The Journal of

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

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Qualification *and* Ability

NOT the least of the services performed by a professional institution is certification of specialized professional qualifications. A university degree or a Diploma in Technology certifies that the holder has benefited from education and training of a certain standard. Corporate membership of a professional institution certifies in addition that the member has practised his particular profession and held a position of responsibility in it.

Without such certification, the task of selecting candidates for posts in industry, government service or the technical branches of the armed forces would be prohibitively difficult. An appointing committee would be faced with the task of assessing the education, training and responsible experience of each individual applicant. Such an assessment involves detailed knowledge of the courses provided by a host of varied educational bodies and a familiarity with the status of an even greater variety of industrial and other occupations. It is the business of professional institutions to have this detailed and specialized knowledge and, through their certifying activity, to place it at the disposal of the community.

Despite the universality of the B.A. degree of the two older universities, education is no longer one and indivisible. Few committees, appointing to a post in industry, will be satisfied by an assurance, however reliable, that a man is well-educated. "Educated in what?", they will ask—and in 1959 the question is legitimate. In the same way, it is not sufficient to certify a man as a qualified professional engineer. "What kind of an engineer?", asks the appointing committee. "Can he do this particular job?"

How many branches of engineering need there be for the purposes of certification? The answer is: enough to provide a *prima facie* answer to the question, "Can he do this job?" In 1959, the statement that a man is a professional Electrical Engineer no longer provides a *prima facie* case for deciding whether he could adapt himself to the task of designing, say, transistor circuits for radar applications. The statement that he is a professional Radio and Electronics Engineer does provide such a *prima facie* case.

In these days of rapid scientific advance, interest and activity can flare up in some specialized sub-branch of engineering, making it necessary for a professional institution to cater for this specialized interest by forming a specialized group within the institution. It is not usual for membership of such a group to be made conditional upon the member having any regular training or professional experience in the particular sub-branch of the subject. Any attempt in these circumstances, to construe membership of such a group as *certification* would reflect upon the integrity of the certification of the institution as a whole.

A quarter of a century ago*, it might have been just legitimate to regard radio and electronics as a specialized sub-branch in which there had been a flare-up of interest and activity. Today, however, the figures of employment, capital investment, production, exports, diversity of application, and volume of publication of scientific literature, all are incontrovertible evidence that Radio and Electronics can no longer be adequately catered for by a specialized group, innocent of specialized certification of professional qualifications.

E.W.

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* The American Institute of Radio Engineers was founded in 1912 and the Australian Institution of Radio Engineers was founded in 1924.

INSTITUTION NOTICES

Council Dinner

The Dinner of the Council and Standing Committees of the Institution will be held in the Lincoln and Manhattan Rooms of the Savoy Hotel, London, on Thursday, April 23rd. The Immediate Past President, Mr. George A. Marriott, and Mrs. Marriott will be Guests of Honour, and the occasion will provide an opportunity to express appreciation of Mr. Marriott's work during his Presidency.

It is hoped that members who are attending will be accompanied by their ladies. Tickets may be obtained on application to the Institution.

Institution Visit

As already announced, a visit to the Luton works of Vauxhall Motors Ltd. has been arranged by the Technical Committee for Tuesday, April 7th.

Members wishing to take part in the visit should send in their names to the Institution as soon as possible; guests' names may also be included on the understanding that preference will be given to members in the event of the number of applications exceeding the places available.

Applications will be acknowledged, but it will not be possible to give confirmation in respect of guests until a fortnight before the visit is due to take place.

Students' Essay Competition

The Council announces that the subject for the Students' Essay Competition for 1959 will be:—

"The Future of Electronics in Industry."

Entries are now invited from registered Students of the Institution as well as from Graduates who are under the age of 23 at the closing date of the competition. Essays, which should be between three thousand and five thousand words in length, should preferably be submitted in typed form, using one side of the paper only. The closing date for both home and overseas competitors is 30th June 1959.

A prize of £10 10s. will be awarded for the best essay; additional prizes may be awarded at Council's discretion for essays which are highly commended. The Council reserves the right to publish the prize-winning essay in the *Journal*.

It will be recalled that the Essay on "The Evolution of Radio Communication" which gained the 1957 prize was published in the June 1958 *Journal*.

Telemetry Symposium

Some of the work which the electronics industry has carried out for the British guided missile programme will be described at an Institution meeting on March 25th. A half-day Symposium on Radio Telemetry is to be held at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, W.C.1, under the chairmanship of Mr. I. Maddock, O.B.E. (Member).

The afternoon session, commencing at 3 p.m., will be opened by an introductory survey of the Ministry of Supply requirements in missile telemetry by an engineer from the Royal Aircraft Establishment. Engineers from industry will then read three papers describing a 24-channel time-division multiplex f.m.-a.m. system.

The titles of the six papers are listed under "Forthcoming Institution Meetings." The papers and associated discussion will be published in the *Journal* shortly after the meeting.

Group Provident Scheme

Following the announcement in the June *Journal*, the Council has set up an Institution Group associated with the Scheme operated by the British United Provident Association. Members wishing to receive further details should write to the General Secretary of the Institution.

Back Copies of the Journal

The Institution has received requests for the following issues of the *Journal* which are now out of print:—

May 1956
December 1956
July 1957.

Members who have copies for disposal of these issues, in good condition, are invited to send them to the Brit.I.R.E. Publications Department, 9, Bedford Square, W.C.1; a payment of 5s. per copy will be made.

It should be noted that these are the *only* back copies which are required at the moment.

BIOLOGY AND ELECTRONICS†

by

Professor A. V. HILL, C.H., SC.D., F.R.S.‡

An Address given at the Inaugural Meeting of the Medical Electronics Group in London on 23rd January 1959.

In the Chair: The President, Professor E. E. ZEPLER.

When the Secretary, on behalf of your Council, invited me to give the inaugural lecture to the Medical Electronics Group of your Institution I replied—much as I welcome its foundation and applaud its purpose—that it would be far better to ask someone who knew something about electronics. Wisely or not he persisted, and an emissary of his, Mr. Copeland, persuaded me that ignorance was not a sufficient disqualification; and that I might be able to tell you various ways in which your activities could help ignorant people like me in some of our problems. With that hope I accepted. It is true that I have been very fortunate, over many years, in the acquaintance and friendship of engineers: and there is, in fact, an intellectual kinship between engineers and physiologists, for both deal with machinery, with things that work; to both the idea of function, of purpose and design, is an essential part of their mental activity. Nearly fifty years ago when I began to do research on the thermodynamics of muscle I thought it would be a good thing to go and consult the professor of engineering at Cambridge, Bertram Hopkinson: for muscle was, and still is, the chief—or at any rate the most versatile—prime mover in the world; and it still provides, as techniques continue to improve, the most exciting scientific problems. Hopkinson, as it proved, could not throw much light on muscle; but I had many pleasant and fruitful contacts with him later, in quite different fields, until he was killed flying in 1918. Keith Lucas, a pioneer in nerve physiology, from whom I learnt very much, was also by instinct an engineer, an instinct which showed itself in many beautiful physiological instruments still in use. He was a director of the Cambridge Scientific Instrument Company, which indeed was founded in the 1870's by an earlier physiologist, Dew-Smith: and later he designed instruments at Farnborough for the Royal Flying Corps, particularly compasses and bombsights, until he too was killed flying in 1916. How Lucas would have enjoyed the speed, ease of precision of the instruments which electronics has produced since—he had nothing better than the capillary electrometer then.

During the first world war again I had much encouragement and help from engineers, particularly Alexander Kennedy a consulting engineer, of Kennedy and Donkin, formerly professor of engineering at University College, London, where he had built the first university engineering laboratory in this country. Kennedy once paid me the compliment, which I have treasured since with many memories of him, of saying that I was an engineer gone wrong. Others were Horace Darwin, also of the Cambridge Instrument Company, and William Hartree whom, after the war, I persuaded to give up engineering and come and work with muscles for 14 years. Later there were Joseph Petavel, Director of the National Physical Laboratory, E. G. Coker, professor of engineering at University College, and his successor Geoffrey Hill, aircraft designer, who once read a joint paper with D. M. S. Watson the zoologist, on "Pterodactyls Ancient and Modern." It was Coker, I suspect, who somehow induced the Institution of Mechanical Engineers to invite me to give the Thomas Hawksley Lecture in 1935, under a title which included the phrase "the development of power and the transmission of messages in the body." That lecture had to be repeated in six other centres, which widely extended my contacts with practical engineers: so, I can

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† Manuscript received 24th January 1959. (Address No. 16.)

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U.D.C. No. 577/8:621.37/8

claim, by proxy, some excuse for addressing the British Institution of Radio Engineers. And in talking of the past I must not forget the present. For many years my work has depended on the skill and artistry of A. C. Downing, who was apprenticed originally to Cromptons at Chelmsford and has become pre-eminent in the field of micro-engineering, as we call it, in physiology and biophysics: and during the last 12 years I have used the electronic instruments specially designed for their job in a biophysics laboratory by B. C. Abbott, now a physiologist in Los Angeles, who spent the war in Signals, by Vincent Attree, an electronics engineer who came to us from the R.A.E. and is now a lecturer in engineering at Manchester, and Keith Copeland, one of your Group, who worked with Attree and fortunately is still at hand to help when things go wrong. For I am too old myself to construct, or to diagnose the complaints of, electronic apparatus—I was brought up on mass, elasticity and friction, and later on direct current and classical electromagnetism, not on electron clouds or holes in semi-conductors: though, as it proved, I wasn't too old to profit by the devices that these electronics engineers thoughtfully put in my hands.

I tell you all this because there must be lots of folk like me, and you can take me as a sample of the sort of people who need your help. Indeed the scope of that help could be much wider than the title "Medical Electronics Group" suggests; a better title would be "*Biological Electronics Group,*" for biology covers much more ground than medicine (which is one branch of it), and offers the same widespread opportunity for the use of electronic methods. It is true that a Medical Electronics Centre was set up in 1955 in the Rockefeller Institute in New York, by no less a person than Zworykin. But its activities, some of which I will refer to later, go far beyond medicine, as indeed yours are bound to do: and before you are too heavily committed to your present limited title I suggest that you might consider the advantages of the wider one.

The scope of your activities, as I see it, may be something like this. Throughout the range of biology there are research workers who have a pretty clear notion of what they want to do but usually rather a vague idea of how electronics can help them to do it. A few of them may have a good amateur knowledge of electronics, they can usually look after themselves: but the majority may spend—or largely waste—much of their time in trying to meet requirements which the professional electronics engineer could satisfy quickly and much more efficiently. But a condition of meeting their needs that way is that personal contact and familiarity should be established, so that the biologist can explain his problems and requirements, and the engineer—given such information—can plan how best to meet them. Sometimes the enterprise will become a joint one, in which biologist and engineer have equal but different shares: but often the needs and problems of the biologist will be met quite simply, from stock so to say, by existing knowledge and equipment. All this I imagine you have in mind, and particularly the motive that your Biological Electronics Group—as I insist on calling it—shall be a means of bringing biologists and engineers together and providing a sort of exchange by which biological requirements, on the one side, can be put in contact with physical knowledge and possibilities on the other.

The physical problems of biology have several characteristics which are rather different from those of ordinary physics or engineering. Chief among these is the very small size of the ultimate biological unit, the living cell; and associated with that is the fact that experimental interference with the cell may change the very things one is trying to examine. Another characteristic is that the fundamental biological event may involve very small physical or chemical changes. One can make these changes greater sometimes by causing the event to be repeated: but too often the chief result of that is to mix up the successive phases of the single event with one another, and so cause confusion. Moreover those changes are apt to be very rapid: and since in all recording devices sensitivity, stability and speed are mutually antagonistic, it is often necessary to work out a compromise.

An example of this sort of thing, from my own experience, may interest you. The messages that travel in nerves are not purely physical waves, though physical effects accompany them: the energy required for their transmission is not supplied impulsively at the start, as it is in ordinary waves. A distributed relay system is present, by which energy is available all along the conductor to maintain the transmission. In order to prove this, attempts were made, over many years starting with Helmholtz in 1848, to measure the heat, if any, associated with the passage of nerve impulses. If the transmitted wave were purely a physical one, then there would be no net heat production associated with its passage, for there was no evidence at all that the wave diminished in size as it went along. If energy *was* provided all along the nerve to assist the passage of the wave, this energy would appear as heat after the wave had passed; and if this heat could be detected and measured a decisive confirmation would be obtained of the existence of the distributed relay system.

For 80 years all attempts to do this were unsuccessful: the heat was too small to measure by available methods. In the end, however, it *was* measured and found to obey quite definite rules. Since 1926, when this was first done, methods have been continually improved and new technical resources have been brought in: and in recent experiments it was possible to record the heat in a single nerve impulse. A sudden burst of heat was found to occur during the actual passage of the wave, followed by a rather slower, but still rapid *absorption* of heat, the net result being a total rise of temperature of about 2 millionths of a degree. Thus the original question was answered and it became certain that energy is required all along a nerve to ensure the passage of an impulse. This energy must be derived from chemical change, for no other source of energy is conceivably available: and thus, as in all scientific research, a new question immediately arises from the answer to an earlier one—what are the chemical changes that occur as an impulse goes by? To that no answer is as yet in sight, nor will it be easy to find one, since the quantities involved are so exceedingly small. But physiologists and biochemists will not be happy till the chemical question is answered, for ultimately all the processes of life are chemical, or physico-chemical, ones. Indeed, if I may hazard a guess, one of the chief opportunities of electronics in the future will be to help to sort out, describe and measure the sequence of events in chemical reactions: it will not be easy, but it should be possible.

You will naturally ask how the heat in nerve was measured. The only practical method was to use a thermopile with a large number of junctions: but this had to be extremely thin, in order to be fast enough, and moreover its insulation had to be very good in order to avoid leak of the currents produced by the nerve itself as the impulse goes by. The best thermopile hitherto constructed gives about 4 mV for 1° C: so a rise of temperature of a 2 millionths of a degree would give only 8 thousandths of a microvolt. That was the whole amount available for measurement, and if one wanted to measure it within even 10 per cent. one would have to read to 8 ten-thousandths of a microvolt. Anyone acquainted with d.c. amplifiers will know that this is quite beyond the range of ordinary electronic amplification: in fact the whole quantity to be measured is below the noise level of any system that could be used. Fortunately, however, a thermopile may have quite a low resistance and one exploits this property to make the measurement possible: it simply has to be coupled to a galvanometer of very high sensitivity, and the earliest successful experiments were made in that way. These showed clearly enough that heat was in fact produced; but sensitive galvanometers are normally very slow, and it was important to find out not only that heat *is* produced, but when. It was necessary therefore to construct much quicker galvanometers. That has taken a good many years.

But galvanometers, like all other instruments, have the unfortunate property that the quicker you make them the less sensitive they become. This is a law of nature which you cannot get round; it applies to balances and mechanical devices of all kinds, just as it does to electrical ones. In general the sensitivity varies inversely as the square of the speed: in electronics you may have other words for it, but the principle is the same. My colleague, Downing, has made a wonderful family of galvanometers, with deflection times of the order of 1/100 sec: but these by themselves are far too insensitive to measure the currents available. Their movements, however, can be amplified by shining the reflected beam from the galvanometer's mirror on the two opposing cathodes of a twin phototube, the output of which is amplified and displayed on a cathode-ray tube.

That sounds easy, but it is not easy at all, because of the third factor which comes into all measurements, stability, or as I suppose you would call it, "noise." It is no good magnifying a deflection 500 times if one magnifies mechanical and other disturbances 500 times as well. This difficulty has been largely got over by two means: first, Downing has made the moving systems of his galvanometers extremely symmetrical (to be precise, with the principal axis of inertia lying along the line of suspension) so that external disturbances affect them relatively little: balancing of his instruments is an essential condition of amplification: and secondly the galvanometers, with their accessories, are mounted in hanging carriages, insulated from the outside world by successive masses and compliances—you will know the physical principle better in terms of successive inductances and capacitances. By such means it is possible under very quiet conditions to amplify the deflection of a galvanometer right up to the absolute limit set by the Brownian movements of its coil. Normally, in Gower Street at least, where all kinds of devilish devices are present, shaking the whole building, only about one-tenth of that amplification is worthwhile: but a 200-fold amplification *is* possible, and has allowed these measurements of small quantities of heat to be made with instruments rapid enough to show, with fair precision, when they occur.

Well, that is the story of a research which has been going on for 110 years and it has been told in five minutes: which is a condensation in the ratio of about 20 millions to 1. You may recognise in it many of the problems which, under a different guise, bother all people who try to measure very small quantities quickly as well as accurately: the physical principles are universal.

I said earlier that I would tell you about the Medical Electronics Centre now functioning at the Rockefeller Institute: I regret to say that it is not yet called a Biological Electronics Centre, so perhaps you will be able to get in first with a new and better name! I shall have to talk to my friend Detlev Bronk, who is President of the Institute, about it. This Centre was established in 1955, a year after Zworykin went to the Institute. As a result of its initiative a small international meeting was held last year in Paris, with the object of bringing together biologists and medical scientists on the one side and physicists and radio engineers on the other. As an outcome, as I understand, of this meeting, the British Institution of Radio Engineers decided to form a Group to further co-operation of the same kind in this country.

The Electronics Centre at the Rockefeller Institute started with a series of small informal conferences to which medical and biological research workers, physicists and electronics engineers, instrument manufacturers and occasionally clinicians, came to exchange views about their problems. A conference on measuring extremely small quantities of protein, such as occur in the transmission of virus diseases, discussed the application of such methods as magnetophoresis, fluorescence, photometry and ultra violet absorption. Discussion of instrumentation in surgery included methods of monitoring the CO_2 content of a patient's blood and providing signals to control a mechanical respirator. Surgery also led to a discussion of the need to keep hospital architects informed of the need in operating rooms to provide space and facilities for proper instrumentation: it is not easy to coerce architects. A conference on electroencephalography produced a plan to define specifications for improved display by electronic apparatus, to be submitted to manufacturers. Running through all discussions was the problem, analogous to one in pure physics, of designing transducers that detect what we wish to observe, measure or control without modifying it so much that the result is meaningless, or the object damaged, or both. A conference this time last year discussed methods and problems in artificial internal organs, kidneys, respirators and oxygenators; also ocular devices, and guidance systems for the blind: also power requirements and power supply for various artificial organs, and the controls and signals necessary to ensure reliability.

Among the instruments developed by the Centre is a very small pressure-sensitive radio transmitter, that can be swallowed (of course without any wires attached to it) and used to record movements along the digestive tract.

Another is a device for observing living cells with three different wavelengths of ultra-violet light, which differently absorbed by the components of the cell, are displayed in three different visible colours on a television tube. Under investigation are devices for measuring the pressure of the fluids inside the eye without disturbing it; and for using the Peltier effect to produce a tiny freezing cell for a microscope stage, so that living specimens can be observed during sudden freezing produced by turning a current on.

Electronics can do many tricks, such as these, that biologists are inclined to regard as magic, but unfortunately there are some it cannot do—at any rate yet—which biologists would like it to very much. Here is an example and a challenge. It is easy by using a current, or a field, of very high frequency to warm the whole of a living tissue, indeed a whole animal if wanted: the word diathermy has been adopted for this, though it is not yet in the Shorter Oxford Dictionary, which in scientific matters is usually 25 years late. I have often thought what a wonderful experiment could be made by warming a whole man—or his lower limbs—a few degrees, quite quickly, in a powerful machine, and then, before he had time to cool down, to let him loose on a track to run 100 yards in eight seconds. For a rise of temperature of 2° would make his muscles move 15 per cent. faster, which could reduce 9·4 sec to 8 sec. But unfortunately the converse process to diathermy is at present quite impossible: that is to say, there is no known method of *cooling* the inside of a living organ or animal other than the prehistoric one of putting it in a cold bath. That method of cooling is bound to be extremely slow, because water (of which living material is chiefly composed) is a very poor conductor of heat: and the process cannot be quickened by using a very low temperature outside because that would freeze, and damage or kill the outer tissues. There is no general physical principle that I have ever heard of that prohibits internal cooling by some method less old-fashioned than applying cold to the surface: but nobody yet has ever thought of a practical one. It would have wide applications in biology and medicine. No doubt you can think of various other devices, at present impossible, which are badly needed in biology: and no doubt some of them will be constructed within the next 10 years.

Electron microscopy comes within the range of your Group: but in spite of the wonders it can perform it has one acute limitation at present, as applied to biology, compared with the light microscope, namely that objects examined by it are totally dehydrated and killed. If somehow that condition could be avoided, what a wonderful tool would be created for examining the structure and mechanism of cells while normally alive. Whether that is a futile dream I do not know. Studies of X-ray diffraction are possible on living material, though if such a rapid process as the contraction of a muscle is to be studied by means of it, a sequence of very short exposures in rapid succession would be needed. I used to talk to W. T. Astbury about this without, so far as I know, much effect: but perhaps methods have greatly improved since then.

A thing I have long wanted myself, and this is more practical, is a simple arrangement that would record directly, preferably as a function of time, the mechanical work done by a contracting muscle, or done on it when it is stretched. It is, of course, quite easy to record force and distance simultaneously against time, or directly one against the other; but then one has to work out the area of the force-distance diagram and that takes time and arithmetic; the quantity wanted, is not recorded, in ergs or kilogram-metres, immediately before one's eyes. Somehow force and distance have to be combined, so that their integral is recorded or displayed directly on a scale or curve. Scientific research, at any rate in biology, is generally like a game of tennis, in which one has to see the result of one's stroke immediately, not wait to develop a photograph and then do arithmetic on it: one's next stroke depends on the result of one's last. There are many possible applications of such an arrangement, on a large scale when human muscular movements are to be measured, on a small scale when an isolated muscle does work, or has work done on it, amounting to a few gram-centimetres. If I could spend several years on it I daresay I could devise something of the kind myself. But it would be a terrible waste of time, for there are probably many people here who could devise something better in a few hours.

Fifteen years ago I had a special friend who used to mock me by making noises which he thought were like mine. If I blew my nose when he was at the other side of the room he would give a loud shriek while he flew across to sit on my shoulder. To *my* ears this shriek was not at all a good copy of the original, but it obviously was to his. If he heard a tap running he would start to make an irregular gurgling noise, with the same sort of rhythm as the tap, but a much higher pitch. He died during the late war so I was unable to carry out on him the experiments which I had planned when I returned to my laboratory. His behaviour gave me a strong impression that he could not hear sounds of lower pitch at all, as he certainly could not make them: but that he copied rather accurately the rhythm and the higher tones of what he heard. It would not be difficult to-day to analyse and compare the sounds which he tried to imitate and his imitations of them; and he was such a forthcoming fellow that all kinds of interesting experiments could have been made with him. No doubt there are many other budgerigars in this country, with the same kind of comic responsiveness as his: and if any of you are acquainted with one, and have a few hours to spare from more serious but less amusing tasks, I hope you will turn your resources of tape recorders, microphones, sound analysers and cathode-ray tubes on to the experiments which my friend's sad end prevented me from undertaking after the war. They would certainly be entertaining and something quite serious, in the field of hearing, might come out of them.

For many years I have been telling athletes that they ought to measure the times of their sprints accurately—and not only total times over the whole distance, but the acceleration at the start, the maximum speed and the slowing that comes on as fatigue sets in. To-day this would be an extremely easy thing to do, the results could be recorded on counters, or by ink writers on moving paper, or displayed in a great variety of ways. If I were a young athlete there

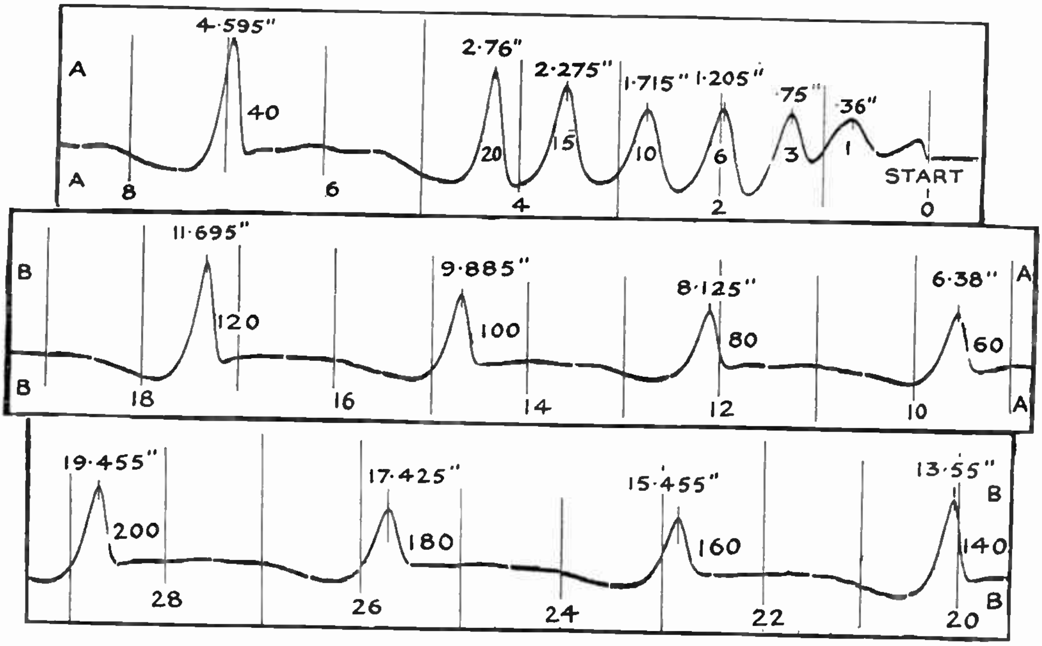

Fig. 1. Record for a first-rate 100- and 220-yards runner over 200 yards. Cut into three portions at AA and BB. Read from right to left and from top to bottom. Distances are given in yards by the side of or beneath the several waves. The cross-lines mark time in units of 0·683 second. The peaks of the waves are marked in for ease of measurement. (Reproduced, by permission of the Royal Society, from Furasawa, Hill & Parkinson, "The dynamics of sprint running," *Proc. Roy. Soc. B*, **102**, p. 36, 1927.)

is nothing I should enjoy more than to experiment with difference techniques of running; measuring accelerations; speeds up and down hill, with and against a wind; even fluctuations of speed over each cycle of movement. Such studies might considerably improve our knowledge of athletics, and possibly also performance: and since national prestige is involved in competitive athletics, as it is in shooting at the moon, this might secure large public support. About 30 years ago I did carry out a series of such experiments at an American university, and the results were extremely interesting. The method was very crude, the only apparatus was a magnetized hack-saw blade tied around the runner's body, a set of coils every few yards along the track, and of course a quick galvanometer to record the induced currents on photographic paper: but crude as it was it showed what could be done. (See Fig. 1.) Similar methods could be used on animals: one hears stories—which I do not believe—of a cheetah or ostrich being able to run at 80 miles/hr.; it would be quite easy with modern devices to find out what the truth is. It might not be very useful, though nobody can tell beforehand; but it certainly would be amusing and that is one of the best motives for scientific research.

Far the largest animal that ever has existed is the blue whale. It provides all kinds of intriguing problems, particularly in connection with respiration and circulation, and the most elementary physiological information is still lacking to tie up with the anatomical facts that are well known. To take an example, in the whole range of land animals, from smallest to largest, the frequency of the heart beat varies approximately inversely as the 0·27 power of an animal's weight. There is no direct evidence about the heart frequency in the whale: but if we allow ourselves to extrapolate 1,700-fold from a man of 70 kg to a whale of 120 tons, the heart rate, according to the formula, should drop from (say) 65 in a man to 12 beats/minute in a whale. One stroke every five seconds does not seem unreasonable in a pump that must weigh nearly a ton: but it should not be impossible to find out experimentally. The whale must not be disturbed or excited, or its heart rate will change: but an electrode dropped in the sea from a buoy could pick up the currents produced by the heart of any whale that came near, and the result could be signalled by radio to a ship or a station ashore. Methods for doing this sort of thing have been well developed by geophysicists examining the ocean floor by sound pulses: and it would be much easier than recording the heart beat, or the brain waves, of a dog or a monkey in a sputnik.

I referred earlier to the expectation that important applications of electronics will be found in future in studying the intermediate chemical, or physico-chemical, processes that go on in living material. The chemistry of the structures of such material and of their products, has been very intensively studied for many years: much more difficult, however, and even more important, is a knowledge of the chemistry of what goes on in between, somewhere so to speak, between the input and the output. Almost the only method at present of studying this is to try to "fix" the living material very quickly, at any given stage, for example by sudden cooling; and then to apply normal chemical methods to it. Incidentally you see here an example of the help that could be given to biochemists by the imaginary invention I referred to earlier, if sudden cooling throughout the depth of a tissue could be obtained by electrical means just as warming can easily be done by diathermy.

There are certain cases in which physical methods can be applied continuously to living tissues to examine what is going on in them, but these are not usually chemically specific. So far as possible one must avoid any manipulation that may injure, or change, the living cell, such as sticking some device inside it—though one can admit that introducing fine capillary electrodes into a cell may, in skilled hands, do little temporary harm, but these are only a fraction of a micron thick. Temperature changes accompanying activity can be picked up by an instrument in close thermal contact with the cells. With changes of hydrogen ion concentration the tissue, e.g. a muscle, can be brought without injury into close contact with a very thin glass electrode, and the alterations of pH inside are then communicated, without too much delay by diffusion, to the recording arrangements outside: in this way a specific chemical change can be investigated. In thin transparent tissues colour changes, or changes in absorption or scattering or polarization of light of different wave lengths, can be studied, and these can often be made to some degree chemically specific. To record such changes rapidly and without disturbance may tax the skill and ingenuity of engineers, for the signal itself may be very small and not capable of being increased without danger of damage, or alteration, to the object examined.

Other physical effects can sometimes be observed during activity in living material, which need rapid, accurate and very sensitive recording. Such for example, is the complicated cycle of volume change that occurs in a muscle when it contracts. This has been known for a long time, it must be related to the chemical and mechanical changes that accompany it: but there is still dispute as to the actual cause and size of the volume changes, and even more as to their interpretation. Modern methods ought to be able to get these questions settled. Volume changes are not chemically specific, but they can be compared with those that accompany known chemical reactions, and so, within limits, can be interpreted chemically. Again, the examination of the internal electrical conductivity of a cell (without sticking electrodes into it); or of the dielectric constants of its material; if the results of such things are to be interpreted properly, they require rapid and error-free recording. Many years ago I ventured to make the pronouncement that the properties of muscles as reported in the text books are chiefly those of the levers used in recording their contractions: that may not be strictly true to-day, at least as regards the levers, though one does see some pretty comic and clumsy devices still: but it probably remains true of most text books. What we used to know as Heath Robinson apparatus still persists, at least in the literature. What is true of muscles is true of a large part of physiology, pharmacology and biochemistry: quicker, more accurate and more sensitive recording would pay good dividends in a variety of studies, so that the properties of the living material, as described, should be less those of the apparatus, and less affected by damage or change inflicted on the material.

This almost becomes a philosophical problem. A living cell is not simply a material object, though it obeys the usual physical laws: it is an event, or rather a continuing sequence of events, in time, space and chemistry. The chief distinction of electronic methods is that they have greatly quickened and facilitated the description of events in time. It is sometimes possible without them, if time is no object, to get down to the absolute limit of measurement: but when things happen as rapidly as they often do in living material, the picture can be largely obscured if recording is not quick enough. Speed is the primary contribution that electronics can bring to biology. But the very small size of some of its recording devices is another contribution of great importance. A man can swallow a small pressure-sensitive radio transmitter to record the movements and pressures along his digestive tract: it is not easy to think of any other kind of device which could do the trick without discomfort, inconvenience and complication. Beautiful pick-up arrangements have been devised for recording pressure and other changes inside the human heart. In recent years one of my chief tools, for mechanical recording, has been the R.C.A. mechano-electronic transducer, a tiny triode with a movable anode, weighing a gram or two. In recent years many instruments have been made much smaller by the use of transistors: and that provokes me to announce still another requirement for your consideration, a transistor which would give a reasonable output when a force, or a couple, is applied to it. That ought not to be so difficult as some of my other requirements and I hope someone can solve it, for physiologists would be greatly in his debt.

Many years ago, while I was reading a paper to the Royal Society, with Rutherford in the Presidential chair, he suddenly remarked—"Hill you make a noise like a physicist." I could not hope to make a noise like an electronics engineer, and in fact had better not, for to him the word "noise" has a specific and rather sinister meaning. But perhaps I have been able to use enough of his jargon to make these remarks intelligible; and perhaps even to qualify me as an honorary elder brother of the new biological electronics group.

REVIEWING THE INTERNATIONAL GEOPHYSICAL YEAR

> *"Physical phenomena occurring on the earth are subject to complex influences, partly of solar origin, the analysis and interpretation of which has hitherto been incomplete and hindered by the lack of carefully co-ordinated observations made simultaneously all over the globe. The object of the International Geophysical Year is to make good these deficiencies by a programme of observations extending over the period from 1st July 1957 to 31st December 1958."*—Sir Cyril Hinshelwood, President of the Royal Society.

THE International Geophysical Year which closed on 31st December, 1958 has provided an unparalleled opportunity for studying the region of the earth's atmosphere extending upwards from about 70 km (45 miles) where the sun's ultra-violet radiation produces the ionized medium which reflects and refracts radio waves. Over 250 observatories have co-operated during the I.G.Y. in the study of the various layers of ionization and information about irregular patches of the ionosphere and extra levels associated with disturbances on the sun will be increased accordingly. Some details of the knowledge which has been gained in this subject and the other fields studied during the observational phase of the I.G.Y. is given in an interim statement which has recently been published by the Royal Society.* Assessment of the fuller implications of the masses of data which are being assembled will of course take several years.

Apart from the routine method of vertical sounding by pulsed radio signals, the I.G.Y. measurements have included studies of absorption using radio waves from radio stars and reflexions from the ionized trails created by meteors, and studies of atmospheric radio noise including that created by lightning flashes. Besides the ionospheric stations operated by the Radio Research Organization of the Department of Scientific and Industrial Research, important United Kingdom contributions to this work have been made by the Cavendish Laboratory, Cambridge; Edinburgh University; University College, Ibadan, Nigeria; King's College, London; Jodrell Bank Experimental Station, University of Manchester; and the University College of Swansea.

Interesting features of the structure of the ionosphere in high latitudes have been revealed at the Royal Society Base, Halley Bay. The most striking is that the maximum ionization density in the F2-layer at noon in winter exceeds the corresponding quantity at noon in summer despite the fact that at the height of the layer the sun neither rises in midwinter nor sets in midsummer. The strong diurnal variation in winter gives electron densities at noon which are ten times those at midnight. Near the equinoxes there is a sudden change from typical winter to typical summer variations. In summer there is a slight inverse diurnal variation, the maximum density at noon being less than that at midnight. It is concluded that the variations of ionization density are mainly due to movements in the ionosphere, the direct ionizing action of the sun being relatively small. Detailed studies confirm that the layer is replenished in winter by ionization moving more or less horizontally.

The studies of irregularities in the ionosphere at the Cavendish Laboratory, Cambridge, and other stations have been extended to include data obtained from observations of the radio transmissions from artificial earth satellites. An hourly I.G.Y. index of meteor activity has been provided from measurements made at Jodrell Bank. Studies of "sporadic E" ionization in the ionosphere have included the use of the back-scatter plan-position indicator at the D.S.I.R. Radio Research Station, Slough. One of the World Data Centres for the Ionosphere is situated at this station and has already received 800,000 photographic records, graphs and tables of data from the 81 stations in the world network which send data direct to Slough or from other World Data Centres.

In the investigations into Solar activity, the flare rocket programme carried through by the U.S. Naval Research Laboratory, in which two-stage solid-propellant rockets have been launched into the ionosphere during the major solar flares, has shown the existence of a power-

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* "Some International Geophysical Year Achievements" (The Royal Society, London, December 1958).

ful flux of solar X-rays in the wave-band 1 to 8 angstroms. It is this radiation which produces the extra ionization in the D-region during a flare and is, therefore, the cause of the short-wave radio fadeouts and long-wave enhancements which are known to occur at these times.

Continuous records of solar radio emissions have been made on many different frequencies at Cambridge and at Jodrell Bank.

Among the most spectacular events of the International Geophysical Year have been the launchings of the first artificial earth satellites by the U.S.S.R. and the U.S.A. The enormous amount of data collected by these new scientific tools for exploring the surroundings of the earth takes many months to analyse and assimilate but the first results of these researches already indicate that there is much new knowledge to be gained from these experiments. The discovery of the belt of high intensity radiation surrounding the earth (the Van Allen belt) was quite unexpected but already some explanations of it have been proposed. A choice between these has been assisted by the observations made on the radiation in the U.S. lunar probe experiments.

Observations in the United Kingdom of artificial satellites launched by the U.S.S.R. and the U.S.A. have enabled British scientists to deduce new information about ionospheric structure from observations of the radio transmissions from satellites. Optical observations by kinetheodolites at Ministry of Supply establishments have been internationally acknowledged as among the most accurate of their kind. Studies by the R.A.E., Farnborough, based on this data, have led to various interesting conclusions affecting our knowledge of the frictional and electrical drag of the atmosphere and of the shape of the earth, e.g. the flattening at the poles is slightly less than previously believed.

Radio and radar observations of satellites made at the Jodrell Bank Experimental Station, University of Manchester, have included the tracking of lunar probes launched in the U.S.A. and the recording of telemetry from the latter for measurements of the intensity of the Van Allen radiation. Equipment for recording telemetry from U.S. earth satellites has been lent by the U.S. Participating Committee and operated at University College, Ibadan, Nigeria and the Radio Research Substation, Singapore. The D.S.I.R. Radio Research Station, Slough and the B.B.C. Technical Receiving Station at Tatsfield have recorded telemetry signals also from U.S.S.R. earth satellites. Amateur radio observers have participated in studies of telemetry and the long-range reception of satellite signals.

Predictions for satellites crossing the U.K. were issued at first by the Nautical Almanac Office and subsequently by the Royal Aircraft Establishment, Farnborough, but responsibility for this service has now been taken over on a permanent basis by the D.S.I.R. Radio Research Station, Slough, where a World Data Centre for rockets and satellites has been established. (See page 631 of the November 1958 *Journal.*)

The International Geophysical Year is the biggest co-operative scientific enterprise that has ever been attempted, and it is natural therefore that its success should have led to suggestions that the programme should be continued in 1959. This was very carefully considered at a meeting of I.G.Y. scientists held in Moscow in the summer of 1958. Whilst first priority will be given to the study and analysis of the information accumulated during the eighteen months of the I.G.Y., observational and data-collecting activities in the geophysical and related sciences will be conducted during 1959 on the same general plan as in 1957-58, under the direction of the C.S.A.G.I. (or its successor) as far as practicable and at such level and in such fields as may be determined. The name "International Geophysical Co-operation 1959" has been suggested to cover the further period of co-operation envisaged at the Moscow meeting.

Calculated Radiation Resistance of an Elliptical Loop Antenna with Constant Current †

by

JAMES Y. WONG, PH.D.‡ and S. C. LOH, PH.D.‡

Summary: Approximate formulae for the radiation resistance of small and large loop antennas of elliptical shape are derived by the Poynting vector method based on the assumption of a uniform current distribution on the loop conductor. Some calculations of radiation resistance are presented for loops of different sizes and shapes in order to illustrate the derived results.

1. Introduction

In a previous paper[1], an expression for the radiation field was obtained for a loop antenna of elliptical shape. In the analysis the current distribution on the loop conductor was assumed to be uniform. This assumption is quite valid when the loop is electrically small. However, when the loop becomes comparable in size to the wavelength, it may be necessary to introduce a number of feed points or phase shifters around the loop conductor in order to maintain a uniform current distribution.

In this paper the above results are utilized to derive approximate formulas for the radiation resistance of the loop antenna. Some calculations of the radiation resistance are presented for loops of different sizes and shapes in order to illustrate the derived results.

2. Determination of the Radiation Resistance

From eqn. (16) of reference 1, the ϕ-component of the radiation field of an elliptical loop antenna with an assumed uniform current distribution of amplitude I_0 is given by the following expression,

$$E_\theta = \frac{ka\eta I_0}{2}\,\frac{\exp(-jkR)}{R}\,J_1(\xi)\sqrt{\sin^2\gamma+(b/a)^2\cos^2\gamma} \qquad \ldots\ldots\ldots(1)$$

where $k = \dfrac{2\pi}{\lambda}$

λ being the free-space wavelength,

$\eta = \sqrt{\mu/\varepsilon}$, the intrinsic impedance of free space,

a is the length of the semi-major axis,

b is the length of the semi-minor axis,

$\xi = ka \sin\theta\,\sqrt{\cos^2\phi + (b/a)^2\sin^2\phi}$

$\gamma = \tan^{-1}\left(\dfrac{b}{a}\tan\phi\right)$

To find the radiation resistance of the loop antenna, the Poynting vector is integrated over a sphere yielding the total power radiated. In terms of the spherical co-ordinates (R, θ, ϕ) the total power radiated is,

$$P = \frac{1}{\eta}\int_0^{2\pi}\int_0^{\pi} E_\phi^2 R^2 \sin\theta\, d\theta\, d\phi \qquad \ldots\ldots\ldots(2)$$

From the derivation for the radiation field, it can be shown that

$$\sqrt{\sin^2\gamma+\left(\frac{b}{a}\right)^2\cos^2\gamma} = \frac{b}{a}\,\frac{1}{\sqrt{\cos^2\phi+\left(\frac{b}{a}\right)^2\sin^2\phi}}$$

Let $x = ka\sqrt{\cos^2\phi+(b/a)^2\sin^2\phi}$, and substitute eqn. (1) in eqn. (2). There results the following expression for the radiation resistance,

$$R_r = \frac{P}{I_0^2} = \left(\frac{ka\eta b}{2a}\right)^2\frac{1}{\eta}\int_0^{2\pi}\int_0^{\pi}\frac{J_1^2(x\sin\phi)}{\cos^2\phi+\left(\frac{b}{a}\right)^2\sin^2\phi}\sin\theta\, d\theta\, d\phi \qquad \ldots\ldots\ldots(3)$$

In order to evaluate eqn. (3), the following identity[2] will be employed:

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‡ Radio and Electrical Engineering Division, National Research Council, Ottawa, Canada.

U.D.C. No. 621.396.677.5.

$$\int_0^{\pi} J_1^2(x \sin \theta) \sin \theta \, d\theta = \frac{1}{x}\int_0^{2x} J_2(y) \, dy \quad \ldots\ldots\ldots(4)$$

where y is any function.

Substituting eqn. (4) in eqn. (3) yields

$$R_r = \left(\frac{ka\eta b}{2a}\right)^2 \frac{1}{\eta} \int_0^{2\pi} \frac{(ka)^2}{x^3} \int_0^{2x} J_2(y) \, dy \, d\emptyset \quad \ldots(5)$$

It does not seem likely that eqn. (5) can be evaluated in closed form, consequently it is necessary to resort to approximate methods in order to evaluate the integral. For small values of x, that is, for small loops ($ka < 2$), one can use the series expansion for $J_2(y)$. Carrying out the term-by-term integration, eqn. (5) reduces to the following approximate formula for the radiation resistance of a loop antenna of elliptical shape.

$$R_r = 20k^4(\pi ab)^2 \{1 - \alpha_1(ka)^2 + \alpha_2(ka)^4 - \alpha_3(ka)^6 + \alpha_4(ka)^8 \ldots\ldots\} \quad \ldots(6)$$

for $ka < 2$, where the coefficients $\alpha_1, \alpha_2, \ldots\ldots$ are defined as follows:

$$\alpha_1 = \frac{1}{5}\left(1 - \frac{e^2}{2}\right)$$

$$\alpha_2 = \frac{1}{56}\left(1 - e^2 + \frac{3}{8}e^4\right)$$

$$\alpha_3 = \frac{1}{1080}\left(1 - \frac{3}{2}e^2 + \frac{9}{8}e^4 - \frac{5}{16}e^6\right)$$

$$\alpha_4 = \frac{1}{31680}\left(1 - 2e^2 + \frac{9}{4}e^4 - \frac{5}{4}e^6 + \frac{35}{128}e^8\right)$$

and $e = \sqrt{1 - \left(\frac{b}{a}\right)^2}$.

For the special case of a small circular loop antenna ($b = a$, $e = 0$), the terms in the bracket can be neglected. Thus eqn. (6) reduces to

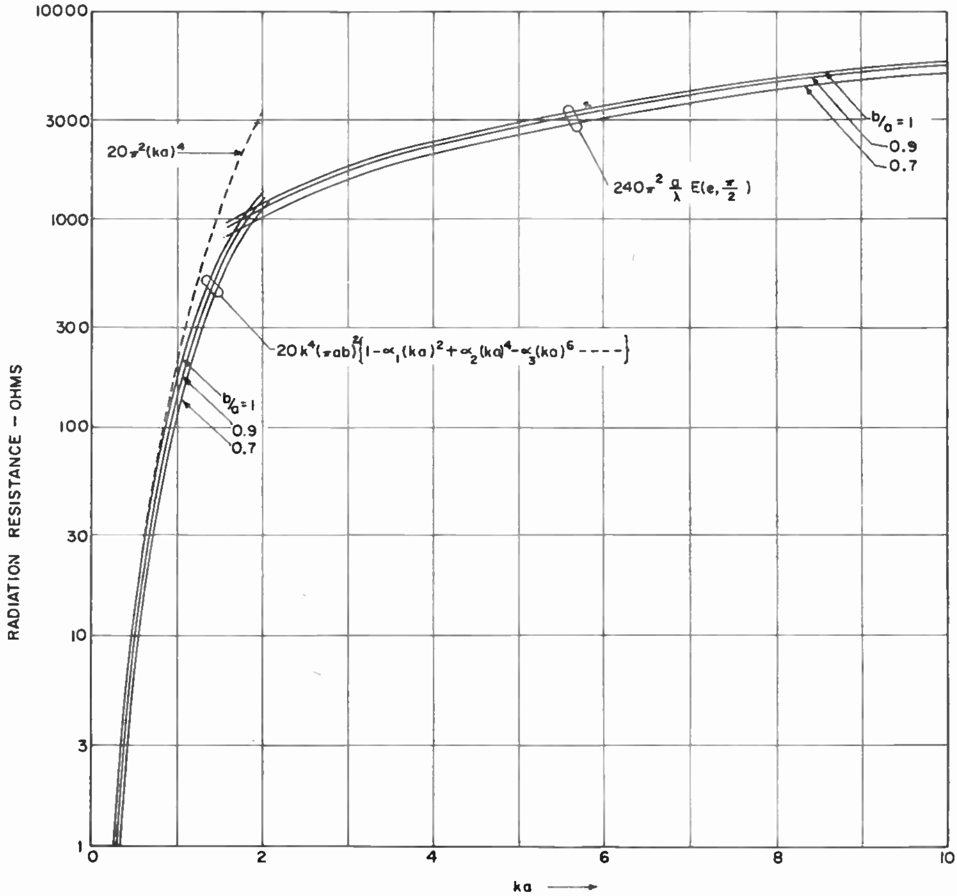

Fig. 1. Radiation resistance of loop antenna as a function of *ka*.

$$R_r = 20\pi^2 (ka)^4 \qquad \ldots\ldots\ldots(7)$$

Equation (7) is the relationship given by Foster[3] for a small single loop antenna ($ka < \frac{1}{3}$) with uniform current.

For large loops ($ka > 2$) an approximate expression can be obtained by employing the following approximation,

$$\int_0^{2x} J_2(y)\, dy \cong 1 \qquad \ldots\ldots\ldots(8)$$

Introducing eqn. (8) in (5) yields

$$R_r = 60\pi^2 \frac{b^2}{\lambda a} \int_0^{2\pi} (1 - e^2 \sin^2 \varnothing)^{-3/2} \; d\varnothing \qquad \ldots\ldots\ldots(9)$$

We recognize that $\int_0^{2\pi} (1 - e^2 \sin^2 \varnothing)^{-3/2}\, d\varnothing$ is an elliptic integral of the third kind which we define as $\Pi(e, 2\pi)$. Hence eqn. (9) can be written as

$$R_r = 60\pi^2 \frac{b^2}{\lambda a} \Pi(e, 2\pi) \qquad \ldots\ldots\ldots(10)$$

In order to facilitate computations, eqn. (10) can be expressed in terms of an elliptic integral of the second kind by employing the following relationship[4]:

$$\frac{1}{1 - e^2} E(e, \varnothing) = \Pi(e, \varnothing) \ldots\ldots\ldots(11)$$

Hence, eqn. (10) becomes

$$R_r = 60\pi^2 \frac{a}{\lambda} E(e, 2\pi)$$

$$\simeq 240\pi^2 \frac{a}{\lambda} E\left(e, \frac{\pi}{2}\right) \qquad (ka > 2) \ldots\ldots\ldots(12)$$

For the case of a circular loop

$$E\left(e, \frac{\pi}{2}\right) = \frac{\pi}{2}, \text{ hence } R_r = 60\pi^2(ka) \ldots\ldots\ldots(13)$$

which is the formula given by Foster for a large circular loop.

3. Calculations

A graph showing the radiation resistance of an elliptical loop antenna as a function of ka is presented in Fig. 1. Three values of ellipticity are shown, corresponding to b/a ratios of 1, 0·9, and 0·7. The curves were computed from the small and large loop approximations given by eqns. (6) and (13) respectively. For the case of a circular loop, a second curve (dashed line) is given for the radiation resistance obtained from Foster's small loop formula of eqn. (7). It can be seen that this approximation is valid for loops of the order of $ka < \frac{1}{3}$.

4. References

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# of current interest . . .

Electronics in the Universities

Soon after his election as President of the Institution, Professor E. E. Zepler was interviewed by the monthly journal "Technology" in connection with some of the points which he made in his Presidential Address.

The article, published in the February issue, points out that Professor Zepler's chair of Electronics was the first in this subject in Great Britain and that it was established as recently as 1949. Electronics in the Universities thus seemed to be regarded as an off-shoot of electrical engineering—in contrast to its importance within the industry. However, Professor Zepler considers that while there is much missionary work still to be done at the Universities, the main battle for its acceptance as a sound University subject has been won.

Asked about the charges of undue specialization, Professor Zepler stressed that there had to be specialists, but that they would "not come to grief if they are sufficiently well-grounded in mathematics and physics." An interesting point was that chemists, for example, took to post-graduate research in electronics remarkably well; and the similarity in many of the fundamental equations provided a link with aeronautical engineering. Professor Zepler said that, in contrast, he was occasionally alarmed by the graduates of some electrical engineering departments who seemed to be well instructed in computer operation and design but deficient in their knowledge of basic circuitry.

Discussing research, Professor Zepler called for more State help for research projects. He had no objection to industrially sponsored research except that much of it was necessarily secret and in undertaking it he wished to retain the right to publish his findings. This conflict of interest often led to difficult problems.

Promotion for Chairman of Indian Advisory Committee

Members in India will be pleased to learn of the promotion to Major General of BrahmD. Kapur, Chairman of the Indian Advisory Committee. Major General Kapur has been Chief Controller of Research and Development in the Ministry of Defence, Government of India, since this post was established early in 1958.

Major General Kapur took an active part in the formation of the Local Section in India in 1951-52, and was appointed by the Council to chairmanship of the Indian Advisory Committee in 1954.

From 1954 to 1956 Major General Kapur was seconded to be the first manager of the Indian Government organization at Bharat Electronics Ltd., Bangalore.

New Director of the Radio Industry Council

In succession to Vice-Admiral J. W. Dorling, C.B. (Member) who retired on medical advice on 31st October 1958 (see *Journal* for January 1958, page 6), the Radio Industry Council has appointed Air Marshal Sir Raymund Hart, K.B.E., C.B., M.C., A.R.C.S. (Member) to the post of Director.

Sir Raymund held the position of Controller of Engineering and Equipment, Air Ministry, from 1956 until his retirement on 31st January 1959; in the course of his R.A.F. service he took a prominent part in the development of ground and airborne radar, having been associated with early work at Bawdsey in 1936. He was elected a Member of the Institution in 1957.

National Lending Library for Science and Technology

The Department of Scientific and Industrial Research will take over part of the former Royal Ordnance Factory at Thorp Arch, near Boston Spa, Yorks, for the use of the new National Lending Library for Science and Technology. Present proposals indicate that the library will begin operating at Thorp Arch in 1961 and become fully operational during the following year. Existing large single-storey buildings will be converted into offices and book-stores, and the site provides adequate room for expansion in the future.

The new library—the nucleus of which already exists in the D.S.I.R. Lending Library Unit now at Chester Terrace, Regents Park, London—will cover all subjects in science and technology, except for some fields of medicine. It will take over the responsibility for the lending service now provided by the Science Museum Library.

Ferroelectrics and Computer Storage†

by

M. PRUTTON, B.SC., PH.D.‡

A paper read before the Institution in London on 29th October, 1958.
In the Chair: Dr. A. D. Booth (Member)

Summary: Some of the known ferroelectric materials are described together with those properties which are of immediate interest to the designer of a computer memory. The experimental techniques used to investigate the switching process in single crystals of ferroelectric materials are reviewed and some information on the new material triglycine sulphate is presented. The results of these observations are used to describe the physical mechanism of the polarization reversal process. It is then shown that this mechanism is such that single crystals are inherently unreliable as storage devices unless periodic regeneration of the stored information is used. A memory device using optical read-out is then described.

1. Introduction

Ferroelectrics are members of the class of crystalline materials known as pyroelectrics which exhibit a permanent electric dipole moment. The special property of ferroelectrics which distinguishes them within their parent group is that their dipole moment is reversible so that they display a hysteresis between their polarization and the applied electric field strength. Single crystals of ferroelectric materials show particularly square hysteresis loops which makes them potentially interesting as storage or logical elements for digital computers. It is the purpose of this paper to survey briefly the physical knowledge of the polarization reversal process in ferroelectric single crystals and then to examine in the light of this knowledge the systems for data storage whose details have been published. A novel system for reading information from a ferroelectric store will then be described.

2. Some Ferroelectric Materials

The presently known ferroelectrics may be grouped into four families on the basis of their crystal chemistries.

(i) The family containing the first ferroelectric to be discovered is known as the "tartrate group" because sodium potassium tartrate (Rochelle salt) is typical of its members.

(ii) The alkali metal dihydrogen phosphates and arsenates form the second family. A typical member of this group is potassium dihydrogen phosphate, KH_2PO_4 (abbreviated as KDP).

(iii) The third and most extensively investigated family is known as the "oxygen octahedra group" because its basic feature is that it contains a small highly polarizable ion situated at the centre of an octohedron of oxygen ions. The best known member of this group is barium titanate, $BaTiO_3$, often referred to as a perovskite-type ferroelectric because of its structural similarity with the mineral perovskite.

(iv) The latest family to be discovered can be described as the "sulphate group." The first member of this group to be found was guanidine aluminium sulphate hexahydrate (GASH) which is fairly typical of the group.[1] Another member of this group is the material triglycine sulphate.

A few of the relevant properties of single crystals of some of these materials are enumerated in Table 1. The values quoted for the coercivities and switching times are intended only as a guide for the purposes of comparison as they are dependent on many parameters such as crystal thickness, temperature and applied voltage or rate of rise of voltage.

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† Manuscript received 10th October 1958. (Paper No. 488.)

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U.D.C. No. 537.227:681.14

Barium titanate has been the subject of the most extensive research through its relatively simple structure which is helpful in a study of the origin of ferroelectricity, and its high saturation polarization and short switching time which makes it interesting as a potential computer element. A thorough review of its properties is given by Jona, Pepinsky and Shirane[2] and details of its application to storage can be found in papers by Anderson[3] and Campbell[4, 5].

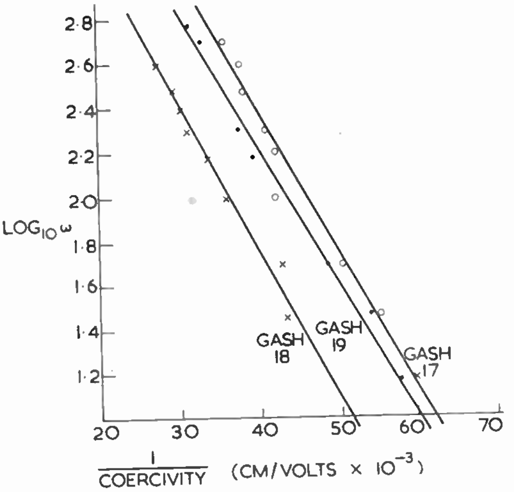

Fig. 1. The variation of coercivity with switching frequency for three typical GASH crystals.

The newly discovered triglycine sulphate[6] may also prove to be of use as a storage element as it shows very low coercivities combined with switching times of the same order as those observed in barium titanate crystals. Comparison is not easy as at room temperature triglycine sulphate is only about 30°C away from its Curie point at which its ferroelectricity disappears so that its properties tend to be very temperature dependent.

3. The Polarization Reversal Process

3.1. *Experimental studies*

The hysteresis loops of ferroelectric materials can be studied by means of the now well-known Sawyer and Tower[7] circuit which can be used to present the loop directly upon the face of a cathode ray oscilloscope. The materials listed in Table 1 have been studied by Wieder[8], Merz[9], and Prutton[10], and they all show a variation in coercivity as the switching frequency and amplitude of the applied switching sine wave are changed. In fact, where f is the switching frequency and E_c the coercivity it can be shown that[8]:—

$$\log f \quad \propto \frac{1}{E_c} \qquad \ldots\ldots\ldots(1)$$

Plots of $\log f$ against $1/E_c$ are shown in Fig. 1 for three typical GASH crystals.

The use of a sine-wave reversing field involves three interdependent parameters, repetition rate, amplitude (peak field) and rate of change of field. The consequent confusion in interpretation in such an experiment can be overcome by using a sawtooth waveform to supply the reversing field, thus providing independently controllable conditions. This technique has been used[10] on single crystals of GASH and the results showed that the switching current and time in this material are determined principally

Table 1

Ferroelectrics

Material	Saturation Polarization μC/cm^2	Coercivity volts/cm	Switching Time microsec	Curie Temperature
BaTiO$_3$	26	1,000	~ 1	120°C
Rochelle Salt	0·25 at 0°C	100	~ 100	- 18°; 24°C
GASH	0·36	2,500	~ 100	~ 300°C
Triglycine Sulphate	2·2	220	~ 5	47°C
KDP	3·0	6,000	—	- 150°C

by the rate of change of field and that they are dependent only to second order on the repetition frequency and peak field.

Further useful observations of the polarization reversal process can be made with switching fields consisting of alternate positive and negative square pulses. If these pulses have rise times which are short compared with the switching time of the crystal, the reversal process takes place under conditions of steady state of field. Such a study has been performed on crystals of $BaTiO_3$ by Merz[9, 9a], and on crystals of KDP and GASH by Wieder[8] and Prutton[10], and the results can be expressed in the form

$$i_{\max} = i_{\infty} e^{-\alpha/E} \qquad \text{.........(2)}$$

$$t_s = t_{\infty} e^{\alpha/E} \qquad \text{.........(3)}$$

where the switching current $i_{\max}$ and time t_s are due to a pulse field amplitude E. The parameter α is dependent upon crystal thickness and material and upon the temperature. It is known as the activation field[9a]. The terms i_{∞} and t_{∞} are the switching current and time for infinite pulse amplitude E. This exponential switching behaviour is shown in Fig. 2 for a typical GASH crystal and in Fig. 3 for a triglycine sulphate crystal. A very significant feature of these graphs and the exponential switching characteristic is that there does not exist any threshold field strength below which no switching occurs. Thus whatever field is applied to a ferroelectric crystal reversal will occur provided that there is sufficient time for it to do so. Both the activation field and the switching time t_s are also functions of the crystal thickness d.

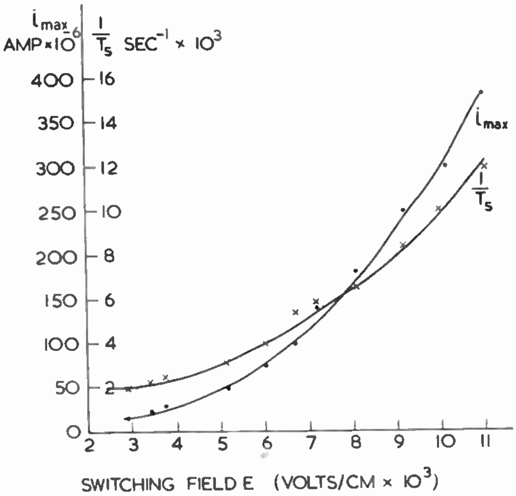

Fig. 2. The pulse response of a GASH crystal.

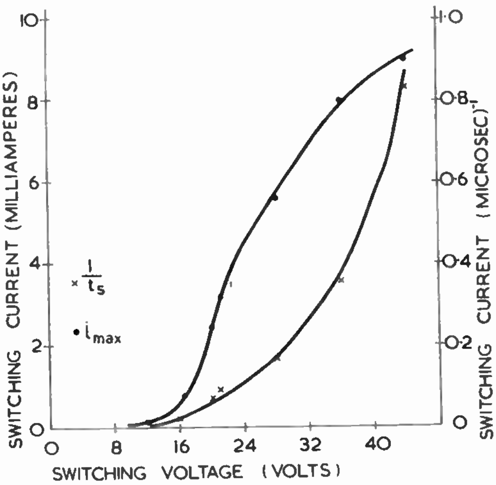

Fig. 3. The pulse response of a triglycine sulphate crystal.

If a ferroelectric crystal is viewed between crossed Nicols in the direction of its optic axis, dark areas are seen wherever the polarization vector is parallel to this optic axis, but light travelling through a region with polarization orientated in some other direction is rotated by the crystal, and so the region appears bright. Using this technique some very beautiful photographs of domain structure in $BaTiO_3$ crystals have been taken by Forsberg[11, 11a], Merz[9] and Little [12], which have proved informative in the interpretation of the polarization reversal process. If structures involving anti-parallel domains are to be studied, Merz has shown that it is necessary to apply an electric field in a direction perpendicular to both the polarization and the direction of viewing. The effect of this straining field is to rotate the polarization vectors of the anti-parallel regions in opposite directions as shown in Fig. 4 so that they have different extinction directions and distinction can be made between them. Using this technique Merz showed that when a field is applied to a single crystal of $BaTiO_3$ long thin "needle-shaped" domains increase in length at the expense of the region of unfavourably orientated polarization while their base area at the surface of the crystal remains approximately constant. Similar wedge or needle-shaped domains have been observed in Rochelle salt crystals by Mitsui and Furuichi[13].

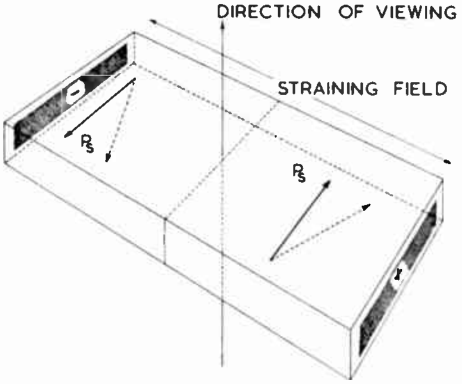

Fig. 4. The effect of a straining field upon the direction of polarization.

3.2. *The mechanism of the reversal process*

The sine-wave, sawtooth and pulse field experiment results are all consistent with a model in which the polarization reversal is due to the formation of nuclei of reversed polarization by thermal agitation at low field strengths and wall motion of these nuclei at higher field strengths. Thus if an energy U_0 is required to form a nucleus which can start to grow in the direction of the applied field, the current i flowing through the crystal is related to the rate of formation of such nuclei dn/dt, thus:

$$i \propto \frac{dP}{dt} \propto \frac{dn}{dt} \propto e^{-U_0/kT}$$

for rate of change of polarization dP/dt and absolute temperature T where k is Boltzmann's constant. If such a nucleation process does account for the low field behaviour in single crystal ferroelectrics, the nucleation energy U_0 must be related to the experimental activation field through the equation

$$\alpha = \frac{U_0 E}{kT}$$

This fact has been used by Merz[9a] and Wieder[8, 17] to show that the thickness dependence of α can be explained by the existence of surface layers in both $BaTiO_3$ and GASH which are permanently polarized in one direction. This has been confirmed by two observers. Chynoweth[14] gives values of the surface layers in $BaTiO_3$ of about 3×10^{-5} cm and Wieder[17] gives a value for GASH of about 6×10^{-3} cm.

At higher field strengths the rate of generation of nuclei can be so fast that the reversal time and rate of change of polarization is dependent principally upon the velocity of the domain walls through the crystal. This velocity increases with increasing applied field strength E until at infinite values of E it has a maximum value of the order of the velocity of sound in the material.

The experimental switching behaviour of the triglycine sulphate crystal shown in Fig. 3 follows the exponential form of eqn. (2) for all values of the applied field strength. This is unlike the behaviour of the GASH crystal shown in Fig. 2 which does become characteristic of a switching speed limited by domain wall velocities for high values of the applied field strength.

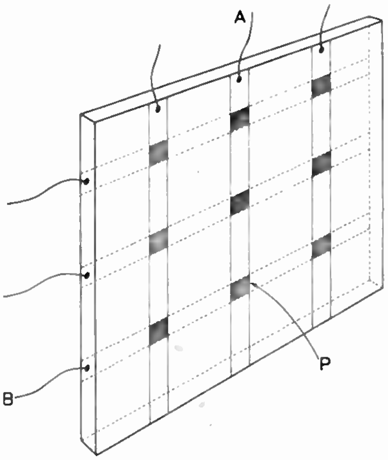

Fig. 5. A nine-element single crystal matrix.

Calculations both of Landauer[15] for $BaTiO_3$, and the author for Rochelle salt, KDP and GASH[16], of the nucleation energy for a semi-ellipsoidal domain at one face of the crystal have failed to agree with observations in magnitude and in form. In these calculations the energy required to form a nucleus of reversed polarization was taken to be that required to form the necessary domain walls and to provide the consequent depolarizing field. They give nucleation energies eight or nine orders of magnitude too large for thermal generation to be possible and removal of the principal simplifying assumptions tends to increase rather than decrease this discrepancy between theory and observation.

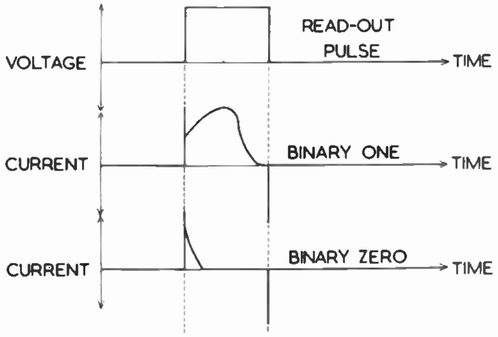

Fig. 6. The outputs from a matrix store.

This failure to explain the observed properties may well be due to the fact that the model has neglected the surface layers in the crystal already containing regions of reversed polarization from which nuclei could form with lower energies than those required by Landauer's model. There are as yet no observations of the domain structure at the surface of ferroelectric crystals which could provide evidence for or against this hypothesis.

4. Some Computer Stores using Ferroelectrics

4.1. *The single crystal matrix*

Any system with several alternative stable states can in principle be used as a means of storing information, and systems with just two such states are particularly useful in applications involving electronic techniques. The square hysteresis loop of ferroelectric single crystals indicates that they have two stable states of opposite directions of the saturation polarization, and a system of storage using crystals was described by Anderson[3] in 1952. This system consists of a single crystal having a set of parallel line electrodes on one face perpendicular to a similar set of electrodes on the opposite face. Each cross point of the two sets of electrodes forms one memory cell capable of storing one binary digit. Such a crystal is shown in Fig. 5. A memory cell P is electrically polarized to represent a binary one by applying half the polarizing voltage to each one of the two electrodes A and B which cross at the location of the cell. Read-out of information from the cell is obtained by applying a reverse polarizing voltage across both the cell and an output capacitor C or alternatively a resistor R. This polarizes the cell to the state corresponding to a binary zero, so that the stored information is destroyed by the operation of reading-out. Outputs corresponding to stored binary zero and binary one are shown in Fig. 6.

The detailed study of the polarization reversal process in ferroelectric single crystals outlined above shows that Anderson's system of storage suffers from one serious disadvantage, which can be understood by considering the equivalent circuits of a crystal memory matrix containing nine cells, as shown in Fig. 7. This circuit is that which applies only if the unwanted columns and rows are left unconnected. If the half voltages are applied to row A and column B, as described in Fig. 5 and the cell P is referred to as C32 using a matrix notation, then the equivalent circuit formed by the remaining cells can be solved. It is found that C22, C12, C31, and C33 have two-fifths of the switching voltage and the remaining four cells one-fifth of the switching voltage across them. Because of the expo-

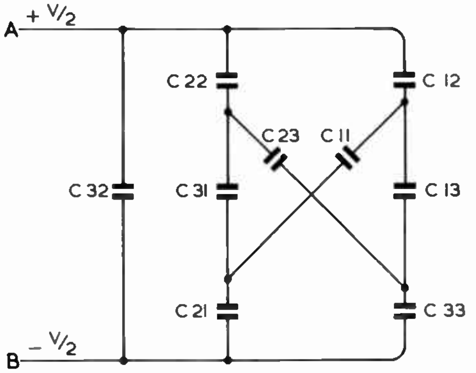

Fig. 7. The equivalent circuit of the nine-element matrix.

nential behaviour of the polarization reversal process all of these eight cells will also be eventually switched by the voltage across them, but will take much more time than that required for C32 to reverse. Thus the writing-in of information into one part of the store interferes with the contents of the rest of the store. Even if the polarization of these unselected sections of the store is only partially reversed by the "stray" voltages, the accumulative effect of many writing-in operations to selected cells may well reverse unselected cells completely. Such a system is therefore inherently unreliable as a storage device.

Campbell[4] has described a crystal matrix in which, if suitable write-in voltages are used. Regeneration of the stored information is required once every 10^3 reading operations. This matrix was designed around $BaTiO_3$ crystals which are very small, in fact they generally grow in the shape of triangular laminae with a hypotenuse about 1 cm long. Crystals of triglycine sulphate show switching speeds about the same as those of $BaTiO_3$ and can be produced from solution in water so as to be at least 2 or 3 cm across and then cleaved to suitable thickness. Thus if such regenerative techniques could be tolerated it would seem that triglycine sulphate may be a more promising material.

4.2. *An optical storage technique*

An alternative method of using ferroelectric crystals as storage elements is to utilize polarized light as the means of reading-out information. The state of polarization of a crystal containing anti-parallel domains can be detected, if the crystal is electrically strained perpendicular to both the direction of polarization and the direction of viewing as described in Section 3.1 above. This property of a ferroelectric crystal can be used to provide read-out facilities, if the crystal is arranged between nearly crossed Nicols or polaroids in such a way that the direction of polarization representing, say, binary zero results in zero light output, whereas the opposite direction of polarization representing binary one results in some light output. A possible arrangement for such a store is shown in Fig. 8 where a number of crystals each with several storage locations are mounted between a flying spot cathode-ray tube and a photomultiplier. Each crystal element of the store carries both a set of pairs of electrodes, each pair being capable of storing one binary digit, and a single pair of electrodes with which the straining field can be applied. These elements can be mounted in a framework between a pair of polaroid sheets which are crossed for light passing through a region of polarization in the direction chosen arbitrarily to represent binary zero.

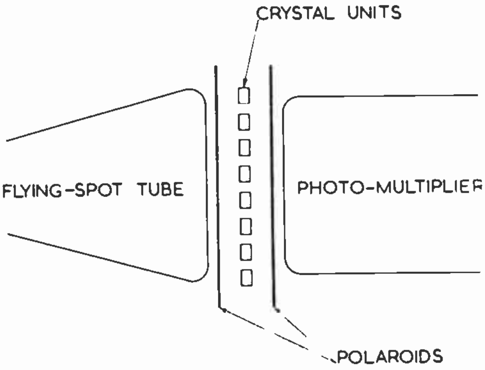

Fig. 8. A storage system using optical read-out.

Information is written into such a store by means of external switching circuits, which operate quite separately from the reading-out arrangements. To read-out a specified memory cell suitable voltages are applied to the normal deflection electrodes of the flying-spot tube in order to position the beam to produce illumination of the specified memory cell. The presence or absence of light on the photo-multiplier tube then indicates the setting of that cell. Alternatively, cyclic scanning voltages may be applied to the deflection electrodes, so that all the memory cells are scanned in sequence by the illumination. The output of the photomultiplier then consists of pulse train which may be applied to a gating system likewise receiving signal synchronized with the deflection voltages, in order to correlate the pulse train significance with the memory cell positions. In both systems the beam of the flying-spot tube is focused to a spot of such a size that it illuminates a single memory cell at a time.

In the two read-out arrangements described above a light detecting device common to all the memory cells is used, and the selection of the particular cell is effected by positioning of the scanning beam. The selection may also be performed in the reverse manner by providing a light source which illuminates all the memory cells uniformly, and by replacing the photomultiplier tube with many photo-electric cells which are aligned with the individual memory cells. The outputs of the photo-electric cells are applied to a switching system which allows the output of any specified cell to be selected at will.

This optical technique of using ferroelectrics as a storage medium has two advantages over many existing methods. In the first place, the use of polarized light in order to read out stored data provides for completely separate arrangements for entering and reading-out. This feature is valuable in that it facilitates the provision of arrangements for entering data into one section of a store at the same time as other data is being read-out from another section of the store. Secondly, the use of polarized light for reading-out provides a means of non-destructive read-out, which may be useful in some applications.

5. Conclusions

Present understanding of the polarization reversal process in single crystals of ferroelectric materials shows that such crystals are inherently unsuited to high speed matrix storage applications through their lack of a definite coercive field strength. Their use in a storage system would thus require other selection techniques not using half voltages but this is generally not an economical solution. As the switching process is governed by the nucleation and growth of domains of reversed polarization it is interesting to speculate as to how such a nucleation could be made to be non-existent or negligible below a certain threshold field. Possibly the controlled introduction of lattice imperfections may result in either the occurrence of irreversible domains from which reversal could start or in a modification of domain wall energies in such a way as to establish a minimum coercive field. Alternatively, the analogy with ferromagnetism suggests the possibility that by using ferroelectric single domain particles of sufficiently small dimensions the reversal process could occur with lower energy by coherent rotation of the polarization rather than by the creation of domain walls. Such a process would be controlled by the anisotropy constants of the material and the coercivity would have a well defined value.

6. References

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DISCUSSION

D. S. Campbell: I would like to re-emphasize the importance of the lack of definite coercive field which appears to be a property common to all ferroelectrics. In very general terms, to have a material that will switch at a field less than the breakdown field, the energy supplied by the applied field can only supplement that available from thermal energy. This is illustrated to some extent by the correlation, admittedly not exact, that exists between coercive field and curie temperature (c.f. $BaTiO_3$ $PbTiO_3$).

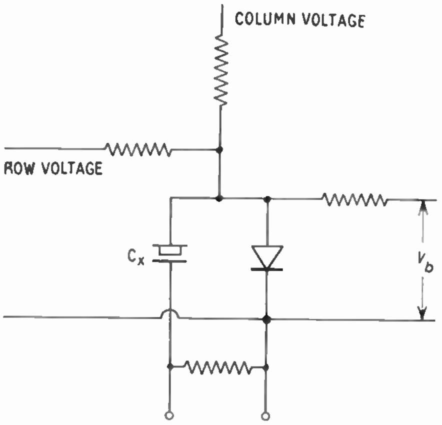

Fig. A. Basic circuit for a surge unit of a ferroelectric crystal diode matrix.

This lack of definite coercive field, as Dr. Prutton has emphasized, is fundamental to the consideration of such materials in a computer. He has shown how this affects the use of a matrix store and has mentioned that various schemes have been suggested for overcoming them. One of these, suggested by Pulvari†, uses a diode at each crossover. Figure A shows the circuit. Dr. Booth has mentioned the criterion that for economic reasons there must be less than one ancillary piece of equipment per storage point, and on this basis such a system is ruled out. But it can be seen that very satisfactory "protection" of the ferroelectric element is obtained since the bias voltage of the diode is only overcome when both *x* and *y* voltages are present. Such a circuit can actually be used with a ceramic material, in spite of the poorer hysteresis loop.

Another point worth mentioning is that a non-destructive optical store using ferroelectrics has been suggested by Ayers and Lynch‡ of the British Post Office Research Station. Their electrode arrangements are rather different to Dr. Prutton's and are illustrated in Fig. 2. Basically a stored "zero" corresponds to a crystal polarized through the crystal thickness and thus non-birefringent as viewed through the thickness. A stored "one" is then obtained by applying a field parallel to the crystal surface between two parallel bars on the same surface and the crystal is then birefringent through the thickness. A field applied through the crystal will re-orientate the crystal back to the original state. The reading system can be very similar to that suggested by Dr. Prutton. However it is found in practice that considerable fields are needed to switch the crystal in this way (150 V is needed for storage of "one" if the bars are spaced 0·2mm from each other on the same surface). It has also been found to be difficult to obtain reproduceability of switching: crystals tend to crack after 20 or more storage cycles.

A non-destructive read-out device based on harmonic detection has been examined. In this system a small d.c. bias is applied to a memory cell and a low voltage r.f. (1 Mc/s) signal also applied. The crystal cell will respond differently, depending on whether the cell is

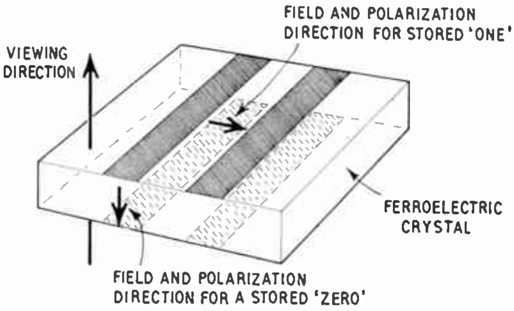

Fig. B. Basic electrode arrangement for optical storage by directional polarization.

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† C. F. Pulvari, "Determining the Usefulness of Barium Titanate Material for Memory Devices in Large Scale Digital Calculators," p. 22. Progress Report No. 6, Contract AF18(600)—106 E.O.R.—468. Catholic University of America, 1953.

‡ S. Ayers and A. C. Lynch, British Provisional Patent Specification No. 15645, May 1957.

storing a "one" or a "zero" and by examining the amount of second harmonic generated, it is possible to determine the cell state. Unfortunately this method is again limited in ferroelectrics by the lack of definite coercive field, the d.c. bias causing low field switching.

Incidentally I would like to ask Dr. Prutton as to whether or not he has any figures to offer on the performance of his store (e.g. voltages needed to obtain adequate birefringence, etc.).

Finally, I think he is being slightly unfair to barium titanate when comparing it to triglycine sulphate, as I believe it is not very easy to obtain crystals of the latter that are thin enough to operate on the 20-30 V that is considered for barium titanate.

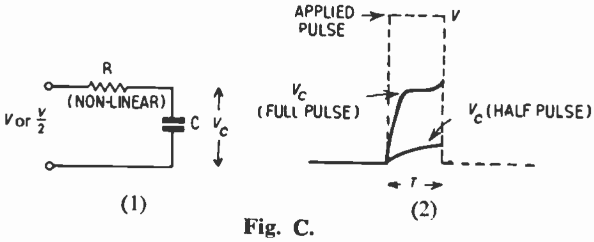
Dr. M. Prutton (in reply): I cannot give Mr. Campbell any detailed figures about the performance of the optical store because the experiments I have carried out so far were only done in order to study the domain structure and not to develop a device. All that can be said is that fields of the order of tens of kilovolts per centimeter are required to produce sufficient birefringence to observe domains using an ordinary microscope.

I do have some crystals of triglycine sulphate from Dr. Pulvari which are sufficiently thin to switch in two microseconds with 45 volts across them. They are quite typical of the sort of samples he uses.

Dr. T. B. Tomlinson (Associate Member): Relative to this lack of definite coercive field in the present known ferroelectric materials—in a case like this where the physicist is unable to produce the answer, the engineer should attempt to circumvent the problem. The storage property would seem to be adequate; the next step therefore is to endeavour to assist the selection property by outside means.

In the diagram (Fig. C), capacitor C represents an element of a ferroelectric matrix and is, for the present, assumed to have constant capacitance: R is a non-linear resistance having a characteristic of the type $i \propto v^n$, where $n \gg 1$. Such characteristics occur, for instance, in silicon carbide devices for which n might have a typical value 4. It is arranged that the switching pulse voltage V is several times greater than the value required to switch C, if directly connected. The width of the pulse T must be adequate to ensure complete switching for a full pulse and R must have a value such that when $V/2$ is applied to the combination, the rate of rise of voltage across C is sufficiently slow that the final voltage developed across C at the end of pulse period T is much less than that corresponding to the switching field, by a factor of five or even more (see Fig. C(2)). When the full voltage V is applied, the initial changing current is greater than that for the half pulse by a factor which approaches 2^4 in the limiting case. Thus, the rise of potential across C is much more rapid and the switching field is developed well within the time T available.

By this means the effective value of "half pulses" could be reduced to "one fifth" pulses or even less and, as is well known, the number of such pulses which are required to cause complete switching is very large indeed. The element C is not in fact a constant capacitance, but this does not affect the basic argument.



(1) (2)

Fig. C.

A system using a separate resistance element for each element of the matrix would be intolerable but a practical form of the device could be as follows. The ferroelectric crystal has the usual electrode system on one side: on the other side is deposited, in a binder, a layer of granular conductive material such as cadmium sulphide suitably activated by gallium or chlorine. Such "semiconducting" layers have been used in solid state "light" amplifiers and have the necessary non-linear properties. The other, crossed, system of electrodes is then deposited on the top surface of this layer, thus providing a non-linear element for the ferroelectric cell at each cross-point. The non-linear property also prevents cross-coupling between adjacent electrodes, provided that the separation distance between electrodes sufficiently exceeds the thickness.

M. Williams: I feel there should be some correlation between coercivity and Curie point in materials where switching is a result of thermal agitation. In a broad sense, the Curie point could be regarded as the temperature at which thermal agitation causes spontaneous switching. The correlation would not apply if thermal agitation were not connected with the coercivity.

R. C. Kell: An exact correlation between room temperature coercivity and Curie temperature would be expected only if, as the temperature is reduced below the Curie temperature, the coercivity followed a similar curve for all ferroelectrics. In practice, however, the rate of increase of coercivity as the temperature falls is much greater in some substances than in others, so that the curves for two different substances could cross each other. It is not particularly surprising, therefore, that potassium niobate has a fairly high coercivity in spite of its high Curie temperature.

D. S. Campbell: Work has been undertaken on resonant type circuits using fixed inductances and variable capacitors with a view to constructing dielectric amplifiers, but we have found that it is very difficult to get a low enough power factor from the ceramic, let alone from single crystal material with their more rectangular hysteresis loops, to obtain any resonance in an *L-C* circuit. (It should be mentioned that some American workers have constructed resonance dielectric amplifiers†.) In a ferroresonance type of circuit working at high frequencies (10 Mc/s) losses give heating effects that in themselves preclude the use of crystals.

In reply to a question on thin evaporated films, barium titanate may be evaporated as work by Feldman‡ in America has shown. There is a loss of oxygen in the process, but subsequent annealing can give a material that shows hysteresis properties in selected areas. Another approach being tried in this country is that of sputtering mixed oxide systems from suitably plated cathodes. It is not feasible to prepare barium titanate films this way, but other high permittivity layers, such as lead titanate, should be possible.

In reply to a question on the possibility of using powdered crystals to give improved coercive field or permittivity characteristics, it should be noted that powdered crystals will have to be orientated before they can act as a whole, and further, non-ordered pure barium titanate ceramics have too high a loss to be of much use as a dielectric (power factor > 10 per cent at 30° C).

Dr. J. C. Burfoot: With barium titanate, we have observed at Queen Mary College some nucleation effects corresponding to i changes, which depend on E but *not* on dE/dt. Dr. Prutton says i and E_c depend strongly on dE/dt. Would he please state the nature of his variations?

In what way will impurities produce an "artificial" E_c where none normally exists, and in which materials?

Dr. M. Prutton (in reply): The dependence of $i_{\max}$ and E_c on dE/dt for single crystals of GASH is described in detail in reference 10 but briefly the dependence of $i_{\max}$ can be written as

$$i_{\max} = i_0 \exp \frac{\beta}{dE/dt},$$

where i_0 and β are constants. This equation only applies for high values of dE/dt however. The value of $i_{\max}$ was only dependent to second order on the values of the field E and the repetition rate. I believe that this sort of behaviour is characteristic of a switching process controlled mostly by the nucleation rate as dE/dt is a measure of the rate of supply of energy to the crystal.

The suggestion that a finite coercivity might result from the introduction of impurities springs from the realization that the crystal surface is important in providing nucleation sites. Lehovic§ has shown that introduction of impurities into a crystal lattice results in surface layers containing a high electric field strength. So that if impurities can be introduced into a ferroelectric in such a way that a permanently polarized surface layer results, then the switching energy is determined not by the energy required to create a new nucleus, i.e. new domain walls, but by the energy required to move already existing walls. This may well have a finite value as it does in ferromagnetics.

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† J. L. Jenkins, *Elect. Manfg.*, **54**, p. 83, Dec. 1954.

‡ C. Feldman, "Formation of thin BaTiO$_3$ by evaporation," *Rev. Sci. Instrum.* **26**, p. 463, May 1955.

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TELEVISION DEVELOPMENTS

New B.B.C. Stations for Far North and South East of the British Isles

Temporary television stations have been provided by the B.B.C. to give a service in the Orkneys and Caithness areas while the main stations, which are due for completion in the Autumn of next year, are being built.

The Thrumster station near Wick came into service on 15th December and transmits on Channel 1 (vision 45 Mc/s, sound 41·5 Mc/s). The Orkney station, at Netherbutton, opened on 22nd December, and transmits on Channel 5 (vision 66·75 Mc/s, sound 63·25 Mc/s). Both transmissions use vertical polarization.

The station at Thrumster receives its programmes by radio from the B.B.C.'s television station at Meldrum and in turn transmits these programmes to the Orkney station. As Thrumster in its temporary reduced-power condition cannot be received direct in the Orkneys, it has been necessary to set up a relaying station. This is on the high ground at Brabstermire, a few miles north of Wick, where the signals from Thrumster are picked up and conveyed to the Orkneys by a microwave radio link.

Both Thrumster and Orkney will be combined television and v.h.f. sound stations. The Orkney station receives its programmes by radio direct from the v.h.f. station at Meldrum.

Television Translator at Folkestone

A new type of low-power television transmitter, known as a "translator," is undergoing extended service trials at Folkestone. This town is typical of small populated areas which are prevented by surrounding hills from obtaining satisfactory reception.

A translator is defined as an apparatus which converts the sound and vision transmission frequencies from one channel to another without demodulation to audio and video frequencies. This simplification increases the reliability of the equipment which can therefore be arranged for automatic operation.

The translator must be on high ground where good reception is possible from an existing station in the B.B.C. network and from where its transmissions can be radiated over line-of-sight paths to the area to be served. In this way only a very low-power output is required, which therefore does not add to the already serious co-channel interference problem.

The Folkestone translator is at Creteway Down where the receiving aerial is in line-of-sight from the B.B.C.'s Dover station and the transmitting aerial has a commanding position overlooking Folkestone. The receiving aerial system consists of a double 3-element array and the transmitting aerial has four tiers of single folded dipoles.

If the sound and vision signals of a television system are amplitude modulated, difficulties are introduced if they share a common amplifier in the translator because of the greater possibility of intermodulation. These difficulties are eased in the systems such as those used on the Continent in which the sound signal is frequently modulated. It is hoped that these and other difficulties have now been overcome with the system developed by the B.B.C. In this equipment, separate channels have been provided for the amplification of the sound and vision signals using common frequency-changing oscillators. The separate channel arrangement reduces the risk of intermodulation and enables separate automatic gain control to be employed to combat the effect of differential fading between the sound and vision signals, which could occur if a translator were dependent upon reception from a really remote B.B.C. station. The automatic gain control voltages are also used to initiate an automatic change-over to reserve translator equipment should the normal unit become faulty.

The double frequency-changing process facilitates the rejection of spurious signals and provides additional protection against "in band" feedback. The first frequency-changing process resembles that in a normal television receiver, producing vision and sound intermediate frequencies of 34·65 Mc/s and 38·15 Mc/s respectively, and the second frequency-changing stage produces vision and sound signal frequencies in the required channel (channel 4, sound 58·25 Mc/s, vision 61·75 Mc/s—the Dover transmitter operates in channel 2 which is 10 Mc/s lower).

The Folkestone translator peak white vision power output is 1·5 watts and in conjunction with the type of transmitting aerial used gives an effective radiated power of 7 watts in the direction of maximum radiation.

GRADUATESHIP EXAMINATION—NOVEMBER 1958—PASS LISTS

These lists contain results for *all* successful candidates in the November Examination. A total of 493 candidates entered for the examination which was held at 59 centres.

LIST 1: The following candidates, having completed the requirements of the Graduateship Examination, are eligible for transfer or election to Graduateship or higher grade of membership.

Candidates in Great Britain

ARMSTRONG, Dennis Howard. (S) *Birmingham.*
BACON, Roy Harold. (S) *Manchester.*
CHESTER, Michael William. (S) *Lowestoft.*
CORBETT, John Richard Galliers. (S) *Birmingham.*
DAVIS, Frank. (S) *Birmingham*
DUNELL, Wilfred Maurice. *London.*
DUNNETT, Paul Wesley. (S) *London.*
ELLIS, Victor Eric Henry. (S) *Newcastle.*
GOULT, Ian Frederick Howard. *London.*
HORE, John Reginald. (S) *London.*
JENNINGS, William John. *London.*
KHAW POH KEAT. (S) *London.*
NEED, Richard John. (S) *London.*
WARBY, Gordon Stanley. (S) *London.*

Overseas Candidates

AGRAWAL, Prem Prakash. *Madras.*
ASLAM, Mohammad. (S) *Rawalpindi.*
BHATTACHERJEE, Amal Kumar. (S) *Bangalore.*
BROOKS, William Gilbert Ernest. (S) *Toronto.*
HERLEKAR, Balvant Vishnu. (S) *Agra.*
HUBBARD, Raymond Thomas. (S) *Oranjemund.*
JEYASINGH, Joshua Daniel Rajamoney. (S) *Bombay.*
KASARABADA, Rama Seshu. (S) *Bombay.*
KHADILKAR, Narayan Shankar. (S) *Bombay.*
MARTENS, Alexander, E. (S) *Toronto.*
NARASIMHAN, K. Srivasachary L. (S) *Agra.*
NARASIMHAN, Villiambakkam Venkatachari. (S) *Madras.*
REID, Keith Gordon. (S) *Montreal.*
ROY, Biman Bihari. (S) *Calcutta.*
SAYWELL, John Stephen. (S) *H.M.A.S. Albatross.*
SIWACH, Hans Raj Singh. (S) *Bombay.*
SOOD, Omkar Nath. (S) *Dehra Dun.*
TEWARI, Man Haran Kumar. (S) *Bangalore.*

LIST 2: The following candidates were successful in the parts indicated

Candidates in Great Britain

AKINYEMI, Isaac Olaonipekun (S) 1. *London.*
ASHLEY, George Albert, 3. *Bristol.*
BILSBOROUGH, Gordon, 3. *London.*
BOWEN, Joseph Alfred Edward (S) 5. *London.*
CACHIA, Saviour (S) 5. *London.*
CODJOE, Joseph Milford Nii-Ahmma (S) 3. *London.*
ELLIS, Brian James (S) 2, 3. *London.*
FRASER, William Morrison (S) 2. *Bristol.*
GONZAGA, Victor Emmanuel (S) 2. *London.*
HALL, Ephraim, 4. *London.*
HERZENBERG, Selwyn Justus (S) 2. *London.*
HOPKINS, Roland Michael Terrence (S) 4. *London.*
HOWES, Bentley Arthur (S) 1. *London.*
JAEGER, Eric (S) 4. *London.*
JINADU, Saula Arema (S) 1. *London.*
JONES, Neil (S) 3. *Cardiff.*
KEMP, Paul Courtney (S) 4. *Plymouth.*
LATTIMORE, Ronald Victor (S) 2. *London.*
MASON, Richard Stanley Walton (S) 3, 5. *London.*
MISHIRKY, Fouad Elias (S) 1. *London.*
OKONGWU, Josiah Onyenagolum (S) 1, 3. *London.*
OLSEN, George Henry (S) 4. *Newcastle.*
ONI, David Adelegan Omofadesola (S) 1, 3. *London.*
PARFITT, Derrick Malcolm (S) 2. *Bristol.*
PARKER, William Robert (S) 1. *London.*
PECK, Horace Cyril (S) 2, 3. *London.*
PERYER, Michael Gregory (S) 2. *London.*
PODLASKI, Jan (S) 4. *Manchester.*
SHAER, Victor (S) 2, 3. *London*
SKINNER, Dennis Grant (S) 1, 2, 3. *London.*
SKINNER, John (S) 1. *Bristol.*
SPARKES, Joseph Thomas (S) 2. *Manchester.*
STEELE, Michael (S) 1. *London.*
THOMAS, David Price (S) 2. *Cardiff.*
WALTHO, Ronald Eardley, 1. *London*
ZUGIC, Velimir (S) 3. *London.*

Overseas Candidates

ABERCROMBIE, Frank Leonard (S) 4. *B.A.O.R.*
AHMAD, Ghulam (S) 3. *Lahore.*
AHMAD, Habeeb (S) 4. *Bombay.*
AHMAD, Saiyed Amin Uddin, 4. *Rawalpindi.*
AJUJA, Om Prakash (S) 1. *Lucknow.*
BANERJI, Sanat Kumar (S) 3. *Delhi.*
BHASIN, Karam Chand (S) 1. *Delhi.*
CHAKRABARTI, Prabhat Kumar (S) 2, 3. *Calcutta.*
CHANDRAMOULI, C. (S) 1, 2. *Madras.*
CHANDRASEKHARAN, Chempath (S) 2. *Madras.*
CHATTOPADHYAY, Anil Baran (S) 3. *Agra.*
DUTTA, Subal Chandra (S) 1. *Bangalore.*
EATER, Lubbertus (S) 2, 3. *Delft.*
FAI, Loke Mun (S) 3, 5. *Singapore.*
FRISCH, Abraham (S) 2. *Tel-Aviv.*
GELLER, David (S) 3. *Tel-Aviv.*
GIRIJ KUMAR, T.K. (S) 1, 2, 3. *Bombay.*
GOLDMANN, Rudolf (S) 1, 2, 3. *San Paulo.*
GOVINDASWAMY, Gunti (S) 1, 2. *Agra.*
GUPTA, Makhan Lal. (S) 1. *Agra.*
HOPKINS, Robert Thomas, 1, 3. *Singapore.*
ISRANI, Indur Kumar P. (S) 2. *Bombay.*
IYER, Rama Padmanabha (S) 4. *Delhi.*
JAGJIT RAI (S) 4. *I.N.S. Valsura.*
JANGRA, Ram Narayan (S) 2, 3. *Banares.*
JOSHI, Devendra (S) 1, 2. *Bangalore.*
JOSHI, Ganesh Bahirao (S) 1, 2. *Bombay.*
KAUSHAL, Ram Sarup (S) 2. *Delhi.*
KHANNA, Kanwal Kumar (S) 2. *Bangalore.*
KRIEGSMAN, Anthonius Hendericus (S) 2, 3. *Delft.*
LEUNG SHIV YVEN (S) 1. *Hong Kong.*
MADNAIK, Bapu Dada (S) 2. *Bombay.*
MALHOTRA, Prem Kumar (S) 1. *Calcutta.*
MARTIN, Ronald Henry (S) 2, 3. *Malta*
MASHIAH, Baroukh Elie (S) 2. *Tel-Aviv.*
MATHUR, Satya Prakash (S) 2, 3. *Lucknow.*
MEDIWAKE, Weerakoon Bandara (S) 2. *Colombo.*
MEHTA, Ardash Kumar (S) 2. *Madras.*
MILAS, Athanasios (S) 2, 3. *Athens.*
MODY, Eruch Rustomji (S) 3. *Bombay.*
MUKHERJEE, Samir Kumar (S) 4. *Delhi.*
NARAYANA RAO, N. (S) 2. *Bangalore.*
NEUMANN, Shimon Siegfried (S) 2. *Tel-Aviv.*
NURTON, George (S) 3. *Zomba.*
PARAMALINGAM, Sivaguru (S) 1. *Colombo.*
PATANGE, Yeshwant Kondiram (S) 3. *Bombay.*
PATHANIA, Dharam Lingh (S) 1. *Delhi.*
PISHARODY, A. P. Unnikrishnam (S) 4. *I.N.S. Valsura.*
PUNIA, Atma Singh (S) 1. *Agra.*
RAFIQUE, Mohammad (S) 2. *Rawalpindi*
RAMAKRISHNAN, Narayanaswami (S) 5. *Trichinopoly.*
RENGARAJALU, S. (S) 4. *Hyderabad.*
ROESENER, Werner (S) 2. *Toronto.*
SADASIVA DASS (S) 4. *Delhi.*
SANDHU, A. A. (S) 2. *Bombay*
SHAH, Shanker Ambalal (S) 2. *Bombay.*
SHARMA, Kamal Kishore (S) 3. *Delhi.*
SHUKLA Avanish Chandra (S) 2. *Lucknow.*
SIMMS, Terence (S) 1. *Hong Kong.*
SPRATT, John Alfred Henry (S) 1. *M.V. Katha.*
SUBRAMANIAM, Vasudeva Ayyar (S) 2. *Delhi.*
TAT LIM ONG (S) 1. *Kuala Lumpur.*
UPADHYAY, Ram Adhar (S) 3. *Calcutta.*
VAN DEN HAAK, William (S) 3. *Delft.*
VENUGOPAL, Menon (S) 4. *Bombay.*
WALKER, Rainer George (S) 2. *Toronto.*
WEISSBERG, Ernst Michael (S) 1. *Tel-Aviv.*
WHITE, William Michael Patrick (S) 3. *B.F.P.O. 40.*
WONG SAU CHAN, Anthony (S) 2, 3. *Hong Kong.*

(S) denotes a Registered Student.

A Comparison between Pulse and Frequency-Modulation Echo-Ranging Systems†

by

L. KAY, B.SC.‡

Summary : A general theory of the operation of frequency-modulation systems has been developed which can be applied to either Asdic or Radar, and the information obtained from such a system is compared with that from a conventional pulse system and a multipulse system. It is shown that the frequency-modulation system lends itself to more variations in the design parameters (such as range resolution, bandwidth of transmission, rate of information at the display) than the pulse system; but the system using the greatest bandwidth will give the best echo/background ratio. Where the echo/background ratio is not the all important factor, the frequency-modulation system can be designed to provide a higher information rate than a pulse system.

List of Symbols

P_{t0} = angular frequency of transmission at the instant t_0.

k = time rate of change of transmission angular frequency.

e = instantaneous transmission voltage.

$\hat{e}$ = peak voltage of transmission.

t = time in seconds.

R = range from transmitter and receiver.

R_M = maximum range for which system is designed.

C = velocity of transmitted wave through medium.

x_r = fraction of the transmission voltage e, received from a reflecting particle at a range R_r

v_r = instantaneous voltage received from a reflecting particle at a range R_r.

v_{fr} = instantaneous voltage at the output of the filter (following multiplier) due to the received voltage v_r.

q_r = constant frequency produced at the output of the filter by echo signal from a particle at range R_r.

v_{fT} = total instantaneous voltage at the output of the filter.

v_{eq} = total instantaneous voltage at the output of the range equalizer.

y_r = fraction of the transmission voltage e received from a particle at a range R_r neglecting absorption and spreading.

B_{FM} = effective bandwidth of transmission in the f.m. system.

T = time to sweep f.m. band = transmission interval in pulse system.

N = number of units of range resolution = number of analyser filters.

τ = response time of the analyser filters.

B_a = bandwidth of an analyser channel.

t_p = pulse duration in seconds.

f_0 = frequency of the pulse transmission.

B_p = bandwidth required to pass pulse of duration t_p.

1. Introduction

A comparison between pulse and frequency-modulation systems was made by Maillard in 1952[1] based on information theory, and this appears to be the only paper dealing with the subject in any detail. Others[2, 3] merely mention some of the related parameters and state that under certain circumstances both systems produce the same result. The present approach is believed to be new, commencing with the transmitted wave and developing, by physical reasoning, the form of the background returns against which an echo is to be detected, the result being compatible with that presented by Maillard.

The author believes that by this means a clearer understanding of an f.m. system is pos-

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sible, particularly for the engineer more conversant with pulse systems, and it is for this reason that the comparison between the two systems is made.

2. Operation of an F.M. Echo-ranging system under Ideally Stationary Conditions

Ideally stationary conditions imply that the medium, the transmitter, the receiver, and the reflecting objects are all stationary relative to one another. Since no movement takes place, each transmission of energy, if similar to the previous transmission, will produce no change in the received signal, the only cause of change in the received signal therefore being a change in the transmission signal.

Since in a frequency-modulation system the transmission is being continuously changed, some variation in the received signal must result, and it is this which will be investigated.

The general principle of operation of an f.m. system[4, 5] is illustrated in Figs. 1 and 2, from which it will be seen that the transmission frequency is varied linearly with time for a period, and then the same frequency sweep is repeated every subsequent period. The system illustrated is of the simplest form, and in practice more complex methods of transmission may be used, but this does not affect the general principle except that due care must be taken in determining the various parameters in the following relationships. It is assumed for the sake of simplicity that the increase in spectrum width due to the sawtooth modulation is small compared with the swept frequency band and can therefore be neglected.

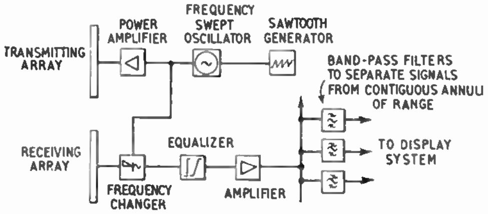

Fig. 1. Simplified schematic of a frequency-modulated Asdic or Radar.

From Fig. 2, the transmission angular frequency, P_{t1}, at any instant t_1 after time $t_0 = 0$ may be expressed by

$$P_{t1} = P_{t0} + \frac{dp}{dt}\, t_1 \qquad \text{.........(1)}$$

In this particular case dp/dt is a constant, therefore we can say

$$P_{t1} = P_{t0} + kt_1 \qquad \text{.........(2)}$$

At the instant t_0 let the transmission signal be

$$e = \hat{e} \cos P_{t0}\, t_0 \qquad \text{.........(3)}$$

The phase change in time t_1 is thus

$$\theta = \int_0^{t_1} (P_{t0} + kt)\, dt$$
$$= (P_{t0} + \tfrac{1}{2}kt_1)t_1 \qquad \text{.........(4)}$$

Thus at the instant t_1 the transmission signal is given by

$$e = \hat{e} \cos (P_{t0} + \tfrac{1}{2}\, kt_1)\, t_1 \qquad \text{.........(5)}$$

which simply expresses the instantaneous value e at the instant t_1; the term $(P_{t0} + \frac{1}{2}\, kt_1)$ is not the frequency of transmission although it has the same dimensions.

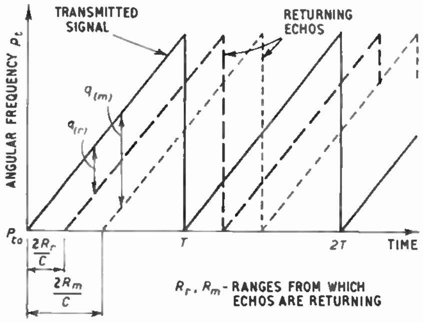

Fig. 2. Frequency/Time graph for a frequency-modulated echo-ranging system.

This signal will arrive at a range R_r at the instant $(t_1 + R_r/C)$, and thus the instant at which a scattered wave from this range will be received adjacent to the transmitter will be $(t_1 + 2R_r/C)$.

Let the received signal be a small fraction x_r of the transmitted signal due to the reflection coefficient, absorption, and spreading of the wave.

Then the received signal may be expressed as

$$v_r = x_r \hat{e} \cos (P_{t0} + \tfrac{1}{2}kt_1)\, t_1 \qquad \text{.........(6)}$$

(Note that the time t_1 is retained, as this expresses the value v_r in relation to that transmitted at time t_1).

The transmission signal at the instant this reflected signal is received, i.e. $(t_1 + 2R_r/C)$ will be

$$e=\hat{e}\cos\left[P_{t0}+\tfrac{1}{2}k\left(t_1+\frac{2R_r}{C}\right)\right]\left(t_1+\frac{2R_r}{C}\right) \qquad \text{.........(7)}$$

The instantaneous frequency will be

$$P_{(t1+2Rr/C)} = P_{t0}+k\left(t_1+\frac{2R_r}{C}\right) \text{......(8)}$$

Relations (6) and (7) express the instantaneous value of the signal received from a reflecting particle at a range R_r, and the signal being transmitted at that same instant.

In f.m. systems, a fraction of the transmitted signal is multiplied with the received signal in a frequency changer (see Fig. 1). Thus multiplying (6) and (7) gives

$$K\left\{\hat{e}\cos\left[P_{t0}+\tfrac{1}{2}k\left(t_1+\frac{2R_r}{C}\right)\right]\left(t_1+\frac{2R_r}{C}\right)\right\}\left\{x_r\hat{e}\cos\left(P_{t0}+\tfrac{1}{2}kt_1\right)t_1\right\}$$

$$=\frac{K}{2}x_r\hat{e}^2\left[\cos\left(2P_{t0}t+P_{t0}\frac{2R_r}{C}+kt_1^2+k\frac{2R_r^2}{C^2}+kt_1\frac{2R_r}{C}\right)+\cos\left(P_{t0}\frac{2R_r}{C}+k\frac{2R_r^2}{C^2}+kt_1\frac{2R_r}{C}\right)\right] \qquad \text{.........(9)}$$

where K represents the modulating factor of the modulator.

Relation (9) is the amplitude of the signal at the output of the modulator and to find the sum and difference frequencies the derivative of the phase angles must be obtained. Thus the sum frequency is given by

$$\frac{\mathrm{d}\left(2P_{t0}+P_{t0}\frac{2R_r}{C}+kt_1^2+k\frac{2R_r^2}{C^2}+kt_1\frac{2R_r}{C}\right)}{\mathrm{d}t}$$

$$=2P_{t0}+2kt_1+k\frac{2R_r}{C} \qquad \text{.........(10)}$$

and the difference frequency is given by

$$\frac{\mathrm{d}\left(P_{t0}\frac{2R_r}{C}+k\frac{2R_r^2}{C^2}+kt_1\frac{2R_r}{C}\right)}{\mathrm{d}t}$$

$$=k\frac{2R_r}{C} \qquad \text{.........(11)}$$

The sum frequency varies but the difference frequency is constant and linearly related to the range from which the signal was scattered.

The latter is the wanted signal and usually the sum frequency is rejected by low-pass filter.

At the output of the filter the wanted signal is given by

$$v_{fr}=\frac{Kx_r\hat{e}^2}{2}\cos\left(k\frac{2R_r}{C}t_1+P_{t0}\frac{2R_r}{C}+k\frac{2R_r^2}{C^2}\right) \qquad \text{.........(12)}$$

$$=K'x_r\cos\left(q_rt_1+\theta_r\right)\left(k\frac{2R_r}{C}t_1+\theta_r\right) \qquad \text{.......(13)}$$

$$=K'x_r\cos\left(q_rt_1+\theta_r\right) \qquad \text{.........(14)}$$

where $q_r=k\frac{2R_r}{C}$; $\theta_r=P_{t0}\frac{2R_r}{C}+k\frac{2R_r^2}{C^2}$;

and $K'=\frac{K\hat{e}^2}{2}$

Hence (14) expresses both the value of the echo signal from a reflecting particle at the range R_r and also its range by the frequency q_r.

Let us now assume that there are a very large number of very small (compared with a likely target) particles irregularly spaced in range and bearing, each producing a signal of the type in relationship (14). The sum of these returns is called "reverberation" in asdic and "clutter" in radar. The total signal at the output of the filter due to background returns can be written as

$$v_{fT}=K'[x_0\cos(q_0t+\theta_0)+x_1\cos(q_1t+\theta_1)+\dots$$
$$+x_n\cos(q_nt+\theta_n)] \qquad \text{.........(15)}$$

where q_0, q_1 . . . q_n are a random progression of angular frequencies. Because of the attenuation of the signal with increasing range, $x_0>x>x_n$. In an f.m. system this decay of amplitude with range is normally corrected by an equalizer (see Fig. 1) which has a gain/frequency characteristic the inverse of the attenuation/range law such that the variation in the value of x_r is due only to the variation in particle size, shape, and composition.

The output from the equalizer can thus be expressed as:—

$$v_{e1}=K'[y_0\cos(q_0t+\theta_0)+y_1\cos(q_1t+\theta_1)+\dots$$
$$\dots+y_n\cos(q_nt+\theta_n)] \qquad \text{.........(16)}$$

where y_r now replaces x_r and is independent of range, i.e., the attenuation factor has been removed. Equation (16) can be expressed more compactly as

$$v_{eq}=K'\sum_{r=0}^{r=n}y_r\cos(q_rt+\theta_r) \qquad \text{.........(17)}$$

Since q_r is a random progression of frequencies, the instantaneous value of v_{eq} is unpredictable; it will in fact be similar in character to noise having an angular frequency spectrum width (q_n-q_0).[(6)] In this particular case q_0 is zero, i.e. the angular frequency of the signal from zero range, and $q_n=kT$ the angular frequency corresponding to the signal from the maximum range since

$$T=\frac{2R_M}{C} \qquad \text{.........(18)}$$

There will of course be signals from ranges exceeding the maximum range, R_M, for which the system is designed, but in practice these are rejected by a low-pass filter following the frequency changer.

It has been shown[7] that for the case of band limited white noise the autocorrelation factor $R\tau=0$ for $\tau=n/B$; (n is an integer). Thus the autocorrelation factor of (17) will be zero *every interval*

$$\frac{2\pi}{q_n-q_0}=\frac{1}{B_{FM}}$$

where B_{FM} is the useful frequency band of transmission. In the time T there will be therefore on the average TB_{FM} completely independent values of v_{eq}.

The voltage v_{eq} is the instantaneous sum of all the signals from the range $R=0$ to $R=R_M$. Before any information can be presented from this composite signal the spectrum must be analysed, the analyser bandwidth being dependent upon the range resolution of the system. The maximum information about N intervals of range is obtained by using N analysers. This follows from the fact that all sections of the spectrum will be analysed simultaneously. The range resolution will thus be R_M/N, the pass band of each filter here being assumed to be ideal. Each analyser filter (see Fig. 1) having a bandwidth B_{FM}/N will receive signals from a range annulus $CT/2N$. Since the input from a random background is similar to noise, the output from each filter will also be similar to noise having a frequency spectrum width B_{FM}/N. Hence the autocorrelation factor of the signal from each filter will fall to zero in N/B_{FM} seconds. In the time for the transmitter to sweep the frequency band B_{FM}, i.e. T seconds, there will be TB_{FM}/N independent pieces of information from each filter.

Since the system has been assumed stationary, the random pattern of fluctuations of the signal from each filter will repeat each transmission cycle.

3. Mechanism of Randomization of Signal Returns

It has just been shown that in a perfectly stationary system the signals for small randomly spaced scatterers vary randomly during a frequency sweep. Let us now consider what is the physical mechanism causing this randomisation. In the time $N/B_{FM}=\tau$ the sum of the signals from an annulus $CT/2N$ completely randomises, i.e. changes from one value to an entirely new unrelated value. The angular frequency of the return from any particle in the annulus changes in this time by

$$k\tau=\frac{2\pi\ B_{FM}}{T}\tau \qquad \text{.........(19)}$$

The mean frequency across the annulus has changed by this amount also. There is thus a change in the number of wavelengths across the annulus.

Let the mean frequency across the annulus at the instant t_1 be

$$\frac{P_1}{2\pi}=f_1$$

Total number of wavelengths in the path difference between signals from near and far edges of the annulus is

$$\frac{R_M}{N}\,\frac{f_1}{C}\times 2 \qquad \text{.........(20)}$$

$$=f_1\frac{T}{N} \qquad \text{.........(21)}$$

The change in the number of wavelengths in time τ is

(change in frequency in time τ) × (time to sweep the annulus)

$$=\frac{k\tau}{2\pi}\times\frac{T}{N} \qquad \text{.........(22)}$$

which from (19) = 1

i.e., there has been one complete wavelength change across the annulus in the time interval τ. (Note: The additional factor 2 in (20) arises from the fact that the energy wave has to traverse the annulus *twice* before the signal from the most distant particle in the annulus can be received.)

Summarizing Sections 2 and 3;

(i) The assumption is made that there is a random distribution of a large number of particles.

(ii) In an f.m. system this leads to a random output wave which can be expressed in the form

$$\sum_{r=0}^{r=n} f_r \cos\,(q_r t+\theta_r)$$

and has a bandwidth B_{FM}.

(iii) If there are N analyser channels, the bandwidth of each is B_{FM}/N. In the time T seconds there are TB_{FM}/N independent pieces of information from one channel output, i.e. the average time per piece is N/B_{FM} which can be called the "randomization time."

(iv) In this time the frequency of transmission has changed sufficiently to cause exactly *one* extra or less wavelength change across the annulus defined by the channel filter.

(v) At any instant the resultant return from the annulus is a function of the mean frequency exciting the annulus at that instant, and is statistically related by the autocorrelation function to what has gone before.

(vi) For two resultant returns to be independent, it is therefore necessary for their mean frequencies to be such that the number of wavelengths across the annulus differ by at least one. *This conclusion is therefore not dependent on the type of system.*

4. Randomization by Frequency in a Pulse and Multipulse System

In a stationary system, if the transmission of a pulse at a constant frequency is repeated the returning signal will be unchanged, since nothing has moved. Quite clearly then, no further information is available after the first transmission period has been completed.

If, however, from Section 3(vi), pulses of constant frequency are transmitted, either simultaneously or in rapid succession, each pulse being of a different frequency, in order to obtain completely independent information from each pulse the number of wavelengths across the annulus illuminated by the pulses must differ by one for each pulse. The change in angular frequency to cause this effect was given by eqn. (19).

$$k\tau = \frac{2\pi\ B_{FM}}{T}\,\tau$$

$$= \frac{2\pi\ N}{T} \qquad \text{.........(23)}$$

i.e. the frequency change is independent of the transmission frequency and dependent only on the range resolution. Thus the change in angular frequency required in a pulse system to produce independent returns is

$$\frac{2\pi N}{T} = \frac{T}{t_P}\,\frac{2\pi}{T} = 2\pi\ B_P \qquad \text{.........(24)}$$

Hence a change in frequency equal to 1/(pulse length) is necessary to cause 2π radians phase shift across the annulus illuminated by the pulse. This will then completely randomise successive returns of clutter or reverberation.

5. Comparison of the F.M. and Pulse Systems under Ideally Stationary Conditions

Comparison of the two systems is rather involved due to changes which can be made in the performance parameters of a frequency-modulation system which cannot always be made in a pulse system. This follows from the relationship in the f.m. system,

range resolution (N)=

$$\frac{\text{bandwidth of transmission}}{\text{bandwidth of analyser channel}} = \frac{B_{FM}}{B_a} \quad \text{...(25)}$$

The bandwidth of transmission can thus be chosen quite independently of the range resolution required. In a pulse system, bandwidth of transmission and range resolution are interdependent parameters since to a first approximation

$$B_P = \frac{1}{t_P} \qquad \text{.........(26)}$$

$$\text{and} \qquad N = \frac{2R_M}{Ct_P} = \frac{T}{t_P} \qquad \text{.........(27)}$$

$$\text{Therefore} \qquad N = TB_P \qquad \text{.........(28)}$$

It can be said that the f.m. system has an additional degree of freedom over the pulse system as the range increment is an independent parameter.

Let both systems have the same mean frequency of operation, bandwidth of transmission, range resolution, and maximum range, and both employ identical radiating and receiving arrays. The pulse system will receive one piece of information from each unit of range every period of T seconds, there being N units of range each equal to R_M/N. It should be remembered that before a completely new sample of information can be received in a pulse system, the pulse of energy must traverse a distance equal to $Ct_P/2$. Since the system is assumed to be perfectly stationary, successive pieces of information from any given range will be the same as the first. Thus there are N independent samples of information in the period of T seconds from a range R_M and successive periods of T seconds provide no new information. (In practice of course the systems or the medium are generally in motion and some change is usually experienced but the general argument remains unaffected.)

The f.m. system receives signals from all ranges continuously but they must be processed in the analyser before they can be used intelligently. Since we have made $B_{FM}=B_P$ and N is the same for both systems, then from (26)

$$B_a = \frac{B_{FM}}{N} \qquad \text{.........(29)}$$

which from (27) becomes

$$B_a = \frac{B_P}{N} = \frac{1}{t_P N} \qquad \text{.........(30)}$$

and from (28)

$$B_a = \frac{1}{T} \qquad \text{.........(31)}$$

Thus the period between successive pieces of information at the output of an analyser filter is T seconds. This is the period between successive samples of information from an annulus in the pulse system.

Alternatively it was shown in Section 2 that in the time to sweep the frequency band B_{FM} there were TB_{FM}/N independent samples of information from an analyser channel.

$$\text{Since} \quad B_{FM} = B_P = \frac{1}{t_P}$$

$$\frac{TB_{FM}}{N} = \frac{T}{Nt_P} = 1$$

As there are N analyser channels, each covering $1/N$th of the range R_M the total information, as well as the information rate, is the same as the pulse system. Successive frequency sweeps will produce no new information.

It is thus clear that under these *special* circumstances both systems have the same theoretical performance.

From (25) however, the f.m. system can employ theoretically a bandwidth of transmission different from that of the pulse system without affecting the range resolution. Increasing both the transmission band and the analyser band by a factor X such that N is unchanged

$$\text{i.e. } N = \frac{B_{FM}}{B_a} = \frac{X\,B_{FM}}{X\,B_a}$$

we have that $$\tau' = \frac{1}{X\,B_a} = \frac{\tau}{X} = \frac{T}{X}$$

where τ' is the response time of the new analyser filters.

Thus in T seconds there will be X completely random variations of the signal from the many particles, but, assuming that the target remains frequency independent, the echo signal will remain constant. Provided the background return due to the transmission is greater than the noise background, the information rate has been increased X times compared with the pulse system and it is shown later that this leads to a $\sqrt{X}$ gain in echo/background ratio when considered over the same time interval as the pulse system.

The argument above assumes that the radiating and receiving arrays can operate over a frequency band of $B_{FM}=X\,B_P$. It follows therefore that the bandwidth of a pulse system could be increased to $X\,B_P$. However from (28) this would increase the units of range resolution X times and the basis on which the two systems can be compared no longer holds good. An increase in range resolution by the pulse system could be considered legitimate but a comparable increase in the f.m. range resolution must follow and there would in fact be no change from the special case given above. If however, the pulse duration t_P is maintained such that N is unchanged, X pulses, each of a different frequency separated by $B_P=1/t_P$ can be transmitted in the band XB_P either in rapid succession or simultaneously.

From Section 4, eqn. (24), the returns from any pulse will be uncorrelated with the returns due to other pulses of a different frequency; hence X times the information is received from this multipulse system as compared with a single pulse system having the same range resolution.

This is the same information rate as was obtained in the f.m. system using a transmission band of XB_p.

It is therefore more general to compare an f.m. system with a multipulse system rather than a single pulse system which is only a special case.

Returning to the comparison of the f.m. system with a single pulse system there are circumstances which can prevent the design of an f.m. system having a range resolution comparable with a pulse system, i.e. the very large number of analyser channels which may be required. For example a pulse system having an N value of 2,000 may be quite practicable, but an f.m. system having such an N value is very difficult owing to the number of channels required. Under such circumstances the foregoing comparison is incomplete and the f.m. system must be studied further in order to relate the information from one with that from the other.

Assuming the limiting case where both systems are using the full bandwidth of the transmitting and receiving arrays, the maximum possible information is then being received by the pulse system and it is further assumed that this can be fully utilized.

The f.m. system will also receive the same information, but if the range resolution of the pulse system is greater than say 200 units a practical limitation is placed on the analyser of the f.m. system and this information cannot be presented in a similar manner to the pulse system.

Let the ratio of units of range resolution

$$\frac{N_P}{N_{FM}} = n$$

The bandwidth of an analyser channel will thus be

$$\frac{B}{N_{FM}} = \frac{nB}{N_P} \qquad \text{.........(35)}$$

which, from (29) gives

$$B_a = \frac{n}{T} \qquad \text{.........(36)}$$

There will therefore be n independent pieces of information at the output of each analyser channel in the period of T seconds compared with only one from each unit of range in the pulse system, but the quality of the information will clearly be inferior because the resolution is worse by a factor of n. In the absence of an echo the background signal will be similar to noise in both systems but since the resolution of the pulse system is n times that of the f.m. system the relative background levels will be

$$\frac{\text{background level in pulse system}}{\text{background level in f.m. system}} = \frac{1}{\sqrt{n}} \,.(37)$$

Thus without any further processing of the signal in the f.m. system, the echo/background level of the pulse system will be $\sqrt{n}$ times greater than the f.m. system and the pulse system would therefore appear to be superior in performance. Employing some form of integration in the f.m. system will however improve its performance.

6. The Effect of a Post-detection Filter as an Integration Device

The output from an ideal analyser filter due to noise and particle returns will in general have a uniform power spectrum density as shown in Fig. 3(a). In order to display the information contained in this "noise" signal it is necessary to rectify it in say a linear detector. The l.f. output power spectrum will then be approximately triangular as shown in Fig. 3(b) and the highest

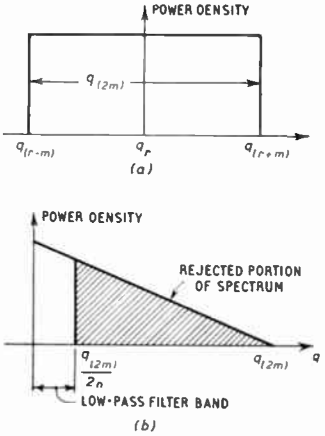

Fig. 3. Effect of linear detector on power spectrum density. (a) Input power spectrum to linear detector; (b) output power spectrum from linear detector and ideal low-pass filter.

angular frequency output will be equal to the angular frequency band at the input. If the filter following the detector has a cut-off frequency equal to the input bandwidth, the output l.f. fluctuation will be similar to the envelope fluctuation of the input to the detector.

An echo signal in one channel can ideally be assumed to be a pure tone. (This assumes that the f.m. sweep is indefinitely long and the echo is from one large object rather than many very small objects.) After rectification in the detector, the wanted output will be pure d.c., the a.f. component and its harmonics having been filtered out. The frequency of the echo signal can be anywhere within the band of the analyser filter (i.e. the target may lie anywhere within the annulus) without affecting the d.c. output. Since the l.f. due to the background is an unwanted signal it can be seen that reducing the output filter band will reduce the unwanted signal without affecting the target signal, thus making it easier to detect the d.c. due to the echo signal.

There is however a limit to which the l.f. output band can be reduced, which is governed by the time in which it is desired to detect an echo. In the comparison between the pulse and f.m. systems given in Section 5 the time was T sec., i.e. the same as the pulse transmission interval, and therefore the final output filter must have a cut-off frequency of at least $1/2T$ c/s.

If the analyser bandwidth is n/T from (36) there will be n random fluctuations in T sec. The ratio of response time of the analyser filter to the response time of the l.f. filter will thus be n. Assuming the triangular output spectrum from the detector, which applies in the presence of a signal only if the signal/noise ratio is less than 1, it may be shown that the ratio of l.f. power at the output of an ideal low-pass filter to that at the input to the filter is given by (see Fig. 3a)

$$\frac{\text{l.f. output}}{\text{l.f. input}} = \frac{4n-1}{4n^2} \qquad \text{.........(38)}$$

$$\text{where } n = \frac{\text{response time of the analyser filter}}{\text{response time of the low-pass filter}}$$

$$= \frac{\text{bandwidth of h.f. noise}}{2 \times \text{low-pass cut-off frequency}}$$

If n is large (36) approximates to $1/n$, i.e. the output "noise" energy is reduced to $1/n$th of the input and so the improvement in signal-noise ratio is $\sqrt{n}$.

Thus substituting this improvement in (37) the detection performance[8] of an f.m. system with a range resolution inferior to a pulse system can be made to approach the performance of the pulse system but in practice will never achieve it. The d.c. resulting from the rectification of the background noise will also be present in the final output but if constant with range it can be "backed off" at the display device. If however it is not constant due to the nature of the background varying with range, the system having the highest resolution will in general give the best detection factor.

7. Noise Considerations

If the bandwidth of both the pulse and f.m. systems is B and the resolution is $1/N$th of the maximum range, the noise voltage due to thermal agitation etc. in the pulse system will be

$$v_n\,(\text{pulse}) \propto \sqrt{B} \qquad \text{.........(39)}$$

and in the f.m. system the noise per analyser channel will be

$$v_n\,(\text{FM}) \propto \sqrt{\frac{B}{N}} \qquad \text{.........(40)}$$

Thus

$$\frac{v_n\,(\text{pulse})}{v_n\,(\text{FM})} \propto \sqrt{N} \qquad \text{.........(41)}$$

It follows from this that the transmitted power in the f.m. system need only be $1/N$th of the transmitted power in the pulse system for both systems to become noise limited at the same range. However, the transmission in the pulse system lasts for the duration of the pulse only and therefore the mean power, which is (peak power)$/N$, is the same as the f.m. system.

As was shown in Section 5, the f.m. system has an additional degree of freedom over the pulse system in that transmission bandwidth can be varied without affecting range resolution or vice versa. Exercise of this feature naturally affects the transmission power, which must be increased in proportion to the increased rate of information required to maintain the same signal/noise ratio.

An f.m. system therefore can possibly be used when the peak power for a pulse system would be prohibitive. This is an important consideration, especially in underwater echo-ranging[5].

8. Conclusions

The basic performance of frequency-modulated echo-ranging systems has been compared with that of a pulse system, and the following conclusions have been reached:—

(i) If the f.m. and pulse systems have identical bandwidth of transmission and reception, identical power and identical resolution, then the detection performances of the two systems are the same.

(ii) The f.m. system has an extra degree of freedom in design, since the range resolution is not tied to the bandwidth. This means that the rate of obtaining information (in the qualitative sense—not in the sense defined in information theory) can be interchanged with range resolution.

(iii) In a period of time equal to that required for the transmitted signal to travel to the maximum range and back, the overall detection performance of the two systems in respect of reverberation and clutter is the same irrespective of the range resolution of the f.m. system provided that post-detector integration is used in the latter system.

(iv) The transmitted bandwidth of the f.m. system can be increased without increasing the range resolution, and this leads to a higher rate of receipt of information; and with post-detector integration this therefore gives a better detection of the signal. But a pulse system can be made to give an equally improved detection (without altering the range resolution) by transmitting other pulses in other frequency bands with centre frequencies separated by the reciprocal of the pulse duration, and then adding the rectified received pulses together.

(v) For a given mean transmitted power, the two systems have the same detection performance in respect of thermal-agitation and other noise arising independently of the transmission. However, the *peak* power in the f.m. case is very much lower than in the pulse system, and this is often important.

9. Acknowledgments

The author wishes to thank Professor D. G. Tucker for many stimulating discussions on this topic. The investigation was made mainly while the author was in the Royal Naval Scientific Service, and the paper is published by permission of the Admiralty.

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News from the Sections . . .

NORTH EASTERN SECTION

At the December 10th meeting of the Section Mr. P. H. Walker, B.Sc.(Eng.) presented a paper entitled "High Resolution Airfield Control and Ground Surveillance Radar."

He first examined the problems of ground surveillance radar systems, relating these problems to the solutions practised for observation of airborne objects and for marine navigation. It was apparent that the majority of the problems were functions of the size of the object to be observed, of the distance of the object from other objects of interest, and of the relation between wanted and unwanted information.

Though not all these problems have been solved satisfactorily, sufficient progress has been made to enable radar systems to be built capable of showing the shape of aircraft on airport runways and of showing man-made and natural features of airfields in sufficient detail for movement control to be maintained in conditions of darkness and dense fog.

In order to achieve the required high resolution or discrimination between targets with aerials of practicable size, it has been necessary to use wavelengths appreciably shorter than has hitherto been found adequate. The most satisfactory results have been achieved using a wavelength of 8 millimeters (Q band) with a pulse length of 0·05 microseconds.

After considering technical aspects of the radar systems developed for ground surveillance, Mr. Walker reviewed operational experience in this country and in the U.S.A. and concluded with some comments on possible future trends.

SCOTTISH SECTION

"The Design and Construction of Precision Toroidal Potentiometers for Data Transmission" was the theme of Mr. H. J. Arnott's paper which was read in Glasgow on December 18th and repeated in Edinburgh on the following evening.

The author dealt mainly with miniature types and began with a brief statement of the basic principles involved. In precision components of this nature it is not possible to standardize to any extent, and he emphasized that before a design can be undertaken it is necessary to have complete information about the system for which the potentiometer is required.

The main features of a potentiometer include the total resistance, angle of coverage, deviation, accuracy of location, wattage, etc. Mr. Arnott dealt with each in turn, showing the factors involved and the methods of controlling them. Various points were illustrated by lantern slides and pen recordings were shown of contact resistance and noise. Methods of obtaining non-linear laws were described, together with the problems introduced when units are ganged. Specimens of several types of potentiometer were shown.

W.R.F.

SOUTH WESTERN SECTION

At the meeting on 29th January Mr. H. G. Manfield presented his paper "Recent Advances in Printed and Potted Circuit Techniques." Starting with details of the various potting resins available the author explained how the properties of the resin varied with the percentage of hardener used. He next showed the change in the parameters of the potted components and explained the causes of failure. Then followed an account of the development of the printed circuit and the problems confronting the designer—the questions of conductor thickness and spacing were examined. Contamination by careless handling and destruction of boards by unskilled soldering were discussed at some length.

Mr. Manfield's account of the work being carried out in the field of micro-miniaturization was of exceptional interest. He spoke first of the great volume of unused space in present day circuit construction and explained how this could be very much reduced by forming resistors at the points at which they were required. This was demonstrated, on slides, by an actual two-stage transistor amplifier which had been constructed in a space of about half a cubic centimetre. It would appear that future development in this field will be concentrated on so changing the crystal lattice of a semi-conductor that the components required for each part of the circuit are formed within the crystal and the whole of a complete and complicated circuit will be contained within a cubic centimetre.

In the discussion which followed, Mr. Manfield answered questions upon the repair of printed circuitry and the protection of such circuits by plastic coverings which could be sprayed or painted on. The question of the encapsulation of iron-cored transformers and chokes brought a long discussion and many ways of avoiding the changes which take place in the core were suggested. The final word was with the author, however, who had two answers, either to pot the windings and to fit the core later, or to avoid the use of chokes by suitable choice of circuitry.

E.G.D.

WEST MIDLANDS SECTION

The paper by the Chairman of the Section, Mr. P. Huggins, on January 21st, carried the intriguing title of "Learning Machines." After first putting the question "Can a machine learn?" Mr. Huggins made the important distinction between learning and imitation, and pointed out the reasons for the present interest in learning machines. He then discussed the design of a circuit which, in its external behaviour, conforms to a pattern of conditioned learning. Other more sophisticated examples of mechanistic learning were Grey Walter's "Tortoise," the Homeostat and Conditional Probability Devices. The design of a machine which, commencing with knowledge only of the rules of the game, can in due course become a proficient exponent, was next described, and the Solartron card punch teacher was referred to in this connection. Mr. Huggins felt that the future of learning machine techniques in industry lay in applying strategy and prediction to continuous optimization.

On December 10th members heard about some of the work of the Motor Industry Research Establishment when a paper on "Electronic Instruments in Motor Vehicle Research" was read by Mr. J. C. Dixon, B.Sc. The majority of the instruments used are concerned with the measurement of mechanical and physical quantities by electrical methods. These include the measurement of strain, force, acceleration, linear and rotational speed, and noise. While the work showed a bias towards the measurement of exhaust noise and road-excited body noise, this was understandable since these form the major part of the Electronics Department programme at present. Mr. Dixon's paper was followed by a short film showing the M.I.R.A. Proving Ground.

SOUTH WALES SECTION

On January 14th Mr. H. Ogden, B.Sc.(Eng.) spoke on "Computer Control of Machine Tools" at the Welsh College of Advanced Technology, Cardiff. The mechanical difficulties in applying the information to machine tools and in obtaining the correct response were most ably explained, and a clear description was given of the theory and practice of measurement by diffraction gratings.

It was apparent that very great increases in productivity could be obtained by using automatic control, provided the machines could be kept supplied and in operation. Planning the information for the computer was not difficult and in some cases could be carried out by the man who was otherwise required to operate the machine. Information could be fed to a machine at a rate far in excess of that required by the fastest modern cutting tools.

Perhaps the most important present day application was for the comparatively small batches of complicated items often necessary for the aircraft industry, although many other cases could be quoted where rapid and accurate drilling, milling, etc. were required.

C.T.L.

APPLICANTS FOR ELECTION AND TRANSFER

As a result of its January meeting the Membership Committee recommended to the Council the following elections and transfers.

In accordance with a resolution of Council, and in the absence of any objections, the election and transfer of the candidates to the class indicated will be confined fourteen days after the date of circulation of this list. Any objections or communications concerning these elections should be addressed to the General Secretary for submission to the Council.

Transfer from Associate Member to Member

BROWN, William Thomas. *Newbury.*
NORTHROP, Edgar Waite, M.Eng. *Chorleywood.*

Direct Election to Associate Member

BLUETT, Raymond Joseph. *Redhill.*
CLEWES, Antony Brasher, B.Sc. *Nottingham.*
DUFOUR, Roland Paul Joseph, L.ès Sc., M.Sc. *Paris.*
GARLAND, Sqdn. Ldr. Dennis John, B.Sc., R.A.F. *Locking.*
HENDERSON, Sqdn. Ldr. Robert, R.A.F. *Croydon.*
HURST, Ivan Lloyd. *Watford.*
JONES, Alec John, B.Sc. *Newport, Mon.*
KENT, Graham Bruce, B.Sc. *Bristol.*
RAMSBOTTOM, Cecil Ernest. *Wolverhampton.*
SIMMONDS, Roy Keetley, B.Sc.(Eng). *Nairobi.*
STEPHENS, Sqdn. Ldr. Stephen James, R.A.F. *Debden.*
TRIM, Richard Morris. *London, E.10.*

Transfer from Associate to Associate Member

PORTER, Francis James Garvie. *Manchester.*
SHELLEY, Irving John. *London, W.4.*

Transfer from Graduate to Associate Member

BOOTY, Martyn. *Ventnor.*
CRAGG, Ralph George. *Greenford.*
FOTHERINGHAM, Peter Ernest Albert. *Waltham Cross.*
GIBSON, Stanley. *Coventry.*
HOPKINS, William Thomas. *Weymouth.*
KULKARNI, Anant Ambadas, M.Sc. *Bombay.*
MATTHEWS, Robert Edward. *Southend-on-Sea.*
ROCHE, John. *Christchurch.*
SANSOM, John Stuart. *Cardiff.*
STYLES, Donald. *High Wycombe.*
WHITMORE, Dennis Ainsworth, B.Sc. *Carshalton.*

Transfer from Student to Associate Member

MALLORY, Edward Thomas. *Guildford.*
ROYLE, Basil Leonard. *Richmond.*

Direct Election to Associate

BEASLEY, Denis Frederick John. *London, S.W.6.*
BILTCLIFFE, Capt. Harry, R.E.M.E. *Melton Mowbray.*
CROUCH, Douglas Frank. *Woking.*
DAVIDSON, Major Francis Albert, R.Sigs. *Bulford Camp.*
DEWELL, Charles William. *London, W.1.*
HOOK, Sqdn. Ldr. Charles Owen, R.A.F. *Compton Bassett.*
MARTIN, Alexander Duncun. *Dykehead Shotts.*
MORRIS, Stanley. *Withnell, Manchester.*
MURRAY, John Keith. *Watford.*
SETHI, Flg. Off. Girdhari Lal, B.A., B.E., I.A.F. *Bangalore.*
STEWART, Robert. *Basingstoke.*
TAYLOR, Capt. Robert Vincent, R.Sigs. *Catterick Camp.*

Transfer from Student to Associate

ALLEN, George Edward Elphick. *Chelmsford.*

Direct Election to Graduate

BRADSHAW, Geoffrey, B.Sc. *Southport.*
BRETT, Robert Frank. *Chelmsford.*
BROWNE, Denis George Prior, B.Sc. *Woodford Green.*
DAY, Harold Michael Chapman. *Liverpool.*
GOWERS, Peter Michael, B.Sc. *Alcester.*
ILLINGWORTH, Lewis, B.Eng. *Southport.*
JONES, Robert. *Liverpool.*
KERR, Gilmour Wilson, B.Sc. *Great Baddow.*
LEE, Brian. *Manchester.*
LEE, Joseph Guy. *London, N.22.*
NORRIE, William Malcolm, B.Sc. *Lee-on-the-Solent.*
OGDEN, William Robert. *Glasgow.*
ROBINSON, Trevor Howard. *Chelmsford.*
SMALL, Ernest Peter. *London, S.W.18.*
SPOONER, Peter William. *Rickmansworth.*
TODD, Robert John. *London, S.E.18.*
TUAKLI, Latekoe Adebowale. *London, S.W.6.*

Transfer from Student to Graduate

GEORGE, Prince Festus. *London, W.8.*
KRISHNASWAMY RAO, M.S. *Bangalore.*
NIRBHAI SINGH, B.A. *Patiala.*
PULLAPERUMA, Don Gilman. *Mt. Lavinia, Ceylon.*
SHAUL, Chacham. *Aharon, Tel-Aviv.*
TURNER, Joseph. *Southsea.*

STUDENTSHIP REGISTRATIONS

The following 57 Students were registered at meetings held in November and December: the names of the 29 Students registered at the January meeting will be published later.

AHUJA, Bal Raj, B.A., B.Sc. *Malaut Mandi.*
AKINMADE, Samuel A. *Ibadan.*
ARUMUGAM, A. R., B.Sc. *Tirunelveli.*
CHIDAMBARA RAO, V.S.S., B.A. *Amalapuram.*
CHITRA PAL SINGH, M.A. *Sirohi.*
DILLIWAY, Roy Pinder. *Cookham.*
EIDE, Arnfinn. *London, S.W.*16.
EXTON, Harold. *Burnley.*
FISHER, J. A. *Woomera, South Australia.*
FLORIDES, George F. *Athens.*
GIDMAN, Joseph Harold. *Stansted.*
GOLDSBROUGH, Frederick. *Gillingham.*
INNES, John Somerville. *Cremorne, N.S.W.*
KARIMI, Abir Ahmed. *Rawalpindi.*
LOGAN, S., B.Sc. *Madras.*
MacDOUGALL, Duncan. *Singapore.*
MITRA, Subimal, M.Sc. *Calcutta.*
NAIK, Vishwanath Waman, B.Sc. *Bombay.*
NAIR, P. B. Krishnan, B.Sc. *Nariyapuram.*
NIGAM, Surendra Kumar. *Jalahalli.*
NJOKU, Augustine O. *London, S.W.11.*
ONDRICH, Milan. *Scarborough, Ontario.*
PALLATH, E. G., B.Sc. *Ernakulam.*
PARFITT, Derrick M., B.Sc. *Shurdington.*
PONNAPU REDDY, Chinna Sivanagireddy, B.A. *Gundlakunta.*
POOLE, Lloyd Williams. *Edgware.**
PRABHU, Felix J. S., B.A. *Mazgaon.*
PRADHAN, Sharadchandra Shankar, B.Sc. *Dombivli.*
PRAN NATH SURI, Capt., M.A., Indian Corps of Signals. *Lucknow.*
RADHAKRISHNAN NAIR, V. K. *Shertallay.*
RAM SURAT SINGH. *Jaunpur.*
RAMACHANDRAN, P. R., B.Sc. *Ernakulam.*
RAMACHANDRAN, R. P. *Singapore.*
RAMACHANDRAN, S., B.Sc.(Eng.). *Trivandrum.*
RAMKRISHNA, Jayanti, M.Sc., B.Sc. *Domalguda.*
RANGASWAMY, S., B.Sc.(Hons.). *Madras.*
RAO, Krishna Bhaskar, B.Sc. *Ernakulam.*
RAPPAI, Vadekkathala Devassy, B.Sc. *Kandassankadava.*
RING, Hans Chanan. *Ramat-Gan, Israel.*
RUTTEMAN, Maarten Hendrik. *Toronto.*
SABARWAL, Narinder Singh. *Nairobi.*
SABBAH, Prosper B. *Kfar-Ata, Israel.*
SAHNEY, Ravish Kumar. *London, W.C.1.*
SAKTHI KUMAR, Conjee Vasudeva, B.Sc. *Madras.*
SAMEL, Shriniwas S., B.Sc. *Bombay.*
SAMUEL, John Colin. *Wraysbury.*
SANDERS, Frank Bundick. *Leigh-on-Sea.*
SEVERANCE, Vincent, B.Sc. *Ernakulam.*
SHAH, Abdul Gaffoor, B.Sc. *Chalakudy.*
SHARMA, Om Prakash, B.Sc. *Amrit Pore.*
SMIKT, Oded. *Rishon Lezion, Israel.*
TALGERI, Gurudutt S., B.Sc. *Bombay.*
THUMIN, Isaac. *Tel-Aviv.*
VAN NIEKERK, Petrus. *Benoni, South Africo.*
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* Reinstatement.

Microwave Ferrite Modulators for High Signal Frequencies†

by

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In the chair : Mr. H. V. Sims (Associate Member).

Summary : This paper discusses the design problems of microwave Faraday modulators for use with signal frequencies at the lower end of the megacycle spectrum. The frequency limitation caused by skin effects in the guide wall is overcome by using the waveguide as a modulating helix. It is shown that the other important factor is ferromagnetic resonance phenomenon in the ferrite at the signal frequencies. Means are suggested for avoiding this limitation by using ferrite compositions which give reasonable performance at both the carrier and signal frequencies. Details of the modulation conversion efficiency of two experimental modulators are given, and these show that a first order sideband output 15-20db down on the input power of an X-band carrier can be realized.

List of Principal Symbols
(Rationalized M.K.S. Units)

B	Magnetic induction, wb/m^2
E	Maximum voltage amplitude of the carrier
H	Magnetic field strength, ampere-turns/m
J_0, etc.	Bessel coefficients
K_1	First order magnetic crystalline anisotropy, joules/m^3
M_s	Saturation magnetic polarization wb/m^2
N_x, N_y, N_z.	Demagnetizing factors
a	Width of turn, m
b	Thickness of turn, m
d	Diameter of ferrite rod, m
f_s	Signal frequency, Mc/s
l	Length of modulating helix, m
ε_0	$8{\cdot}85 \times 10^{-12}$
μ_0	$4\pi \times 10^{-7}$

μ_i	Initial permeability, henry/metre,
μ_r	Relative permeability, $\mu/\mu_0 = \mu'_r - j\mu''_r$
μ_+	Permeability of positive circularly polarized wave
μ_-	Permeability of negative circularly polarized wave
α	Attenuation constant
β	Phase constant
γ	Gyromagnetic ratio
∂	Skin depth
ε	Permittivity, farads/m
λ_0	Free-space wavelength, m
ρ	resistivity, ohm – metre
θ	Faraday rotation angle
ω	Carrier angular frequency, c/s
ω_1	Signal angular frequency
ω_0	Resonance angular frequency
ω_M	Polarization angular frequency

1. Introduction

The amplitude modulation of a single frequency carrier by a signal, which may be a single frequency or comprise a number of frequencies all lower than the carrier, can be achieved by means of any non-linear circuit element—a rectifier for example. When the carrier is in the microwave part of the spectrum, a crystal diode can be used as the modulator, but it has the disadvantage of limited power handling capacity.

There is another type of modulator, which makes use of the Faraday effect of high resistivity ferromagnetic materials. This modulator

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is capable of handling larger powers than a crystal diode, and is a waveguide structure. The signal frequency is fed to a magnetizing winding on the structure and magnetizes a ferrite rod in the waveguide circuit, as shown in Fig. 1. The modulation is the result of a change in Faraday angle, consequently the form of modulation can be described as angular modulation.

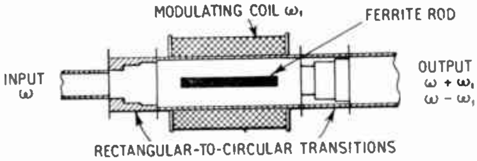

Fig. 1. Ferrite modulator.

The Faraday effect, upon which the operation of the modulator depends, is a rotation of the plane of polarization of a linearly polarized carrier. The angle of rotation depends upon the value of the magnetizing field supplied by the signal.

Ferrite modulators for signal frequencies up to the kilocycle part of the spectrum have been described in the literature[1, 2], and they may be of two kinds:— (i) Longitudinal Magnetic Field devices (ii) Rotating Transverse Field devices. The Faraday effect is utilized in the former, but in both kinds of modulators there is the problem of obtaining sufficient time-varying magnetic field through the waveguide structure in order to magnetize the ferromagnetic rod. This can be achieved by making the waveguide sufficiently thin when the signal frequency is not much greater than 1Mc/s, but necessitates a new approach when the frequency is higher. With longitudinal field devices, it is possible to do away with the waveguide in the vicinity of the magnetizing coil, thereby avoiding the field penetration problem, but then carrier leakage problems arise. In the present paper both difficulties are overcome by making the waveguide itself function as the modulating winding: the waveguide becomes a close-turn helix. Even when the field penetration problem is overcome, there is another limitation to the signal frequency which arises from the energy dissipation in the ferromagnetic material. For in the megacycle part of the frequency spectrum the phenomenon of ferromagnetic resonance occurs, and in order to limit this effect, the magnetic material must be specially designed for the signal frequency as well as for the carrier frequency. Materials which are satisfactory for the microwave carrier frequency may not be satisfactory at high signal frequencies.

It is not intended here to indicate what applications exist for microwave modulators operating at high signal frequencies. The paper is concerned with showing that practical modulators can be made—at least for X-band carrier frequencies—and gives some details regarding their design parameters together with the measured modulation efficiency of an experimental modulator.

2. Angular Modulation

Consider a linearly polarized electromagnetic wave having an instantaneous voltage $\overline{E} = E \cos \omega t$. If its polarization angle θ is varied sinusoidly, then the instantaneous angle is given by $\overline{\theta} = \theta \cos \omega_1 t$, and the cartesian co-ordinates of the carrier give

$$E_x = E \cos \omega t \sin (\theta \cos \omega_1 t) \quad \ldots\ldots\ldots(1)$$

and

$$E_y = E \cos \omega t \cos (\theta \cos \omega_1 t) \quad \ldots\ldots\ldots(2)$$

Equations (1) and (2) represent a modulated output which can be expanded in terms of Bessel functions giving:—

$$E_x = E \Big[J_1(\theta) \Big\{ \cos (\omega + \omega_1)t + \cos (\omega - \omega_1)t \\ - J_3(\theta) \Big\{ \cos (\omega + 3\omega_1)t + \cos (\omega - 3\omega_1)t \Big\} + \ldots \Big] \quad \ldots\ldots\ldots(3)$$

and

$$E_y = E \Big[J_0(\theta) \cos \omega t - J_2(\theta) \Big\{ \cos (\omega + 2\omega_1)t \\ + \cos (\omega - 2\omega_1)t \Big\} - \ldots\ldots\ldots \Big] \quad \ldots\ldots\ldots(4)$$

where J_0, J_1, etc. are Bessel coefficients of the polarization angle.

A rectangular waveguide has the property of selecting either the x, or the y components of the output of the angular modulator, and by orientation can select the odd order sidebands with suppression of the carrier. For certain cases some means may be needed to absorb the energy of the other components. A suitably disposed resistive card, or a dummy load at an appropriate part in the waveguide structure, can be arranged to do this.

The Bessel coefficients of eqns. (3) and (4) represent the amplitude of the various modulation components. If the power of the unmodulated carrier is taken as unity, then the quantity $-20 \log_{10} J(\theta)$ represents the power in decibels by which a particular output component is below the power of the unmodulated carrier. This power output will be a function of the maximum polarization angle of the modulator.

Figure 2 shows the reduced output carrier power ratio, the first- and third-order sideband power ratios, and the second-order sideband power ratio, all as a function of the polarization angle. It may be seen from the figure, and from eqn. (3), that the power in either of the first-order sidebands cannot be better than 5db below the unmodulated carrier power. To achieve this, a polarization angle of 108 deg. would be necessary. The power in either of the third-order sidebands would then be 15db below that of the first-order sideband.

Whether it would be desirable to aim for such a large angle as 108 deg. depends upon many factors—not the least being the linearity of the modulating device. Consequently in practice a smaller angle may be preferable and the first-order sideband would then be, say, 10—20 db down on the carrier. Non-linearity, which in this case means that the polarization angle is not a linear function of the signal amplitude, results in intermodulation products in the output. The conventional ways of keeping these products small compared to the wanted quantities entails keeping the percentage modulation small in relation to the carrier amplitude, and the use of negative feed-back systems. The use of the latter with ferrite modulators has been described by Clarke *et alii*[1].

3. Faraday Modulators

The conventional longitudinal field ferrite modulator consists of a ferrite rod partially filling a circular waveguide over which the modulating coil is wound. The circular guide is provided with suitable circular-to-rectangular waveguide transitions for fitting the device into the normal rectangular waveguide system. The input and output rectangular waveguides are oriented at 90 deg. with respect to each other in order for the output guide to transmit the odd-order sidebands and to suppress the carrier and the even-order sidebands. The modulator is then a double odd-order sideband modulator with suppressed carrier as shown in Fig. 1.

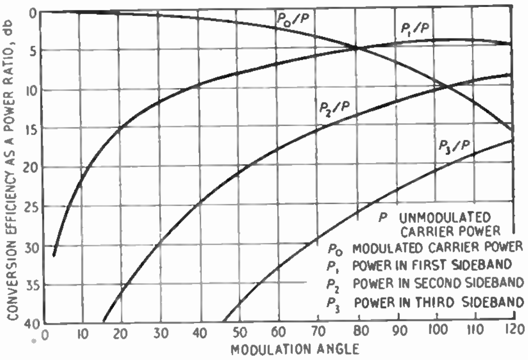

Fig. 2. The power conversion as a ratio of the modulation products to the unmodulated carrier.

The conditions realized in practice with a Faraday modulator differ somewhat from the theoretical conclusions of Section 2.

(i) The relationship between the signal amplitude and the polarization angle is not entirely linear, and there is hysteresis between the magnetizing field and the angle. The situation is somewhat similar to the $B.H$ relationship of a ferromagnetic material. This has the effect of giving rise to undesirable intermodulation products and may require a negative feed-back system. In the present paper no consideration can be given to this form of distortion. For in the experimental model, the distortion was not measured because the main aim was establishing the possibility of a ferrite modulator for high modulating frequencies.

(ii) The modulator functions because there is a different phase-shift given to the positive and negative circularly polarized components of the linearly polarized carrier. Unfortunately, it can happen that each wave component is not equally attenuated. The output wave, instead of being linearly polarized, is then elliptically polarized. This nullifies to some degree the isolation of the E_x and E_y components provided by the output rectangular waveguide structure.

Carrier break-through into the odd-order sideband output then occurs. Elliptical polarization can be minimized by paying attention to the geometry of the ferrite rod and its surrounding waveguide, but even so it may be found necessary to arrange for a direct current bias winding. By adjusting the bias current, which is equivalent to a rotation of the input and output rectangular waveguides with respect to each other, any unavoidable carrier breakthrough can be reduced to a negligible amount. The bias winding is also necessary in order to improve the linearity of the modulator.

(iii) The circular waveguide cavity and its ferrite rod cause multiple wave reflections to occur. These limit the bandwidth of the device, although they can be utilized to give an increased sideband output for a given input signal. In the double-pass form of modulator described later, the end of the modulator is short circuited so that the wave is deliberately reflected back through the modulator in order to obtain twice the rotation angle of a single-pass modulator. It is worth mentioning that the Faraday microwave switch makes use of multiple reflections in order to reduce the amount of switching current and the size of the switch.

4. The Microwave Carrier

The conditions as regards the waveguide portions of the modulator and its ferrite rod do not differ greatly from those for a Faraday isolator, except that the input and output rectangular waveguides are displaced by 90 deg. instead of by 45 deg.

The carrier is a linearly polarized wave, and as shown by Polder[3] the ferrite material characteristic must be expressed in the form of two scalar permeabilities, μ_- and μ_+. For a saturated ferromagnetic medium having negligible magnetic loss, and for $\omega_0 < \omega$, these permeabilities are given by

$$\mu_{\mp} = 1 \pm \omega_M / \omega \pm \omega_0 \qquad \text{.........(5)}$$

where ω = angular frequency of the carrier

ω_0 = resonance angular frequency of the medium $= \gamma \mu_0 H$ ....(6)

ω_M = polarization angular frequency $= \gamma M_s$ ....(7)

H = internal static longitudinal field in the medium, ampere turns/m

M_s = saturation magnetic polarization, wb/m^2

$\mu_0 = 4\pi \times 10^{-7}$

γ = gyromagnetic ratio $= 17{\cdot}6 \times 10^{10}$ angular cycles/wb/m^2.

The quantity μ_- applies to the negative circularly polarized component of the wave, and μ_+ to the positive one. There will be two propagation constants:—

$$\Gamma_{\mp} = j\omega \left\{ \varepsilon (\mu_{\mp}) \right\}^{\frac{1}{2}} = \alpha_{\mp} + j\beta_{\mp} \qquad \text{.........(8)}$$

where ε = permittivity of the medium

If the magnetic loss can be ignored, so that the only loss is that due to the dielectric and conduction effects, then as shown by Hogan[4], the change in phase is given by

$$\beta_{\mp} = \omega \left\{ \frac{|\varepsilon| + \varepsilon}{2} \right\}^{\frac{1}{2}} \left(\mu_{\mp} \right)^{\frac{1}{2}} \qquad \text{.........(9)}$$

and the attenuation is given by

$$\alpha_{\mp} = \omega \left\{ \frac{|\varepsilon| - \varepsilon'}{2} \right\}^{\frac{1}{2}} \left(\mu_{\mp} \right)^{\frac{1}{2}} \qquad \text{.........(10)}$$

The Faraday effect, which results from the different phase velocities of the two circularly polarized components of the linearly polarized wave, is given by

$$\frac{\theta}{1} = \frac{\omega}{2} \left\{ \frac{|\varepsilon| + \varepsilon'}{2} \right\}^{\frac{1}{2}} \left\{ (\mu_-)^{\frac{1}{2}} - (\mu_+)^{\frac{1}{2}} \right\} \text{ radians/m} \qquad \text{.........(11)}$$

One important fact shown by eqn. (5) is that the permeability component μ_- can have a negative value. This occurs when

$$\omega_M + \omega_0 > \omega \qquad \text{.........(12)}$$

Such a negative quantity, by virtue of the square root and the j coefficient in eqn. (8), will result in a contribution to the attenuation of the negative circularly polarized component. Since there is no similar contribution to the attenuation of the positive circularly polarized component, a marked increase in the attenuation of the negative wave component will result in an elliptically polarized output wave. The discrimination afforded by the rectangular waveguide, due to its 90 deg. relationship with the input guide, will then be reduced, and carrier break-through into the odd-order sideband output will result.

It is therefore necessary that the saturation polarization and the applied field be such that μ_- is not negative over any part of the modulating fieldcycle, nor when any bias field is applied.

4.1. *Ferromagnetic Resonance Frequency:* ω_0

It has been shown by Kittel[5], that for a saturated ferromagnetic structure where the applied field is much larger than the coercivity of the material, the resonance frequency is given by

$$\omega_0 = \gamma \left[\{ \mu_0 H_a + (N_x - N_z) M_s \} \times \{ \mu_0 H_a + (N_y - N_z) M_s \} \right]^{\frac{1}{2}} \quad \ldots\ldots\ldots(13)$$

where H_a = applied field in the z direction, ampere turns/m and N_x, N_y, N_z = demagnetizing factors such that

$$\overline{N}_x + \overline{N}_y + \overline{N}_z = 1\cdot0$$

If the cylindrical ferrite rod is assumed to be a long prolate ellipsoid, then $N_z \cong 0$ and $N_x = N_y = \frac{1}{2}$, with the result that

$$\omega_0 = \gamma (\mu_0 H_a + \tfrac{1}{2} M_s) \quad \ldots\ldots\ldots(14)$$

If the rod is not magnetically saturated, i.e. $H_a < H_c$, where H_c is the coercivity, then, because of the random orientations of the crystals in the ferrite rod and the magnetic crystalline anisotropy, there will be a number of discrete resonances of which an upper one is given by

$$\omega_0 = \omega_M \quad \ldots\ldots\ldots(15)$$

Therefore if the ferrite is unsaturated over any part of the modulating cycle, as it well might be, it is essential that the permeability component μ_- does not then become negative. This means, as a result of eqns. (12) and (15), that the magnetic polarization angular frequency must be such that

$$\omega_M < \omega/2 \quad \ldots\ldots\ldots(16)$$

Equation (16) enables the maximum permissible saturation magnetic polarization of the ferrite to be determined.

When the ferrite rod is saturated, then eqns. (6), (12) and (14) enable the permissible upper limit of the applied field to be found, since then in order to avoid μ_- becoming negative

$$\gamma \mu_0 H_a < \omega - 3/2\, \omega_M \quad \ldots\ldots\ldots(17)$$

4.2. *The Magnetic Conditions for an X-band Carrier*

The experimental modulator was designed for X-band frequencies where ω lies in the range $5\cdot5 \times 10^{10}$ to 7×10^{10}.

For a carrier of 3 cm wavelength, where $\omega = 20\pi$ Gc/s, eqn. (16) shows that the saturation polarization of the ferrite rod must not exceed 0·18 wb/m^2.

The magnesium-manganese ferrite rods developed for X-band Faraday isolators have a saturation polarization of 0·16 wb/m^2, and are therefore satisfactory at X-band carrier frequencies.

The applied field, as given by eqn. (17), must not exceed 0·116 wb/m^2 (1160 oersteds) which is unlikely to constitute a limiting feature, since it will be shown that the modulating field is very small.

4.3. *The Geometry of the X-band Modulator*

The rectangular waveguide sections were standard X-band waveguide, 0·9 in. × 0·45 in., connected by stepped transitions to a 0·9 in. dia chamber containing the ferrite rod.

In such an arrangement the energy of the carrier devides between the airspace in the circular chamber and the ferrite rod as determined by the propagation constants of the positive and negative components. Because μ_- is less than μ_+, more of the energy of the negative circularly polarized wave travels in the air space while more of the positive wave component travels in the ferrite rod. The ratio of the energy division varies with frequency, with rod diameter, and with field. The Faraday rotation is less than given by eqn. (11), for that equation is based upon an unbounded ferromagnetic medium. The attenuation is also less than if all the energy of the wave was propagated through the ferrite.

The Faraday rotation is greater, the greater the diameter of the ferrite rod, but the actual diameter has to be limited by the necessity of avoiding the propagation of undesirable modes. A 0·63cm ($\frac{1}{4}$ in.) diameter ferrite rod is capable, by virtue of its permittivity being higher than that of air, of propagating waves in the X-band spectrum, e.g. a 3·2cm wave. Any increase in diameter beyond such a limit results in excessive attenuation and ellipticity. It can be assumed that the limiting diameter for a magnesium-manganese ferrite, where $\varepsilon \cong 10\varepsilon_0$, is given by

$$d/\lambda_0 \leqq 0\cdot2 \quad \ldots\ldots\ldots(18)$$

where d = diameter of ferrite rod,

λ_0 = free space wavelength.

The attenuation of a magnesium manganese ferrite rod 5·08cm (2 in.) long and 0·63cm ($\frac{1}{4}$ in.) dia. at X-band frequencies is guaranteed to be less than 0·3 db—it is usually less than 0·1 db. Therefore at low carrier powers, a ferrite rod of the maximum permissible diameter is generally satisfactory as regards its microwave attenuation. Only for large powers does it become necessary to reduce the rod diameter below the critical figure in order to avoid overheating the rod by the carrier. The lower Faraday rotation, as a result of a reduction in diameter, has then to be increased by an increase in rod length.

5. The Modulating Signal

In the present study of a high-frequency Faraday modulator, no attempt has been made to consider the behaviour with a signal input composed of a band of frequencies. The measurements of the conversion efficiency were made at a number of discrete frequencies at the lower end of the megacycle band, but the signal oscillator, the amplifier, and the magnetizing coil tuning were readjusted each time for a specific signal-frequency. The experimental modulator is therefore better described as a single signal frequency modulator.

It was shown in the previous section that the applied field, which includes any bias field and the field resulting from the modulating signal, has to comply with eqn. (17). At X-band frequencies this condition is easily met, for consideration of distortion effects show that very small modulating fields are desirable and large bias fields are unnecessary.

The magnetization processes in a ferromagnetic material are the result of reversible and irreversible domain movements. The irreversible domain displacements occur at medium fields, and they cause large changes in permeability with field (i.e. changes in inductance of the modulating coil) and cause a large hysteresis loss. At a high signal frequency this hysteresis loss is extremely likely to cause overheating of the ferrite rod. Since the hysteresis loss and the intermodulation distortion fall rapidly with reduction in modulating field, it becomes desirable to use as small a modulating field as possible, i.e. a small number of ampere-turns on the modulating coil.

At very small fields where the domain effects are then reversible, the apparent real permeability of a ferrite material is constant, and the apparent imaginary permeability is relatively small up to a frequency which is a function of the kind of ferromagnetic material. Figure 3 shows the low field frequency spectrum of a series of proprietary nickel zinc ferrites.

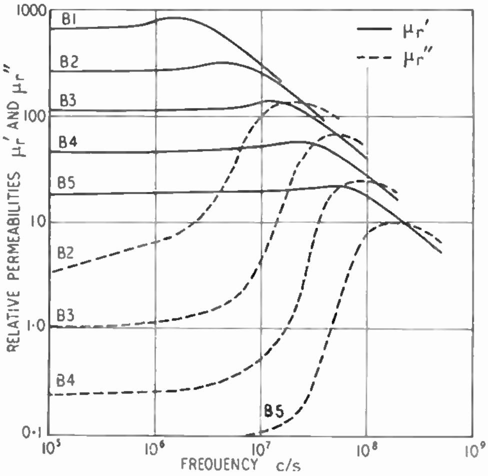

Fig. 3. The relative permeability spectrum of nickel zinc ferrites (Mullard).

It is clearly shown by this figure that, beyond a certain frequency, the loss term μ''_r increases rapidly as a result of some kind of resonance phenomenon. The smaller the initial permeability of the material, the higher the frequency at which this resonance phenomenon occurs.

The high value of the limiting frequency for the B5 grade of ferrite is due to its small zinc content compared with the other grades, and to its high porosity.

Unfortunately, in order to obtain a high Faraday rotation (which as may be seen from eqn. (11) requires the permittivity to be as large as possible) a porous ferrite is undesirable. Thus the usual ferrites for Faraday rotation devices have dense structures and because reversible domain wall movements then become likely, the resonance effects tend to occur at lower frequencies than for porous ferrites and to have a broad loss spectrum. Figure 4 shows Rado's[6] initial permeability spectrum for a low porosity magnesium-manganese ferrite. It may be seen that the ferrite used by Rado had an initial permeability comparable to that of the B5 ferrite.

The Faraday rotations for the low porosity magnesium-manganese ferrite R1, and the high porosity nickel zinc ferrite B5 are given in Fig. 5, and the disadvantage of porosity may be readily appreciated.

It is possible to ascribe the reduced Faraday rotation of a highly porous ferrite to a reduced dielectric constant due to the air in the pores of the material. For as shown by eqn. (11) a high dielectric constant is necessary in order to give a high Faraday rotation. This suggests replacing the pores in a nickel ferrite by a non-magnetic material having a higher permittivity than air e.g. by excess magnesia.

Then, provided the magnesia exists as a second phase and not as magnesium ferrite, and provided it is of the critical size to anchor the domain walls, the magnetization process at the signal frequency will proceed by domain rotation and not by domain wall movements. Thus by avoiding domain wall movements, any magnetic loss should only arise from electron spin resonances, and these should occur beyond the 10Mc/s signal frequency.

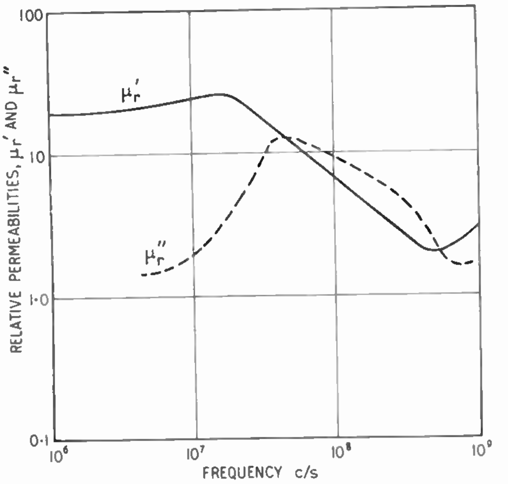

Fig. 4. The permeability spectrum of a magnesium manganese ferrite (Rado, Wright & Emerson[6]).

The Larmor resonance frequency of a spinning electron is given by

$$\omega_0 = \gamma \mu_0 H \qquad \text{.........(19)}$$

and for a magnetization process due only to domain rotation, the spontaneous field H in a ferromagnetic material arises from the magnetic crystalline anisotropy. This field is found by equating, the magnetic energy to the crystalline anisotropic energy, i.e.

$$H = \frac{2\,|K_1|}{M_s} \qquad \text{.........(20)}$$

where K_1 = crystalline anisotropic energy, joules/m³.

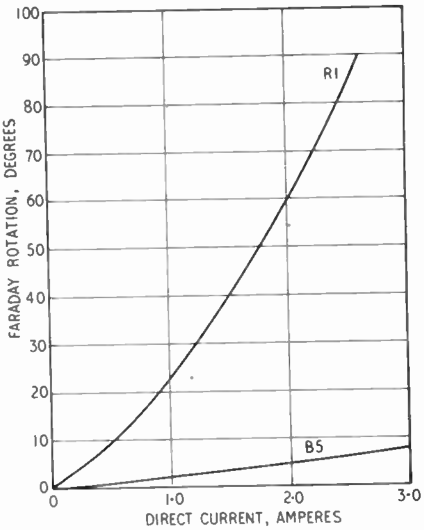

Fig. 5. Faraday rotation with 14-turn helix at 3·12cm. ferrite rods 4 in. long plus ¾ in. tapers each end. ¼ in. dia. R.1, Dense magnesium-manganese ferrite. B.5, Porous nickel-zinc ferrite.

When domain rotation is the only mechanism contributing to the permeability, it is easily verified that the internal field as given by eqn. (20) is also given by

$$H = \frac{M_s}{\mu_i - \mu_0} \qquad \text{.........(21)}$$

For a polycrystalline material a 2/3 averaging factor is necessary in eqn. (21) in order to take account of the random orientation of the crystals. It may then be found that this spin resonance is given by

$$\omega_0 = \frac{2}{3}\gamma\frac{M_s}{\left(\frac{\mu_i}{\mu_0} - 1\right)} \qquad \ldots\ldots\ldots(22)$$

For the ferrite B5, $M_s = 0{\cdot}19$ wb/m², and $\mu_i = 18\mu_0$; eqn. (22) then gives the resonance frequency as 209 Mc/s. This frequency is in line with the peak in the imaginary permeability curve for the B5 material shown in Fig. 3. The peak in the resonance curve of Rado's material occurs at a lower frequency and the resonance absorption band is wider. It was to explain the difference between resonance curves like those of Figs. 3 and 4 that Rado suggested that the effects of domain wall resonances cannot be ignored in ferrites having a low porosity.

The remarks in this section with respect to the kind of ferrite can be summarized by saying that for modulating fields at the lower end of the megacycle spectrum, domain wall resonances must be avoided, and a porous ferrite is unsatisfactory from the aspect of Faraday rotation. A nickel ferrite composition with excess magnesia, and having a saturation polarization around 0·16 wb/m² might offer a satisfactory solution to the ferrite problem.

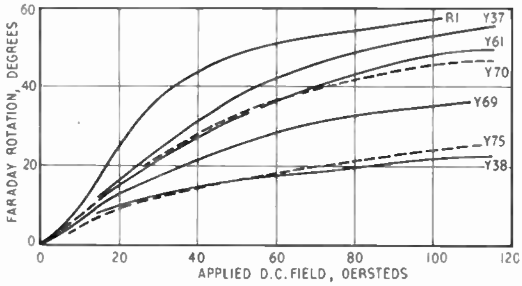

Fig. 6. The Faraday rotation of various ferrite compositions. All specimens 1·65 in. long × 0·2 in. dia. measured at λ = 3·08 in. cm. in 0·9 in. dia. circular guide.

At the time the experiments upon the modulator were being made, there were available a number of short ferrite rods of nickel ferrite of various compositions. These had been originally supplied for experimental work on high-power ferrite isolators. The Faraday rotations of a number of those ferrites in comparison with that of the magnesium manganese ferrite, R1, are shown in Fig. 6. In order to ascertain their suitability at high signal frequencies, a number of them were compared with the R1 ferrite upon a temperature basis in a modulator. The temperature rise of the ferrite, as measured by a thermocouple, was taken as the criterion of suitability at high signal frequencies. The results of the temperature measurements are given in Fig. 7.

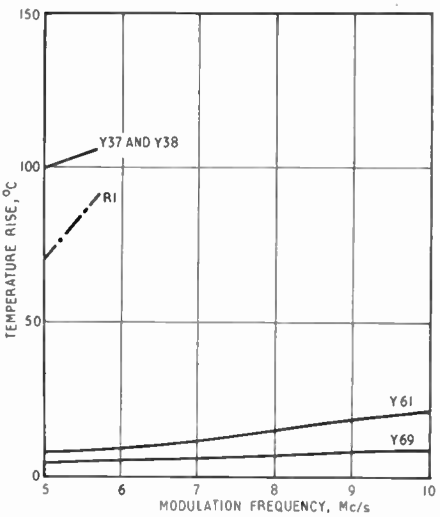

Fig. 7. Temperature rise of ferrite rods. Modulation frequency. (Rods 1·65 in. long × 0·2 in. dia. in 14-turn helix. Rods supported in foamed alkyd resin.)

Unfortunately the experimental nickel ferrite rods were not long enough to be used in the ferrite modulators. All the measurements relating to the experimental modulators described in the subsequent sections of this paper were therefore made upon the magnesium-manganese ferrite R1.

6. The Signal Winding

When the signal winding is situated on a conducting waveguide, the varying magnetic field produced by the signal induces eddy currents in the guide wall. These eddy currents not only dissipate some of the signal energy, but can also prevent the field from magnetizing the ferrite rod in the waveguide. At high frequencies the skin effects are more serious than the eddy current loss effects because of the high conductivity of the guide. The skin depth is given by the standard equation:—

$$\delta = \left\{\frac{10^7 \rho}{2\pi \omega_1}\right\}^{\frac{1}{2}} \quad \text{(in metres)} \qquad \ldots\ldots\ldots(23)$$

where ρ = resistivity of the wall = $1{\cdot}73 \times 10^{-8}$ ohm -metre, for copper,

and ω_1 = angular frequency of the signal.

At a frequency of 10 Mc/s, the skin depth is only 0·021 mm (0·00082 in.) and clearly a very thin guide wall would be required if the ferrite rod was to be magnetized by the signal.

For the modulator described by Clarke[1], the guide was a P.T.F.E. tube coated with a silver paint, but Clarke did not use signal frequencies greater than 20 kc/s. Boronski[7] has commented upon two kinds of thin walled guides for microwave switches at pulses of 1 μsec duration. He found 0·002 in. thick silver plating unsatisfactory, but was satisfied with vacuum evaporated aluminium of unspecified thickness on a perspex tube.

The limitations caused by the conducting waveguide can be overcome by making the signal winding part of the waveguide circuit, the winding having the form of a helix of the same inside diameter as the circular guide.

In so far as the part of the helix constituting the turns is concerned, skin effects now only affect the current carrying capacity of the helix, and not the magnetization of the ferrite.

The turns can therefore be quite thick, and were 0·13 mm (0·005 in.) in the experimental helices. The slotted circular ends of the helix were made 0·001 in. thick because of the radial field component, but at the very small fields which had to be used, no flux-penetration difficulty was anticipated, since the flux density in the helical slot was very small.

The field produced by a long helix is given by

$$H = IN/l, \text{ ampere-turns/m} \qquad \ldots\ldots\ldots(24)$$

where I = peak current = $S.a.b.$

N = number of helical turns $\cong l/a$

l = length of helix, m

a = width of turn, m

b = thickness of turn, m

and S = peak current density, amp/m^2

In terms of the current density, the field is given by

$$H = Sb, \text{ ampere-turns/m} \qquad \ldots\ldots\ldots(25)$$

but if the current density is defined from the aspect of the thermal rating of a low frequency, or direct current, then the effective thickness resulting from the skin effect must be used in eqn. (25) instead of the actual thickness of the turns. For although there are proximity affects due to the adjacent turns, these can be ignored when the turns are wide, as occurs in the waveguide helix. The effective area of the turns to the modulating signal current is then $2\delta a$, where δ is given by eqn. (23).

The signal field of the helix is then

$$H = 2S\delta = \frac{0{\cdot}42\,S}{(10^7 f_s)^{\frac{1}{2}}}, \quad \text{ampere-turns/m} \qquad \ldots\ldots\ldots(26)$$

where f_s = frequency of the signal, Mc/s, and when the helix is made of copper.

The permissible current density would depend upon such factors as radiation and convection cooling of the structure and the heat sink of the mass of waveguide circuit. For an arbitrarily assumed r.m.s. current density of $6{\cdot}2 \times 10^6$ amps/m^2 (3000 A/in.^{2}) at 10 Mc/s, the field would be only 260 ampere-turns/m (3·2 oersteds.)

Because the helix is a single-layer coil, the field is independent of the number of turns. This field is limited by how hot the helix can be permitted to become by reason of its current carrying capacity. As a result of such a limitation, the fields are never likely to be very much greater than shown by the example. Such small fields are no disadvantage however, for it has already been stated earlier, that to minimize inter-modulation distortion and to avoid overheating the ferrite rod, very small signal fields are necessary.

6.1. *The Microwave Carrier Conditions*

A helical waveguide functioning with the normal TE$_{11}$ mode of a circular guide will radiate part of the carrier through the helical track. Such spurious radiation will constitute an insertion loss, and its magnitude will depend upon the length of the track and its width. Obviously the width of the track must be made as small as possible, and the number of turns must not be large. The waveguide helices will therefore tend to require large signal currents.

The manufacturing process adopted to ensure the minimum spacing between the turns was that of electroforming the helix upon a stainless steel mandrel. A helical slot and the corresponding longitudinal slot for the ends of the helix were cut in a stainless steel mandrel to give a suitable number of turns. The slot was filled with "Araldite" flush with the surface of the mandrel. In the copper electroforming bath, copper deposits over the mandrel without sticking to it, but it does not deposit over the Araldite. As the copper builds up in thickness, it tends to overhang the track, and would eventually result in short-circuiting the turns. This behaviour enables the helical track to be made very narrow by close control of the width of the slot in the mandrel and the thickness of the turns.

Figure 8 shows two experimental mandrels and helices, one for 14 turns and the other for 5½.

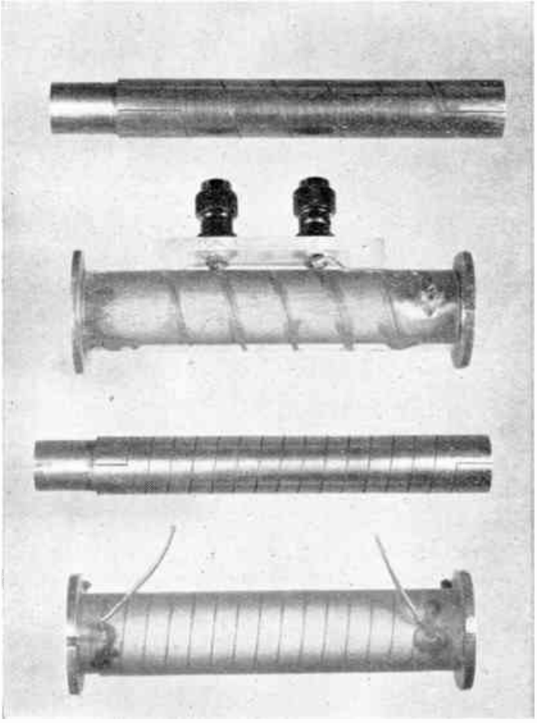

Fig. 8. Stainless steel mandrels and waveguide helices.

The length of these helices, approximately 14cm (5½ in.) between the waveguide coupling flanges, was determined by the longest ferrite rod available for the modulator experiments. This ferrite rod was a magnesium-manganese ferrite 0·63cm (¼ in.) dia. It had an overall length of 14cm (5½ in.) tapered 1·9cm (¾ in.) from each end.

The insertion loss of the 14-turn helix for an X-band wave was measured with the helix forming part of a normal waveguide optical type bench. It was found to be 1·2db. This loss fell to 0·5db with the ferrite rod inserted. Thus the reduction in attenuation must be attributed to a reduction in radiation loss caused by the microwave energy being concentrated in the ferrite rod.

The insertion loss of the empty 5½ turn helix was 0·5db.

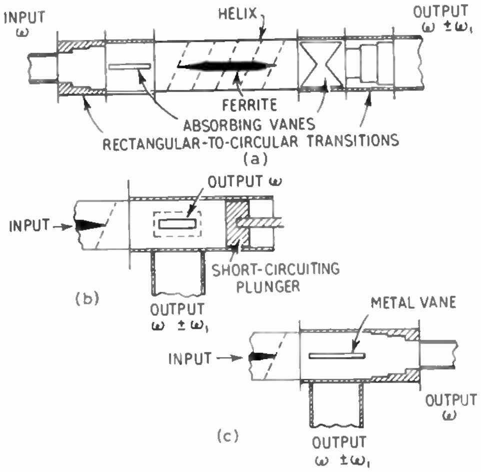

Fig. 9. Single-pass modulators (a) Single port output; (b) Double port output; (c) Double port output.

6.2. *The Signal Conditions*

The calculated inductance of the 14-turn helix is 1·0 μH assuming it to be a long solenoid and choosing an arbitrary length for the helix. The inductance measured at 10 Mc/s was 1·37 μH, which increased to 2·5 μH when the ferrite rod was inserted.

The field strength of the helix was calibrated by measuring the Faraday rotation given by the helix and its ferrite with direct current magnetization. This Faraday rotation versus current relationship, shown in Fig. 5, was then compared with that given by the helix and its ferrite situated inside a magnetizing coil whose field had been calibrated. It was found that a current of one ampere gave a field of 114 ampere-turns/m. This was in good agreement with the calculated figure of 119 ampere-turns/m obtained by means of eqn. (24).

At 10 Mc/s, a peak current of one ampere corresponds to an r.m.s. current density of 290 A/cm^2 (1870 $A/in.^2$), taking into account the skin effect and the cross-section of the turns. There were 3 turns per inch on the 14-turn helix.

The result of Q measurements at 10 Mc/s were as follows:—

	Isolated Helix	*Helix in Waveguide Circuit*
Helix empty	205	165
Helix with ferrite rod	93	80

With 2·5 μH for the helix and its ferrite, then a voltage of 157 would exist across the helix for a current of one ampere at 10 Mc/s.

The X-band frequency measurements, together with those at the 10 Mc/s signal frequency indicated that a helical waveguide modulator should be a practical proposition for high signal frequencies.

7. The Modulator System

There are a number of ways in which a waveguide helix ferrite modulator may be coupled to the microwave circuit.

Figure 9 shows the arrangements for operating as a single-pass modulator having a variety of output ports. Figure 9(a) is a common arrangement with the outgoing rectangular guide at 90 deg. to the incoming guide. The resistive cards were fitted in the modulator in order to absorb the carrier and even-order sidebands during the experimental measurements. Figures 9(b) and (c) are two-port output systems giving the reduced amplitude carrier plus even-order sidebands at one port, and the odd-order sidebands at the other. These ports are sited on an extension of the waveguide helix which can be made by a modification of the stainless steel mandrel.

For the purpose of measuring the modulator output, the arrangement shown in Fig. 9(a) was used, the output being connected to an X-band spectrum analyser. The helix was tuned by means of a variable capacitor in order to obtain the maximum current from the signal oscillator and its power amplifier. In order to minimize any carrier break-through resulting from an elliptically polarized output, a variable direct current bias was fed, via a choke, to the helix. The results of the power measurements are given in Fig. 10. These conform reasonably well with the theoretical values deduced from Figs. 2 and 5, where the signal current was obtained from the readings of a thermal meter.

The output of such a modulator can be increased by using a longer ferrite rod, which in turn means a longer modulating helix. An alternative system is to use the double-pass modulator shown in Fig. 11. The input is first fed into a polarization resolver, or "thruplexor," connected to the waveguide helix. The output end of the helix is short-circuited by means of an adjustable plunger. The wave thus passes through the ferrite rod twice, and double

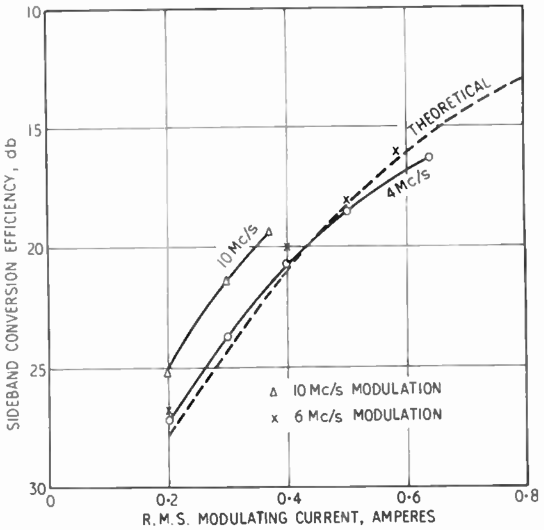

Fig. 10. Side-band conversion efficiency, single-pass modulator $\lambda_0 = 3\cdot12$cm.

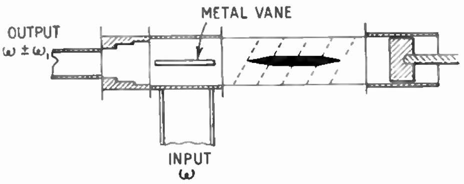

Fig. 11. Double pass modulator.

the Faraday rotation is obtained compared with the single-pass system. The attenuation is also doubled, but as shown by the experimental results in Fig. 12, there is a gain in output of about 3db compared with the maximum theoretical gain of 5db. Because the reflected carrier plus the even order sidebands now appear at the input port, it is necessary in order to obtain a good v.s.w.r., to fit a ferrite isolator at the input end to absorb this reflected energy without interfering with the input power.

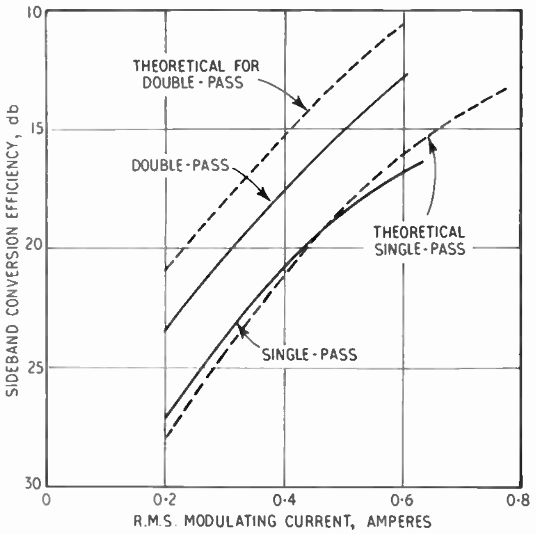

Fig. 12. Sideband conversion efficiency for a double-pass modulator single frequency 4 Mc/s.

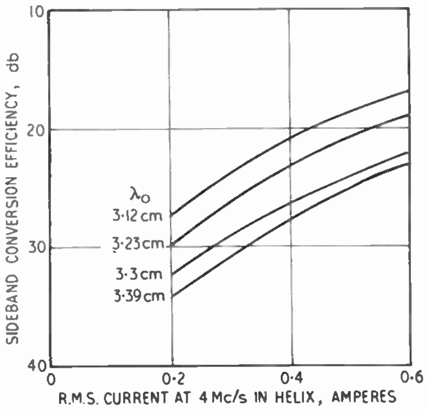

Fig. 13. Variation of sideband conversion efficiency with wavelength of carrier at 4 Mc/s modulation.

While the double-pass modulator is structurally more complicated than the single-pass device, there is a gain in efficiency, and it is also no longer necessary to insulate one end of the helix guide from the waveguide circuit in order to avoid short-circuiting the signal.

Since the Faraday angle, and consequently the conversion efficiency of the modulators, is a function of the rod parameter d/λ_0, it will be dependent upon the carrier frequency. Figure 13 shows the effect of varying the frequency of the carrier.

8. Observations

The result of the experimental investigation has shown that X-band ferrite modulators can be made to have first order sideband conversion efficiencies around 15-20db for signal frequencies at the lower end of the megacycle band. The main problem at these high signal frequencies lies in avoiding the ferrite overheating and approaching too close to, or even exceeding, its Curie point. The usual X-band microwave ferrites are unsatisfactory, and special ferrite compositions become necessary. A frequency of 10 Mc/s is getting close to the practical limit for a material which has a cubic crystal structure and which still has to have a reasonably permeability.

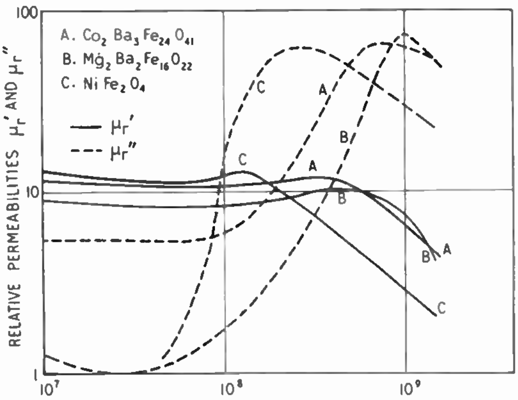

Fig. 14. The relative permeability spectrum of (a) cobalt barium ferrite, (b) magnesium barium ferrite and (c) nickel ferrite. (Jonker, Wijn and Braun[8].)

It is therefore of interest to examine the frequency spectrum of new hexagonal materials (which have been described by Jonker *et alii*[8]), in relation to that of a cubic spinel ferrite. Such a spectrum has been published by those authors and is reproduced in Fig. 14. If the microwave behaviour of these magneto-plumbite ferrites is satisfactory, they should be suitable for signal frequencies in the 100 Mc/s region.

The experimental modulators described in the present paper were based upon standard air filled X-band waveguide practice. It would however appear that the use of a dielectric material in the guide would be beneficial. This would reduce the spurious radiation from the helical track, reduce the diameter of the helix and its ferrite, as well as permitting simpler rectangular to circular waveguide transitions. The dielectric filled modulator would then follow the present tendency of P.T.F.E. filled Faraday isolators. The main problem with a dielectric filled modulator would be the removal of the heat from the ferrite rod. The problem would be eased if the loss caused by the modulating signal could be reduced by new ferrite compositions, and a better heat dissipation obtained by a dielectric which has a better thermal conductivity than P.T.F.E. It is understood that there is such a dielectric, namely sintered boron nitride.

9. Acknowledgments

The author is indebted to his late colleagues E. R. Passfield and S. J. W. Bromet for their help and for much of the experimental data.

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Radio Engineering Overseas . . .

The following abstracts are taken from European and Commonwealth journals received in the Library of the Institution. Members who wish to borrow any of these journals should apply to the Librarian, stating full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the Journal unless otherwise stated. The Institution regrets that translations cannot be supplied.

COIL DESIGN

In designing a series of similar choke coils with ferro-magnetic core, e.g. for an a.c. network analyser, there exist given fixed constructive relations between geometric quantities of choke coils. A Yugoslavian engineer has studied—making some assumptions and approximations—the relationship between the quality of the choke coil $Q = \omega L/R$ and the total mass m of the core with the winding. He proves that the mass m of the choke coil increases with the third power of the quality factor Q.

"Dependence of mass of choke coils on Q," M. M. Brezinscak. *Elektrotehniska Vestnik*, **26**, No. 7/8, pp. 225-7, 1958.

MICROWAVE STRIP LINE

Some aspects of wave propagation along a parallel strip transmission line and through a coaxial line to strip line transition junctions are discussed in an Australian paper. The design criteria for the line are stated and a description is given of a method of measuring the properties of strip lines, employing a conventional coaxial line standing wave indicator connected to the strip line through an unknown junction. The method uses the variation of the standing waves as a function of the strip line length to derive both the line and junction parameters. Results for three line sizes are given for wavelengths in the 8 to 11 cm range.

"Measurement of the properties of a strip line and its transition junction," F. Norman. *Proceedings of the Institution of Radio Engineers, Australia*, **19**, pp. 788-794, December 1958.

MATERIALS FOR MICROWAVES

Materials which are absorbent to s.h.f. waves are characterized by the following two variables: wave impedance of the boundary surface and air; internal absorption from the point of view of attenuating energy passing through the material.

These two conditions are best realized according to two different techniques described in a French paper.

1. A mixture of a porous plastic substance and carbon powder gives a dielectric constant of nearly 1. The front face is embossed and the plastic substance is either foam rubber (supple substance) or polystyrene (rigid substance). The absorption is centred on a frequency of 3000 Mc/s or higher according to the fineness of the carbon, and covers a wide band. The reflection coefficient varies little with angle of incidence. This material is used for camouflaging objects which are fixed sources of radar echoes or in the construction of anechoic chambers at u.h.f.

2. The second method uses an absorbent plastic of quarter wavelength thickness, at the frequency under consideration, which is glued directly on thin copper or aluminium sheet, or on copper gauze. The absorbent load is magnetic in nature when carbonyl iron is used, electric when carbon is used. The absorption is in a narrow band. These materials have been mainly manufactured for S and X bands. They take up little room and are resistant to weather, and are used for camouflaging from radar small naval units, the super-structure of warships, buoys, and aerodrome run-way beacons, etc. They are also used for radome covers during ground tests of airborne radar equipments and for wave guide terminations.

"Some absorbent materials at s.h.f.," H. G. Stubbs. *L'Onde Electrique*, **38**, pp. 809-818, December 1958.

MANUFACTURE OF COAXIAL CABLE

Existing measurement methods for tests during the manufacture of coaxial cables with solid dielectrics are first briefly described in a recent German paper. On the basis of these methods, a novel method for continuous measurements of the capacitance of coaxial cables by means of a water jacket as a test electrode has been evolved which uses an electronic "impedance transformer" for an accurate limitation of the test length of the water electrode. The equivalent electric circuit for this test tube is given and is used for the design of the impedance transformer. The stability of multistage impedance transformers is briefly discussed.

"Continuous measurements of the capacitance of coaxial cables during manufacture," D. Wolff. *Nachrichtentechnische Zeitschrift*, **12**, pp. 29-32, January 1959.

WAVEGUIDES

Investigations of the properties of disk-loaded and helical waveguides have been carried out at the Research Institute of National Defence, Stockholm, with the original intention of determining the properties of the helical waveguide; however, in the course of the work it appeared that some of the properties of the helical waveguide could be explained by reference to the disk-loaded waveguide. For that reason the dispersion curves and coupling impedances of both types of waveguides were calculated and the influence of various circuit parameters investigated. The dispersion curves of three manufactured slow-wave structures have been measured with different methods. This work is relevant to the design of slow-wave structure of these types.

"Investigations of the disk-loaded and helical waveguide," Bengt T. Henoch. *Transactions of the Royal Institute of Technology*, No. 129, Stockholm, Sweden, 1958.

CAVITY RESONATORS

When cavity resonators are connected with transmission lines, all technically possible cases can be reduced to the case of a cavity or its equivalent circuit in series or in parallel to the characteristic impedance of the transmission line. The Q-value of such cavities can be determined from the mismatch and from the position of the minimum at frequencies near resonance when a standing wave indicator is used. The usual method of measurement given in the literature for the case of a cavity in a parallel circuit is systematically expanded in a recent paper to cover a number of technically interesting types of coupling. Some simple equations for the evaluation of the measurements are given for the discussed types of cavity coupling and are proved theoretically.

"Q-value measurements by means of a standing wave indicator on cavity resonators connected with transmission lines," Hans W. Urbarz. *Nachrichtentechnische Zeitschrift*, **11**, pp. 571-576, November 1958.

SEMI-CONDUCTOR DEVICES

The electrical properties of a storing switch transistor have been further investigated by the author of a paper on the same subject which was published in the *Brit.I.R.E. Journal* for November. A square root law exists for the relationship between the collector impedance in a cut-off state and the collector voltage, while the base impedance changes very little with voltage. The family of curves for the input characteristics, which resemble those of thyratrons, is discussed. The on-off ratio, i.e. the ratio of impedances in the cut-off state and in the conducting state, lies in the order of 1×10^5 to 5×10^5. The temperature response of the most important electrical properties of switch transistors with different base materials is described.

"The electrical properties of a storing switch transistor," W. v. Munch. *Nachrichtentechnische Zeitschrift*, **11**, pp. 565-571, November 1958.

TRANSISTOR CONVERTERS

Methods of design of converters encountered in the literature mainly employ single transistor circuits. A Polish paper presents an equivalent circuit of a push-pull transistor converter, along with a method of finding explicit relations between particular parameters of this kind of circuit. It has been shown that for practical purposes it is sufficient to consider a triangular wave of current charging the output capacitor. Formulae derived under this assumption lead to consistent results, sufficient for the practical design purposes, especially for the design of the transformer. A rigorous analysis of the phenomena considered is more involved however and will be covered fully in a subsequent paper.

"Design of d.c. push-pull transistor converters," T. Konopinski and M. Politowski. *Prace Instytutu Tele- I Radiotechnicznego*, **11**, No. 3, pp. 3-16, 1958.

ELECTRO-OPTICAL MEASUREMENT OF DISTANCE

In an article on the electro-optical measurement of distance, a method is analysed in which the phase of the modulation envelope of a reflected light beam is compared with the phase of the transmitted beam, modulated by a Kerr cell or vibrating crystal. The main advantage of the equipment is stated to be its relatively great precision and the possibility of measurement in inaccessible terrain.

"Electro-optical measurement of distance," B. Sokolik. *Slaboproudy Obzor, Prague*, **19**, pp. 678-681, October 1958.

STORAGE DEVICES

A recent German paper shows how periodically repeated noisy groups of signals with a large bandwidth can be combined by means of a storage method to form a single group of signals with a smaller bandwidth and an improved signal/noise ratio. The integration of corresponding instantaneous values in the signal groups is carried out effectively in an electronic line charge storing tube. Commercially available cathode-ray tubes can be used as storage tubes. The recording and pickup processes are carried out simultaneously and with the same anode voltages. The operation of such tubes is described. For the purpose of assessing the integration characteristics an equipment has been designed which shows these characteristics on an oscilloscope. The operation of this equipment and the results obtained are described.

"An electronic line storage device for bandwidth compression of periodically repeated signals, particularly for radar p.p.i. displays," K. Lange. *Nachrichtentechnische Zeitschrift*, **11**, pp. 619-627, December 1958.

AERIAL MEASUREMENTS

The horizontal radiation patterns of standard rhombic antennas at the transatlantic radio receiving station for short-waves at Eschborn have been measured by means of statistical methods. Values for the side-lobe level as well as for the backward radiation level at different frequencies have been derived from these measurements.

"The horizontal radiation patterns of rhombic antennas for receivers in short wave-links," H. Bohnenstengel, W. Kronjager, and K. Vogt. *Nachrichtentechnische Zeitschrift*, **11**, pp. 605-610, December 1958.

RADAR DISPLAYS

The distribution of targets on radar p.p.i. displays as well as a method of determining the number of targets is described in a German paper. The representation of frequency spectra and their relationship with the signal content is discussed with the aid of examples. A method of suppressing the low frequencies by means of a signal controlled carrier modulation is described and the resulting modified spectra are shown.

"The statistical properties, the frequency spectrum and the suppression of low frequencies in signals for radar p.p.i. displays," H. Groll and E. Vollrath. *Nachrichtentechnische Zeitschrift*, **12**, pp. 33-40, January 1959.

ELECTRONIC SPEED MEASUREMENT

A direct reading electronic equipment has been designed in Bengal Engineering College for measuring the rotational speed of machines over a wide range extending up to gas turbine speed with an accuracy better than 1%. The instrument is based on an electronic pulse technique and provides for extra facilities for recording the instantaneous speed and for measuring a drift of speed of 0·5% of full scale. It is also provided with a relay to cut off power from the rotating machine at a preset speed.

"A multipurpose electronic tachometer," S. M. Zoha. *Journal of Technology (Bengal Engineering College)*, **3**, pp. 33-42, June 1958.

RELIABILITY IN SHIPBOARD ELECTRONIC EQUIPMENT

Discussing naval technical development, a Member of the Institution who is at present attached to the Royal Australian Navy suggests that it appears to follow a pattern of slow broad progress broken at random intervals by major steps forward. There is now, once again, an epoch of great change. The high speed of the modern aeroplane and submarine and the extreme potency of the weapons which either may carry are forcing shipborne antidotes to entirely new extremes of complication without which there can be no hope of destroying their targets. This necessity is leading to the development of electronic systems characterized by "size" and "complexity" of a different order of magnitude to anything hitherto met with at sea. An existing equipment in its late design stages and shortly to go into service contains 7,000 valves and 60,000 components. It is merely one of the many facilities fitted in a modern major warship. Equipments of this order of size are in fact becoming rather general in the fields of weapon control, air direction, and guided missiles. Such very large systems, built up, in the main, of essentially commercial quality valves, resistors, capacitors and other electronic components, clearly present their special problems if a high order of reliability is to be achieved. The special hazards of service at sea and the particular problems imposed by great size are discussed. At the detailed design level the author suggests a number of possible approaches for the achievement of high reliability. He cites existing examples for each approach and invites discussion by specialists. Considering such systems as a whole the statistical pattern of component failure is discussed, and taking practical examples the probable period of fault free operation is derived. Typical figures are cited. The importance of rapid repair under battle conditions is stressed. No very firm conclusions can be drawn as experience to date is limited, but the indications are that some of the inherent difficulties outlined in this paper are as yet unsolved.

"The problems of reliability and maintenance in very large electronic systems for shipboard use," G. C. F. Whitaker. *Proceedings of the Institution of Radio Engineers, Australia*, **19**, pp. 757-774, December 1958.

PRODUCTION TECHNIQUES

An apparatus for testing the solderability of wire has been described in which a globule of solder is split in two by the wire under test, which has first been dipped in the flux. After some time, varying from 0·1 sec to more than 30 sec, the two halves flow abruptly together over the wire. This time is taken as a measure of the solderability of the wire. The apparatus has also been used for investigations into the influence of the composition and quantity of the solder, of the soldering temperature, of the composition of the flux and of the surface condition of the wire. These investigations were concerned in particular with the dip-soldering process employed for printed wiring.

"An apparatus for testing the solderability of wire," J. A. ten Duis. *Philips Technical Review*, **20**, No. 6, pp. 158-161, December 1958.