored and the better selected for onward transmission. All three dishes are 3·7 m diameter paraboloids fitted with radome windows. Beam angle is 1° to half-power points, gain 44·6 dBi at 6·175 GHz. Transmitted power is 10 W and path attenuation over the link 144 dB.

The equipment, GEC's Mark III version, uses phase-locked oscillators—the first occasion the Post Office has used this technique in its microwave network. Phase locking ensures a low-noise radio source, with commensurate improvement in the signal/noise ratio of the link. The technique also enables phase modulation to be adopted for the supervisory circuits located in the sub-telephony band. The telephony band itself is, of course, frequency modulated.

Telephony multiplexing for the link follows Continental practice. The supergroups (each of 5 groups of 12 circuits) transmitted by both cable and radio links from London are multiplexed at the radio station in three stages: five supergroups combined to make a mastergroup (300 circuits); three mastergroups combined to make a supermastergroup (900 circuits); two supermastergroups combined to make the complete telephony traffic band of 1800 circuits.

In France, the bearer is demodulated to base band and the traffic demultiplexed to the two supermastergroups, which are fed directly into a new French radio system which extends them to Paris. One supermaster group carries circuits terminating at the French capital, the other circuits with destinations beyond. At present engineers in both countries are setting up the multiplexing stages, measuring system attenuation between input in one country and corresponding output in the other at spot frequencies across the entire width of the traffic band.

This cross-Channel link carries many international calls routed across France to other countries, notably Italy, Spain, Switzerland, Austria, Yugoslavia and Greece. Of the extra 1000 circuits to be provided initially, 430 will be to France, 200 to Italy and 240 to Switzerland. Communications with the Continent account for the largest part of Britain's international telecommunication services, which are doubling every five years. Of the 30 M calls made abroad in 1973–74, 24·5 M were to mainland Europe, with about the same number received in this country from there. The Post Office estimates that this two-way traffic will grow to 80 M calls in the next 18 months. To meet this growth, the Post Office is engaged in a major expansion programme for the telecommunication services with Europe. By the end of 1978, the extra microwave links, plus new high-capacity submarine cable systems, should enable the Post Office to increase the number of telephone circuits to Europe to 20,000—more than twice the present number.

The Designer and Restrictions of Economy

The role of the designer is even more important in times when economy and conservation of resources has become a cardinal principle of good government and good management. This is the point emphasized by the Design Council in the introduction to its Twenty-Ninth Annual Report* covering the year ended 31st March 1974. 'A designer, particularly one working in three dimensions, will both by training and by instinct look for the simplest, most economical solution to a problem. Indeed designers have been among the earliest advocates of conservation of energy and materials and many may even welcome the new restrictions as a recall to sober, functional, socially valid yardsticks.'

The Report mentions several new activities undertaken by the Council but pays special attention to the new role of the Design Council in the engineering industries. Early in the year under review, extra funds from the Government made possible some real progress under the seven headings previously selected for action: visiting advisory services; a survey of sources of engineering design expertise; periodical publications; exhibitions; courses and conferences; annual awards; and general promotion through the press and broadcasting.

The Council was greatly encouraged by the initial receptions given by engineering firms to its visiting advisory service, for it had long planned that its team of highly qualified field officers supported by its Record of Engineering Design Expertise should be the spearhead of its engineering activities. The field officers were briefed to visit manufacturers, to help them to diagnose specific engineering design problems or opportunities for design improvement, and to draw attention to the sources of technical expertise from which help could be obtained. Information research staff provided essential support to the officers in the field, and continued to build up a Record of Engineering Design Expertise so that information about sources of help could quickly be made available. The field officers were not required to give technical advice except on those occasions when the problem related directly to the field officer's own expertise.

Visits during the year showed that the Service is generally welcomed by British industry, and the encouraging results of a pilot survey were substantiated by later experience. Of the 407 contacts made with engineering companies, approximately one-third led to immediate action, and a further third felt that, while they had no immediate problems calling for specialized assistance, they welcomed the existence of the Service and indicated a clear intention of using it in the future should the need arise. The range of engineering problems encountered was extremely wide and specialists were recommended to advise on such matters as the redesign of a power transmission system for a railway traction unit, the redesign of pneumatic valves for vehicle application, foundry techniques for large iron castings, the reduction of high noise levels in pneumatic tools, and many other problems.

In October 1973, the well-known magazine *Engineering* was purchased, and its subsequent editorial content increasingly reflected the aims of the Council's engineering programme. The Report describes the purpose of *Engineering* as providing technical information to assist practising engineering designers in their work; informing Britain's engineering industries about the Council's new engineering activities; clarifying the role of the engineering designer and improving his status; and relating these aims to the specific problems of the electronic, electrical and mechanical engineering industries, including such related fields as civil engineering.

*Published by the Design Council, 28 Haymarket, London SW1Y 4SU, price 30p.

Technical News

Satellite Communications for Merchant Shipping

ESRO has awarded a £11M prime contract to Marconi Space and Defence Systems for the detailed design and development of the communications payload of the new maritime satellite MAROTS. This is a satellite which is intended to provide ship-to-shore communications links without the disadvantages of the present, highly congested, conventional high-frequency radio circuits.

MAROTS will use the basic structure and control system of the OTS satellite which are being developed by the MESH consortium led by Hawker Siddeley Dynamics. The launch of MAROTS is scheduled for the Autumn of 1977 when it will be injected into a geostationary orbit some 23,000 miles high over the Atlantic, with an intended minimum three-year life span.

Marconi are also to study and define the basic parameters of the ship-borne and shore-based terminals. The former will be made as simple as possible and to this end MAROTS is to be equipped with a high efficiency 'shaped beam' antenna coupled with an L-band transistor power amplifier. Ships will use the L-band frequencies (390–1550 MHz) to communicate to and from the satellite. As shore terminals will be able to use more sophisticated equipment the shore-to-satellite frequency will be in the 14 GHz band while the satellite-to-shore communication will use the 11 GHz band.

This experimental and pre-operational ESRO satellite will meet the requirements of the Inter-Government Maritime Consultative Organization (IMCO) and have, as far as possible, the characteristics of a future world-wide operational maritime communication system.

Australian P.O. to Split

The Australian Post Office is to be split into two separate authorities, one for postal services and the other for telecommunications, including the Overseas Telecommunications Commission. (The OTC operates Australia's cable, radio and satellite links with other countries.) The two new statutory authorities will be outside the control of the Public Services Board. The change has been recommended by a Royal Commission and the Postal Corporation and the Telecommunications Corporation will each have responsibility for organisation, staff, pay and conditions of employees.

Engineering Design Guides

Under the sponsorship of the Design Council, the British Standards Institution, and the Council of Engineering Institutions, a series of 'Engineering Design Guides' has recently been launched, published by the Oxford University Press.

The books are concise and practical in approach, and give advice on the best modern methods of design procedures and techniques. Each Guide is written by an expert on the subject covered, and the Guides as a series are wide-ranging in scope, extending from nuts and bolts to the use of glass in engineering design. Some are on topics of general interest to all engineers, such as those on fastening systems, while others are more specialized and examine such themes as heat exchangers. Guides likely to be particularly relevant to the design requirements of electronic engineers will deal with Welding Processes; Soldering; Selection and use of thermoplastic and thermosetting plastics; Metal corrosion; Manufacture by numerical control; Engineering ceramics; Designing for computer graphics; Electrostatic hazards; and Permanent magnets.

The first four titles in this series are:

Introduction to Fastening Systems by D. H. Chaddock—20 pages, 29·7 × 21 cm. 80p

Adhesive Bonding by J. Shields—24 pages, 29·7 × 21 cm. £1·00

Miscellaneous Fasteners by F. M. Keeley—23 pages, 29·7 × 21 cm. £1·00

Rolling Bearings by T. S. Nisbet—43 pages, 29·7 × 21 cm. £1·80.

The Guides do not merely provide basic and up-to-date reference information; they also include theoretical explanations which will help the engineer to a fuller understanding of the practical advice given. Designed for quick and accurate reference, they are intended to be used as working tools by engineering designers, draughtsmen, students and all those involved in engineering design. They are fully illustrated with diagrams and tables providing much valuable data, and each Guide includes a short, highly selective bibliography.

A Television Inspection System

A closed-circuit television system is being used at the Ferranti Wythenshawe factory to help check the complex printed circuit boards used in *Argus* computers. The method avoids the risk of eyestrain inherent in some optical methods.

Nowadays printed circuit boards accommodate thousands of minute components, often as in the case of those made at Ferranti, in several layers to achieve the required packing density. So that through-connexions can be made, tight dimensional tolerances have to be applied during manufacture, and it has been found that precise checking can only be carried out using a magnified image.

The miniature television camera shown in the photograph is scanning a photographic negative which is used in the manufacturing process. The beam is accurately positioned so that any out-of-tolerance dimensions can be detected by an operator watching the screen. The magnification obtained by this method is up to fourteen times.

New Books Received

All the books which are described below are available in the Library and may be borrowed by members in the United Kingdom. A postal loan service is available for those who are unable to call personally at the Library.

Illustrations in Applied Network Theory

F. E. Rogers. Butterworths, London, 1973. 21·5 × 13·5 cm. 228 pp. £5·00 (boards). £2·50 (limp).*

Contents: General principles for passive and active network analysis. Transient response and its correlation with frequency response. Simplifying procedures, theorems and equivalences. Power transfer and allied concepts. Examples of non-linearity and the response of networks to non-sinusoidal waveforms. Electronic amplifiers with feedback circuits.

Although this book deals primarily with the analysis of passive linear networks, active networks and non-linear elements are also considered. The presentation is admirable. Each section begins with an introduction which contains the basic principles and relevant theory in a concise form, followed by worked examples. Comments relating to special difficulties and the application of novel methods are then given.

The text is very well written and the examples are not merely repetitious; each demonstrates a specific point and together they cover a wide range of applications. This approach is more efficient and provides greater student motivation than a more conventional text which tries to allow for all difficulties, many of which are not easily explained without reference to examples, and many of which are self-evident so that an explanation is unnecessary, if not confusing.

Certain problems are solved using different methods, which is valuable not only for assessing comparative efficiency, but for inspiring confidence in the validity of a method when first used, e.g. the Laplace transform.

No student of network theory should be without this book, and many practising engineers could learn something from it.

J. K. Stevenson

(Mr. Rogers (Member 1963), is a Senior Lecturer in the Department of Electrical and Electronic Engineering, Polytechnic of Central London.)

Random Pulse Trains: Their Measurement and Statistical Properties

C. H. Vincent. Peter Peregrinus, Stevenage, 1973. 23 × 15 cm. 264 pp. £7·50.

Contents: Linear rate measurement. Further aspects of linear rate measurement. Dead time and derandomization. Logarithmic ratemeters. Period meters and excursion detection. Relationships to random noise and pseudorandom sequences. Some special problems.

No. 13 in the IEE Monograph series, this book is intended to fill a gap in existing published material in this interdisciplinary field. Some previous publications have been limited in scope, in that they were written with either a particular piece of equipment in mind, or to meet the requirements of a specific experiment. This book, however, aims to be theoretical, since its approach is towards the solution of statistical problems not from the point of view of established practices or current engineering limitations, which is necessary before genuinely optimal solutions can be sought. Specific circuit details are included only to demonstrate the theory, since this theory can be applied in terms of any current device technology, whereas the latter approach dates as the technology changes. A sound collection of references and specific index add to its usefulness, although the lengthy errata slip is a pity.

(Dr. Vincent (Fellow 1964) is a Superintendent in the Applied Physics Department, Atomic Weapons Research Establishment—see September 1974 Journal, p. 514.)

Metals, Ceramics and Polymers

Oliver H. Wyatt and David Dew-Hughes. Cambridge University Press, 1974. 22·5 × 15 cm. 640 pp. £12·00.

Contents: Atomic structure. Crystal structure. Electron theory of crystalline solids. Wave mechanical theory of electrons in solids. Equilibrium diagrams and microstructure. Mechanical properties. Plasticity: 1 Macroscopic theory; 2 Physics of plasticity. Ceramics and glasses. High polymers. Physics of fracture. Methods of strengthening materials. Iron-carbon system: cast irons and steels. Electrical properties: 1 Metals; 2 Semiconductors and insulators. Magnetic properties of solids.

The Materials Scientist is an all-rounder who has to acquire a knowledge of the structure of materials, the properties of materials, and an understanding of many engineering concepts. Generally text-books for the Materials Scientist concentrate on one or two of these aspects to the detriment of the remaining. However, the authors of the book 'Metals, Ceramics and Polymers' have made a commendable effort to cover all three aspects in a logical and integrated manner. The text is analytical whenever possible, detailed throughout and contains numerous references to modern materials of commercial significance.

For these reasons I am sure that this book will be bought by many teachers and research workers in the materials field, as well as by experienced engineers or pure scientists, who wish to increase their knowledge of materials. It is a most useful general 'reference' book to have in one's office or laboratory.

On the other hand, because of the breadth of topics and the detailed approach, the style of writing is concise and rather formal. I feel that all but the most mature of undergraduate students would find it less readable than many of the other, perhaps less ambitious, textbooks available. In addition, the cost is £12·00, which is considerably more than most of the established Materials Science undergraduate text-books published in recent years.

In summary, a good comprehensive book, which will probably be widely used as a general Materials Science 'reference' book rather than an undergraduate text-book.

Rees D. Rawlings

(Mr. Wyatt is a Senior Principal Scientific Officer at the Royal Aircraft Establishment, Farnborough. Mr. Dew-Hughes is a Reader in the Physics of Materials, University of Lancaster.)

2nd International Symposium on Information Theory

Akademiai Kiado, Budapest, 1973. 24 × 16·5 cm. 451 pp. £8·40.

The papers presented at this second Symposium in 1971 have been published as a separate volume rather than in the quarterly, *Problems of Control and Information Theory* of the Akademiai since they are on an advanced level. Attended by scientists from twenty countries, the Symposium concentrated on mathematical problems of information theory and its applications, under the following headings: information theory, algebraic codes, probabilistic coding, communication systems, quantum channels, statistical methods, feedback channels, random processes, source encoding, correcting codes and communication channels.

Machines—Masters or Slaves of Man

Meredith Thring. Peter Peregrinus, Stevenage, 1973. 23 × 15·5 cm. 115 pp. £1·95.

Contents: The vital need for a 21st century utopia. The misuse of technology. How can technology provide an adequate standard of living for everyone in a crowded world? Life in the creative society. The role of education. Politics in the creative society. Economics in the creative society. How can we get to the creative society?

A stimulating, but also original and sobering, personal appraisal of the current state of our technological society, this book examines the good and bad effects of engineering on the future we are creating for the world. An outline is given of Professor Thring's projection of an alternative technology-based utopian society where quality of life is the aim, rather than the exponential production and acquisition of goods. The aim should be to make machines serve rather than dominate man, and through 'humanitarian politics' and 'good engineering' to replace the affluent society by Creative Society. The book is aimed at awakening the man in the street, and the conscience of the engineer to the dangers as well as the possibilities of our present condition in the hope that people will come to insist upon a government able to 'redirect society into a direction where the quality of life' is improved.

(Professor Thring is head of the Department of Mechanical Engineering at Queen Mary College, London.)

Problems in Physical Electronics

R. L. Ferrari and A. K. Jonscher, (Editors) Pion, London, 1973. 23·5 × 15·5 cm. 273 pp. £6·00.

Contents: General concepts of physical electronics (A. K. Jonscher, R. L. Ferrari). Electron emission (H. Ahmed). Motion of electrons in vacuum (A. Gopinath). Vacuum electronics devices (P. R. McIsaac). Electrical properties of ionized gases (A. von Engel). Conduction of electrons in solids (A. K. Jonscher). Electrical properties of dielectrics (B. K. P. Scaife). Solid state devices (P. N. Robson). Optoelectronic devices (J. W. Allen). Masers and lasers (W. A. Gambling, D. C. Hanna, R. C. Smith, G. C. Thomas). Electronic noise (A. van der Ziel). Gyromagnetic media (R. L. Ferrari).

Aimed at the near graduate and post-graduate level, this volume will serve students and teachers alike in electronics–cum–electrical engineering and solid-state physics. Written by some fourteen proven and internationally-known specialists, the twelve different chapters serve to define the subject of physical electronics as a whole, as seen through the eyes of the named editors.

Each chapter has its own introduction, mainly in the form of a compact summary of the relevant basic theory. This is followed, in each case, by some fifteen to thirty carefully chosen and graded problems, mostly of a highly practical nature. The solutions which follow these are formal and thorough, and bear testimony to the specialists' didactic aim and skill. The essence of each chapter topic emerges as a synthesis of the tutorial concepts convered by the chosen problems.

The editors have succeeded in obtaining a well-ordered blend of the separate authors' styles, motations and even units used, the latter being mainly SI. This has added purpose and clarity to the various expositions. The book as a whole thus serves to convey to the reader that he has come closer to discovering what the theory and practice of 'physical electronics' is all about. It is eminently suitable as an aid to self-study.

E. Robinson

MOS Field-Effect Transistors and Integrated Circuits

Paul Richman. Wiley-Interscience, London, 1973. 22·5 × 14·5 cm. 259 pp. £7·50.*

Contents: The field-effect at the surface of a semiconductor. The capacitance of a MOS structure as a function of voltage and frequency. Three-terminal characteristics of MOS-field-effect transistors. The effect of temperature variations on the electrical characteristics of MOS-field-effect transistors. The silicon-silicon dioxide system. High-frequency operation of MOS field-effect devices.

Described in the preface as 'a graduate engineering text', this book covers basic semiconductor device physics and theory, electrical characteristics and fabrication methods of m.o.s.f.e.t.s. Means by which changes can be made to improve electrical performance and lead to the development of smaller, faster devices are outlined. The book is aimed at students of both electrical engineering and semiconductor device physics, and also at engineers professionally engaged in the semiconductor industry. Extensive references, select bibliographies and practical problems follow each chapter, thus extending the reader's awareness by referring him to other contemporary documentation.

(Mr. Richman is Vice-President, Research and Development, Standard Microsystems Corporation.)

Electronic Circuit Analysis

J. T. Wade, P. L. Edwards and J. E. Clark. Wiley, Sydney, N.S.W., 1973. 24 × 14 cm. 640 pp. £12·00.*

Contents: Rectification. Diode clipping circuits. Diode clamping circuits. Diode logic. Diode characteristics. Zener diode characteristics. Zener diode applications. Introduction to the transistor. Transistor logic. Simple cascading techniques. Transistor characteristics and ratings. Performance limitations in common-emitter amplifiers. Field-effect transistor characteristics. Junction field-effect transistor: applications. Vacuum tube diodes. Vacuum tube triodes and pentodes. Basic semiconductor theory.

This textbook is designed for technical college students in electrical engineering and electronics, and also for those studying electronics as a support subject to another discipline, such as chemical or mechanical engineering. The authors have adopted a unified approach aimed at developing the reader's practical ability to analyse basic electronic circuits, linear and digital. These techniques are applied to all circuits regardless of the device used so that students can later incorporate into their experience innovations resulting from new developments in device technology.

(Mr. Wade is with the N.S.W. Department of Technical Education, Mr. Edwards is Principal of Canberra Teachers College and Mr. Clark is Director of the Phonetics Laboratory at the University of Sydney.)

Logical Design of Switching Circuits. (2nd Edition)

Douglas Lewin. Nelson, London, 1974. 22·5 × 15 cm. 404 pp. £4·75.*

Contents: Introduction to digital systems. Principles of switching algebra. Design of combinational switching circuits. Design of combinational switching circuits II. Sequential switching circuits. Design of synchronous sequential circuits. Design of asynchronous sequential circuits. Circuit implementation. Automatic design of logical systems. Logic design with complex integrated circuits.

Whilst the main body of the text has not been much altered in this second edition, a new chapter on designing with complex integrated circuits has been added, thus bringing the book up to date with recent developments in integrated circuit technology. MILSPEC logic symbols have been substituted in the diagrams throughout.

(Professor Lewin (Member 1960) occupies the Chair of Digital Processes at Brunel University.)

Introduction to the Physics of Electronics

Myron F. Uman. Prentice-Hall, Englewood Cliffs, N.J., 1974. 22·5 × 15 cm. 416 pp. £8·85.*

Contents: Elements of equilibrium statistical mechanics. Nonequilibrium statistical physics. Election beams and plasma electronics. Elements of quantum mechanics. Electrons in solids. Metals. Semiconductors. Semiconductor junctions. Multi-junction devices. Field-effect devices. Integrated circuits.

An introductory text for students of electrical engineering possessing background knowledge of electromagnetics, thermodynamics and quantum mechanics.

The author sets out to detail the physical principles of electronic devices to provide both an introduction to the study of device physics and preparation for further study of device modelling and applications. The aim is to develop an understanding of the basic physical concepts underlying the mechanism of electrical conduction.

(Mr. Uman is Assistant Professor of Electrical Engineering, University of California, Davis.)

Piezoelectric Ceramics

J. van Randeraat and R. E. Setterington (Editors). Mullard, London, 1974. 21 × 14·5 cm. 211 pp. £4·00.

Contents: The piezoelectric effect in ceramic materials. PXE ignition of gases. PXE flexure elements. Ceramic resonators in electrical filters. PXE sound and ultrasound air transducers. Echo sounders. PXE high intensity transducers. PXE delay line transducers.

Piezoelectric ceramics have been developed in the last 25 years to provide materials with properties suitable for a wide range of applications. The book describes the properties of a comprehensive range of piezoelectric ceramics, and how they may be used to make transducers for various applications. The main application areas, both domestic and professional, are described, including details of the associated electronic circuitry.

Book Supply Service

As a service to members, the Institution can supply copies of most of the books reviewed in the *Journal* at list price, plus a uniform charge of 25p to cover postage and packing.

Orders for these books, which are denoted by an asterisk (*) after the price, should be sent to the Publications Department at Bedford Square and **must** be accompanied by the appropriate remittance.

Forthcoming Institution Meetings

London Meetings

Wednesday, 22nd January

COMPONENTS AND CIRCUITS GROUP

Colloquium on THERMIONIC EMISSION DEVICES

POSTPONED

Wednesday, 29th January

JOINT IEE/IERE MEDICAL AND BIOLOGICAL ELECTRONICS GROUP

Sensing, Sizing and Sorting of Cells: the Laser Sorter

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

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

Wednesday, 29th January

COMMUNICATIONS GROUP

Speech Engineering

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

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

Wednesday, 5th February

AUTOMATION AND CONTROL SYSTEMS GROUP

Hybrid Computers and Applications

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

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

Wednesday, 12th February

AEROSPACE, MARITIME AND MILITARY SYSTEMS GROUP

Channel Approach Aid for Milford Haven Conservancy Board

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

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

Wednesday, 26th February

COMMUNICATIONS GROUP

Low Attenuation Corrugated Waveguides

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

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

Wednesday, 5th March

COMPONENTS AND CIRCUITS GROUP

Colloquium on EXPLOITING THE PROM

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

Thursday, 6th March

EDUCATION AND TRAINING GROUP

Colloquium on MODULAR COURSES

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

Wednesday, 12th March

AEROSPACE, MARITIME AND MILITARY SYSTEMS GROUP

Acoustic Holography

By Professor J. W. R. Griffiths (*University of Technology, Loughborough*)

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

Wednesday, 19th March

AUTOMATION AND CONTROL SYSTEMS GROUP

Colloquium on ON-LINE CALCULATORS AND INSTRUMENTATION

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

Wednesday, 9th April

AEROSPACE, MARITIME AND MILITARY SYSTEMS GROUP

Colloquium on RADAR AND ASSOCIATED SYSTEMS FOR VEHICLE GUIDANCE

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

Thursday, 10th April

JOINT IERE/IEE COMPUTER GROUP

Colloquium on COMPUTERS IN TRANSPORT

IERE Lecture Room, 10 a.m. Details to be announced.

Wednesday, 23rd April

COMPONENTS AND CIRCUITS GROUP

Colloquium on RECENT DEVELOPMENTS IN TURNTABLE DESIGN

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

Wednesday, 30th April

INAUGURAL MEETING OF THE MEASUREMENTS AND INSTRUMENTS GROUP

Colloquium on MEASURING INSTRUMENTS FOR THE TESTING OF MATERIALS AND COMPONENTS

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

Wednesday, 7th May

COMMUNICATIONS GROUP

Colloquium on MILLIMETRIC WAVE PROPAGATION

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

Wednesday, 14th May

MANAGEMENT TECHNIQUES GROUP

Colloquium on THE JAPANESE ELECTRONICS INDUSTRY

IERE Lecture Room. Further details to be announced.

Wednesday, 21st May

EDUCATION AND TRAINING GROUP

Colloquium on THE CEI EXAMINATION AND THE COLLEGES

IERE Lecture Room, 2.30 p.m. Further details to be announced.

Thursday, 22nd May

JOINT IERE/IEE COMPUTER GROUP

Colloquium on DISTRIBUTED INFORMATION SYSTEMS

IERE Lecture Room, 2.30 p.m. Further details to be announced.

Southern Section

Wednesday, 22nd January

Hybrid Integrated Microwave Amplifiers

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

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

Wednesday, 29th January

Underwater Imaging

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

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

Thursday, 6th February

Bubble Memories

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

Farnborough Technical College, 7 p.m.

Tuesday, 11th February

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

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

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

Wednesday, 12th February

Electronic Ignition—is it worth it?

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

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

Friday, 14th February

Electricity in the Entertainment Business

By J. H. Brooks (*BBC*)

Newport Technical College, 7 p.m.

Wednesday, 26th February

Time Series Feature Detection

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

Lanchester Theatre, Southampton University, 6.30 p.m.

Tuesday, 4th March

Electronics in Yachts

By P. I. Pelham (*Brookes & Gatehouse*)

Bournemouth College of Technology, 7 p.m.

Wednesday, 5th March

Project Management in the 1970s

By R. H. Bradnam (*Urwick Technology Management*)

Brighton Technical College, 7 p.m.

Wednesday, 12th March

ANNUAL GENERAL MEETING OF THE SECTION, 7 p.m.

followed by

LOUDSPEAKER ENCLOSURES

By A. Dyke (*Plessey, Roke Manor*)

Room AB 011, Portsmouth Polytechnic, Park Road.

Thursday, 20th March

Time Series Feature Detection

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

South Dorset Technical College, 6.30 p.m.

Wednesday, 26th March

JOINT MEETING WITH IEE

Halfday Symposium on Television Topics

(Including a tour of I.B.A. Laboratories)

IBA, Crawley Court, Winchester, 2.30 p.m.

Thames Valley Section

Thursday, 23rd January

Optoelectronics Devices

By M. Miller (*Texas Instruments*)

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

Wednesday, 12th February

CAD of Type 2 Digital Phase Lock Loops

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

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

For synopsis, see November Journal (p. 639).

Thursday, 6th March

Liquid Crystals and Device Applications

By I. A. Shanks (*RRE Malvern*)

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

Tuesday, 8th April

PROJECT MANAGEMENT

By Dr. I. Maddock (*Department of Industry*)

J. J. Thomson Physical Laboratory, University of Reading, Whiteknights Park, Reading, 7.45 p.m.

South Western Section

Wednesday, 22nd January

Mobile Radio in the Era of Spectrum Congestion

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

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

Thursday, 6th February

JOINT MEETING WITH THE IEE

Television Engineering—A Look into the Future

By M. Cox (*Michael Cox Electronics*)

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

Wednesday, 19th February

JOINT MEETING WITH RAeS AND IEE

Engine Testing using Advanced Techniques

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

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

Tuesday, 11th March

JOINT MEETING WITH IEE

Ambisonics

By Professor P. B. Fellgett (*Reading University*)

Main Lecture Theatre, University of Bath, 6 p.m. (Tea 5.30 p.m.)

Monday, 7th April

JOINT MEETING WITH IEE

Telemetry

By C. J. Williams (*Quindar-Wirral Automation*)

Queen's Building, Bristol, 6 p.m. (Tea 5.30 p.m.)

Wednesday, 23rd April

Oceanography

By M. J. Tucker (*Institute of Oceanographic Sciences*)

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

Monday, 5th May

ANNUAL GENERAL MEETING

The Royal Hotel, Bristol, 7 p.m. (Tea 6.30 p.m.)

Kent Section

Thursday, 6th March

Flight Recording in Civil Aviation

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

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

Thursday, 3rd April

ANNUAL GENERAL MEETING at 7 p.m.

followed by

PRESENTATION OF CERTIFICATES OF CORPORATE MEMBERSHIP

By Harvey F. Schwarz (Past President)

followed by

NAVIGATION HAZARD WARNING SYSTEMS USING RADAR AND COMPUTER

By Bruce Williams (IBM (UK))

The Tollgate Motel, Watling Street, Gravesend, Kent.

East Anglian Section

Wednesday, 5th February

Radar Approach to Weather Forecasting

By Professor E. Shearman (*Birmingham University*)

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

South Midland Section

Wednesday, 5th February

Active Filters

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

The Foley Arms, Malvern, 7.30 p.m.

Thursday, 13th March

G. C. Club, G.C.H.Q. Benhall, Cheltenham. 7.30 p.m. Details to be announced.

Thursday, 17th April

Engineering Innovation in Mini-computer Design

By A. Colvin (*CAI*)

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

To be followed by Annual General Meeting.

Friday, 23rd May

A Social Function at Evesham to be arranged.

West Midland Section

Thursday, 20th February

JOINT MEETING WITH IEE AND IPOEE

Communications—Bit by Bit

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

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

Thursday, 6th March

JOINT MEETING WITH IEE

Developments in Train Control and Automation

By B. Mellitt (*University of Birmingham*)

Lanchester Polytechnic, Coventry, 7.15 p.m.

Tuesday, 22nd April

ANNUAL GENERAL MEETING

Followed by

Quadraphonics

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

The Polytechnic, Wolverhampton, 7 p.m.

East Midland Section

Thursday, 13th February

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

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

Tuesday, 4th March

JOINT MEETING WITH IEE

The Implementation of Arithmetic Processes in LSI Microelectronics

By P. Van Cuylenburg (*Texas Instruments*)

Edward Herbert Building, Loughborough University, 7 p.m. (Tea 6.30 p.m.)

Yorkshire Section

Thursday, 20th February

JOINT MEETING WITH IEE

Oracle—Information by Domestic TV

By G. A. McKenzie and P. R. Hutt (*IBA*)

Yorkshire Television Studios, Leeds, 6.30 p.m.

Wednesday, 19th March

Digital Techniques Applied to Television

By Dr. O. Downing

Bradford University, 6.30 p.m.

Friday, 25th April

ANNUAL GENERAL MEETING

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

Merseyside Section

Wednesday, 12th February

Solar Energy

By W. R. Crooks (*North East Liverpool Technical College*)

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

Wednesday, 12th March

The Application of Computers to the Wide Area Control of Road Traffic

By D. W. Honey (*Liverpool Corporation*)

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

North Eastern Section

March

JOINT MEETING WITH BRITISH ACOUSTICAL SOCIETY

Details to be announced.

Wednesday, 9th April

Military Communications by Satellite

By W. M. Lovell (*Marconi Space and Defence Systems*)

South Wales Section

Wednesday, 5th February

JOINT MEETING WITH IEE

Digital Techniques in Broadcasting

By Dr. C. J. Dalton (*BBC*)

Chemistry Lecture Theatre, Room 164, UWIST, Cardiff, 7 p.m.

Wednesday, 12th March

Impulse Measurement Techniques

By J. Kuehn (*Bruel and Kjaer*)

Department of Applied Physics and Electronics, UWIST, Cardiff, 6.30 p.m. (Tea 5.30 p.m.)

Thursday, 10th April

JOINT MEETING WITH IEE

Tomorrow's World in Microwave Communications

By T. R. Rowbotham (*Post Office Research*)

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

Scottish Section

Wednesday, 22nd January

The Allen Electronic Organ

By A. Bogie

Venue to be announced.

JOINT MEETINGS WITH IEE

Optoelectronics

Dr. W. Oliver (*Robert Gordon's Institute of Technology*)

Wednesday, 5th March

Napier College of Science and Technology, Colinton Road, Edinburgh EH10 5DT, 7 p.m.

Thursday, 6th March

Glasgow College of Technology, Hanover Street, Glasgow, 7 p.m.

Recent Accessions to the Library (*continued from opposite page*)

Uman, Myron F.
'Introduction to the physics of electronics.' *Prentice-Hall*, 1974. [December 1974].

Mandl, Matthew
'Handbook of modern electronic data.' *Reston Publishing Co.*, 1973.

Squires, Terence L. and Deason, Michael
'Beginner's guide to electronics.' *Newnes-Butterworths*, 1974. 3rd ed.

Buchsbaum, Walter H.
'Buchsbaum's complete handbook of practical electronic data.' *Prentice-Hall*, 1973.

Hunter, Lloyd P. *ed.*
'Handbook of semiconductor electronics.' *McGraw-Hill*, 1970.

Semiconductor Devices

'D.A.T.A. book of discontinued integrated circuits'. 1974–75 ed. *D.A.T.A.* REF.

'Digital integrated circuit D.A.T.A. book.' Autumn 1974 ed. *D.A.T.A.* REF.

'Linear integrated circuit D.A.T.A. book.' Autumn 1974 ed. *D.A.T.A.* REF.

'Power semiconductors.' Autumn 1974, 1st ed. *D.A.T.A.* REF.

'D.A.T.A. book of discontinued transistors. 1974–75 ed. *D.A.T.A.* REF.

'Transistor D.A.T.A. book.' Autumn 1974 ed. *D.A.T.A.* REF.

Richman, Paul
'MOS field-effect transistors and integrated circuits. *Wiley*, 1973. [December 1974].

Information Theory

Petrov, B. N. and Csaki, F. *eds.*
'Second international symposium on information theory.' Held at Tsahkadsor, Armenia, USSR 1971). *Akademiai Kiado*, 1973.

Radio

American Radio Relay League
'Radio amateur's handbook.' *A.R.R.L.*, 51st ed. 1974.

Eastwood, Sir Eric *ed.*
'Wireless telegraphy.' *Applied Science Publishers*, in series Royal Institution Library of Science, 1974.

Wireless World
'Guide to broadcasting stations.' *Butterworths*, 1973. REF.

Computers

Lewin, Douglas
'Logical design of switching circuits.' *Nelson*, 1974. 2nd ed. [December 1974].

Bishop-Miller, W. B. and Yousefzadeh, B.
'Solution of problems in computer and control engineering.' Vol. 1 *Pitman*, 1974.

Charlesworth, A. S. and Fletcher, J. R.
'Systematic analogue computer programming.' *Pitman*, 1974.

Rippingale, R. C.
'Programming by telephone in BASIC.' *Pitman*, 1973.

Audio Equipment

'Sound verdict'.
Annual index to audio articles and equipment reviews during the past year in 14 periodicals. Camden Libraries. Nos. 1–6, 1969 to 1974, plus supplements for 1974.

Biography

Williams, L. Pearce
'Michael Faraday. A biography.' *Chapman & Hall*, 1965.

Pike, W. T. *ed.*
'British engineers and allied professions in the twentieth century. Contemporary biographies.' *W. T. Pike & Co.*, 1910.

History

Sarnoff, David
'Looking ahead. The papers of David Sarnoff.' *McGraw-Hill*, 1968.

Swift, John
'Adventure in vision. The first twenty-five years of television.' *John Lehmann*, 1950.

Recent Accessions to the Library

This list of additions to the Library covers the period September to December 1974. With the exception of titles marked 'REF', *which are for reference in the Library only, these books may be borrowed by members in the British Isles by personal call or by post. Information on loan conditions can be obtained from the Librarian, Mrs. S. A. Clarke. The dates shown in brackets refer to reviews or shorter notices which have appeared in The Radio and Electronic Engineer.*

New Periodicals

Communication and Broadcasting. Summer 1974 Vol. 1 No. 1 —Quarterly journal of Marconi Communication Systems Ltd.

Electronics Information and Planning. Vol. 1 Nos. 1–8, Oct. 1973 to May 1974.
—Monthly journal of Electronics Commission, India.

IBA Technical Review. No. 4 September 1974.

Independent Broadcasting. No. 1 August 1974.

Conference Proceedings

Control Aspects of New Forms of Guided Land Transport. IEE Conf. Pub. No. 117. 1974.

Precision Electromagnetic Measurements. (Digest) IEE Conf. Pub. No. 113. 1974.

European Conference on Circuit Theory and Design. IEE Conf. Pub. No. 116. 1974.

International Conference on Frontiers in Education. IEE Conf. Pub. No. 115. 1974

URSI Symposium on Electromagnetic Wave Theory. IEE Conf. Pub. No. 114. 1974.

Gas Discharges. IEE Conf. Pub. No. 118. 1974.

Fifth colloquium on Microwave Communications, Akademiai Kiado, Budapest, 1974. (5 vol.)

International Broadcasting Convention. IEE Conf. Pub. No. 119. 1974.

General Reference Works

Collocott, T. C. & Dobson, A. B. *eds.*
'Chambers's dictionary of science and technology.' *W & R Chambers*, 1974. REF.

Aslib
'Index to Theses accepted for higher degrees by the universities of GB and Ireland and the CNAA.' Vol. XXII 1971–72. *Aslib*, 1974. REF.

Education and Science, Dept. of.
'Scientific research in British universities and colleges.' 1973–74 Vol. 1 Physical sciences Part 1: sections 1–36; Part 2: name and subject indexes. *HMSO*, 1974. REF.

Corbett, Lindsay
'Electronics: a bibliographical guide.' Vol. 3 *Macdonald*, 1973. REF.

Jackson, K. G.
'Dictionary of electrical engineering.' *Butterworths*, 1973. REF.

Aslib
'Directory of Information Resources in science, technology and commerce.' *ed.* Brian J. Wilson. Vol. 1 *Aslib*, 1970. REF.

Engineering

Thring, Professor Meredith W.
'Machines—masters or slaves of man?' *Peter Peregrinus*, 1973. [December 1974].

Finance

Rockley, L. E.
'The non-accountant's guide to finance.' *Business Books*, 1970. [October 1973].

Public Administration

Cabinet Office.
'Government research and development: a guide to sources of information.' *HMSO*, 1974. REF.

Economics of Electronics Industry

National Economic Development Office.
'Company financial performance in the electronics industry 1969/70–1972/73.' *N.E.D.C.*, 1974.
'Industrial review to 1977: Electronics.' *N.E.D.C.*, 1973.

Education

'Commonwealth Universities Yearbook, 1974.' *Association of Commonwealth Universities.* REF.

Signal Processing

Helms, Howard D. and Rabiner, Lawrence R., *eds.*
'Literature in digital signal processing.' *IEEE Press*, 1973.

Physics

Vincent, C. H.
'Random pulse trains. Their measurement and statistical properties.' *Peter Peregrinus*, 1973. [December 1974].

Electricity

Mullard Limited. (*eds.* J. van Randeraat & R. E. Setterington.)
'Piezoelectric ceramics.' *Mullard*, 1974. 2nd ed. [December 1974].

Materials

Wyatt, Oliver H. and Dew-Hughes, David
'Metals, ceramics and polymers. An introduction to the structure and properties of engineering materials.' *Cambridge U.P.*, 1974. [December 1974].

Electrical Engineering

Say, M. G.
'Electrotechnology.' *Newnes-Butterworths*, 1974.

Paddock, J. O. and Galvin, R. A. W.
'Engineering principles for part 1 electrical and telecommunications technicians.' *English U.P.*, 1973.

Eurolec United Kingdom Ltd.
'Connectors on offer in the United Kingdom. A buyers' guide and directory 1975.' *David Rayner*, 1974. REF.

Maissel, Leon I. and Glang, Reinhard, *eds.*
'Handbook of thin film technology.' *McGraw-Hill*, 1970.

Miller, Gary M.
'Linear circuits for electronics technology.' *Prentice-Hall*, 1974.

Circuit Theory

Meadows, R. G.
'Problems in electrical circuit theory.' Part 2, *Cassell*, 1974.

Oliver, Frank J.
'Practical relay circuits.' *Pitman*, 1973. [April 1974].

Rogers, F. E.
'Illustrations in applied network theory.' *Butterworths*, 1973. [December 1974].

Electronics

Ferrari, R. L. and Jonscher, A. K.
'Problems in physical electronics.' *Pion*, 1973. [December 1974].

Mullard Data Book 1974/5.
'Abridged data on electronic components.' *Mullard*, 1974. REF.

Olsen, G. H.
'Electronics. A handbook for engineers and scientists.' *Butterworths*, 1974. 2nd ed.

Lenk, John D.
'Handbook of electronic components and circuits.' *Prentice-Hall*, 1974.

Wade, J. T. and others
'Electronic circuit analysis: a first course.' *Wiley*, 1973. [December 1974].

(*continued on opposite page*)

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

Applicants for Election and Transfer

The Membership Committee at its meetings on 28th December 1973 and 26th November 1974 recommended to the Council the election and transfer of 22 candidates to Corporate Membership of the Institution and the election and transfer of 8 candidates to Graduateship and Associateship. In accordance with Bye-law 23, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communication from Corporate Members concerning those proposed elections must be addressed by letter to the Secretary within twenty-eight days after the publication of these details.

Meeting: 28th December 1973 (Membership Approval List No. 201)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Graduate to Member

CARRINGTON, Philip John. *Huntingdon, Cambs.*
SIERTSEMA, Winfred John. *Kennington, Oxford.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Graduate to Member

PRABHU, Ramachandra. *Bangalore, India.*
RATAN, Bhakt. *Sindri, Bihar.*
SMIKT, Oded. *Rehovot, Israel.*

Meeting: 26th November 1974 (Membership Approval List No. 202)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Member to Fellow

DENNY, Ronald Maurice. *Ealing, London W.5.*
DUCKWORTH, Brian Gordon. *Stamford, Lincolnshire.*
HAIG, Philip Ernest. *Wembley, Middlesex.*
HOLT, Alan George James. *Newcastle-upon-Tyne.*
LEWIN, Douglas William. *Ealing, London W.5.*
REES, Gareth Huw. *Wellingore, Lincolnshire.*
TUCKER, John Drew. *Old Coulsdon, Surrey.*

Transfer from Graduate to Fellow

HUGHES, William Eric. *Marlow, Buckinghamshire.*

Transfer from Graduate to Member

DENMAN, Derek. *Earls Court, London.*
HAILSTONE, Michael William John. *Blackwater, Hampshire.*
QUINN, William Michael. *London S.W.19.*
RAAB, Michael Louis. *Windsor, Berkshire.*
SAWYER, David Peter. *St. Helens, Lancashire.*
THORNTON, Arthur Roger David. *Southampton, Hampshire.*
THURLEY, Derick James. *Streatham, London.*

Direct Election to Member

CROFTS, Andrew. *Milton Keynes, Buckinghamshire.*
FLORENCE, Stanley. *Bearsden, Glasgow.*
RIMINGTON, John William. *London, N.13.*
TURNEY, Peter Alan. *Basingstoke, Hampshire.*

NON-CORPORATE MEMBERS

Direct Election to Graduate

GOILLAU, Peter James. *Poole, Dorset.*
PHILLIPS, Ian. *Malmesbury, Wiltshire.*

Transfer from Student to Associate Member

HUNT, Christopher Douglas. *Braintree, Essex.*
RUBAROE, Gramini Tissa. *Stubbington, Hampshire.*

Direct Election to Associate Member

HAUXWELL, Michael John. *Burton Upon Trent, Staffordshire.*
JOYCE, Patrick Donald. *St. Helens, Isle of Wight.*
PARKINSON, Christopher Derek Thomas. *Amesbury, Wiltshire.*
RIDDIOUGH, Alan. *Barnsley, Yorkshire.*

STUDENTS REGISTERED

ABRAMS, Anthony Austin. *Rushden, Northamptonshire.*
ALCOCK, Christopher Stanley. *Stafford.*
ALLINGTON, Kevan John. *Bath.*
APPLEGATE, Barry Victor. *Beeston, Nottinghamshire.*
BAILEY, Nicholas Raymond. *Stafford.*
CUSHING, Richard Andrew. *Twickenham, Middlesex.*
EDGAR, Thomas Henry. *Gateshead, Tyne and Wear.*
JENNINGS, Paul Ian. *Stafford.*
KENDALL, Leslie. *Wednesbury, West Midlands.*
LUK, Leung Ping. *Penylan, Cardiff.*
NAYAR, Bimal Kumar. *London N.W.2.*
TOUT, Michael John. *Corsham, Wiltshire.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Member to Fellow

PROCTOR, Eric James. *Hong Kong.*

Transfer from Graduate to Member

FASANYA, Tim Ife. *Lagos, Nigeria.*
WONG, Sin Pui. *Kowloon, Hong Kong.*

Direct Election to Member

PICKFORD, Harold David. *Teheran, Iran.*
RAZZAQ, Abdul. *Islamabad, Pakistan.*
YOUNG, Gordon Henry. *Vanves, France.*

STUDENTS REGISTERED

CHOO, See Chiah. *Singapore.*
CHAN, Kwok Wai, Joseph. *Hong Kong.*
CHAN, Chi-Hong. *Kowloon, Hong Kong.*
CHAN, Cheong Loong. *Seberang Perai, West Malaysia.*
HO, Yu Sum. *Kowloon, Hong Kong.*
KWAN, Hon Keung. *New Territories, Hong Kong.*
KAYODE, Oludipe B. *Ibadan, Nigeria.*
KWAN, Man Keung. *North Point, Hong Kong.*
KWOK, Leung Bute Albert. *Kowloon, Hong Kong.*
LAU, Wai Man. *Kowloon, Hong Kong.*
LAU, Kin Wa, Henry. *North Point, Hong Kong.*
LEE, Ting Fai. *Shaukiwan, Hong Kong.*
LEUNG, Wai Chiu. *Hong Kong.*
LEUNG, Hoi To. *Kowloon, Hong Kong.*
LO, King Chuen. *Kowloon, Hong Kong.*
LO, Pui Kwan Henry. *Chai Wan Estate, Hong Kong.*
MAK, Ho Kong. *Kowloon, Hong Kong.*
NG, Kai Ming. *Kowloon, Hong Kong.*
NG, Kwok Cheung Anthony. *North Point, Hong Kong.*
NGAI, Chi Yuen. *Kowloon, Hong Kong.*
POON, Ka Fat Albert. *Hong Kong.*
SEOW, Sin Khiang. *Singapore.*
SIU, Wan Chi. *Kowloon, Hong Kong.*
TAN, Kim See. *Malacca, Malaysia.*
TANG, Kang-Shun, *Kowloon, Hong Kong.*
WONG, Bing Leung. *Kowloon, Hong Kong.*
WONG, Hing Fai. *Hong Kong.*
WONG, Kwan Hon. *Kowloon, Hong Kong.*
YAN, Sum Kwok. *Kowloon, Hong Kong.*
YU, Kook Mong, Edward. *Kowloon, Hong Kong.*
YUE, Lai Chor. *Kowloon, Hong Kong.*
YUEN, Chung Him. *Kowloon, Hong Kong.*