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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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AN INVITATION

Membership of a professional Institution, in common with any other really worthwhile activity, involves certain obligations as well as privileges. Apart from the privilege of status within one's chosen profession, membership entitles one to receive the *Journal*, make use of the Library and other information facilities, and last, but not least, to attend meetings.

The principal object of the Institution is expressed in its motto "Scientia Pro Hominibus"—the advancement of science for the benefit of mankind. This is particularly emphasized in the detailed objects of the Institution "... to facilitate the *exchange* of information and ideas on radio science and engineering ...". Every member on his election undertakes to help towards fulfilment of this object and one way is, of course, to participate in local Section meetings. Indeed, it might be said that attendance at meetings is both a privilege and an obligation incurred at the time of being elected a member of the Institution.

In addition to the meetings held in London, there are today no fewer than seven local Sections holding regular meetings at centres throughout the British Isles. Overseas, the Sections in India, New Zealand, Pakistan and South Africa cater for a large proportion of the Institution's membership. It is fair to say, therefore, that the Institution provides an opportunity for the majority of its members to hear and discuss technical papers.

An examination of the Programme of Section Meetings to be held in the British Isles during the 1956-57 session shows that papers on an extremely wide variety of technical subjects are to be read. These range from Transistors and Colour Television to Automation and Computers. There will thus be few members who

cannot find at least one meeting in the programme of their local section which will be of professional value and interest to them.

The papers for reading at Local Section meetings are mainly chosen for their wide general interest, and with the object of providing an opportunity for engineers to hear about the achievements and problems in other fields of radio and electronic engineering. It cannot be emphasized too often that an achievement in one field may lead to a solution of a problem in another quite different field. Thus the opportunities afforded for both technical and informal discussions with other engineers are invaluable.

Arrangements for these meetings are in the hands of the Local Section Committees, assisted where necessary by the Programme and Papers Committee. Every member should recognize the hard work put in by some fifty representative members who serve on these Local Committees in obtaining speakers, considering and selecting papers, and making all the other arrangements needed for the smooth running of meetings. Recognition of this work can best be shown by support of the Local Section's meetings; it is a regrettable fact, however, that these meetings do not receive the support that they deserve. It is no comfort to learn that similar apathy is experienced by other professional and scientific bodies.

A programme booklet, a notice of meeting, or even details published in the *Journal* really form invitations to members to attend the meetings of their Local Sections. Now that a new session of meetings has started, every member should try to give an affirmative answer to the question, "Will you accept the invitation to attend at least some of the meetings to be held this winter?"

NOTICES

Admiral of the Fleet Earl Mountbatten of Burma, K.G.

The President and Council of the Institution have offered congratulations to Admiral the Earl Mountbatten of Burma, K.G., P.C., G.C.S.I., G.C.I.E., G.C.V.O., K.C.B., D.S.O., Vice-Patron of the Institution, on his appointment as Admiral of the Fleet.

Earl Mountbatten joined the Royal Navy in 1913, and has held a number of appointments in the Signals Branch. He was elected a Member of the Institution in 1935, and was subsequently a member of the General Council and a Vice-President. Admiral Mountbatten was elected the 9th President of the Institution in 1946.

Obituary

The Council of the Institution has learned with regret of the death of the following member, and has expressed sympathy with his relatives.

Archibald Montgomery Low (*Member*) died at his home in London on 13th September, aged sixty-eight years. Educated at St. Paul's School, Mr. Low was a graduate of the Imperial College of Science and Technology. During the first World War he served in the R.N.V.R., and subsequently in the R.A.F., being concerned with experimental work on radio controlled equipment. From 1919 to 1922 he held an Honorary Assistant Professorship of Physics at the Royal Artillery College.

Mr. Low was well known for his writings popularizing science, and for numerous inventions and patents; he was a very active member of the Institute of Patentees, and served as its President for some years. Mr. Low did a considerable amount of consultancy work, particularly in the field of noise measurement and abatement.

He was closely associated with the forming of the Radio Association in 1922. In 1933 he was elected a Member of the Brit.I.R.E.

City and Guilds Insignia Awards

Three Insignia Awards were made by the City and Guilds of London Institute for 1955 in the group Electrical Industries, one of which was to Harold Arthur Odell (*Associate Member*). Mr. Odell, who is with the Iraq Petroleum Company Limited, obtained his award for a thesis entitled "Design and Development, Installation and Operation of a Teleprinter System for Control of Oil Movement in an Oilfield and Pipeline System."

City and Guilds Examination Results

The City and Guilds of London Institute has recently published a summary of the results of its examinations held during 1955. Once again, there was an increase in the number of entries, the total for all subjects being 103,251, or 8,149 more than in the previous year. In the subject of Telecommunications Engineering, the total number of candidates was 34,794, an increase of 2,313. It is however of interest to note that the number of Full Technological Certificates awarded was only 69, two more than last year. The Certificate is only granted after success in thirteen examination papers and usually takes five years part-time study.

The great majority of candidates for the Telecommunications Engineering subjects entered for the Intermediate Examination only; there was a considerable reduction of entries for the higher grades. For instance, there were only 230 entrants for Telecommunications Principles V in the United Kingdom, and 32 overseas.

The Institution offers its congratulations to two members of the Institution who obtained prizes. Mr. M. B. Oakes (*Graduate*) was awarded a prize of £2 0s. 0d. for Telecommunications Principles IV, and Mr. J. Flens (*Graduate*) a similar prize for Radio IV.

Institute of Navigation Award

The Gold Medal of the Institute of Navigation has been presented jointly to W. J. O'Brien and H. F. Schwarz (*Member*), who originated and developed the Decca Navigator System.

Mr. O'Brien was the author of the paper on "Radio Navigational Aids," describing the Decca System, which was presented at the 1947 Radio Convention and subsequently published in the *Brit.I.R.E. Journal* for October 1947. The paper was awarded the Heinrich Hertz Premium for that year.

Correction

The following minor amendments should be made to the paper "The Electric Field of a Dielectric Heating Work Circuit," published in the August issue of the *Journal*:—Page 416, Fig. 4: At the point marked D, " $t=ra$ " should read " $t=+a$ "; page 418, Fig. 6: Caption (b) should read "Upper plate $V=V_0$ "; page 418, second column, line 8, should read ". . . Fig 6b," instead of ". . . Fig. 5b,".

THE DEKATRON IN A DIGITAL DATA TRANSMISSION SYSTEM *

by

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*Read before the Merseyside Section of the Institution on 9th November, 1955.
In the Chair: Mr. R. A. Spears.*

SUMMARY

In data transmission systems used to transmit numerical information over considerable distances for control or indication purposes, the information is sent as a serial train of digits to conserve bandwidth, each digit having two possible states. The paper describes a system for the transmission of such information using the Dekatron tube in a number of roles. These tubes enable the functioning of the timing system to be monitored so that faults may be quickly and easily located by visual observations of the behaviour of the glow discharges.

1. Introduction

The term data transmission implies the transmission of some kind of factual information from one location to another and, generally, the received information is reconstituted into its original form to be used immediately for control or indication purposes. Where the distance is short, the information can usually be transmitted over a number of wires and no long distance communication problem arises. Where the distance is great, a system is required to enable, in many cases, a large amount of information to be transmitted over a single pair of wires or over a single radio link.

In order that the information shall retain its original form with minimum error it is desirable to employ a system in which the data is represented in digital form, each digit having only two possible states, a major advantage being that the signals may be regenerated with little chance of error provided that distortion and noise are kept within reasonable limits.

Various devices for encoding numerical information in digital form are well known. For example, a shaft angle may be converted to digital form by means of a coder in the form of a multisegment stud switch‡ from which a

code of connections or potentials may be obtained representing the position of the wipers with respect to some zero datum position according to a binary or modified binary scale. Another device for converting a shaft angle to digital form has been described by Barker§ in which the code is photographically produced on a circular glass plate attached to the shaft, the code elements being read serially by radial scanning.

Digital data, however, does not invariably imply numerical information. For example, it may be required to transmit for control purposes the positions of a number of independent switches each having, say, "off" and "on" conditions represented by digital "0" and "1" states. Here no question of digital significance arises, each digit having identical significance. In the case of the numerical transducer or coder, however, digital significances are allocated in accordance with some scale of binary form.

In order to conserve bandwidth in the transmission medium it is usual to transmit in serial manner samples representing the states of the individual digits existing in parallel at the sending end, the train of signals being used to modulate a voice frequency telegraph sender (v.f.t.). The process for producing the

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U.D.C. No. 621.387:621.398.

‡ E. A. Johnson, British Patent No. 653,909.

§ R. H. Barker, "A transducer for digital data transmission systems," *Proc. Instn Elect. Engrs*, **103B**, pp. 42-51, January 1956.

modulating signal, known as "dynamicising," is carried out by a device known as a "dynamiciser." The train of signals received by a voice frequency telegraph receiver is sorted digit for digit into a series of storage locations at the receiving end thereby re-constituting in digital form the original information in parallel. This process, known as "staticising," is carried out by a device known as a "staticiser."

This paper describes the application of the Dekatron tube to the dynamiciser and staticiser elements in a transmission system of this type.

2. The Elements of the System

Elementary forms of dynamiciser and staticiser can be visualized as consisting of two identical stud switches one at each end of the transmission link, the wiper arms being connected together. The digital information existing in parallel is applied to the contact studs of the switch at the sending end in the form, say, of one of two direct potentials representing the "0" (space) and "1" (mark) states respectively. By rotating the wiper of the sending switch at a uniform speed, samples of each of the digit potentials are extracted from the wiper arm as a serial train, each digit being allocated a definite location in the train of signals and being sampled for a definite length of time. Each digit occupies what is known as a "slot" in the train of signals and the time taken to make one complete rotation is known as the cycling time, the complete cycle of information being known as a "frame."

If now the switch at the receiving end is rotated in time synchronism with that at the sending end, the wipers previously having been set on corresponding studs, each piece of information, as sampled by the sending switch, will be presented separately on the respective studs of the receiving switch and may be stored for one complete cycle when the state of the store will be altered if the information has changed.

These are the basic principles of the transmission system and various subsidiary features will now be discussed.

2.1. The Timing System

In order that the two switches shall run in synchronism, it is necessary to drive them from timing devices, say two oscillators, the frequencies of which are either locked together or are very close to one another. If they are not locked, there will be a continuous drift of

one switch with respect to the other so that in time information will slip out of position and be allocated to the wrong storage locations.

Assuming that the driving signals are locked in frequency, it is necessary to phase one switch wiper to the same position as the other when starting, otherwise the information will be stored in the wrong locations. Some characteristic signal must, therefore, be sent down the line to set the receiving switch to the correct position on starting up. If the oscillators are not locked in frequency, but the frequencies are so close together that no detrimental drift can occur during one cycle of the switch, and the phase controlling signal is sent out at a fixed position during each rotation, then the two wipers may be kept running in sympathy by a repeated resetting action.

2.2. The Synchronizing Signal

The synchronizing signal must be of such a form that it can be distinguished from the variable information and filtered out for utilization. Several possible synchronizing signals may be suggested. One type is a mark signal of double amplitude which may be filtered by a simple clipping operation but this form is wasteful of v.f.t. sender available power and spurious line signals of high amplitude may be accepted by the sync. filter and cause incorrect resetting.

Another well known type of signal, the one used in the present system, consists of a block of space signals. In order that it may be distinguished from the variable information, it is necessary to divide up the frame into blocks by the insertion of a number of permanent mark digits. Since all the variable signals in any block may be spaces, the synchronizing block of spaces is made at least one slot longer than any other block.

2.3. The Permanent Marks

The permanent marks serve another useful purpose when an amplitude modulated (a.m.) v.f.t. system is used. Since all the variable information may be spaces when the v.f.t. sender is quiescent, the permanent marks provide regular signals for operating the automatic gain control circuits in the receiver. In the case of frequency modulated (f.m.) v.f.t. systems, in which a tone signal is always present, these signals serve no useful purpose for a.g.c. and merely allow the synchronizing signal to be distinguished.

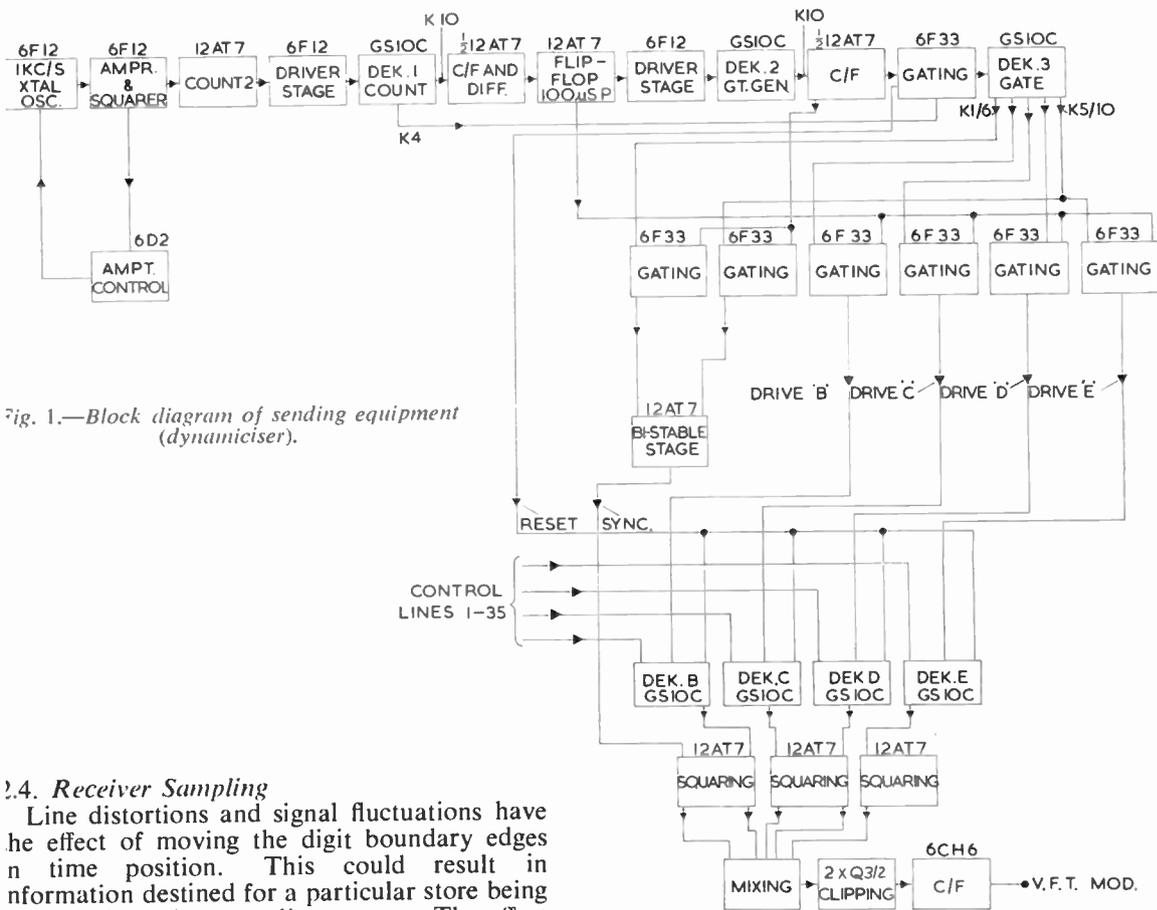


Fig. 1.—Block diagram of sending equipment (dynamiciser).

2.4. Receiver Sampling

Line distortions and signal fluctuations have the effect of moving the digit boundary edges in time position. This could result in information destined for a particular store being accidentally fed to an adjacent one. The effect of amplitude variations can be reduced by amplifying a horizontal slice from the received signals. The effect of boundary displacements can be avoided by allowing the stores to be fed from narrow vertical slices from the received signals, the timing of the samples occurring at approximately the mid position of each digit.

2.5. Bandwidth, Digit Change Rate and Frame Length

Several factors influence the design of a transmission system of this type.

- (a) The number of digits to be sent.
- (b) The maximum rate of change of any one digit.
- (c) The bandwidth limitations of the transmission link.

A convenient rate for telegraph line circuits is 50 digits per second, which requires a

bandwidth of 100 c/s and this, together with item (b), determines the maximum frame length in order that no information changes are lost. For information that changes slowly, very long frames can be used, but where large numbers of rapidly changing digits are to be sent, short frames generated in parallel may be required associated with tone multiplexing in the transmission link.

3. Features of a System using Dekatron Tubes

Figures 1 and 3 are the block diagrams of the sending and receiving equipments respectively which in conjunction with the waveforms diagram (Fig. 2), enable an overall picture of the system to be obtained. Individual circuits are shown in Figs. 4, 5, 6, 7 and 8 to which references are made in the relevant portions of the text.

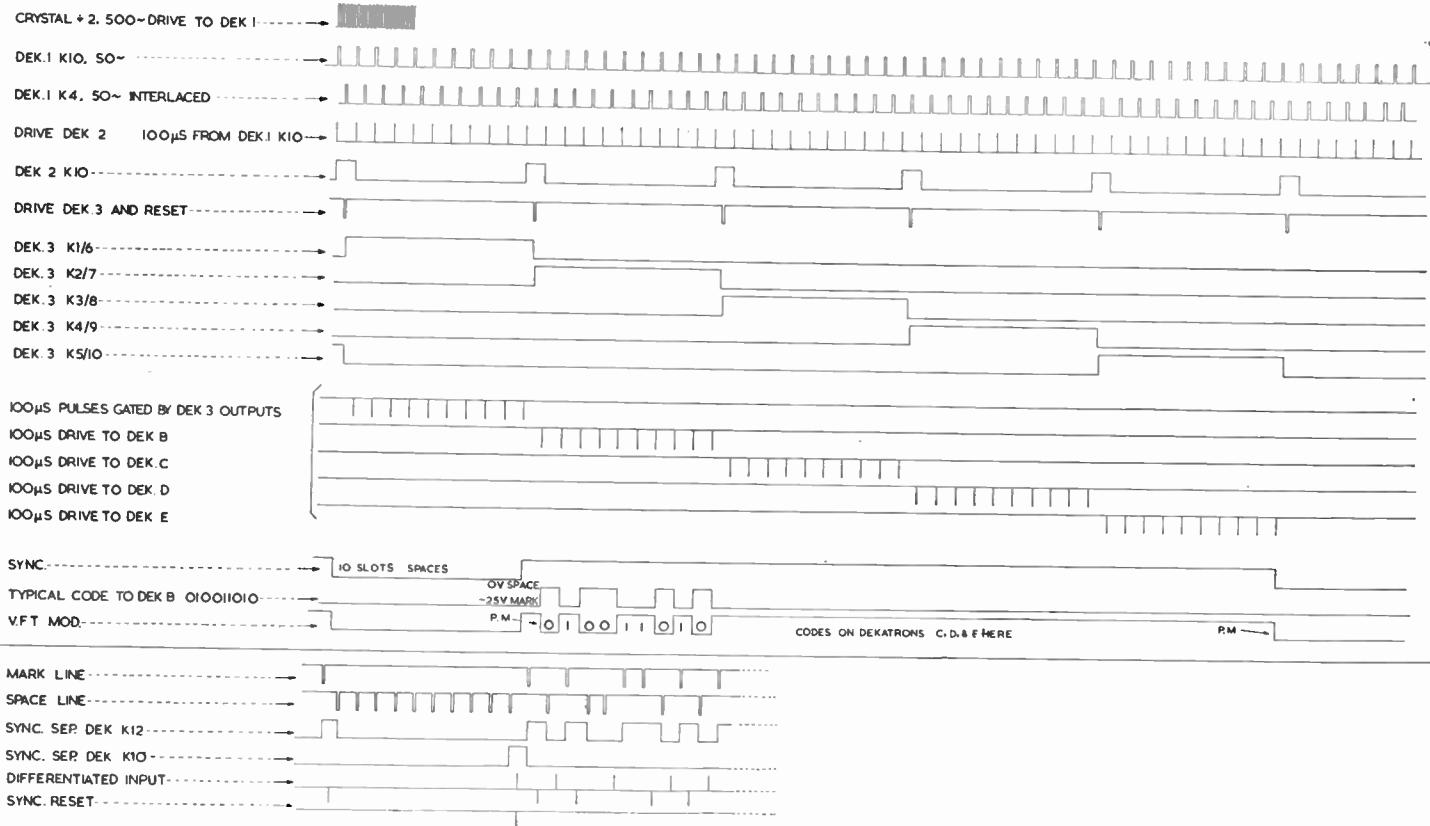


Fig. 2.—Waveforms.
 (Note: Timing of receiver is a maximum of 2 millisecc late due to reset to K9 of Dekatron 1.)

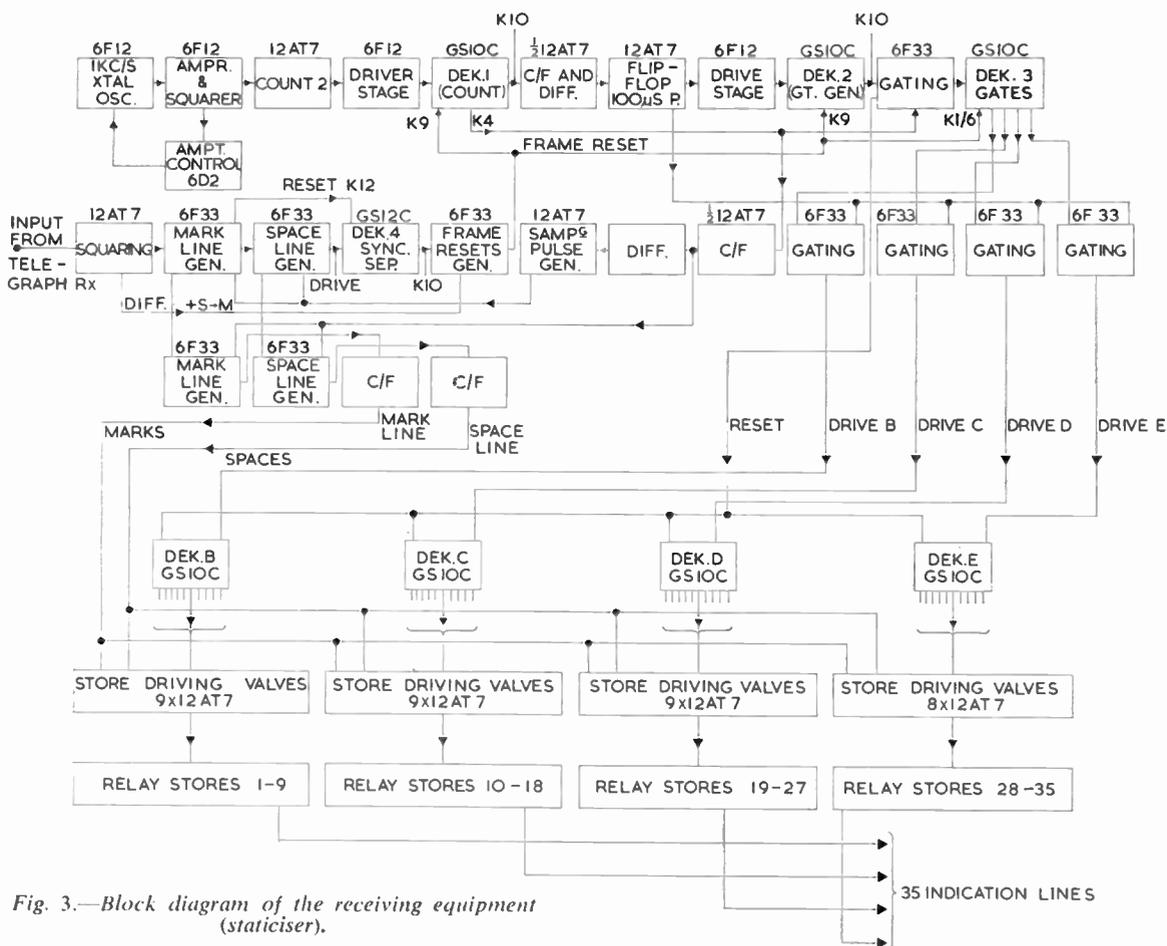


Fig. 3.—Block diagram of the receiving equipment (staticiser).

3.1. The Dekatron

The Dekatron was first described in a paper by Pollard and Bacon in 1950.* Since then its use has become widespread in counting and switching applications. The inherent rugged simplicity and self-monitoring properties provide high reliability and the rapid and easy location of faults.

One important feature of the tube is exploited in the Dynamiciser. Being a gas-filled tube it exhibits an almost constant potential difference between the anode and any cathode. It can thus act as a sampling switch. Direct potentials representing the digit states are applied to the

respective cathodes of a set of tubes, the discharges being stepped around the sets of cathodes in sequence by driving signals derived from a timing system.†

3.2. The Frame of Information

Choosing a basic slot width of 20 milliseconds, a frame consisting of 50 slots carrying digital information can be arranged as follows:

- 3 blocks each containing 9 work digits and a permanent mark
- + 1 block containing 8 work digits and a permanent mark
- + 10 synchronizing space digits and a permanent mark.

It will be seen that if all the work digits (variable information) are spaces, the synchronizing signal contains one space more than any one of the work blocks.

* R. C. Bacon, J. R. Pollard, "The Dekatron," *Electronic Engineering*, 22, pp. 173-177, May 1950.
 † Prov. Pat. No. 34162/53.

A complete frame is sent in one second and no digit may vary more often than this, otherwise information will be lost. Of the 50 slots, 35 carry variable digital information for utilization in the storage system.

The blocks are arranged in this fashion to suit the divided sampling switch employing the ten-cathode Dekatron. An alternative frame arrangement is possible making available the same number of work digits as follows:

- 8 blocks each of 4 work digits and a permanent mark
- + 1 block of 3 work digits and a permanent mark
- + 5 synchronizing spaces and a permanent mark.

This frame arrangement requires the use of an additional Dekatron in the dynamiciser switch and employs more components but is advantageous when using an a.m. v.f.t. system because of the increased number of permanent marks available for a.g.c. purposes.

3.3. *The Dynamiciser (Fig. 4)*

Four Dekatrons B, C, D and E form the digit sampling switch. Direct potentials representing the digit states are applied to cathodes K1 to K9 of the tubes, B, C and D and to cathodes K1 to K8 of tube E. Earth potential defines a space or "0" digit and -25 volts with respect

to earth defines a mark or "1" digit. Cathodes K10 of each tube are connected together.

In order that each Dekatron shall contribute its quota of signals at the correct time, four blocks each consisting of ten pulses drive the discharges of the four tubes in sequence so that each makes a scanning cycle and then rests. Cathode K10 in each case is the "rest" cathode and, in order that a scanning cycle will always start from a rest cathode, resetting pulses are applied to cathodes K10 five times per frame when all tubes are resting together. This occurs at the time when the permanent marks are being inserted in the frame, the cathodes K10 being tied to the mark defining potential, but the permanent mark generated after tube E has cycled is over-ridden by the first space of the synchronizing pulse and the permanent mark inserted at K9 of tube E takes its place.

The anodes of the tubes are connected through ballast resistors to the grids of mixing triodes V1 and V2. These share a common anode load resistor and the cathodes are connected together and taken to a stabilized potential source produced by the series stabilizing stage V3b, the d.c. amplifying stage V4 and the reference neon V5. This potential is adjusted by the potentiometer control to hold the grid bases of the mixing triodes at the mean potential of the Dekatron anode excursions.

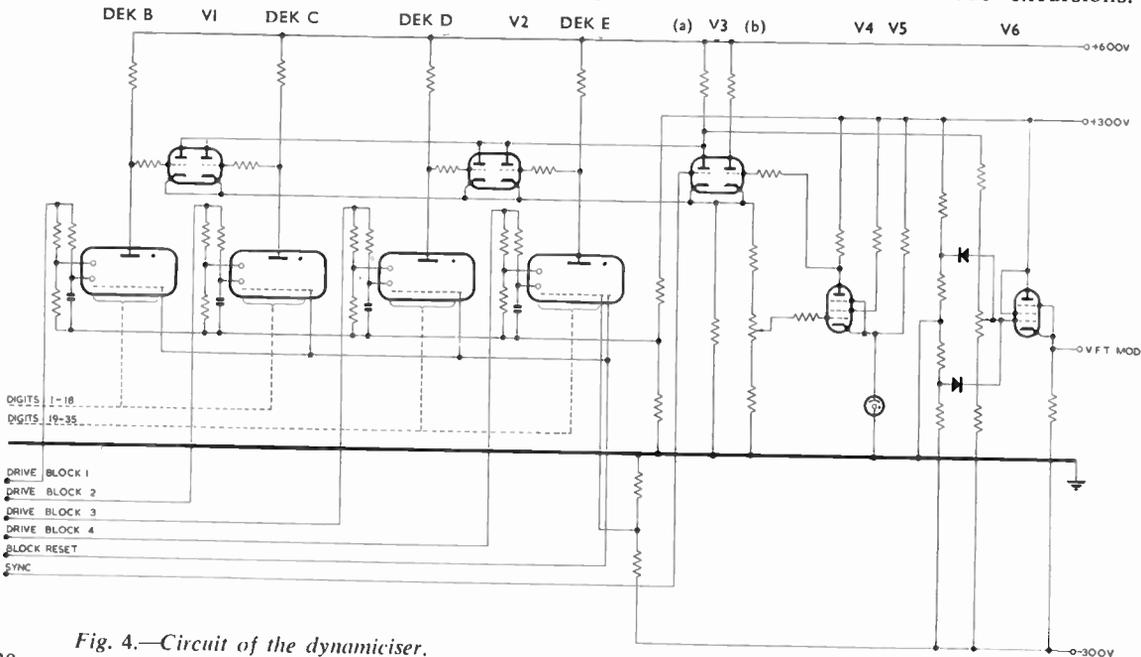


Fig. 4.—Circuit of the dynamiciser.

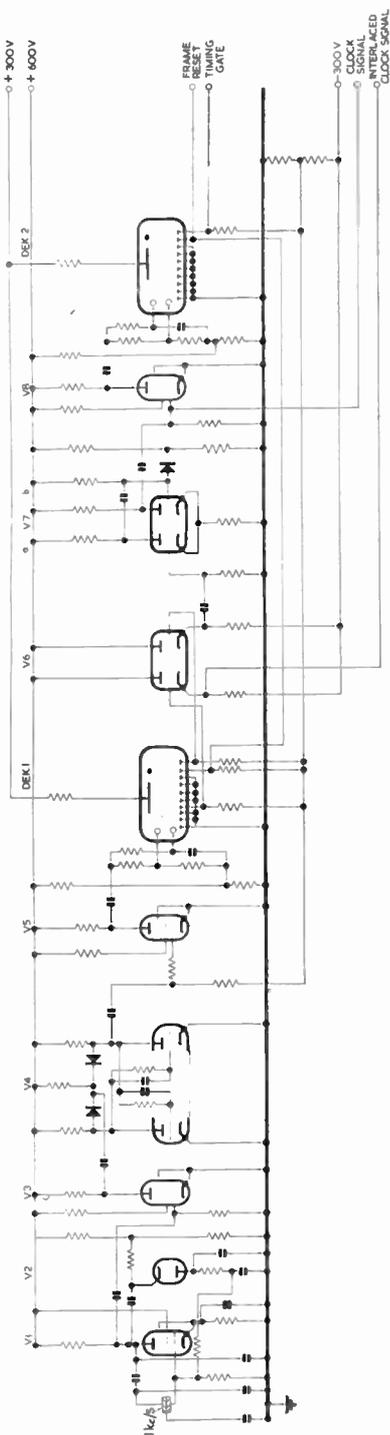


Fig. 5.—Circuit diagram of the oscillator.

The anode to cathode gas gap potential is approximately 185 volts. When the discharge invests a cathode tied to a space defining potential, the potential of the anode is +185 volts, and when it invests a cathode tied to a mark defining potential, the potential of the anode is +160 volts. The random variations of gas gap potential are around ± 5 volts from cathode to cathode and from tube to tube and these are adequately swamped by the 25 volts swing produced by the digit defining potentials. A "mark" potential always cuts off a mixing triode and a "space" potential drives it into grid current.

The positive-going synchronizing signal of duration 200 milliseconds is applied to the grid of mixing stage V3a.

Across the anode load resistor of the mixing stages appears the serial train of signals consisting of the samples of all the digits, the permanent marks and the synchronizing signal, and this is reduced in level and clipped in amplitude to produce from the cathode follower stage V6 an output at low impedance, varying between +12.5 volts representing marks and -12.5 volts representing spaces. This is the modulating signal for the v.f.t. sender.

3.4. The Oscillator and Timer (Figs. 5 and 6)

The various driving and resetting signals and the synchronizing signal are generated in this part of the equipment. The crystal controlled oscillator stage V1, having an amplitude-limiting bias feedback rectifier V2, produces a sine wave of 1000 c/s. This is squared in stage V3 and is frequency divided to 500 c/s in the counter stage V4. The output from V4 is differentiated, the positive-going differential pulses being shaped in V5 to provide pulses of approximately 100 microseconds width for driving Dekatron 1. The output from cathode K10 of this Dekatron, consisting of positive pulses of width approximately 2 milliseconds and recurrence frequency 50 c/s, is applied to the grid of the cathode follower stage V6, the output of which is differentiated. The positive-going differential pulses are used to trigger the flip-flop stage V7 which produces positive-going pulses of width 100 microseconds. This signal is the master "clock signal." A similar signal known as the "interlaced clock signal," because the pulses are interlaced in time with respect to those of the clock signal, is produced from cathode K4 of Dekatron 1, the pulse width being maintained at 2 milliseconds.

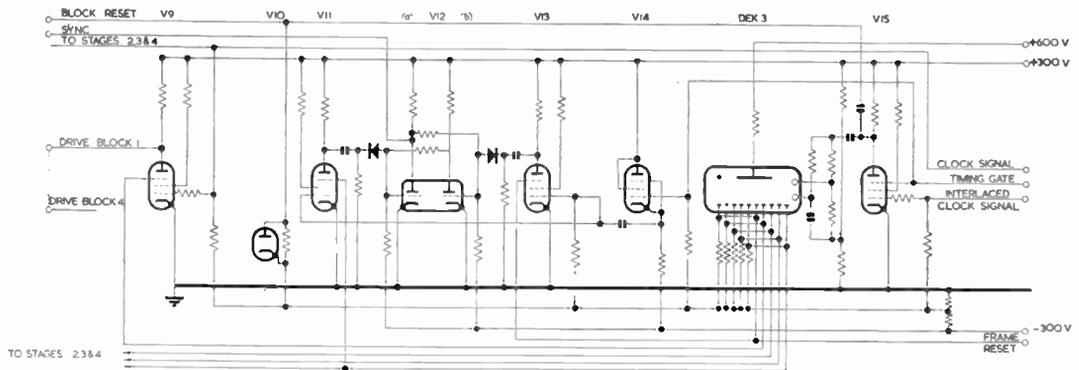


Fig. 6.—Circuit diagram of the timer.

The clock signal is applied to stage V8 to drive Dekatron 2 and the output from cathode K10 of this tube, known as the "timing gate," is of width 20 milliseconds and recurrence frequency 5 c/s. It will be appreciated that every tenth interlaced clock pulse will always occur within the timing gate period. V15 is a stage using a valve having a short suppressor grid base characteristic. The interlaced clock signal is applied to the control grid and the timing gate signal is applied to the suppressor grid. In the absence of both signals the electron stream is cut off from the anode by virtue of the standing negative bias applied to each but during the timing gate a negative pulse is produced at the anode coincident with every tenth pulse in the interlaced clock signal. This signal, known as the "block reset" signal, is applied to the rest cathodes K10 of the Dekatrons B to E inclusive in the dynamiciser:

This same signal is also used to drive the block defining Dekatron 3. Since cathodes K1 and K6, K2 and K7 and so on are strapped in pairs, one cycle of this Dekatron will define the basic block periods for two complete frames. The outputs from the cathode circuits, each 200 milliseconds long, are timed from the interlaced clock signals and four of these signals are applied to the respective suppressor grids of four identical gating stages of which V9 is representative. The clock signal is applied to the control grids of the four stages in parallel. These stages behave in similar manner to the action of stage V15 described above. From the respective anodes of these stages, four successive blocks each of ten pulses coincident with the clock signal pulses are produced and these are applied respectively as driving pulses to the

Dekatrons B to E inclusive in the dynamiciser.

To define the synchronizing signal a pulse equal in length to ten slots (200 milliseconds) is required and this must commence when the discharge in Dekatron E arrives back on the rest cathode K10 and end when Dekatron B receives its first drive pulse. This signal is generated in the Eccles-Jordan stage V12 which is controlled by two pulses. One of these pulses is generated at the anode of stage V11 by gating the differentiated leading edge of the pulse from the cathode K10 of Dekatron 2 with the pulse from the cathodes K5/10 of Dekatron 3. The other is produced at the anode of stage V13 by gating the same differentiated edge with the pulse from the cathodes K1/6 of Dekatron 3. The first signal triggers the Eccles-Jordan stage and the second returns it to its original state. The waveform at the anode of V12a is applied to the mixer stage V3a in the dynamiciser. Since it will be seen later that resetting occurs only once per frame, the frequency difference between the two oscillators must be of a low order to keep relative drift during a frame period within reasonable limits. A tolerance of ± 0.01 per cent. in frequency is adequate.

3.5. The Receiver Oscillator and Timer

The oscillator and timer at the receiver are basically similar to that at the sender. One difference is that no synchronizing signal is required and resetting facilities are provided at cathode K9 of Dekatron 1, cathode K9 of Dekatron 2 and cathodes K5/10 of Dekatron 3. Resetting of these tubes occurs once per frame by the leading edge of the permanent mark following the synchronizing signal.

At the receiver, the four blocks each of ten clock pulses are used to drive the four store

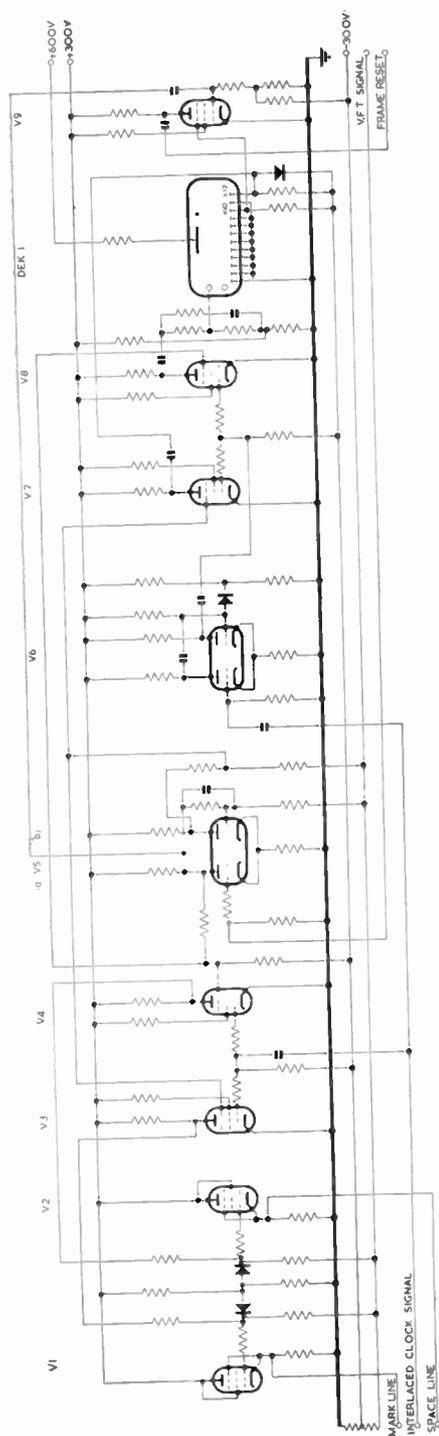


Fig. 7.—Circuit diagram of the slicer and sync separator.

defining Dekatrons whose discharges cycle round the cathodes in sympathy with those in the dynamiciser. The block reset signals are used to reset the discharges in the four store defining Dekatrons as in the dynamiciser.

3.6. Slicer and Sync. Separator (Fig. 7)

The incoming signal from the v.f.t. receiver, of amplitude ± 12.5 volts with respect to earth, is applied to the Schmitt slicer stage V5. This stage squares the signal by rapidly changing its state as the drive passes through earth potential and, in effect, produces an amplified version of a thin horizontal slice of the incoming signal. In-phase and antiphase versions of this signal appear at the anodes V5a and V5b respectively. These are applied to the suppressor grids of two gating stages V3 and V4 which operate in a manner similar to the gating stages previously described. To the control grids in parallel are applied the interlaced clock pulses of length 2 milliseconds from cathode K4 of Dekatron 1. These pulses, occurring near the mid-position of each incoming digit, act as sampling pulses and produce a negative-going pulse at the anode of V4 only each time a mark signal is received and a similar pulse at the anode of V3 only each time a space signal is received. These sampled mark and space signals are reduced in level and clipped to provide negative-going pulses from the cathode follower stages V1 and V2. These outputs are known as the mark and space lines respectively. The pulses extend from a standing level of +75 volts with respect to earth to a level of +25 volts with respect to earth.

Similar mark and space line signals are generated by stages V7 and V8 but here the sampling pulse width has been reduced to about 100 microseconds. The output from V8 is used to drive the 12-cathode Dekatron 1 and the output from V7 is used as a reset signal applied to cathode K12. Dekatron 1, therefore, counts spaces and is reset by marks. On receipt of the tenth space digit sample near to the end of the synchronizing signal the discharge invests cathode K10 and remains thereon until the following permanent mark sample causes resetting to cathode K12.*

When the receiver is first switched on, the phase of the incoming signal with respect to the locally generated interlaced clock signal is unknown and will remain so until the first synchronizing pulse is produced. Should the

* Prov. Pat. No. 2199/54.

interlaced clock pulses coincide with the transitions in the incoming waveform the Dekatron 1 will not receive 10 space pulses during the synchronizing signal and this condition may persist for some time due to the slow relative drift of the oscillators. To minimize this possibility, the mark and space signals feeding Dekatron 1 are made as narrow as possible.

The positive-going differentiated edges of the sliced incoming signal occurring on each space to mark transition are applied to the control grid of a gating stage V9, the output from the cathode K10 of Dekatron 1 being applied to the suppressor grid. A negative-going pulse appears at the anode of V9 only during the transition at the leading edge of the permanent mark following the synchronizing signal and is used to reset the Dekatrons 1, 2 and 3 in the oscillator and timer.

It will be observed that resetting does not take place to cathode K10 of Dekatrons 1 and 2 in the oscillator and timer since forward drive pulses are obtained from these cathodes and the reset would interfere with this action. There is therefore a maximum lag of 2 milliseconds in the timing at the receiver behind that at the sender, but this is relatively unimportant since the sampling pulses are appropriately timed with respect to the reset position.

3.7. The Storage System (Fig. 8)

The four Dekatrons, driven and reset by the blocks of clock pulses and the block reset pulses respectively from the oscillator and timer, define the 35 storage locations. Two representative store drive circuits are shown at V10 and V11. The store itself is a miniature, bi-stable, magnetically locked relay of the rocking armature type fitted with two coils, one in each anode circuit of the driving stage. A pulse of 7 milliamperes (min.) to 15 milliamperes (max.) and 2 milliseconds width through either coil is capable of driving the relay which has a transit time of the order of the driving pulse width.

The control grids of each half of the double triode driver stage are connected in parallel to a Dekatron cathode load resistor and when the driver stage is connected to the mark line from

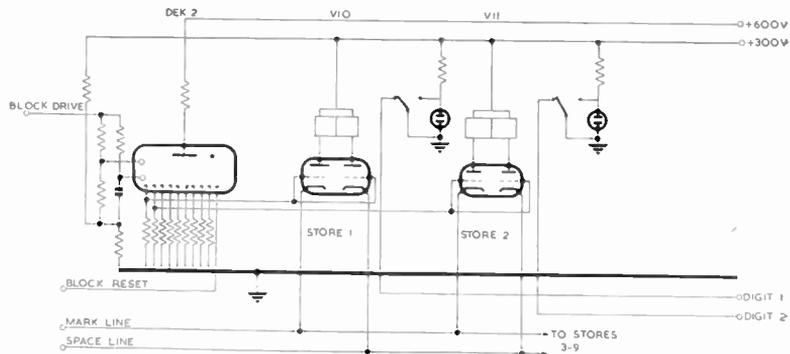


Fig. 8.—Circuit of the stores.

the slicer and synchronizing separator while the cathode of the other half of each driver stage is connected to the space line.

The cathode of one half of each double triode discharge invests that cathode the potential at the control grids is raised from earth to +25 V.

In the absence of a store-defining signal from a Dekatron to the control grids, any store driver stage remains biased beyond cut-off since there remains 25 volts of bias at the peaks of the negative going mark or space line pulses.

In the presence of a store-defining signal, a pulse of current of the order shown is drawn through the appropriate coil of the store relay connected to this driver stage and sets the armature of the relay to the appropriate position which is maintained until the same period in the next frame when the position is confirmed by a similar pulse or reversed by a pulse through the other coil from the second half of the driver.

4. Power Supplies

Unstabilized supplies are adequate, the only critical voltage required being that applied to the cathodes of the mixing stages in the dynamiciser which is separately stabilized.

5. Component Tolerances

Component tolerances are not critical and practically all stages will operate satisfactorily when the valve emissions have dropped to as low as 30 per cent. of normal.

6. Acknowledgments

The authors wish to thank the Directors of Metropolitan-Vickers Electrical Company Limited for permission to publish this article, Dr. L. W. Brown for his helpful encouragement and interest, and Mr. F. Moss for his valuable contributions on storage relay design.

S.B.A.C. EXHIBITION 1956

Although essentially an exhibition for manufacturers of aircraft and aircraft components, the Society of British Aircraft Construction Exhibition has each year included more and more radio and radar equipment. This year it included many applications of electronics to production techniques, much of which was by no means exclusive to the aircraft manufacturing industry. Two examples of electronically controlled template manufacturing machine tools were included. The first used a special digital computer to enable the template to be prepared directly from dimensional information, thus eliminating the hand work at present necessary using conventional techniques. The second example used similar dimensional information but had analogue interpolation circuits to devise the contour using a minimum of data points.

Radar.—As one would expect, radar and navigational aids form a very large part of the radio equipment on show at the exhibition and the exhibition site is particularly useful for full-scale demonstration of large equipments. There was a comprehensive display of fixed and mobile installations, airfield approach radar, medium range surveillance radar, equipment providing moving target indication, and airborne equipment. An interesting development was the demonstration of a combined precision approach and medium-range surveillance radar. There were two examples of radar simulators designed to train controllers for ground control interception without the necessity for flying actual aircraft.

The most notable development in the radar field was the use of a microwave link for the transmission of radar information from the radar site to an operations room many miles away. The system demonstrated transmitted radar information as well as a television picture from London Airport to Farnborough (a distance of 20 miles) using one repeater. It is of interest that the repeater made use of travelling-wave tubes. The signal, which was frequency modulated, was transmitted in the 40 Mc/s band and occupied a band width of 8 Mc/s. This development will enable radar information from a number of remotely sited radar heads to be routed to one operations centre.

Communications.—The tendency in the communications field was for the greater use of the v.h.f. and u.h.f. bands and with it the remote manual control of frequency selection. There were a few new receivers and one of the features which all manufacturers stress is the very accurate re-setting facility achieved. A complementary trend is towards operation by the pilot of all communications equipment, thus removing the need for long periods of watch-keeping. A new selective calling attachment has been developed to unmute the pilot's receiver when a message for him is being sent.

The use of airborne teleprinters has been experimentally tried by the British Overseas Airways Corporation and the equipment was shown at the exhibition. It operates on frequencies between 90 and 100 kc/s and has been very successful on trans-Atlantic air routes for passing routine flight information.

Guided Weapons.—For the first time guided weapons were on show to the public at the exhibition. The Fairey Fireflash was the main weapon exhibited although others were on view, as was a complete guided weapons system. The use of printed circuitry and potted assemblies which form the basis of the electronic equipment carried in these guided weapons was demonstrated by a number of radio manufacturers. Undoubtedly guided weapons will figure very prominently in future exhibitions as will the equipment associated with their guidance and testing.

Test Equipment.—Equipment for development testing formed a very large part of the accessories exhibition; strain gauges, accelerometers, vibration generators with their associated recorders were on show, as was a new universal servo-test set and an electronic tachometer. This instrument has an accuracy better than 0.005 per cent. at 20,000 r.p.m.

Vibration testing figured in a number of manufacturers' exhibits applications ranging from small valves to vibration testing of a complete guided missile. An interesting application on this latter test was the use of a high power stroboscope for illuminating several areas simultaneously. Vibration and other data were recorded over telemeter links.

THE IMPORTANCE OF VISUAL AIDS IN THE TEACHING OF ADVANCED RADIO AND ELECTRONIC ENGINEERING *

A Discussion Meeting held in London on 6th April, 1956.

In the Chair: Mr. G. A. Taylor (Member)

SUMMARY

The advantages of various visual aids are described and demonstrated: written notes, the use of the blackboard and wall charts, lantern slides and film strips, films and demonstration equipment. A list of 56 films and 15 film strips available in Great Britain is appended, covering nearly all aspects of radio and electronic engineering and industrial applications. Information is given on their content and length, and on the sources from which they may be obtained.

The Discussion was opened by Mr. R. H. Garner, B.Sc.(Eng.) (*Associate Member*)†

Those concerned with teaching in one form or another, whether it be practical subjects for City and Guilds Certificates, or for the Higher National Certificate, or even an external engineering degree, are all immensely concerned with the greatly expanding syllabuses with which they are confronted. It does not matter which subject is taught: more material is going into the syllabuses, more material has to be remembered and reproduced by the students and it is incumbent upon all teachers to try to help students to assimilate these facts, which are required for two purposes—to enable them pass examinations, and, even more important, to make them useful members of the radio and electronics profession.

How can this information be got over to the students? The human being can accept information in two ways as is shown in Fig. 1. The first way, which has been practised for a very long time, is from a lecturer or instructor speaking to an audience. A lecturer may be able to cover all aspects of the subject, but the great expansion of syllabuses makes this almost impossible, and all the lecturer can really do is to point the way; as an alternative, a number of lecturers may be employed to cover different aspects of a given syllabus. The lecturer makes use of the spoken word and the instrument through which this reaches the brain is the ear; a message may thus be

sent to the brain which influences the memory, and after some delay, which may be determined, this message is made to influence the motor area. The motor area in its turn will enable an examination to be written, or the operation of radio equipment, or whatever is required, to be performed.

The lecturer may also make use of the eye to assist him in conveying the ever-increasing amount of information by the use of pictorial illustrations. It may be possible eventually to use other senses of the body, such as the sense of touch, which is already used by the blind student to read braille.

Where information is to be assimilated by the ear, a number of aural aids may be employed. The recording of lectures on a tape recorder, whether for record purposes or for adding extra material or to provide lecture notes for film strips, is an example. The sound track of a film is an essential part of it, and provides a combination of the aural with the visual aid.

To return to visual aids, there are several methods of getting information to the brain through the eye. Firstly, there is the written word such as through lecture notes. These may be dictated, handed out, or compiled by the students themselves and the method used depends on the type of audience and other factors. But notes are generally of great value.

Associated with written notes is blackboard work; the use of chalk and a blackboard is inconvenient, and there have been a few developments to make it easier or cleaner. One

* Discussion Meeting No. 12.

† Principal, Coatbridge Technical College, Lanarks. U.D.C. No. 371.3:621.37/9.

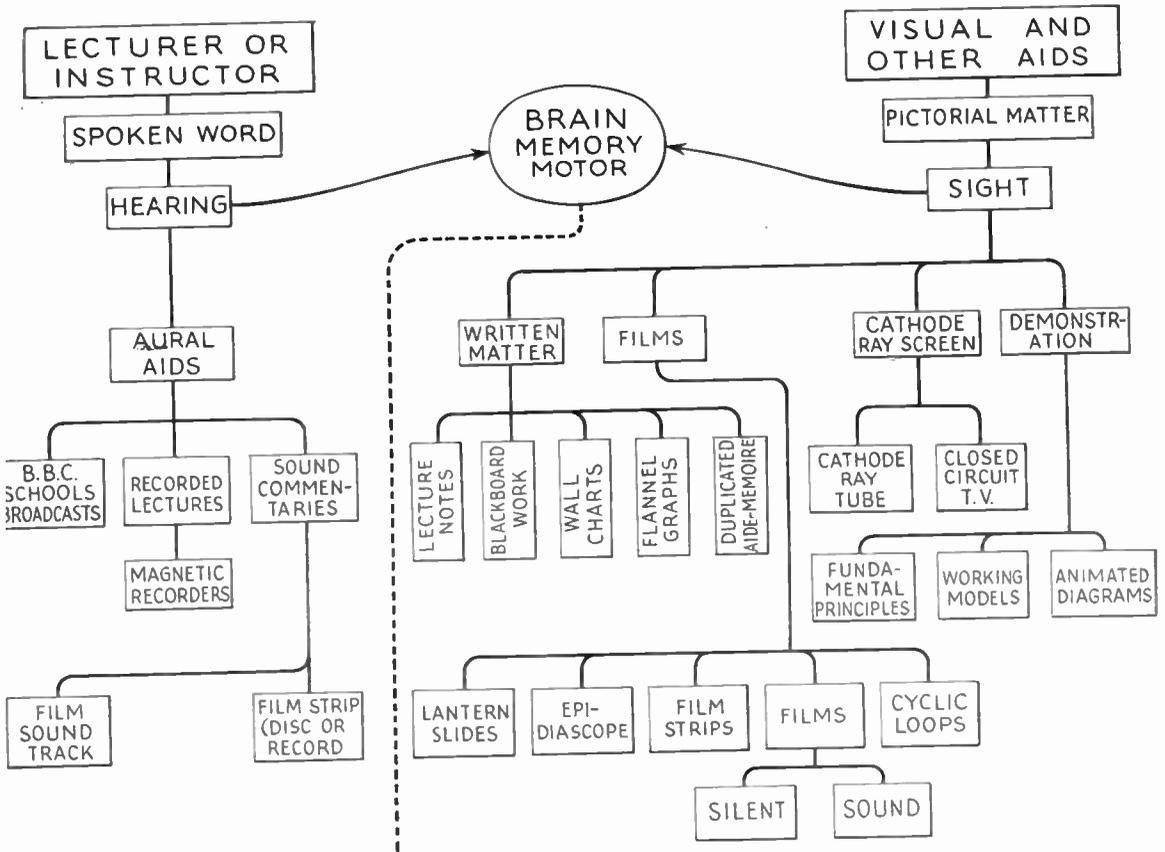


Fig. 1.—The relationship of visual and aural aids to teaching.

departure, which has been tried in some larger institutions, is the use of the "Belshazzar" screen, on to which is projected the magnified image of matter written on a small stage on the lecture bench. This is, however, an expensive method, and is not yet in wide use.

Another application of the visual aid which must be mentioned is the wall chart, which has the advantage that it can be permanently displayed and not just put up for each lecture. Students are able to look at wall charts while waiting for the next lecture; involuntary assimilation of this type is very valuable, and should be encouraged by the production of more and better wall charts. Although colleges could prepare charts for their own uses it would

be a great improvement if aids of this sort could be pooled. Then there is the "flannel graph," where outlines of components, etc., are cut out of cloth and can be easily placed in position on a cloth-covered board; circuits may be built up with this device very simply, by placing the component parts on the board, where they will stay without further fixing.

Films of several types are available to assist the lecturer, and the type used will depend upon whether the concept to be displayed is moving or static. The lantern slide is used to great advantage in much technical lecturing, and many colleges have built up valuable collections of slides which may be shown repeatedly, and added to if necessary.

Although the usual size for lantern slides is $3\frac{1}{4}$ in. x $3\frac{1}{4}$ in., or $4\frac{1}{2}$ in. x $3\frac{1}{4}$ in. on the continent, a useful recent development has been the 2in. x 2in. slide. This may be displayed over the same projector as the film strip, with a consequent saving in space and equipment. The 2in. x 2in. slide gives a very clear image, and lends itself easily to back projection, so that extra staff for demonstrating are unnecessary.

The epidiascope is used where it is desired to project pictures without the need to make slides. The brilliancy of the image is not very high, however, and the size of the picture is limited. Also, the epidiascope contains an expensive lamp, which may not survive being moved about from one lecture theatre to another, as it would have to be in the average technical college.

The most valuable contribution to visual aids during recent years is the film strip, which has the advantages of the lantern slide without its cumbersome size. A lecture of thirty or more slides can be put on a film strip and conveniently carried in the waist-coat pocket. A great deal of information can be condensed on to a film strip at no great cost by simply compiling the photographs and other details and putting them in the hands of a commercial photographer who will supply a first copy at a cost of about £1 (depending on the number of frames). The strip can be duplicated cheaply, and can, moreover, be modified from time to time and kept up to date.

Two examples may be taken as being typical of the film strips which may be used.

[These were shown at the meeting.]

First there are the professionally made strips devised by industrial firms which are accompanied by lecture notes. Professionally made strips are very valuable where the subject matter can be easily fitted into the course. More often in advanced work such strips are not available and as a second example there is the home-made strip made by a lecturer.

[This strip dealt with pulse techniques.]

These can be very simple and effective and avoid tedious blackboard work in which waveforms, for example, can be misleading unless accurately drawn.

Film strips also have the advantage that they can be used again and again and can be referred to at the end of the lecture. The film strip is however unsatisfactory for the continuous depiction of information and the moving picture or film is essential in putting over advanced techniques and particularly abstract ideas.

It is fortunate that other bodies who can afford to make films for their own use are interested in radio engineering; I refer mainly to the Services and a particularly good example is an advanced technical film which will be described later by Mr. N. Davis, who was technical adviser to the film company.

The only problem is the supply of suitable films. For the really advanced work very few films exist but the total number available is steadily increasing and in order to help all educationalists, the Institution is to take on the task of disseminating information on this subject. (A preliminary list of films appears as an appendix to this report.)

Film is also used in the form of a closed cyclic loop which repeats a particular operation over and over again. An example is generation of e.m.f. by the cutting of lines of force. This can be repeated until it is fully understood. Although a useful device for many purposes the loop has the disadvantage that it is rather difficult to store and handle.

Display of information on a cathode ray tube is a recent addition to visual aids which can be used to show the action of a circuit by illustrating a waveform. It may also be used as a display for closed circuit television which, although expensive, will no doubt be increasingly adopted, particularly where it presents useful advantages over other methods. Examples are the testing of jet engines where noise prevents live presentation and atomic work where radiation is a serious hazard.

Experimental lecture room demonstrations not only provide convincing evidence in support of particular points, but also help to replace laboratory experimental work on phases of the syllabus where time does not permit experiments to be performed.

A piece of demonstration equipment which merits a special mention is the classroom demonstration panel built by the Philco Training Division.

DISCUSSION

Norman Davis (*Associate Member*)*: The subject of waveguides is a particularly difficult one for the pupil to understand because it deals with something abstract and intangible and film is an ideal way of providing the class with the same mental picture.

The R.A.F. film "Waveguides" does two things, it gives this visual concept of the patterns of magnetic lines of force and electric lines of force and their resultant, and it "stretches" time and shows the movement of these patterns under various conditions. The film has a colour convention which in a subject such as this has very many advantages. It must be realized that a film of this type cannot stand entirely on its own—it must follow careful instruction. It is never shown in its entirety which consists of five parts lasting for a total of 1½ hours.

[Two parts of this film were shown during the meeting.]

P. A. Charman:† The classroom demonstration equipment is based on the idea of building up a complete radio receiver or transmitter using panels to represent each stage; on the circuit diagram of each stage the actual component appears over its symbol. The result is that, from the study of the circuit diagram, definite results can be obtained since work in the laboratory can be continued where work in the classroom finishes. Thus the link between the classroom demonstrations and the laboratory experiment is maintained.

This equipment is intended mainly for the technician rather than the engineer, although the engineer can undoubtedly gain practical experience with it.

R. S. Roberts (*Member*)‡: The most important visual aid is still the lecturer's black-board but the next most important group is undoubtedly the film, film strip and film loops. There is certainly a need for some central register of such films so that all lecturers can find whether or not the films required are readily and cheaply available.

The film has its most important application at the commencement of the student's training when we are trying to implant fundamental new ideas. It is also important when we come to really complicated subjects such as the waveguide. The emphasis should therefore be on these two types of film rather than a large number of general interest films which do not serve any real purpose other than the entertainment of the audience.

I was particularly pleased when Mr. Garner mentioned closed circuit television. There is a great future for closed circuit television in the technical colleges particularly where processes are involved which are of the type that cannot be described in the lecture room. I have had some experience with a system using display monitors in the lecture room with an intercommunication system to enable lecturers to draw attention to some particular process being carried out. It is a very valuable aid but a very expensive one at the moment.

B. R. Webster (*Associate Member*)§: I am particularly concerned with the teaching of the more advanced student and I think it is regrettable that the majority of the Higher National and post-Higher National students are forced to pursue their studies after working hours and arrive at the colleges in a somewhat tired state. At the same time the lecturers concerned are probably somewhat fatigued from the day's work and all this makes it particularly necessary that evening work should be clear and vital.

I find the film strip to be particularly useful in two respects. First of all, it enables the lecturer to have ready something he has been able to give time to, particularly in the question of layout and drawing. Secondly there is the valuable facility of being able to refer back whenever necessary.

Major R. B. Brenchley (*Associate Member*)¶: In the Services we have always had tremendous difficulty in obtaining material for students. Visual instruction is essential because it economizes in instructional time and gets ideas over quickly and more reliably.

* Civilian Instructor, Royal Air Force.

† Philco Training Division.

‡ Northern Polytechnic.

§ Hendon Technical College.

¶ War Office.

I am pleased to learn that the Institution will maintain an index of this type of information.

On the question of notes there is the point as to whether notes should be written by the student, or prepared and distributed afterwards. My own experience is that if students do try and write their notes they occupy far too much effort in doing so and do not follow a closely reasoned argument. All they can do afterwards is to read their notes at leisure when they may have missed the main point. On the other hand, if a student is free to concentrate on the work in hand, his memory of the instruction can be aided by properly thought-out notes which are distributed afterwards. Any worthwhile lecture must keep the attention of the students on its merits and not by the use of note-writing.

Instructor Lt.-Com. Waddell*: In the training of maintenance technicians in the Services it is necessary at all stages in training to use,

* H.M.S. Collingwood.

both in demonstration and in laboratory work, chassis and designs which lean towards the practical equipment which the student will have to use. In other words, the equipment must have the minimum of terminals and use the form of construction common in the equipment to be serviced.

G. A. Taylor (Member)†: I have been associated with the production of film strips for instruction up to third year National Certificate courses and I would like to refer to the point made by Mr. Garner on lecture notes being provided by the manufacturer of the film strip. These are provided to give guidance to the lecturer particularly on matters of fact as presented in the film strip and they are not intended to take the place of the instructor or his lecture notes. A good lecturer will undoubtedly produce his own lecture notes for the film strip based on those provided. In the case of a poor instructor, these notes might well form the full basis of his work.

† Mullard Ltd.

APPENDIX

Instructional Films on Radio and Electronic Engineering

The following lists give a selection of films and film strips suitable for visual instruction. The reference letters after each title are a guide to the names of the distributors given at the end of the appendix, e.g. BEDA (British Electrical Development Association).

All films are 16mm, with sound unless otherwise stated. Further information, including arrangements for loans, may only be obtained from the distributors, whose addresses are also quoted at the end of the appendix.

Basic Radio

“Putting Free Electrons to Work.” BEDA No. 15. 9 minutes.

Introduction to diode and triode and light sensitive cells.

“The Electron.” CFL VI058 or USIS. 16 minutes.

Nature of electrons, types of electron flow, electromotive force.

“The Cathode Ray Tube.” BTH/CFL, 1195. 33 minutes.

Principles of operation of C.R.T. and description of its application to radar.

“The Cathode Ray Oscillograph.” GB. 25 minutes.

Details of construction, function of component parts and principles of operation are described. Applications to ionospheric work are discussed.

“Principles of Gasfilled Tubes.” USIS. 15 minutes.

Explains by animation the theory of ionization applied to gas-filled tubes; control of current in circuits employing gas-filled tubes.

“The Diode.” USIS. 17 minutes.

Basic features of the diode tube; control of electron flow in the tube; photo-electric cells; X-ray tubes; the diode as a rectifier.

“The Triode.” USIS. 13 minutes.

Explains the triode amplifier circuit, amplification of steady and alternating voltages, distortion and amplification of audio frequency signals.

“The Principle of the Klystron.” Dance Kaufmann/EFVA. 551 K13 Loop film.

Diagrammatic representation of the movement of a stream of electrons which arrive in a random distribution at the velocity modulating zone.

"Secret Writing of the Electron." Philips/Sound Services, A434. 22 minutes.

A brief outline of the use of cathode ray oscillographs and how waveforms are produced.

"Centimetric Oscillators," Parts 1, 2 and 3 (Colour). Admiralty, A454. 10, 14, 15 minutes. Shows the limitation of conventional oscillators,

describes the klystron and the magnetron.

"Waveguides," Parts 1, 2, 3, 4 and 5. Air Ministry. 20 minutes each part. (Colour.)

Includes animated diagrams to present the movement of the electric and magnetic fields in the various modes in waveguides.

Communication and Radar

"Beam Telephony." Admiralty, A235. 40 minutes.

Use of v.h.f. as telephony link between U.K. and Continent during last war.

"Ultra Sons." Institut Français (Commentary in French). 11 minutes.

Short scientific description of radar, and its uses aboard ships.

"Precision Echo Sounding," K-H, 20 minutes. Describes the principles and applications of modern ultrasonic echo sounding for ships.

"Marine Radar," K-H, 22 minutes.

The principles and applications of modern marine

radar are described, and the planning of the layout and instructions to users are dealt with.

"Radar Record." M-VE. 10 minutes.

Ciné record of an actual marine display during a voyage from Manchester to Greenock.

"Radar Goes to Sea." M-VE. 28 minutes. Marine radar applications.

"Radar Weather," Part 1. RRE, T.F.37. 15 minutes.

Theoretical causes and effects of super-refraction.

"Radar Weather," Part 2. RRE, T.F.39. 15 minutes.

Meteorological aspects of super-refraction.

Industrial Electronics

"Automatic Computing with the EDSAC." Cambridge. 7 minutes. (Silent.)

A descriptive account of the principles of operation.

"Twentieth-Century Touch." BTM/Sound Services, A467. 40 minutes.

Application of Hollerith punched card system in Hec general purpose digital computer.

"Figures at Work." BTM/Sound Services, A398. 40 minutes.

Punched card systems and their application to stock production control.

"The Ferranti Pegasus Computer." Ferranti. 10 minutes.

Deals with programming, teleprinter tape, high-speed reader, console, prefabricated package construction, fast storage unit, magnetic drum storage unit, and output teleprinter unit.

"Exploring with a Microtimer." CFL, V1108. 12 minutes.

Use of high-speed camera to investigate cutting of stainless steel.

"High Frequency Soldering." CFL, V1076. 17 minutes.

Principles and function of r.f. circuit, setting up

and its use for soldering.

"High Frequency Heating." BEDA, No. 14. 9 minutes.

Fundamental principles of heating by high frequency current in conductors and non-conductors.

"Electronics." BTH. 35 minutes.

Principle of the electron valve and its application to industry.

"Electrons on Parade." USIS. 14 minutes.

Shows the uses of electrons in industry in manufacture of valves.

"Electronics in Industry." BTH. 35 minutes.

Outlines the many widely different uses of electronic control.

"Industrial Applications of Ultrasonics", Mullard/Sound Services, A444. CFL 2025. 19 minutes.

Simple explanation of principles and shows a series of applications.

"Principles of Ultrasonics." Mullard/EFVA, 538A1. 15 minutes.

Deals with the generation and application of ultrasonics and demonstrates the relation between sonic and ultrasonic waves.

“A New Approach to Production Improvement.” Philips/CFL, 2032. 43 minutes.

The applications of electronic measuring instruments, resistance welding, h.f. heating are included in a general review of modern techniques.

“Mona-matic Magic.” USIS. 40 minutes.

Main features of the electronically-controlled engine lathe and its use.

“Quality Control through Statistical Methods: Acceptance Sampling.” USIS. 18 minutes.

Describes quality control procedures, particularly as applied to ball-bearings.

“Quality Control through Statistical Methods: Process Control.” USIS. 12 minutes.

Process control procedures as illustrated by mass production of ball-bearings.

Manufacturing Processes

“Manufacture of Radio Valves.” Mullard/Sound Services, A328/CFL 2026. 26 minutes.

Assembly of valve from component parts showing works method of manufacture.

“Made for Life.” Mullard. 34 minutes.

Shows development and manufacture of cathode ray tubes including control of raw materials, production and quality.

“Special Quality Valves.” Mullard. 27 minutes.

Development and manufacture of valves designed to withstand the severe conditions of vibration and shock such as are encountered in military equipment and aircraft.

“Printed and Potted Circuits.” RRE, T.F.60. 10 minutes.

An account of the techniques involved.

“The First Automatic Factory.” CFL. 18 minutes.

A description of the first layout and operation of J. A. Sargrove’s automatic process for the production of electronic circuits.

“Project Tinkertoy.” GB. 27 minutes.

Shows the modular system of automatically producing electronic circuits.

“R.F. Induction Heating.” USIS/GB. 9 minutes.

General methods used in r.f. heating of small parts.

“Coaxial.” USIS. 13 minutes.

Manufacture and installation of coaxial cable and description of use for multi-channel telephony communication.

Applied Physics

“Linear Accelerator.” Mullard/EFVA, 556A2. 12 minutes.

Theory of nuclear transmutations; production of hard X-rays; design of travelling wave linear accelerators.

“Principles of the Cyclotron.” Dance-Kaufmann/EFVA, 558K1. Loop film.

The film shows a diagram of the apparatus, and illustrates the effect of the D-shaped electrodes on the magnetic field to accelerate particles.

“Discharge through Gases.” Mullard/EFVA, 540A18. 11 minutes.

Shows the discharge patterns which occur when pressure is progressively reduced and explains the theory of discharges through rarefied gases.

“The Electron Microscope.” M-VE/CFL, 2006. 18 minutes.

General principles and some particular examples of its use in research.

“Terra Incognita.” Philips/Sound Services, A385. 28 minutes.

Principles of the light microscope, and the electron microscope and a short account of the uses of the electron microscope.

“The M.R.C. Cyclotron.” RRU. 10 minutes.

Layout, demonstration of the unit, etc.

“Atomic Energy.” GB. 11 minutes.

Basic principles of atomic energy, radioactivity fusion and fission.

“Atomic Radiation.” GB. 12 minutes.

Radiation production and protection.

“Atom Smashers.” GB. 14 minutes.

Machines and techniques for production of radiation; accelerators, the synchrotron.

“Atomic Physics,” Part I—V, GB, Five sound films in black and white, 1, 2, 2, 2, 3, reels (With teacher’s notes.)

Describes the development of atomic theory through various discoveries of atomic particles culminating in fission.

“Research in Engineering.” M-VE. 42 minutes.

The work of an electrical research laboratory.

“Division of Radiophysics 1949.” ASLO. 17 minutes.

Describes research work being carried out by the Division on: radio-astronomy, moon echoes radar meteorology, radio-controlled model’s rain-making, electronic computing, radar aids to navigation and airport control.

FILM STRIPS

This list gives similar information to that given for films. All the strips are on 35 mm film and are usually accompanied by explanatory notes.

"Magnets and Magnetic Materials." Mullard/EFVA, 546 G43, 24 frames.

It describes "hard" and "soft" magnetic materials, the applications of permanent magnets, eddy currents losses and magnetic ferrites.

"Thermionic Valves: the Diode and Triode", Mullard/EFVA, 546 G50, 29 frames.

Shows thermionic emission, types of cathode, the space charge, the anode and anode current, characteristics of the diode and triode and the static and dynamic characteristics of amplifiers.

"The Cathode Ray Oscilloscope." Mullard/EFVA, 546 G51, 22 frames.

Studies the principle and construction of the cathode ray tube and its operation in an oscilloscope. Typical applications of the cathode ray oscilloscope are illustrated.

"Introduction to Radio." Mullard/EFVA, 551 G1, 38 frames.

An introductory account of the principles of radio transmission. The following topics are illustrated: the crystal detector, the tuning coils and capacitors, valve detection, propagation of radio waves.

"The Triode Valve." Dance-Kaufmann/EFVA, 551 G3, 26 frames.

A brief discussion on the basic theory of the valve, photographs are used to illustrate; the grid, rectification of an alternating current, characteristic curves of triode valves and manufacturing techniques.

"The Radio Valve," Parts 1 and 2. Mullard/EFVA, 551 G4, 32 frames.

An introduction to electronics and radio valves; the behaviour of electrons in an electrostatic and electromagnetic field, and the potential distribution between the electrodes of different valves. Part 2 gives a classification of the different types of valve, and the characteristics of each.

"The Radio Valve," Part 4. Mullard/EFVA, 551 G6, 20 frames.

The meaning of valve characteristics; these include normal ratings, static characteristics, and limiting values.

"The Radio Valve," Part 5. Mullard/EFVA, 551 G7, 37 frames.

Explains basic valve circuits for transmission, reception and reproduction of sound and indicate briefly the principles of transmission. The circuit of an a.c. mains superheterodyne receiver is given followed by details of the individual circuits.

"The Radio Valve," Part 6. Mullard/EFVA, 551 G10, 49 frames.

The application of electronics to industry: induction heating and dielectric heating. Equipment for the two methods is shown.

"The Electron." CFL, H58, 42 frames.

The structure of atoms and arrangement of electrons; electron flow in conductors.

"Elementary Principles of the Cathode Ray Oscillograph." GB, 553 G2, 31 frames.

An introduction to the structure and use of the oscillograph. The setting up of a time-base and the method of synchronization are shown.

"The Cathode Ray Tube," Part 1. Mullard/EFVA, 553 H3, 32 frames.

Various forms of cathode-ray tube are illustrated, and their applications indicated.

"The Cathode Ray Tube," Part 2. Mullard/EFVA, 553 G4, 32 frames.

The general construction of a typical television tube is illustrated by diagrammatic view and the processes of manufacture.

"Atomic Physics," Parts I-IV, GB, 557 G6-10. Five film strips in black and white, 35, 41, 38, 26, 39 frames.

Gives an account of the electron and deals with Thomson's work on positive rays; Aston's mass spectograph; X-rays and radioactivity; nuclear theory; atomic number; the neutron and isotopes; particle accelerators.

"Atomic Energy." VIS/EFVA, 557 A13, 63 frames.

The structure, classification and uses of the atom and atomic energy. Principles of the cyclotron, the atomic bomb and the uranium pile.

ADDRESSES OF DISTRIBUTORS OF TECHNICAL FILMS

Admiralty: Director of Naval Stores, Dept. NS 10c, Admiralty, London, S.W.1 (Whitehall 9000, Ext. 937).

Air Ministry: Director of Technical Training, Adastral House, Theobalds Road, London, W.C.1 (Holborn 3434).

ASLO: Australian Scientific Research Liaison

Office, Africa House, Kingsway, London, W.C.2 (Holborn 3422).

BTH: British Thomson-Houston Co. Ltd., Publicity Dept. (Film Division), Rugby (Rugby 2121).

BTM: British Tabulating Machine Co. Ltd., 17 Park Lane, London, W.1 (Hyde Park 8155).

Cambridge: The Director, Mathematical Laboratory, Cambridge University.

CFL: Central Film Library, Government Building, Bromyard Avenue, London, W.3 (Shepherds Bush 5555); Scottish Central Film Library, 16/17 Woodside Terrace, Charing Cross, Glasgow, C.3; Central Film Library of Wales, 42 Park Place, Cardiff (Cardiff 30441).

EFVA: Educational Foundation for Visual Aids, 33 Queen Anne Street, London, W.1 (Museum 5742); Foundation Film Library, Brooklands House, Weybridge, Surrey (Weybridge 4478).

Ferranti: Ferranti Ltd., Computer Sales, 21 Portland Place, London, W.1 (Langham 9211).

GB: Gaumont-British Film Library, Aintree Road, Perivale, Middx. (Perivale 7481).

K-H: Kelvin & Hughes Ltd., New North Road, Barkingside, Essex (Hainault 2601).

Mullard: Mullard Educational Service, Mullard House, Torrington Place, London, W.C.1 (Langham 6643).

M-VE: Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester 17 (Trafford Park 2431).

Philips: Philips Electrical Ltd., Film Section Century House, Shaftesbury Avenue, London W.C.2 (Gerrard 7777).

RRE: The Director, Radar Research Establishment, St. Andrews Road, Great Malvern Worcs. (Malvern 1400).

RRU: Radio-therapeutic Research Unit (Photographic Section), Hammersmith Hospital, London, W.12 (Shepherds Bush 4594).

Sound Services: Sound Services Ltd., 269 Kingston Road, Merton, London, S.W.15 (Liberty 4291).

USIS: United States Information Service Films Section, 5 Grosvenor Square, London W.1 (Grosvenor 9000); United States Information Service, 56 George Street, Edinburgh; United States Information Service, Sunlight House, Quay Street, Manchester 3.

Note from the Education and Examinations Committee :

The Institution receives many requests for advice on instruction material. The lists given in this report are by no means exhaustive, but include material of proved training value, with a minimum of advertising content. The Education Committee would appreciate receiving advice from members who are able, from experience, to suggest additions to the above lists. In this way it is hoped to maintain in the Institution a continuing and up-to-date reference on instruction material. Such information should include a brief synopsis of the detail shown in the film or strip.

The Committee gratefully acknowledges the co-operation of firms and distributors in making available the information from which the above lists were compiled.

APPLICANTS FOR MEMBERSHIP

New proposals were considered by the Membership Committee at a meeting on 4th October, 1956, as follows: 39 proposals for direct election to Graduateship or higher grade of membership, and 45 proposals for transfer to Graduateship or higher grade of membership. In addition, 64 applications for Studentship registration were considered. This list also contains the names of three applicants who have subsequently agreed to accept lower grades than those for which they originally applied.

The following are the names of those who have been properly proposed and appear qualified. In accordance with a resolution of Council and in the absence of any objections being lodged, these elections will be confirmed 14 days from the date of the circulation of this list. Any objections received will be submitted to the next meeting of the Council with whom the final decision rests.

Transfer from Associate Member to Member

LAKIN, Ralph Thornton, M.B.E. *Mansfield.*
ROGERS, Ronald Frank. *London, N.21.*

Direct Election to Associate Member

BRENCHLEY, Major Raymond Basil, R.E.M.E. *London, S.W.3.*
COOK, William Frederick. *Chelmsford.*
GRIFFITHS, Hugh Bowcn. *High Wycombe.*
LANGLOIS, Lieut.-Com. Frederick David, R.N. *Portsmouth.*
SCUTT, Reginald Herbert. *Nairobi.*
SHANNON, Lieut.-Com. George Edwards, R.N. *Fareham.*
WEARN, Capt. Ronald Victor, R.E.M.E. *Arborfield.*
WILLIAMS, Gilbert Harold. *London, W.4.*

Transfer from Associate to Associate Member

BURNETT, Wg. Cdr. Reginald George, M.B.E., R.A.F. *Singapore.*
EADIE, William Rowland. *Glasgow W.4.*
KYNASTON, John Alfred Charles. *Cardiff.*
PLANT, Sqdn. Ldr. Arthur Frederick, R.A.F. *White Waltham.*

Transfer from Graduate to Associate Member

GODD, Joseph Rodney. *Banstead.*
HIRST, Capt. Raymond, R.E.M.E. *B.A.O.R.10.*
KHAN, Lieut. Sultan Ahmad, B.Sc., R.P.N. *Karachi.*

Transfer from Student to Associate Member

FISHER, Jack Edward. *Watford.*

Direct Election to Associate

HUMPHRISS, Ernest Lawton. *Woolton, Liverpool.*
LEACH, Errol Wentworth. *Nassau, Bahamas.*
QURAIISHI, Capt. Jameel Ahmad, B.Sc., P.E.M.E. *Quetta.*

Transfer from Student to Associate

MARKS, Charles Quin. *Bridgnorth.*

Direct Election to Graduate

BALAAM, John James. *Southall.*
BIRD, George Harold. *Sandiacre, Notts.*
BISHOP, John Reginald. *Thame, Oxon.*
COGGER, Edward Ernest James, *London, S.E.23.*
CROSBY, Allan. *London, N.W.10.*

DEENEY, Alfred Columba. *Dublin.*
HARMAN, Reginald Richard. *Wembley.*
HARRI, John Michael. *London, S.W.20.*
HAYNES, Donald Patrick. *Stammore.*
HUBBLE, Raemond Arthur. *London, S.E.22.*
HUGHES, William Eric. *Pinner.*
LOCKWOOD, Peter. *Luton.*
McCANN, Malcolm Richdale. *London, S.E.27.*
McCARTNEY, Thomas. *Liverpool 4.*
McDERMID, Geoffrey Ronald, B.E. *Dunedin, N.Z.*
McGOW, Peter Charles. *Glasgow S.4.*
MAY, Reginald James. *London, N.W.6.*
PHILLIPS, Kenneth. *Harrow.*
PRICE, Leslie William Stewart. *Ilford.*
READ, Flt. Lt. Ian Stuart Foster, R.A.F. *Manchester 9.*
SCIVYER, John. *Potters Bar.*
SKINNER, Sydney Lonsdale. *Wooburn Green, Bucks.*
SMEED, Norman Peter. *Chelmsford.*
TAPP, Lieut. Edward William, R.A.N. *Worthy Down.*
WRIGHT, Percy. *New Eastwood, Notts.*

Transfer from Student to Graduate

ARDITTI, Joseph. *London, N.W.3.*
BARRETT, Brendan. *Coventry.*
BELL, John Stanley. *Wallington.*
BHATIA, Madan Mohan Sunnomal. *Kalyan, India.*
BHOWMICK, Saurendra Nath. *Bangalore.*
BUEHLER, Walter. *Montreal.*
CLEARY, Alan. *Twickenham.*
DAWES, James Peter. *Cambridge.*
DEV, Abinash Chandra. *Silchar, Assam.*
FLENS, Jan. *Cambridge.*
KAR, Saroj Kumar. *Bangalore.*
KING, Anthony Sydney. *Alton, Hants.*
KRISHNAN, Bal Jhanb, B.Sc. *London, W.2.*
LAKDAWALA, Homi Feroze. *London, S.W.7.*
McCONNELL, Geoffrey James. *London, S.E.15.*
MAJUMDAR, Amal Kumar. *Carshalton, Surrey.*
MEHTA, Mahendrakumar Chandulal. *London, W.12.*
MILLS, Samuel John. *Crawley.*
NARAYANA RAO, Nannapaneni, B.Sc. *Guntur.*
SHARP, Gregor Hugh. *Sydney, New South Wales.*
STRANGE, Norman Edward. *Brentford.*
TYE, Alfred Henry. *Coventry.*
VENKATESWARAN, Vadakanthara Venkatachalan. *Bangalore.*

STUDENTSHIP REGISTRATIONS

ABERCROMBIE, Frank Leonard. *Henlow.*
ADAMS, William Edward. *Stranraer.*
ALI, Mohammad Nadir, B.Sc. *London, N.W.6.*
BHATIA, 2nd Lt. Rajendra Nath, M.Sc., Indian Sigs. *Poona.*
CAVALOUSKI, Charles. *Padstow, N.S.W.*
CLAPP, Ernest Henry. *London, W.6.*
CLARK, William Thomas R. *Romford.*
COLLINS, John Anthony. *Burton-on-Trent.*
COTTRILL, Norbert Francis. *London, W.2.*
*DOCKERTY, William Harold. *Farnborough, Hants.*
DUMONT, Gilbert Camille. *Jumet, Belgium.*
FLAWITH, Donald Edward Thomas. *Basingstoke.*
FORSTER, Dennis John. *Ruislip.*
GADHOKE, Har Bhajan Singh. *Kanpur.*

GELLER, David. *London, N.5.*
GELLERT, Josef. *London, N.W.11.*
GONZAGA, Victor Emmanuel. *Seremban, Malaya.*
GROVER, Amrit Lal. *Ludhiana.*
*GUPTA, Tara Chand. *New Delhi.*
HICKMAN, D. *Pembroke Dock.*
HOBDEN, Roland John. *Croydon.*
HODGKINSON, Howard Miles. *London, W.14.*
Hsu, Wei Kung. *Southampton.*
JACKSON, Derek Ronald. *Dagenham.*
JAROSZ, Jerzy Jan. *Ilford.*
JENKINS, Cyril Victor B. *Pontypridd.*
JOHNSON, Kenneth. *Lytham St. Annes.*
JONES, George Augustine. *London, W.2.*
KAUFMAN, James Bryan. *Nottingham.*
KHARE, Madhav Dattatraya, B.Sc. *Barrackpore, W. Bengal.*
LAWRENCE, Dennis. *London, S.W.14.*

McGOWAN, John Stuart. *Dunedin, N.Z.*
MACGREGOR, Henry George. *London, N.W.10.*
MANTEL, Juval. *Haifa.*
MASHIAH, Baroukh Elie. *Tel-Aviv.*
MATHINULLA KHAN, B.E. *Madras.*
MEADOWS, Desmond Frederick. *Fordingbridge.*
MORGAN, Frederick Richard, B.Sc. *Egham.*
NAGABHUSHANA, Maganur P., B.Sc. *Bangalore.*
NAGARAJARAO, B. G., B.Sc. *Tumkur, Mysore State.*
NARASIMHAN, Villimbakkam Venkatachari. *Chingleput, Madras State.*

Note.—The names of the other 23 students registered at this meeting will be included in the next list.

* Reinstatement.

THE SUPPRESSION OF RADIO INTERFERENCE

About 80 delegates, representing 17 countries and five international organizations, attended the fifth plenary session of the International Special Committee on Radio Interference (C.I.S.P.R.) in Brussels on July 24 to 27, 1956, under the chairmanship of Mr. O. W. Humphreys (Director of the G.E.C. Research Laboratories). The delegates split up into three sub-committees, dealing with (a) limits of interference and methods of control; (b) measurement of radio interference; and (c) safety aspects of suppression techniques.

The drafting of specifications for the interference measuring apparatus on frequencies between 150 kc/s and 30 Mc/s is nearing completion and work is now proceeding on equipment for frequencies between 25 and 300 Mc/s.

It is recommended that limits applied to the interfering voltage at the terminals of appliances should lie within the following ranges:

Frequency band to be protected	Limit of interfering voltages at terminals
150-200 kc/s	500-1500 μ V
200-285 kc/s	500-1000 μ V
525-1605 kc/s	500-1000 μ V

For these requirements, measurements should be made according to the C.I.S.P.R. method and, for appliances in large scale production, the limits applied on a statistical basis. They do not represent absolute maxima which must never be exceeded.

The C.I.S.P.R. is awaiting proposals from the I.E.C. regarding the measurement of radiation from radio and television receivers and will then endeavour to formulate limits for the interference from both frequency-changing oscillators and time-bases.

The manner of interpreting and applying limits for interference caused by appliances in large-scale production is obviously of importance but, apart from the statistical methods used in the United Kingdom (as laid down in B.S. 800) very little information is available on present practices. All concerned were therefore recommended to study the British procedure and send in their observations.

Many administrations regularly publish statistics on interference complaints but these

have no common basis for comparison. The C.I.S.P.R. therefore recommends that the statistics should identify interference from the following sources and be compiled separately for the different wavebands:

- (a) low-power appliances incorporating motors, thermostats, contacts, etc., as used in households, shops, offices and small workshops;
- (b) sound or television broadcasting receivers;
- (c) gaseous discharge lamps;
- (d) industrial, scientific or medical radio frequency apparatus;
- (e) high-tension lines.

Regulations in many countries forbid the use of capacitors connected to the outer metalwork of double-insulated appliances, thus making it more difficult to achieve a satisfactory degree of suppression of radio interference, and it is asked that further study be given to the safety aspects which could arise if capacitors were to be so connected.

There is at present a lack of uniformity in the procedures for specifying the earth leakage currents due to the presence of radio interference suppression capacitors. The C.I.S.P.R. therefore recommends that consideration be given to the significance of high-frequency leakage currents which can flow in such capacitors, and that when specifying the methods of measuring leakage currents, the adoption of 2000 ohms as the value of the resistance to be inserted in the earth lead should be considered.

Meanwhile, the leakage currents to earth for various types of appliance for adequate suppression are specified as follows:

Type	Leakage Current
Fixed, permanently earthed	5 mA
Double-insulated and all-insulated	3.5 mA
Earthed portable	0.5 mA

Some of the matters under review by the C.I.S.P.R. have been the subject of discussion at Brit.I.R.E. meetings which have been reported in the *Journal*. These include: M. Smith, "Radio and Television Interference," August 1956; E. M. Lee, "Current Radio Interference Problems," November 1952.

A METHOD OF ANALYSING THE PERFORMANCE OF TANDEM-CONNECTED FOUR-TERMINAL NETWORKS*

by

P. W. Seymour, (Associate Member)[†]

SUMMARY

After a brief review of the classical quadripole theory, definitions are given of the reference parameters of a quadripole and reference operation between nominal impedances. Use is then made of these definitions to analyse a simple case involving tandem-connection of two quadripoles. A graphical technique for calculation purposes is introduced, and a simple example of the application of the results derived is given. Brief reference is made to the scope of the generalized treatment of this subject.

1. Introduction

A study of the classical theory of the four-terminal network shows that its overall electrical properties can, at any given frequency, be expressed in terms of three independent network parameters. These independent network parameters may be defined in various ways, and amongst those commonly encountered in the literature are the image and iterative parameters. The image parameters, which are of interest here, consist of the image transfer constant and the image impedances.

The telecommunications design engineer, who is mainly concerned with the determination of a suitable configuration of elements for a network, and the calculation of the element values, can make considerable use of the image parameters, because they may be expressed solely in terms of the elements of the network. Thus, by following established methods of design, the configuration and values of the elements of a network, which will have prescribed image transfer constant and image impedances, may be determined. This, in turn, leads to prescribed electrical performance under conditions of image operation.

There is, however, another aspect of network performance which the user of telecommunications equipment encounters. This aspect will be better appreciated if first it is recalled that, to obtain a specified standard of overall

performance from a transmission system, it is necessary to specify a set of performance characteristics for the individual equipment units of the system. These individual equipment units are usually of the four-terminal type, and may as a rule be represented by linear four-terminal networks of suitable configuration. Where linear two-terminal networks are encountered in a transmission system they can be regarded as part of an adjacent four-terminal network in the system. Unlike the design engineer, the user of telecommunications equipment is not predominantly interested in the detailed circuit arrangements existing within a four-terminal network, but rather he is interested in its resultant performance when it is appropriately connected in a transmission system. From the equipment user's viewpoint, therefore, it may be said that an equipment unit is merely a box, possessing four terminals, and, in general, acceptable if its performance characteristics conform with certain prescribed requirements.

It follows that one of the problems facing the user or purchaser of transmission equipment is that of specifying the performance requirements of the individual units of equipment in such a manner that the overall performance requirements of the complete transmission system are satisfied, irrespective of the source from which the equipment purchase is made, while at the same time permitting the equipment designers the greatest freedom possible.

In many cases it has been found more practicable to specify the insertion, or operating characteristics of a network, between appropriate nominal impedances (to be defined later),

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U.D.C. No. 621.372.5.

rather than to specify its required performance characteristics in terms of, say, its image transfer constant.

Further, it is convenient to specify the network impedances in terms of the input and output return losses obtained when the network is operating between nominal impedances, rather than in terms of the image or iterative impedances. Analysis of tandem-connected network performance in terms of the operating and return losses of the individual networks can offer many advantages, particularly when simple graphical methods of calculation are developed. In this paper, as an introduction to the technique, a simple case involving tandem-connection of two four-terminal networks only is considered. It may be noted here that the term "four-terminal network," or quadripole," is taken to cover all equipments units from, say, the simple transformer to a complete carrier telephone system, and that the formulae presented have general application.

2. Review of Classical Quadripole Theory

With reference to Fig. 1, the insertion factor of a quadripole may be defined as follows. In Fig. 1a, a source of impedance Z_s and e.m.f. E is connected directly to a load impedance Z_L . Let the voltage and current in the load in this condition be represented respectively by V_1 and I_1 . In Fig. 1b a quadripole has been inserted between the source and load impedances. Let the voltage and current now existing in the load impedance be represented respectively by V_2 and I_2 . Then $Z_L = V_1/I_1 = V_2/I_2$, so that $V_1/V_2 = I_1/I_2 = G$, say. The parameter G , which is a complex number, is defined as the insertion factor of the quadripole introduced between Z_s and Z_L .

The insertion loss of the quadripole is defined as $IL(\text{db}) = 20 \log_{10} |G|$. Further, the insertion phase shift of the quadripole operating between Z_s and Z_L is given by φ , the angle of G . Thus, if $G = a + jb$, $\varphi = \tan^{-1} b/a$. A study of the insertion factor G shows that it may be written as the product of five terms, so that the insertion loss, expressed in decibels, becomes the sum of five loss terms,

$$IL(\text{db}) = 20 \log_{10} |G| = -A_1 + A_2 + A_3 + A_4 + A_5.$$

The physical, rather than the mathematical significance of these terms are of interest here. Firstly, $-A_1$ is due to the mismatch existing between Z_s and Z_L . A_2 is due to the mismatch

between the input image impedance Z_{01} of the quadripole and Z_s , while A_3 is due to the mismatch between the quadripole output image impedance Z_{02} and Z_L . A_4 accounts for a phenomenon called interaction, which may be physically regarded as a repeated transfer of diminishing electrical energy within the quadripole, between input and output terminals.

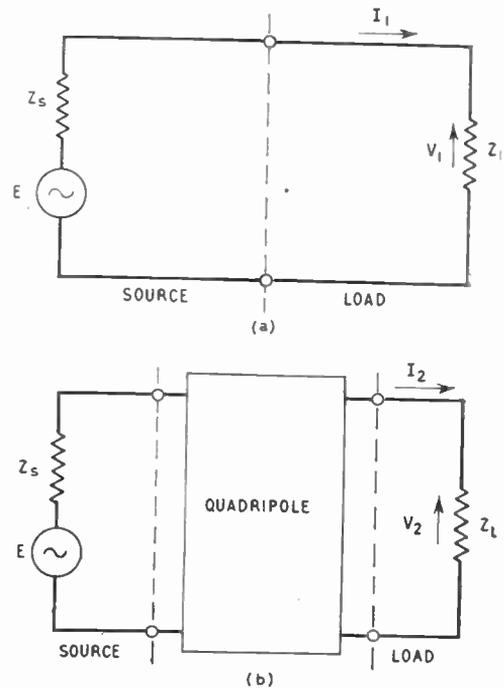


Fig. 1.—Illustration of definition of insertion loss.

Interaction arises from the imperfect matching conditions existing at both input and output of the quadripole; it vanishes if either the quadripole input or output is terminated by its appropriate image impedance, and becomes negligibly small if the quadripole attenuation is high. A_5 is the image attenuation constant of the quadripole, expressed in decibels.

For the foregoing it will be appreciated that the estimation of the performance of a particular quadripole, from a study of its insertion loss and insertion phase shift characteristics over a range of frequencies, can lead to a more representative result than a study of the real and imaginary parts of the image transfer constant over the same range of

frequencies. This is because it is unlikely that the quadripole will, in practice, be operated on a strictly image matched basis between equal source and load impedances, under which condition the insertion loss expression reduces to the single term A_s .

In connection with the loss resulting from the insertion of a quadripole between a source and a load, it may, therefore, be said that:

- (a) The quadripole image attenuation constant, expressed in decibels, does not accurately represent the decibel change of load power resulting from the insertion, except in the somewhat idealistic case of symmetrical image operation, and
- (b) The insertion loss of the quadripole, expressed in decibels, accurately represents the decibel change in load power resulting from the insertion, but can lead to somewhat misleading numerical solutions in cases where the direct connection of source and load impedances produces a mismatched condition.

As an example of this fact, it will be recalled that the differential or hybrid transformer of Fig. 2, sometimes used as a 2/4 wire termination for a carrier telephone channel, provides, when ideal, and correctly matched, a 3 db image attenuation loss from Hybrid Line to Hybrid In, and from Hybrid Line to Hybrid Out. From consideration of insertion principles, the insertion loss of the transmission path from Hybrid Line to Hybrid In, operating between a 600 ohm source and a 600 ohm load impedance, is also 3 db; but the insertion loss of the transmission path from Hybrid Line to Hybrid Out, operating between a 600 ohm source impedance and a 300 ohm load impedance, is 2.5 db, a result which may be unexpected to some. The physical significance of the subtraction of 0.5 db from the image attenuation loss of 3 db is simply that, upon insertion of the Hybrid Line to Hybrid Out transmission path between the originally mismatched source and load impedance, although the ratio of power transmitted from Hybrid Line to the 300 ohm load impedance at Hybrid Out still corresponds to an attenuation loss of 3 db, the hybrid has acted as an impedance matching device between source and load, and has thus removed the original transmission loss of 0.5 db. The effective loss upon insertion is, therefore, $3 - 0.5 = 2.5$ db.

In view of the foregoing it would appear that a "loss" term, representing a comparison of load power under inserted quadripole conditions, and under conditions of transmission from source to load impedance via a suitable ideal matching device, is required. Such a loss term would account for the image attenuation constant of the quadripole and the various reflection phenomena mentioned, but would avoid source to load impedance mismatch. In this paper, therefore, the conception of "operating loss" is used after the fashion of F. B. Llewellyn.*

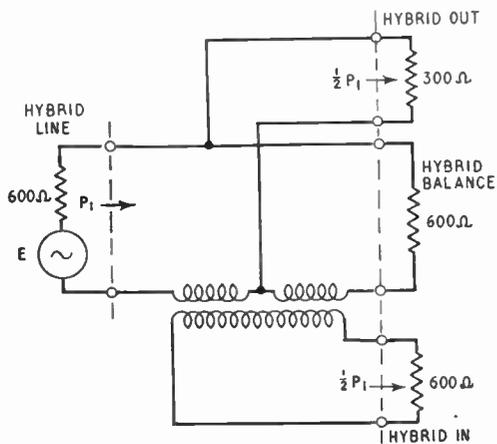


Fig. 2.—Differential or hybrid transformer.

3. Definition of Operating Loss

Operating loss may be defined by the expression $OL (db) = 20 \log_{10} |G/B|$, where B is the insertion factor of an ideal transducer, which, when inserted between source and load impedances, effects perfect matching between them.

To understand this more clearly, let P_0 be the load power when source and load impedance are directly connected, P_1 be the load power when source and load impedance are connected via the ideal transducer or matching device, and P_2 the load power when operation is carried out via the quadripole. Then, by definition, $|G|^2 = P_0/P_2$ and $|B|^2 = P_0/P_1$ so that $|G/B|^2 = P_1/P_2$. Thus the square of the operating factor modulus, $|G/B|^2$, is equal to the ratio of the

* F. B. Llewellyn, "Some fundamental properties of transmission systems," *Proc. Inst. Radio Engrs*, 40, pp. 271-283, 1952.

power in the load impedance when source and load impedance are perfectly matched, to the power in the load impedance when operation is carried out via the quadripole. Since $20 \log_{10} |G/B| = 20 \log_{10} |G| - 20 \log_{10} |B|$, it follows that the expression for operating loss is simply that for insertion loss less the term $-A_1$. Thus, when a quadripole is inserted between a source and load impedance, and no reflections occur at its input and output terminals, the operating loss becomes equal to the quadripole image attenuation constant, expressed in decibels.

4. Reflection Coefficient and Return Loss

The term return loss is closely related to the term reflection coefficient, or return current coefficient, and is a logarithmic measure of the amplitude relationship existing between the current reflected from a mismatched junction of impedances, and that transmitted under matched or reflectionless conditions. Return loss is frequently used as an implicit measure of impedance, partly because it is more convenient to express and measure an impedance in terms of its return loss, against a chosen impedance, than in any other terms; and partly because the return loss is, in many respects, a more convenient indication of performance than the impedance value.

The inverse reflection coefficient, A , between impedances Z and Z_N may be expressed as

$$A = \frac{(Z/Z_N) + 1}{(Z/Z_N) - 1}$$

while, in turn, the return loss of Z against Z_N may be written

$$RL (db) = 20 \log_{10} \left| \frac{(Z/Z_N) + 1}{(Z/Z_N) - 1} \right|$$

or $RL (db) = 20 \log_{10} a$, where $a = |A|$. It is now apparent that a may be regarded as a known real number indicating the degree of inequality existing between Z and Z_N . Z_N is generally a known nominal impedance of zero angle, for instance 600 ohms or 75 ohms.

It can simply be shown that the locus of $Z/Z_N = r + jx$, for a constant value of a , is a circle of radius $2a(a^2 - 1)$ and centre at $[(a^2 + 1)/(a^2 - 1), 0]$. If, for example, $a = 10$, the return loss is $20 \log_{10} 10 = 20$ db, and the corresponding circle for Z/Z_N has a radius of 0.202 and centre at (1.02, 0).

Assuming further that $Z_N = 600$ ohms, zero angle, then the circle representing Z may be found by multiplying all dimensions of the circle for Z/Z_N by 600. The radius of this circle will, therefore, be 121.2 ohms, and the centre will be at (612, 0). It will thus be seen that any impedance Z , having a return loss of 20 db against a nominal impedance $Z_N = 600$ ohms, zero angle, terminates on a circle of radius 121 ohms and centre at (612, 0).

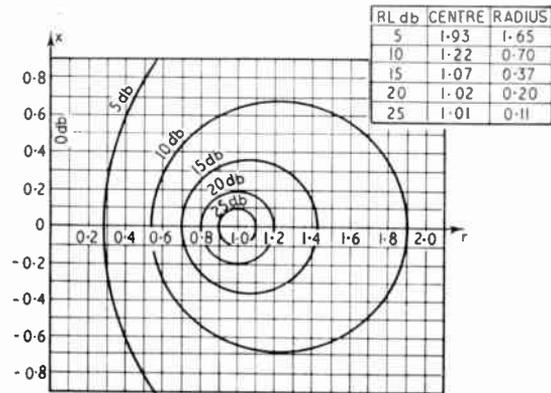


Fig. 3.—Circles showing $Z/Z_N = r + jx$ for some typical return loss values.

Similar circles may be drawn for other values of return loss. In order that the circles may find general application, they are usually drawn to represent the complex ratio Z/Z_N , rather than the complex values of Z corresponding to a chosen nominal impedance Z_N . Fig. 3 shows a family of return loss circles representing $Z/Z_N = r + jx$ for various values of return loss.

5. Operating Loss of Tandem-connected Quadripoles

In the approach made in this paper to the estimation of the performance of tandem-connected quadripoles, use is made of the reference parameters of the individual quadripoles, as distinct from, say, the image parameters. The reference parameters depend on the particular source and load impedances chosen. The latter, termed the nominal impedances, are often of zero angle, and in many cases correspond closely to the image or design impedances of the quadripole. Analysis in terms of the reference parameters results in final mathematical expressions of simple form, and leads to a graphical method of calculation which is extremely labour saving.

A precise definition of the reference parameters may now be obtained from Fig. 4. As shown, the input and output impedances of the quadripole may, under reference conditions, be referred to respectively as the reference input impedance, Z_{R1} , and the reference output impedance, Z_{R2} , while the corresponding return loss of each of these reference impedances against the appropriate nominal impedance may be referred to as the reference input return loss, RL_{R1} , and the reference output return loss, RL_{R2} . Similarly the operating factor, L , and the operating loss, OL , under reference conditions will be referred to respectively as the reference operating factor and reference operating loss. The reference return losses and the reference operating loss may be collectively referred to as the reference loss parameters.

In order to calculate the overall operating loss of tandem-connected quadripoles Q_1 and Q_2 , operating between nominal impedances Z_{N1} and Z_{N3} , consider, first, Q_1 operating under reference conditions between Z_{N1} and Z_{N2} . Then, by application of Thevenin's theorem at the output terminals of Q_1 , it is easy to show that the equivalent source at these terminals consists of an e.m.f.

$$E_{11} = \frac{E_1 \cdot Z_{R2} + Z_{N2}}{L_1 \cdot 2\sqrt{(Z_{N1}Z_{N2})}}$$

acting in series with an impedance Z_{R2} . In this expression, L_1 is the reference operating factor of Q_1 , E_1 is the e.m.f. driving Q_1 via Z_{N1} , and Z_{N2} , Z_{R2} are as shown in Fig. 5. Similarly, application of potentiometer theory and the definition of operating factor to quadripole Q_2 ,

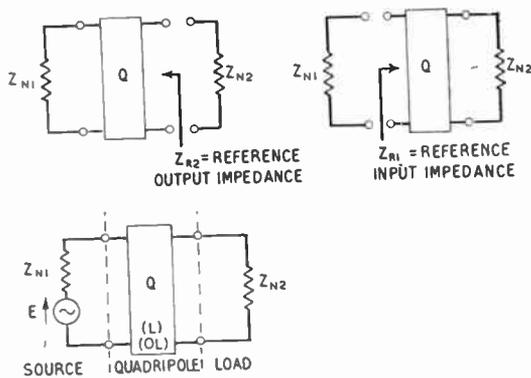


Fig. 4.—Quadripole operating under reference conditions.

operating under reference conditions between Z_{N2} and Z_{N3} enables the relationship existing between any voltage developed at the input terminals of Q_2 and the corresponding current flowing in the load impedance Z_{N3} , to be written as

$$\frac{I \text{ (load)}}{V \text{ (input)}} = \frac{1}{2L_2\sqrt{(Z_{N2}Z_{N3})}} \cdot \frac{Z_{R3} + Z_{N2}}{Z_{R3}}$$

where L_2 is the reference operating factor of Q_2 , and Z_{N3} and Z_{R2} are as shown in Fig. 5.

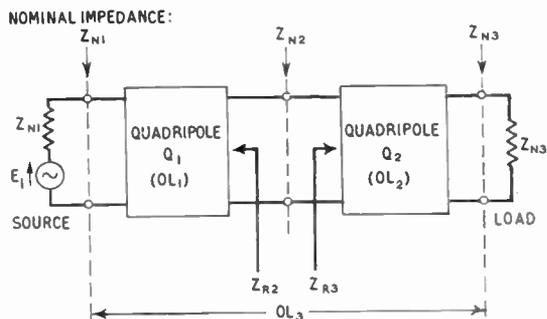


Fig. 5.—Tandem-connection of quadripoles Q_1 and Q_2 .

Since, when Q_1 and Q_2 are tandem-connected as in Fig. 5, $V \text{ (input)}$ becomes, by simple potentiometer theory, $E_{11}Z_{R3}/(Z_{R2} + Z_{R3})$ it is possible to relate the driving voltage E_1 and the load current $I \text{ (load)}$ by means of the expressions given. Thus, by elementary algebra

$$I \text{ (load)} = \frac{E_1}{L_1 L_2} \cdot \frac{(Z_{R3} + Z_{N2})(Z_{R2} + Z_{N2})}{2(Z_{N1}Z_{N2})^{1/2} \cdot 2(Z_{N2}Z_{N3})^{1/2} \cdot (Z_{R2} + Z_{R3})}$$

Consider now Z_{N1} matched to Z_{N3} by means of an ideal impedance matching transducer of impedance ratio Z_{N3}/Z_{N1} . The load current in this condition is easily obtained as $I_0 = E_1/2\sqrt{(Z_{N1}Z_{N3})}$. The reference operating factor, L_3 , for the tandem-connected arrangement of quadripoles Q_1 and Q_2 , operating between Z_{N1} and Z_{N3} , may now be written

$$L_3 = I_0 / I \text{ (load)} = L_1 L_2 \cdot \frac{2(Z_{R2}/Z_{N2} + Z_{R3}/Z_{N2})}{(Z_{R3}/Z_{N2} + 1)(Z_{R2}/Z_{N2} + 1)}$$

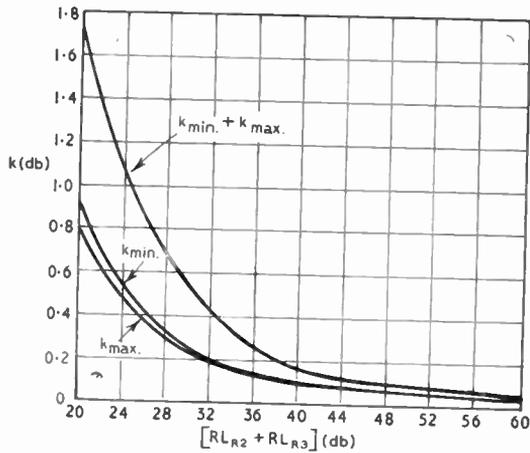


Fig. 6.—Graphs for the determination of k_{max} and k_{min} .

$$k_{max} = 20 \log_{10} \frac{a_{R2} a_{R3} + 1}{a_{R2} a_{R3}} \quad k_{min} = -20 \log_{10} \frac{a_{R2} a_{R3} - 1}{a_{R2} a_{R3}}$$

when $RL_{R2} = 20 \log_{10} a_{R2}$ and $RL_{R3} = 20 \log_{10} a_{R3}$ are known.

Introducing now the reference inverse reflection co-efficients

$$A_{R2} = \frac{(Z_{R2}/Z_{N2}) + 1}{(Z_{R2}/Z_{N2}) - 1} \quad \text{and} \quad A_{R3} = \frac{(Z_{R3}/Z_{N2}) + 1}{(Z_{R3}/Z_{N2}) - 1}$$

and substituting the expressions for impedance ratios derived from these into the previous expression, it is possible to write L_3 in the simple form

$$L_3 = L_1 L_2 \cdot (A_{R2} A_{R3} - 1) / A_{R2} A_{R3}$$

where $K = (A_{R2} A_{R3} - 1) / A_{R2} A_{R3}$

The overall reference operating loss, OL_3 , is thus

$$OL_3 = OL_1 + OL_2 + 20 \log_{10} |K| \text{ (db)}$$

An examination of $|K|$ shows that its extreme values become the real numbers

$$|K|_{min} = \frac{a_{R2} a_{R3} - 1}{a_{R2} a_{R3}} \quad \text{and} \quad |K|_{max} = \frac{a_{R2} a_{R3} + 1}{a_{R2} a_{R3}}$$

The examination also shows that $|K|$ may assume any value between $|K|_{min}$ and $|K|_{max}$.

If, therefore, the reference input and output impedances Z_{R3} and Z_{R2} are represented by their respective return losses RL_{R3} (db) and RL_{R2} (db)

against the nominal impedance Z_{N2} , it follows that the limits $|K|_{min}$ and $|K|_{max}$ of $|K|$ may be calculated.

The calculation of a precise value of $|K|$ between the limits $|K|_{min}$ and $|K|_{max}$ would require explicit knowledge of the impedances Z_{R2} and Z_{R3} .

Defining now $k_{min} = -20 \log_{10} |K|_{min}$ and $k_{max} = 20 \log_{10} |K|_{max}$, it is possible to predict the maximum and minimum values of OL_3 . Thus OL_3 may lie in the range

$$OL_1 + OL_2 - k_{min} \leq OL_3 \leq OL_1 + OL_2 + k_{max} \text{ (db)}$$

In order to facilitate rapid calculations, graphs are presented in Fig. 6 which show the variation of k_{max} , k_{min} , and $(k_{max} + k_{min})$, expressed in decibels, as the return loss sum $RL_{R2} + RL_{R3} = 20 \log_{10} (a_{R2} \cdot a_{R3})$ varies between 20 db and 60 db.

6. Determination of Frequency Response Limits of a Transmission System

As an application of the foregoing principles, it is of interest to determine the overall frequency response limits of a simple transmission system consisting of tandem-connected quadripoles Q_1 and Q_2 . To facilitate analysis,

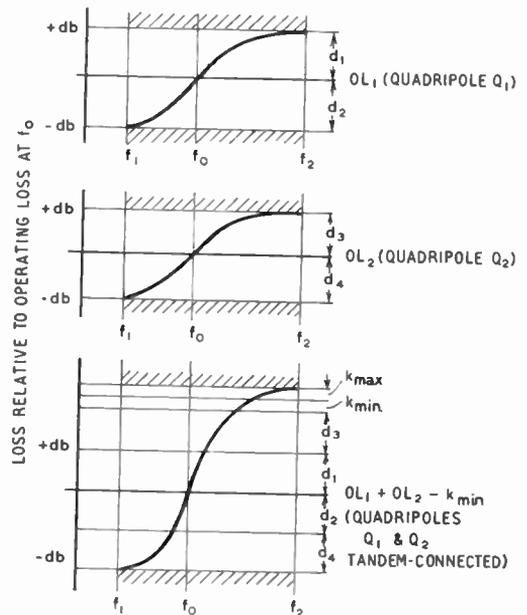


Fig. 7.—Tandem-connection of quadripoles Q_1 and Q_2 . Case (a).

et it be assumed that the system provides a single channel of reference frequency f_0 , and upper and lower frequency limits f_2 and f_1 respectively.

Further, let it be assumed that extreme frequency response limits, leading to a most unfavourable combination upon tandem-connection, are chosen for Q_1 and Q_2 , as shown in Fig. 7. In order to determine the overall frequency response limits of the transmission system, formed from the tandem-connection of Q_1 and Q_2 , it is convenient to consider two extreme cases, later combining the results.

Case (a).—The assumptions made are as follows:

- (i) The overall operating loss at f_0 is $OL_1 + OL_2 - k_{min}$.
- (ii) The overall operating loss at f_1 is $OL_1 + OL_2 - (d_2 + d_4) - k_{min}$.
- (iii) The overall operating loss at f_2 is $OL_1 + OL_2 + (d_1 + d_3) + k_{max}$.

It follows from these assumptions that the response limit at f_1 becomes $-(d_2 + d_4)$, whilst that at f_2 becomes $+(d_1 + d_3) + (k_{min} + k_{max})$.

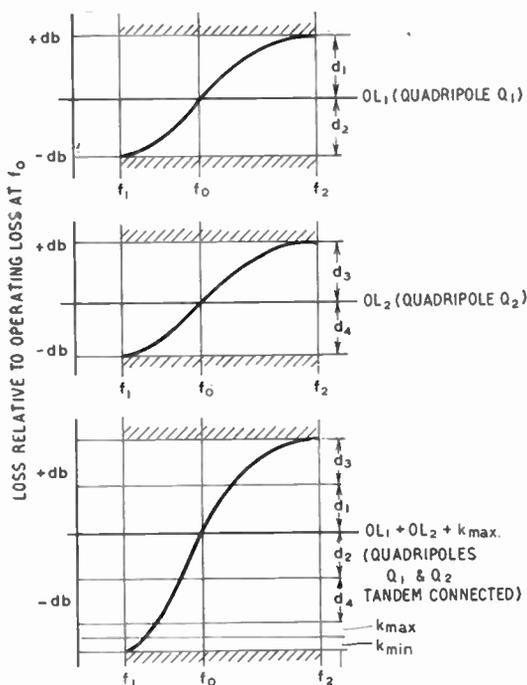


Fig. 8.—Tandem-connection of quadripoles Q_1 and Q_2 . Case (b).

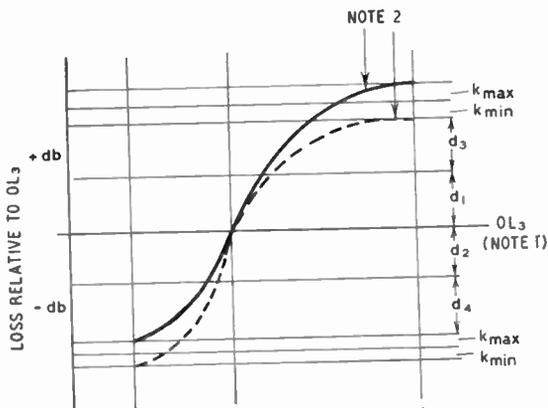


Fig. 9.—Summation of response limits for tandem-connected quadripoles Q_1 and Q_2 . (Refers to Figs. 7 and 8.)

- Note 1.— $OL_1 + OL_2 - k_{min} \neq OL_3 \neq OL_1 + OL_2 + k_{max}$.
- Note 2.—Dotted characteristic corresponds to $OL_3 = OL_1 + OL_2 + k_{max}$. Full line characteristic corresponds to $OL_3 = OL_1 + OL_2 - k_{min}$.

The resultant limits so obtained are also shown in Fig. 7, and it will be noted that the range between these limits is

$$[(d_1 + d_2 + d_3 + d_4) + (k_{min} + k_{max})],$$

and that the upper limit has been widened by an amount $(k_{min} + k_{max})$ relative to the direct summation of individual response limits, $(d_1 + d_3)$.

Case (b).—The individual response limits of quadripoles Q_1 and Q_2 , and the overall operating losses at f_1 and f_2 are again as assumed in Case (a), but it is now assumed that the overall operating loss at f_0 is $OL_1 + OL_2 + k_{max}$. Under these conditions the response limit at f_1 becomes

$$-[(d_2 + d_4) + (k_{min} + k_{max})],$$

and at f_2 simply $+(d_1 + d_3)$.

Referring to Fig. 8, it is seen that again the range between the limits is

$$[(d_1 + d_2 + d_3 + d_4) + (k_{min} + k_{max})]$$

and that in this case the lower limit has been widened by an amount $(k_{min} + k_{max})$ relative to the direct summation of the individual response limits, $(d_2 + d_4)$.

It is convenient to combine the results of Cases (a) and (b) as shown in Fig. 9. Since the overall operating loss at the channel reference frequency, f_0 , may range from $OL_1 + OL_2 - k_{min}$

to $OL_1 + OL_2 + k_{max}$, it becomes essential, in the light of the results obtained for the extreme cases considered, to widen both upper and lower response limits from $(d_1 + d_3)$ and $-(d_2 + d_4)$ to $[(d_1 + d_3) + (k_{min} + k_{max})]$ and $-[(d_2 + d_4) - (k_{min} + k_{max})]$ respectively.

However, it should be clearly recognized that the range between the extreme turning points of an overall frequency response characteristic plotted on Fig. 9 cannot, from the study of Cases (a) and (b), exceed

$$[(d_1 + d_2 + d_3 + d_4) + (k_{max} + k_{min})]$$

even though the range between the response limits of Fig. 9 is seen to be

$$[(d_1 + d_2 + d_3 + d_4) + 2(k_{max} + k_{min})].$$

7. Conclusion

An approach to the theory of quadripole performance differing from the classical approach has been indicated. The practical use of the reference loss parameters has been demonstrated, and formulae have been obtained which enable a prediction to be made of both the precise overall operating loss of tandem-connected quadripoles Q_1 and Q_2 , of known individual operating losses OL_1 (db) and OL_2 (db) respectively, and the maximum and minimum overall operating losses that may be expected as a result of this tandem-connection. The former case applies when the reference impedances Z_{R2} and Z_{R3} are explicitly known, while the latter case applies when Z_{R2} and Z_{R3} are implicitly known in terms of their respective

return losses, RL_{R2} (db) and RL_{R3} (db), against the nominal impedance Z_{N2} .

The formulae presented in this paper are applicable to a certain special condition of tandem-connection only. However, a general theory, covering non-reference operation of quadripoles, has been developed. This theory to be published soon, enables overall operating loss characteristics of a transmission system to be determined when quadripoles are added or removed, and permits synthesis of transmission systems in terms of tandem-connected quadripoles.

8. Acknowledgment

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* S. Dossing and P. W. Seymour, "Loss characteristics of tandem-connected transmission equipment," *Telecommunication J. Aust.*, 9, pp. 152-162, 1953.

EQUIPMENT FOR THE CONTINUOUS VECTORIAL DISPLAY OF ALTERNATING VOLTAGES IN THE FREQUENCY RANGE 5 kc/s to 3 Mc/s *

by

E. C. Pyatt, B.Sc.(Eng.)†

SUMMARY

A sinusoidal alternating voltage is generated and applied to the input of an unknown four-terminal network; the output voltage of the network is displayed on the Argand diagram reproduced on the screen of a cathode-ray tube. As the frequency is varied, the circle diagram of the network is traced on the screen and resonances are indicated by loops in the trace.

The broad principles are given of an equipment working in the frequency range 5-215 kc/s, which has already been described elsewhere. Full details are given of a second equipment for the frequency range 100 kc/s - 3 Mc/s. Frequency calibration means are discussed. The chief applications of these two designs are described—the assessment of electromechanical transducers, and as bridge detectors in electromechanical measurements of elastic constants. Numerous electrical circuit applications, such as the display of Nyquist diagrams, would also be possible.

1. Introduction

Useful information about the electrical characteristics of a four-terminal network can be obtained from a simultaneous plot of the amplitude and phase of the output voltage relative to the input voltage, as the frequency is varied. The output voltage vector can be displayed as a point on the Argand diagram, which can conveniently be reproduced on the screen of a cathode-ray tube. As the frequency is varied, loops in the trace indicate resonances in the network; the frequency scale of the loops provides a measure of the corresponding Q values.

2. Previous Equipment

An equipment to provide this facility in the frequency range 5 kc/s–215 kc/s has already been described.‡ This has been in use at the National Physical Laboratory for nearly a year, principally for the assessment of electromechanical transducers and as a bridge detector in electromechanical measurements of elastic constants. Fig. 1 is a block diagram indicating

the principle of the method used in this equipment. Two outputs of the test frequency are generated at A and B with a phase difference of 90 deg., and these are used as “carrier frequency” inputs for two identical phase-sensitive detectors. A separate output in phase with one of them is fed to the network under test. The output from the network is fed to the “signal frequency” terminals of both phase-sensitive detectors. In the detector outputs a.c. components are suppressed, leaving only a d.c. component having a magnitude proportional to $E \sin \varphi$ in the one and $E \cos \varphi$ in the other, where E is the voltage at the output of the network and φ is the phase angle of that voltage relative to the phase of the input. These two d.c. voltages are applied to the Y- and X-plates of the tube respectively, giving the spot a resultant deflection from the centre proportional to E at an angle with the horizontal of φ . The spot thus locates the end of the output voltage vector on the Argand diagram displayed on the tube face.

The accuracy of the method depends on balancing simultaneously two phase/frequency

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† Communication from the National Physical Laboratory, Teddington, Middlesex.

U.D.C. No. 621.317.755:621.317.32.

‡ E. C. Pyatt, “Equipment for the vectorial display of alternating voltages in the frequency range 5-215 kc/s,” *J. Sci. Instrum.*, **32**, pp. 469-471, December 1955.

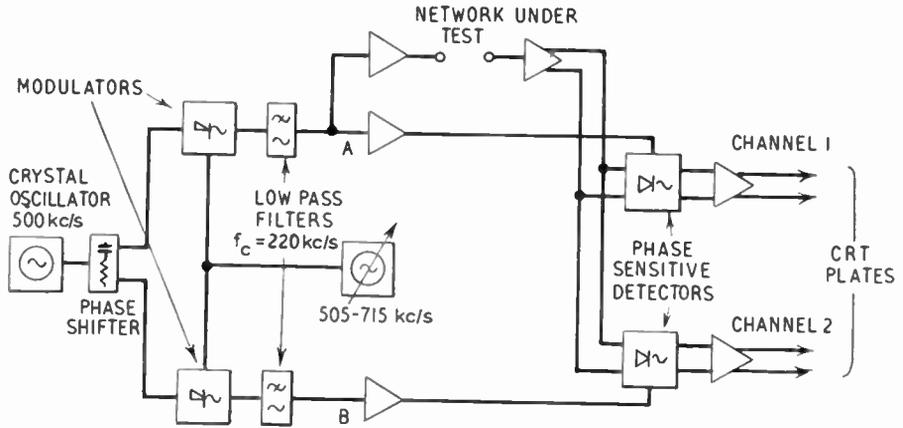


Fig. 1.—Vectorial display of alternating voltages in the frequency range 5-215 kc/s.

characteristics in different parts of the equipment. Firstly, Channel 1 must be balanced against Channel 2 from the phase shifter through to the phase sensitive detectors (thus including balancing one low-pass filter against the other); secondly, the phase change from A through the "system under test" terminals (when these are shorted) to the phase-sensitive detector must balance that in Channel 1 between point A and the phase-sensitive detector. It was found possible by comparatively simple phase equalization to do this balancing in this frequency range so that the phase angle error fell within ± 3 deg., but it was felt that a more simple method not involving so many balancing paths might be preferable in an equipment to work at higher frequencies.

3. Basic Description of Present Equipment

When it was decided, therefore, to extend the range of the equipment to 3 Mc/s, a new circuit was designed to cover the range 100 kc/s to 3 Mc/s. This uses the same power supplies and feeds the cathode-ray tube display panel of the original equipment. Fig. 2 is a block diagram of the circuit principle.

Two crystal oscillators having a frequency difference of 50 kc/s feed two separate modulators; the second input frequency for each modulator is derived from a variable oscillator. The modulators are followed by low pass filters, which pass the lower sidebands and suppress upper sidebands and input signal frequencies. Thus at points C and D in Fig. 2 are outputs

of f kc/s and $(f+50)$ kc/s respectively. (f is the test frequency and equals the difference between the frequency of the variable oscillator and the frequency of the higher frequency crystal oscillator). From C the circuit divides into one channel passing through the system under test to one modulator, the second channel passing direct to a second modulator. The second input frequency for each modulator is derived from point D. A low-pass filter selects the lower sideband of the output from each of these modulators, and this has always a frequency of 50 kc/s irrespective of the value of f . At points E and F therefore are outputs of 50 kc/s having a phase difference equal to the phase change through the network under test. The output at point E, i.e. the wave which has passed through the network, is used to derive a circular time base for the display cathode-ray tube. The amplitude of the circular trace is thus a measure of the attenuation of the network. The output at point F is squared and differentiated to produce a pulse, which is applied as a brightening pulse to the grid of the display cathode-ray tube. Suitable manipulation of the brightness control of the tube enables the spot alone to be seen and its radial displacement and angular position on the screen are a measure of the attenuation and phase change in the network under test.

It can be seen that the only part of the circuit where phase shifts will affect the accuracy of the results lies in the two channels between point C and the circular time base and grid pulse generators. The portion of these

channels on the output side of the modulators works always at one frequency and in consequence presents no problem at all for phase compensation. The accuracy of the equipment hinges therefore on producing identical circuits in the two channels between point A and the output of the two modulators.

4. Detailed Description

The crystal oscillator frequencies are 4 Mc/s and 3.95 Mc/s, the oscillator circuits being of conventional types. (For most applications it is sufficient for these crystals to be of the same type, but if excessive operating temperatures are likely temperature-controlled crystals can be used or crystals selected to have similar temperature coefficient/temperature relations). The variable oscillator range is 4.1-7.0 Mc/s. The modulators are of the suppressor grid type using pentode CV 2209 (6F33), and these are matched to two-section low-pass filters by cathode followers (CV 136; EL91). The filters, which have $R_0=500$ ohms, $f_c=3.2$ Mc/s, one section constant- K and the other with $f_\infty=3.975$ Mc/s, select the lower sideband 100 kc/s to 3 Mc/s or 150 kc/s to 3.05 Mc/s respectively and suppress upper sidebands and input frequencies. Thus, corresponding to a frequency $(f+4000)$ kc/s from the variable oscillator, a frequency f kc/s appears at point C and a frequency $(f+50)$ kc/s appears at point D.

The wave of frequency f kc/s at point C is fed to the network under test through amplifier (CV 138; EF 91) and cathode follower (CV 136) stages. The maximum voltage obtainable at the network input is 900 mV. The output from

the network under test is amplified in a variable- μ stage (CV 454; 6BA6) to provide control of gain, then passes via an amplifier (CV 138) stage to the suppressor grid of a modulator valve (CV 2209; 6F33). The control grid of this valve is fed from point D with frequency $(f+50)$ kc/s via a single stage amplifier (CV 138). A transformer in the modulator valve anode circuit matches this to a two-section low-pass filter, having $R_0=500$ ohms, $f_c=75$ kc/s, one section constant K and the other with $f_\infty=100$ kc/s, which passes lower sideband (always 50 kc/s) and suppresses upper sidebands and other unwanted frequencies. The 50 kc/s output signal is fed to a single stage amplifier (CV 138), which has to be tuned in order to suppress further the unwanted demodulation products arising from harmonics generated in various parts of the circuit. The output is at point E.

From point C an identical channel omitting only the network under test provides a second 50 kc/s output at point F. The 50 kc/s signal at point E has an amplitude proportional to the attenuation of the network and a phase relative to the phase of the 50 kc/s signal at point F equal to the phase change in the network.

The signal from point E is passed to a 90 deg. phase shifter, the two outputs of which feed the X and the Y plates through push-pull amplifiers (all CV 138). The signal at point F is squared and differentiated; the resulting pulse triggers a blocking oscillator, which produces the narrow brightening pulse for the cathode-ray tube grid.

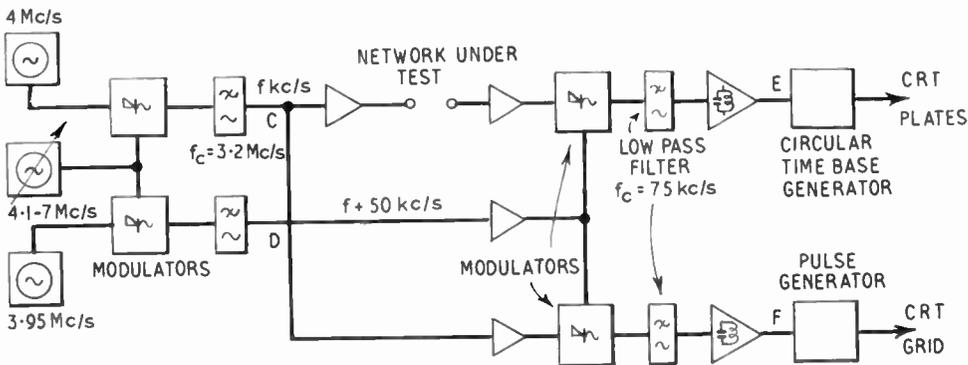


Fig. 2.—Vectorial display of alternating voltages in the frequency range 100 kc/s to 3 Mc/s.

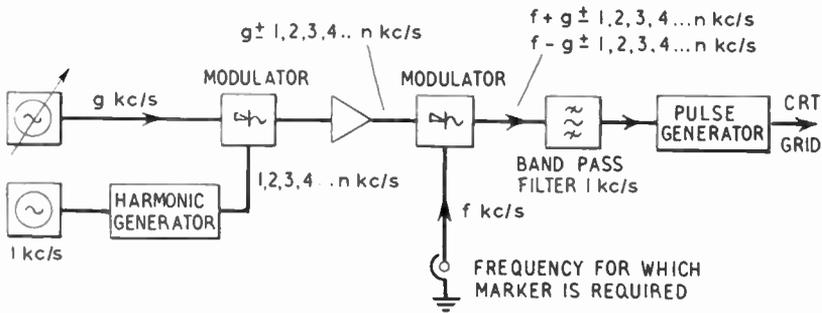


Fig. 3.—
Additional circuits for
frequency calibration.

The amplification of the whole system is such that at maximum gain 30 mV at the output of the network under test produces a deflection of 1 cm on the cathode-ray tube screen. The tube is of the compass type (CV 961; NC 13) having equal X and Y deflection sensitivities. The screen diameter is 5½ inches and it carries a circular scale of degrees. Power supplies and controls are all conventional.

Provided that the network under test presents a suitable impedance to the measuring system, the phase angle error probably lies within ±5 deg. The accuracy could be improved by more careful design of the amplifier circuits and by individual selection of components in order to balance the two channels. The addition of a cathode follower probe with low input capacitance for connecting the network output to the equipment would increase the scope of the possible measurements.

4.1. Frequency Calibration Circuits

In the first equipment the variable oscillator incorporates a means for displaying a frequency calibration on the cathode-ray tube screen during operation. A 100-tooth gear wheel cam on the incremental tuning capacitor operates a miniature switch at each tooth. A separate output derived from the variable oscillator via a cathode follower is fed to the grid of a valve, which is switched on and off by the cam-operated switch in its cathode. The output of this valve is connected to the grid of the cathode-ray tube, which is biased beyond cut-off for the normal condition of no input. The electron beam is suppressed therefore until the cam switch operates when the spot on the screen becomes visible. Fig 5 shows an example of the use of this calibration device in practice. The spacing of the resulting bright spots on the trace varies from 25 c/s at 5 kc/s to 70 c/s at 215 kc/s. The

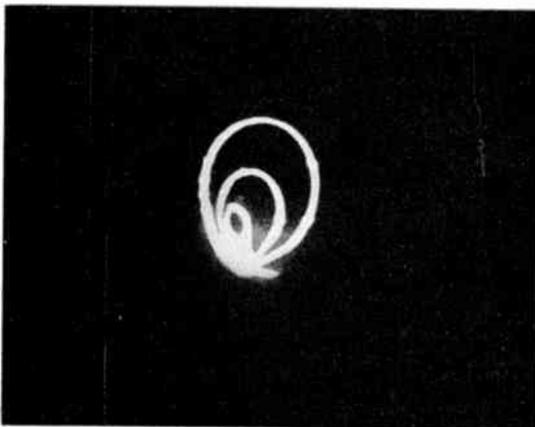


Fig. 4.—Circle diagram of barium titanate crystal. The resonance frequencies are 97.7 kc/s (large loop), 134.5 kc/s and 170.0 kc/s (small loop).

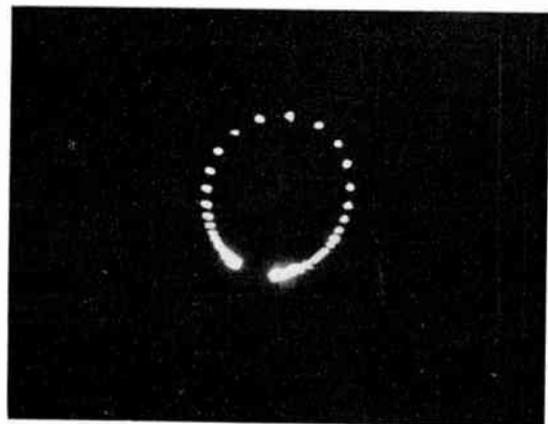


Fig. 5.—Portion of circle diagram of barium titanate crystal. Resonance frequency 32.2 kc/s; dot spacing 33 c/s; Q approximately 100.

variation of dot interval with dial setting is a drawback to this system and in the present case the alternative shown in Fig. 3 will be used. A modulator valve derives its first input from a variable oscillator, having a frequency g kc/s close to f kc/s and its second input from an accurate 1 kc/s oscillator via a harmonic generator and equalizer. The modulator output includes therefore frequencies of $g \pm 1, 2, 3, 4$ kc/s, etc. The modulated wave is fed to a second modulator via a high pass filter to remove unwanted signals at the input frequencies. The second input for this modulator is derived from the equipment, and is the variable frequency for which the calibration marks are required. The second modulator output is filtered by a narrow band 1 kc/s band pass filter. As f is varied an output is obtained from the band pass filter whenever f differs from g by a simple multiple of 1 kc/s, i.e. at intervals of 1 kc/s. The pulses thus obtained applied to the grid of the display cathode-ray tube produce the "dotted line" trace as before, but with the dots at a fixed frequency interval.

5. Applications

5.1. *The Assessment of Electromechanical Transducers*

Circle diagrams of electromechanical transducers can be plotted by displaying the voltage across a small resistance in series with the transducer. The method is particularly valuable in cases where high power is being handled in the transducer and conventional

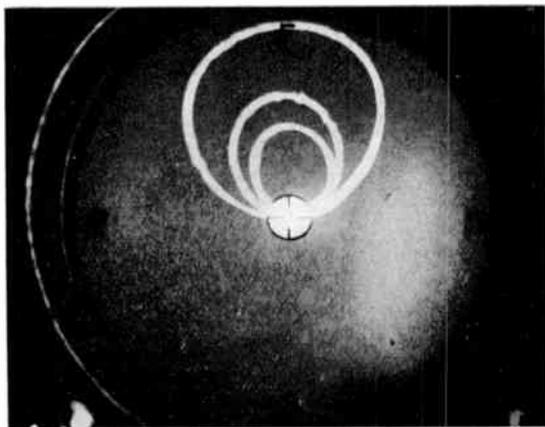


Fig 6.—Circle diagram for three parallel resonance circuits. Resonance frequencies 46.2 kc/s, 100.4 kc/s, and 160.4 kc/s.

bridge methods can no longer be so easily employed. The drive frequency derived from the equipment may need amplification for some applications; the phase change of the additional amplifiers will then have to be determined separately. Resonance frequencies and corresponding Q values can be rapidly determined from the circle diagram and the results used to estimate transducer efficiencies. Once the position of an interesting portion of the circle diagram has been located in the frequency spectrum by this method, it can, if necessary, be plotted in more detail by conventional methods. Figs. 4 and 5 show some typical examples of measurements on barium titanate transducers.

5.2. *Bridge Detector*

The vectorial display equipment has greatly facilitated the use of some of the methods of measuring the elastic constants of small metal strips and disks, developed by Bradfield at the National Physical Laboratory (to be published). Frequently the mechanical resonances are of very small amplitude and only produce very small impedance changes in external circuits. The transducer forms one arm of a shielded bridge, which is fed with the drive frequency and balanced approximately at a frequency near resonance. The vectorial display equipment is connected to the detector terminals of the bridge and the frequency is varied until resonance is indicated by a small loop in the cathode-ray tube trace.

5.3. *Electrical Measurements*

Although the equipment was not designed primarily for electrical measurements, it is obvious that the display of Nyquist diagrams of amplifiers or of the phase and amplitude characteristics of electrical networks could readily be carried out with its aid. Fig. 6 shows a circle diagram obtained from three parallel resonance circuits.

6. Acknowledgments

This work has been carried out as part of the research programme of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory. Mr. G. Bradfield instigated the development; Mr. D. Moss carried out some of the wiring. The author wishes to acknowledge the helpful suggestions of Mr. H. Pursey during the course of the development.

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 FOSTER, Edward Selwyn. *St. Anne-on-Sea.*
 FOX, Gerald Johnson. *Doncaster.*
 FRANCIS, Raymond John. *Liverpool.*
 FROST, Colin Peter. *Nottingham.*
 FRY, Donald Edward. *Manchester.*
 FURNEVAL, Brian. *Houghton-le-Spring.*
- GALF, Graham Edward. *Fareham.*
 GARIAND, Brian. *Blackpool.*
 GEDDES, Kenneth William. *Blackpool.*
 GIBBS, Alan John. *Brighton.*
 GIBSON, Michael. *Castleford, Yorks.*
 GILGALLON, Robert. *Glasgow.*
 GITTOES, Jack Allan. *Lyminster.*
 GLOVER, William Bateman. *Birmingham.*
 GODFREY, Neville Ernest. *Leicester.*
 GODFREY, Raymond Horace. *Eastbourne.*
 GOODWIN, Alan. *Leeds.*
 GOUGH, James Henry. *Birmingham.*
 GRAYSON, Ivor Joseph. *London, E.8.*
 GREENWOOD, Brian James. *Cheadle.*
 GRIFFIN, Brian James. *Wigan.*
 GRIMMOND, Anthony. *Eastbourne.*
 GROSVENOR, George Victor. *Cambridge.*
- HARLOW, Norman. *Middleton, Lancs.*
 HARPER, William. *Dundee.*
 HARRISON, Charles Keith. *Oldham.*
 HARTLEY, Norman Derek. *Rochford.*
 HARTY, Gordon Christopher. *Bristol.*
 HARWOOD, Robert Pickersstaff. *Blackpool.*
 HAWKES, James Fairfield. *Wirral.*
 HEALY, Patrick Bartholomew. *Glasgow.*
 HEATHERLEY, Clive. *Bristol.*
 HESLOP, Peter Graham. *Sheffield.*
 HICKS, Bernard William. *Ware.*
 HIGGS, David John. *Bletchley.*
 HILTON, Alan. *Huddersfield.*
 HOBBS, Ronald Joseph. *Warrington.*
 HOLDEN, Eric. *Rossendale.*
 HOMER, Harry. *West Hartlepool.*
 HONEYWOOD, Edward Rodney. *Purley.*
 HORNE, Geoffrey Russell. *Dewsbury.*
 HOUGH, Peter Terence. *Doncaster.*
 HOWARD, Keith. *Haver.*
 HUDSON, Gordon Mason. *Lincoln.*
 HUGHES, Brian Howell. *Birmingham.*
 HUMPHREY, Brian John. *Shrewsbury.*
 HUNTON, Ian William. *Yatesbury.*
 HYDE, John David. *Newton Abbot.*
- ISON, Michael Roy. *Cambridge.*
- JACKSON, John Greenwood. *Southport.*
 JARMAN, Thomas Alec. *London.E.1.*
 JENNINGS, Ernest Wesley. *Redcar.*
 JESSUP, George Calthorpe. *Manchester.*
 JOHNSON, Colin. *Newton-le-Willows, Lancs.*
 JORDAN, Edward Patrick. *Newcastle-on-Tyne.*
- KAY, William. *Bolton.*
 KEAN, Donald Lionel. *Warminster.*
 KELLY, Michael Fredric. *Worthing.*
 KENDRICK, Roy William. *Northfleet.*
 KIBBEY, Colin Frederick. *Bristol.*
 KING, David Hugh Evelyn. *Brighouse.*
- KNIGHT, Peter Charles. *Oakham.*
 KNIGHT, Robert Kenneth. *Southill.*
 KNOTT, Peter Gaythorn. *Enfield.*
- LARDEN, George Edward. *Birmingham.*
 LAWTON, David Harold. *Shaw, Lancs.*
 LAYTON, James John. *Rayleigh.*
 LEIGH, Ronald. *Wigan.*
 LLOYD, Brian. *Bristol.*
 LOCKWOOD, Peter. *Luton.*
 LONSDALE, Philip. *Liverpool.*
 LOWE, Stanley, Gerald. *Manchester.*
 LUMSDEN, Alexander. *Paisley.*
 LUNN, David Ian. *Stockport.*
 LUNNON, Barrie James. *Leichworth.*
- MCBRIDE, Robert. *Glasgow.*
 MCCORMICK, John. *Salford.*
 MCCLACHLAN, Alan Stewart. *Glasgow.*
 McNABB, Robert K. *Liverpool.*
 MACNAMARA, Terence. *Bradford.*
 MADDISON, Eric Leonard. *Bolton.*
 MAGUIRE, John. *Manchester.*
 MAILES, Leslie. *Southall.*
 MARTIN, Ernest Howard. *Heckmondwike.*
 MARIAND, Frank. *Wigan.*
 MASON, Alan Francis. *Burton-on-Trent.*
 MASON, Malcolm Ewart. *Grimby.*
 MATHERS, Chapman. *St. Monace, Fife.*
 MEADOWS, Laurence Wesley. *Birmingham.*
 MILLER, Herbert Spencer. *Wickford, Essex.*
 MILMAN, Arthur. *Bailey.*
 MILLS, Arthur Lyndon. *Mansfield.*
 MILNE, Robert. *Penicuik, Midlothian.*
 MOYNEAUX, William. *Warrington.*
 MORRELL, Alan Edward. *Nottingham.*
 MOSS, George Charles. *Shrewsbury.*
 MOSS, Peter Arthur. *Northolt Park.*
 MURPHY, Michael Joseph. *Tullaghan.*
 MUSGROVE, James Alfred. *Blackpool.*
- NEAL, Clifford. *Blackpool.*
 NICOLINI, Denis. *Hull.*
 NOBLE, Daniel Ferguson. *Ayr.*
- PARKER, David. *Wakefield.*
 PARKIN, Alan. *Sunderland.*
 PARRY, Alan Edward. *Wirral.*
 PEAD, Brian Francis. *Berkeley, Glos.*
 PEARSON, Hugh Davidson. *Glasgow.*
 PETERS, Brian. *Bury.*
 POLINS, Robert Ivor. *London, E.17.*
 PONTIN, Paul Stephen. *Torquay.*
 POWELL, Keith. *Hull.*
 PRESTON, John. *Higher Bebington, Ches.*
 PROUD, Albert William. *Ryton-on-Tyne.*
 PUZCEK, Jerzy. *Croydon.*
- RANDALL, Derek William. *Leicester.*
 RANN, Peter B. *Greenford.*
 RATCLIFFE, Roy Barker. *Wigan.*
 RAWSTHORNE, George. *Liverpool.*
 REYNOLDS, Lyn. *Manchester.*
 RHODES, Gerald. *Barnsley.*
 RHODES, Robert. *Pontefract.*
 RICHARDSON, Alfred. *Saltham.*
 RIGBY, Thomas Peter. *Furncorn.*
 RODGERS, Colin. *Riddings, Derbyshire.*
 RONCONE, Francis T. *Dundee.*
 ROSS, Kenneth. *Stoke-on-Trent.*

OWLANDS, Derek John. *Uxbridge.*
LUTHERFORD, Peter. *Liverpool.*

ARGENT, Dennis Keith. *Stoke-on-Trent.*
ENHOR, Brian. *Leeds.*
HAKESPEAR, Eric Claud. *Birmingham.*
HARP, Ernest Leslie. *Southend-on-Sea.*
HAW, Anthony George. *Cheadle.*
HAW, Derek Alwyn. *Brighouse.*
HIPLEY, Brian Maurice. *Driffield, E. Yorks.*
HIRLEY, David. *Manchester.*
JMPSON, Reginald Percy. *Colchester.*
KINNER, Peter James. *Stoke-on-Trent.*
KINNER, Tony. *Maldstone.*
KLINGER, John Richard. *West Kirby.*
MALLWOOD, Cyril. *Bicester.*
SMITH, Charles Roger. *Peterborough.*
SMITH, John William. *Swanley.*

SOUTTER, James Ross. *Edinburgh.*
STEVENS, Robert. *Edinburgh.*
STOCK, Ronald Michael. *Colchester.*
STOKES, Michael John. *Barnsley.*
STREET, Cecil Robert. *Horsham.*
SUMNER, Arnold. *St. Annes-on-Sea.*
SUTTON, Peter Vernon. *Windsor.*

TAYLOR, Christian Andrew. *Fraserburgh.*
THOMAS, Peter Llewelyn. *Shrewsbury.*
THOMAS, William. *Hull.*
TURNER, Alan James. *Liverpool.*
TURNER, Peter Alan. *Southend-on-Sea.*

VALENTINE, Keith Jack. *Cheadle.*
VENN, Terence Leslie. *Torquay.*
VIGORS, Raymond Hedley. *Middlesbrough.*

WALKER, Kenneth Bernard. *Solihull.*
WALTON, Brian Victor. *Walsall.*
WALTON, Eric Harvey. *Liversedge.*
WARDLE, Stewart. *Leek.*
WESTWOOD, Stanley. *Bristol.*
WHALLEY, Peter Barry. *Cleethorpes.*
WILLIAMS, Colin. *Sheffield.*
WILSON, Alexander Anderson. *Edinburgh.*
WILSON, Alan Charles Edward. *London, W.7.*
WINFIELD, Samuel George. *Plymouth.*
WINTER, Patrick Rex. *Uckfield.*
WOOD, John Windsor. *Manchester.*
WOOLGAR, R. J. *Chichester.*

YATES, James. *Bacup.*
YOUNG, Derek. *Cheadle.*

The following 79 candidates, referred in the Practical Test in 1955, now qualify for the Certificate :

ALLENBY, Norman Appleyard. *Cleckheaton.*

JARON, Anthony John. *Cambridge.*
JARTON, John Stephen. *Cambridge.*
BATES, Alan. *Brighouse.*
BENNETT, James Thomas. *South Shields.*
BERESFORD, David Robert. *St. Helens.*
BLACK, Andrew Millar. *Welwyn.*
BOLESWORTH, James. *Glasgow.*
BRADLEY, Eric. *Aisworth, Notts.*
BROSTER, John. *Wirral.*
BROWN, Kenneth. *Leeds.*
BROWN, Richard John. *Worthing.*
BURDITT, John Terence. *Ibstock, Leics.*
KUNTS, Robert. *Helensburgh.*

CHINN, Milton Desmond. *London, N.6.*
COLES, William Thomas. *Plymouth.*
COX, Victor Michael. *Leeds.*

DALE, Peter Ringolds. *Salford.*
DUTTON, Joseph Donald. *Northwich.*

EASTON, Gavin Livingstone. *Shotts, Lanarks.*
EDGE, James Joseph. *Liverpool.*
ELLIOTT, Lawrence. *Mirfield.*

FIRSTBROOK, Walter. *Chadderton.*

GAY, William Conn. *Glasgow.*
GILLMAN, Robert Arthur Ivan. *Bromsgrove.*

GLENN, Jack Baden. *Gainsborough.*
GOODISON, Brian Anthony. *St. Helens.*
GORDON, Joseph. *London, E.1.*
GRIFFIN, Roy. *Sandiacre, Notts.*

HOMAN, John Albert. *Higham Ferrers.*
HOUGH, Charles William. *Birkenhead.*
HUGHES, John Chassels. *Paisley.*

IVERS, George Joseph. *Manchester.*
JAMES, Leslie John. *London, S.E.9.*
JENKIN, Kenneth John. *Redruth.*
JOHNSON, Robert. *Glasgow.*

KNOTT, Graham Trevor Peter. *Ely.*

LEWIS, Ivor. *Bristol.*
LOAKES, Michael Brian. *Hugglescote, Leics.*
LUTRELL, Edward Richard. *Glasgow.*

MCGEACHIE, Alexander. *Paisley.*
MCINTYRE, James. *Glasgow.*

McKENZIE, Ian. *Huddersfield.*
MARGERISON, James. *Blackburn.*
MARSH, Peter. *Nottingham.*
MARTIN, John Arthur. *Woking.*
MIDDLETON, Laurence. *Ayr.*
MINNS, Ralph. *South Croydon.*
MOORE, Geoffrey Frank. *Morecumbe.*
MORRIS, Alan. *Bolton.*

NOYCE, Peter Frederick. *Colden Common.*

PERRY, Raymond Charles. *Walsall.*
PETTO, John. *Ayr.*
PLADGEMAN, John Derek. *Leicester.*
POND, Cyril Arthur. *Stroud.*
POVALL, Charles John. *Birkenhead.*
PRESBURY, Peter Wilfred. *Nottingham.*
RICHARDS, Stanley Ralph. *Elbarton, Devon.*
RICHARDSON, Colin William. *Newcastle-on-Tyne.*

RUSHWORTH, Arthur. *Huddersfield.*
RYAN, Peter Leo. *Auchterarder, Perth.*
SHARPE, Donald. *Orpington.*
SHAW, John Boler. *Brighouse.*
SMITH, Michael David. *Grantham.*
SMITH, Raymond George. *Birmingham.*
SOUTGATE, Leslie Herbert. *Hailsham.*
SPARKES, Edward Ernest Victor. *Rhondda.*
STANLEY, Joseph William. *Bradford.*

TENNENT, Brian Harry. *Brighton.*
THAKER, Kantial Jethalal. *London, N.19.*
THOMSON, John. *Glasgow.*
TURNER, Brian. *Hullfax.*
TYMM, Gordon Turner. *Burnley.*
VANDOME, Ignatius Gerald. *Preston.*
WALSH, Patrick John. *Dublin.*
WATKINSON, Thomas. *Leeds.*
WATSON, Ivor George. *Wesigate-on-Sea.*
WILLIAMS, John Andrew. *London, S.E.4.*
WILSON, William Arthur. *South Shields.*

The following 185 candidates passed the written papers but were referred in the Practical Test :

ADAM, Norman Sydney. *Glasgow.*
ALLEN, Royston Arthur. *Birmingham.*
ANDRUS, David George. *Liverpool.*
ASPINALL, Thomas. *Leigh, Lancs.*
ASTBURY, Dennis Henry. *Manchester.*

BAILEY, Malcolm. *Doncaster.*
BARRETT, John Charles. *Twickenham.*
BEIRNE, Patrick Ronald. *Dagenham.*
BELL, Albert Charles Joseph. *Portsmouth.*
BELL, Trevor Henry. *Hemel Hempstead.*
BENNETT, Ivan Hammond. *Stockport.*
BETHELL, Charles Stanley. *Liverpool.*
BETTERIDGE, Albert. *Birmingham.*
BHATTI, Abdul Hafiz. *London, W.8.*
BLIGH, David George. *Lolworth, Cambs.*
BOYES, Fred. *Blackpool.*
BOYLE, Kevin Thomas. *Bradford.*
BROOKS, Anthony Brian. *Wallington.*
BROWN, Alexander R. *Glasgow.*
BROWN, Raymond Stenson. *Sandiacre, Notts.*
BULLOCK, Thomas Charles. *Greenford.*
BULTITUDE, Brian. *Bristol 3.*
BUTLER, Alan James. *Larkhall, Lanarks.*

CAIVERT, Allan. *Billingham, Co. Durham.*
CHALCRAFT, Geoffrey. *Steving, Sussex.*
CHALLEN, Bernard Charles. *Oldham.*
CHAMBERS, Keith. *Blackpool.*
CHAPMAN, Derek John. *Cleethorpes.*
CHRISTIE, Mrs. Mary Westran. *Glasgow.*
COCKBONE, Michael Kenneth. *Wirral.*
COLLIER, Arthur Alexander. *Birmingham.*
CONROY, Francis. *Liverpool.*
COOKE, Robert. *Nottingham.*
COOPER, John. *Uttoxeter.*
COSTELLO, William Anthony. *Cheadle.*
COTTON, Benjamin David. *Wellington, Salop.*

COULTHARD, Denis. *Middlesbrough.*
COWEN, Simon Bernard. *London, S.W.5.*
CRAMPTON, Roy. *Sheffield.*
CRAWLEY, Anthony Page. *Loughborough.*
CRESSWELL, William. *Houghton-le-Spring.*
CROCKETT, Brian Frederick. *Bromsgrove.*
CUDMORE, Derek Robert. *Paignton.*

DAVIS, Bernard Peter. *Westcliff-on-Sea.*
DAVIS, Edward William. *Westcliff-on-Sea.*
DE COENE, Victor. *Birmingham.*
DEVILLEREZ, Colin James. *London, S.W.2.*
DEXTER, Philip Graham. *Keighley.*
DUFFIELD, George Ernest. *London, E.1.*
DUGAN, George Noel. *Nottingham.*
DUNN, Alfred Austin. *Birmingham.*
DYSON, Maurice George. *Castle Bromwich.*

EDDY, Gordon Raymond. *Torquay.*
EVANS, David. *East Barnet.*
EVANS, John Warren. *Birmingham.*
EVANS, Terence Egan. *Birmingham.*

FARMER, James Henry. *Motherwell.*
FARRELL, John James. *Belfast.*
FAWCETT, Jack Trevor. *Hullfax.*
FOX, Frederick William. *Carnforth, Lancs.*
FRAME, William. *Hamilton, Lanarks.*
FREEMAN, Raymond Douglas. *Nottingham.*
FULLER, Frank Arthur James. *Romford.*

GARTON, Dennis. *Penketh, Lancs.*
GAVIN, Gerald. *Biggar, Lanarks.*
GETTY, John Ramsay. *Glasgow.*
GITTINS, Ronald Edward. *Walsall.*
GLANCY, Charles. *Stirling.*
GOOD, Henry Baync. *Newcastle-on-Tyne.*
GORDON, Donald William. *Southampton.*
GREEN, Frank. *Middleton, Lancs.*

GREENWOOD, Dennison Arthur. *Lancaster.*
GREIG, Charles William. *Glasgow.*
GRIFFITHS, Peter Morris. *Bury.*

HAMMOND, Ivan William. *Hertford.*
HARGREAVES, Dennis George. *London, S.W.8.*
HARLOW, Terence Albert. *Leicester.*
HARVEY, James. *Paisley.*
HAWKSLEY, Peter. *Leicester.*
HAYWOOD, Trevor Harold. *Walsall.*
HENRY, John. *Kirkintilloch.*
HOGG, James Fraser Salter. *Dundee.*
HOLMAN, Roger Keith. *Cote Mullen, Dorset.*
HORSFALL, Peter John. *Todmorden, Lancs.*
HOWELL, Joseph Leslie. *Shrewsbury.*
HUBBARD, Anthony Francis. *Gidea Park.*

IBBS, Kenneth Douglas. *West Bromwich.*

JEFFRIES, John Stanley. *Erith.*
JESSNER, Walter. *London, E.17.*
JOHNSON, Brian. *Driffield, Yorks.*

KEEFE, Richard. *Grimsby.*
KEY, William Arthur. *Shrewsbury.*
KNIBBS, John Spence Couper. *Glasgow.*
KNIGHT, David John. *Morden.*

LACEY, James Edgar. *Plymouth.*
LANGDON, Trevor Lawrence. *Bristol.*
LAVENDER, Trevor Dyke. *Dudley.*
LAWRENCE, Clifford Roy. *Southampton.*
LAWRENCE, Tennyson Bancroft. *London, N.W.6.*
LEA, Geoffrey. *Birmingham.*
LEE, Leslie. *South Shields.*
LEISK, David. *St. Mawgan, Cornwall.*
LEONARD, Leslie Ernest. *London, S.E.22.*
LODGE, Brian Frederick. *Pontefract.*

Radio Servicing Certificate Examination (contd.).

- LONGLAND, Alan George. *Houghton, Hunts.*
LUM, John Brian. *Huddersfield.*
- MCGEACHIN, John. *Glasgow.*
MCGREGOR, Sidney. *London, E.17.*
MCKAY, William. *Maybole, Ayrshire.*
MACLURE, John Lennox. *Glasgow.*
MAITLAND, Walter. *Belfast.*
MASON, Paul Arthur. *Langley Mill, Notts.*
MERCER, Robert. *Preston.*
MIDDLETON, William George. *Birmingham.*
MIELNICKI, Michel. *London, S.W.9.*
MILLAR, Thomas Love. *Bannockburn.*
MITCHINSON, James. *Manchester.*
MIVAL, Colin James. *Cambridge.*
MUNRO, Alistair Robert Lindsay. *Kirkaldy.*
- NELSON, Leonard Howarth. *Bolton.*
NISBET, William. *New Stevenston, Lanarks.*
NOBLE, Roy. *West Harilepool.*
- O'BRIEN, William Joseph. *Ilford.*
OWEN, Edward James. *Fleetwood.*
- PARKER, Alan John. *Smethwick.*
PATCHETT, Robert. *Manchester.*
PATERSON, George. *Stirling.*
PAUL, Ivan Neville. *East Croydon.*
PEARSON, Rodney William. *Huddersfield.*
PICKARD, Frederick William. *Bexhill-on-Sea.*
- PICKEN, John Frederick. *Bromsgrove.*
PLUMMER, Roy John. *Bexleyheath.*
POOLE, Richard Allan. *London, E.C.1.*
PRICE, Brian Robert. *Nottingham.*
- RATCLIFF, Stanley. *Chertsey.*
REILLY, Joseph. *Glasgow.*
REVELL, Brian Walker. *Grimsby.*
RIDLEY, Michael. *Barnet.*
ROBINSON, Jeffrey Lucas. *Weston-super-Mare.*
ROBINSON, Michael. *Liverpool.*
ROSS, Brian. *Newcastle, Staffs.*
ROWNEY, Peter Thomas. *Stafford.*
RUSSELL, Dermot James. *London, N.4.*
RUSSELL, Michael John. *Birmingham.*
- SANDS, Edwin David. *Nottingham.*
SEROKA, Marian. *West Croydon.*
SHARMAN, Harold. *Spalding.*
SHAW, James Trevor. *Preston.*
SHEPPARD, Jeffrey Laidlaw. *Hertford.*
SHIPLEY, John. *Colne, Lancs.*
SHIPWAY, John Edwin. *Addington, Surrey.*
SHIRVELL, Archibald James. *Basildon.*
SIMPSON, Derek William. *London, W.12.*
SMAGGASALE, Roy Edward. *Barking.*
SMITH, Donald. *Leicester.*
SMITH, Eric Kenneth. *Eastwood.*
SMITH, Raymond. *Hull.*
SMITH, Walter William. *Plymouth.*
- SPONG, Ivan. *Leicester.*
STEINMETZ, Frank. *Epsom.*
STEPHENS, Robert George. *Leicester.*
STOBO, Alexander. *Wishaw, Lanarks.*
SUNDERLAND, Donald. *Halifax.*
SUNDERLAND, Donald. *Keighley.*
SWAIN, Ronald James. *Colnbrook, Bucks.*
- THOMAS, Allan R. *Derby.*
THORPE, John Norman. *Leicester.*
TOWNLEY, David. *Accrington.*
TURTLE, Frederick Henry. *Derby.*
- VINCE, Derby Donald. *Derby.*
- WALKER, Gordon Henry. *Weston-super-Mare.*
WALLACE, James. *Maybole, Ayrshire.*
WARD, Gilbert. *Slough.*
WATERS, Gerald Arthur. *Felbridge, Sussex.*
WATKIN, Arthur Raymond Myles. *Wirral.*
WATSON, George Lorraine. *Lyme Regis.*
WEAVER, Douglas Brian. *Croydon.*
WILDSMITH, Joseph H. *Uttoxeter.*
WILLIAMS, Haydn Canning. *Brighton.*
WILSON, Ronald. *Sheffield.*
WILTSHIRE, Leslie Edward. *Ilkeston.*
WINDSOR, Terence Edwin. *Carrickfergus.*
WINSLOW, Michael. *Cleethorpes.*
WOLLAND, Edward Roy. *Bristol.*
WOOD, Paul Wylam. *Burnsley.*

TELEVISION SERVICING CERTIFICATE EXAMINATION—1956

A total of 134 candidates sat the examination which took place in May of this year.

The following 54 candidates satisfied the examiners in the entire examination :

- ALLEN, Arthur. *Leeds.*
APPLEBY, Brian Lawrence. *Wolverhampton.*
- BAKER, Gilbert Howard. *Bradford.*
BARKER, John. *St. Helens.*
BARR, George Salmond. *Alloa.*
BUCHAN, Peter Bernard. *Hereford.*
BUCKMAN, Douglas George. *Chatham.*
BURNS, Robert Alan. *Ramsgate.*
- CHAIK, Edward Cyril. *Driffield, Yorks.*
CHESSUN, Dennis Eddie. *Tunbridge Wells.*
COOK, Samuel John. *Shotton Colliery.*
COUPAR, William John. *Blairstown.*
CRISP, Frederick Joseph. *London, S.E.23.*
CROSS, Raymond. *Darwen, Lancs.*
- ELLIS, John Holton. *Newcastle-on-Tyne.*
EVANS, Ian Stewart. *Wirral, Cheshire.*
- FOSBERRY, Robert. *Chichester.*
- HARDWICK, Gerald. *Harrogate.*
- HARRISON, Arthur. *Warrington.*
HELIWELL, Fred. *Halifax.*
HENDERSON, Alan. *Kyton-on-Tyne.*
HORTON, Dennis Victor. *Birmingham.*
HUDSON, Robert. *Egham.*
HUNTER, Thomas. *South Shields.*
- KELLY, Donald. *Bury.*
KITCHING, Terence. *Leeds.*
KNIGHT, Michael John. *Bristol.*
- LISTER, Arthur George. *Grimsby.*
- MCDONALD, Robert. *Paisley.*
MC LAUGHLIN, Robert Cairns. *Hamilton.*
- MERA, John Charles. *South Benfleet.*
MOYES, Peter. *Mirfield.*
- NEWBY, Denis George. *Stourbridge.*
- PITCHER, Richard Dennis. *Leicester.*
PITT, Ernest. *Cullercoats, Northumberland.*
- REED, Graham George. *Cambridge.*
RENSHAW, Mathias. *Birkenhead.*
RUSSELL, Brian. *Blackpool.*
- SINGLETON, Allan. *Ilminster.*
SNOWDEN, John. *Manchester.*
SPANSWICK, Kenneth George. *Walsall.*
SQUIBB, Derek Charles. *Southampton.*
STEPHENSON, Brian Stanley. *Hyde, Cheshire.*
STICKLER, Rex. *Rhondda.*
SYKES, Alan Walter. *Leeds.*
- TURNER, Michael Leonard. *Wembley.*
TURNER, Robert. *Dunmurry, Co. Antrim.*
- WEBB, Walter Thomas Patrick. *Watford.*
WEST, Christopher Robert. *Derby.*
WILSON, Eric. *Leeds.*
WINNETT, John Terence. *Camberley.*
WOOD, Colin Michael. *Heanor, Derbyshire.*
WRIGHT, Ronald Herbert. *Hull.*
- YEATS, Thomas James. *Liverpool.*

The following 6 candidates, referred in the Practical Test in 1955, now qualify for the Certificate :

- ASHLEY, Raymond James George. *London S.E.18.*
BOWLING, Cyril James. *Poole, Dorset.*
- DICKINSON, Bernard. *Preston.*
RAWE, Dennis Gerald. *Hadley, Essex.*
- REECE, Raymond Dennis. *Gosport.*
WALTON, Brian. *Ossett, Yorks.*

The following 51 candidates passed the written papers but were referred in the Practical Test :

- ADAMS, Bertram Kenneth. *Bristol.*
ANDERSON, Bertram. *Bathgate, West Lothian.*
ARMSTRONG, William. *Ayr.*
- BRITTON, John David. *Derby.*
BROOKER, Fredrick David. *Liverpool 1.*
BURNSIDE, John Norman. *Paisley.*
- CANTRELL, John Raymond. *Birmingham.*
CHRISTIE, Francis Dickson. *Glasgow E.1.*
- DAVIES, David Harris. *Colwyn Bay.*
- FRANCE, Henry Thomas. *Liverpool.*
FROST, Alfred. *Newport, Mon.*
- GIBBONS, Donald Elvin. *Thornton Heath.*
- HARRISON, Peter Gerard. *Wallasey.*
HAWES, David Charles. *London N.19.*
HIRST, Cyril. *Oldham.*
HOOD, Joseph Acland. *Bedford.*
- HOPKINSON, Frank Keith. *Birkenhead.*
HUSSEY, David John. *Liverpool.*
- LAFFERTY, Archibald. *Stirling.*
LAMMERS, Leslie Albert. *Rochford.*
- MCCARTNEY, William. *Paisley.*
MCKENZIE, James Angus. *Dundee.*
MANTON, Harold James. *Southall.*
MASON, Francis Noel. *Liverpool.*
MILLER, Alfred Henry. *Stafford.*
MILLS, Barry Ronald. *Birmingham.*
MITCHELL, Albert David. *Shrewsbury.*
MOORE, John Derek. *Southwick, Sussex.*
- NEWELL, Derek William. *Doncaster.*
- OWEN, Hugh Carnell. *Birkenhead.*
OWINGS, Albert. *Liverpool.*
- PAYNE, Kenneth Rutherford. *Brighton.*
PRATT, Reginald James. *Bexhill on Sea.*
- SEDGELEY, Thomas Howard. *Leicester.*
SIMMONDS, Patrick. *Westgate on Sea.*
SLACK, Thomas Adrian. *Smethwick.*
SMITH, Derek Richard. *Nottingham.*
SMITH, George Frederick. *Sunderland.*
STOTT, Robert Henry. *Pruddhoe.*
SWEENEY, William. *Port Glasgow.*
- TAYLOR, James Gray. *Glasgow N.W.*
TILLEY, David Albert. *Leicester.*
TOMLINSON, Edward George. *Derby.*
TOOHEY, Joseph Bernard. *Liverpool.*
TUCKER, Anthony Hal. *Leicester.*
TURNER, John Sefton. *Birmingham.*
- VINCETT, Percy Albert. *Barking.*
- WILSON, Neil Black. *Clydebank.*
WINDSOR, Douglas Charles. *London, W.5.*
WOOD, Brian. *Accrington.*
WOOD, John Stuart. *Darlington.*

INFLUENCE OF A PARASITIC AERIAL IN A RECTANGULAR ARRAY*

by

G. Boudouris, E.S.E., E.P.A. (Associate)†

SUMMARY

A rectangular aerial array has a parasitic element placed at its centre. All the aerials making up the array are symmetrical half-wave dipoles parallel to one another and not displaced in the sense of their axes, and the system radiates in free space. The aerials are assumed to be thin and in the form of wires. Radiation diagrams and the gain of the network are considered from the double standpoint of the influence of the parasitic element and of the geometric configuration of the rectangle. The formulæ produced are developed in the form of graphs. Some comments relative to the case of earthed dipoles are given.

1. Geometric Configuration and Variables

The rectangle of aerials as described in the summary is characterized by two variables (Fig. 1): the half length of the diagonal s and the form ratio of the rectangle.

Thus $\zeta = \frac{a}{b}$, with $a \geq b$, therefore $\zeta \geq 1$... (1)

Instead of s in metres, the corresponding electrical length measured in radians or degrees is used, so that

$$S = 2\pi \frac{S}{\lambda} \text{ radians, or } 360 \frac{S}{\lambda} \text{ degrees,(2)}$$

where λ is the wavelength. With the aid of these two variables, the two sides of the rectangle are given by the formulae:

$$\left. \begin{aligned} a &= 2s \sin \gamma \\ b &= 2s \cos \gamma \end{aligned} \right\} \text{ in metres}$$

$$\left. \begin{aligned} A &= 2S \sin \gamma \\ B &= 2S \cos \gamma \end{aligned} \right\} \text{ in radians or degrees.....(3)}$$

with $\gamma = \arctan \zeta$, $45^\circ \leq \gamma < 90^\circ$ (4)

The length S will be the principal variable while the form factor will be used as a parameter, except where the phenomena are being studied as a function of ζ when the roles of

the two variables are reversed. The range of values to be considered is

$$0 < S \leq 720^\circ \text{ (or } 0 < 2s \leq 4\lambda)$$

$$\text{and } 1 \leq \zeta \leq 3 \text{(5)}$$

and, in some cases, $1 \leq \zeta \leq 5$.

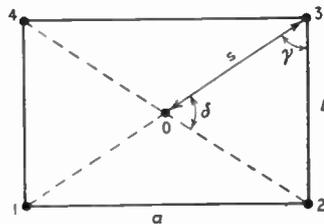


Fig. 1.—The rectangular array with parasitic aerial.

Finally, into the formulae produced there is introduced as an auxiliary variable the angle δ between the two diagonals of the rectangle (Fig. 1), linked with γ and ζ by the relations:

$$\delta = 2(90^\circ - \gamma) = 2(90^\circ - \arctan \zeta),$$

where $0 < \delta \leq 90^\circ$ (6)

To facilitate applications, Table 1 (overleaf) has been drawn up:

Note.—The present paper follows and generalizes upon the subject of the paper "Radiation patterns and gain of a four-antenna array located at the corners of a square around a central parasitic antenna" which appeared in *J.Brit.I.R.E.*, 9, pp. 427-439, December 1949. The problem was suggested by an accident which occurred at the Athens radio transmitting station in 1945, necessitating the creation of a temporary array.

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Table 1

ξ	γ	$\sin \gamma = \cos \frac{1}{2}\delta$	$\cos \gamma = \sin \frac{1}{2}\delta$	δ
1	45°	0.7071	0.7071	90°
1.2	50.20°	0.7682	0.6402	79.61°
1.5	56.31°	0.8321	0.5547	67.38°
2	63.43°	0.8944	0.4472	53.14°
3	71.57°	0.9487	0.3162	36.87°

2. Aerial Currents

The four active aerials, placed at the corners of the rectangle, are fed at their mid-points by equal currents, in phase. Let I be one of these currents, and let I_0 be the parasitic current in the central aerial (unfed). The self impedance of the parasitic aerial is given by Z_1 and the mutual impedance between the parasite and one of the active aerials by Z_s . The following well-known relation can then be formulated:

$$0 = Z_1 I_0 + 4Z_s I \quad \dots\dots\dots(7)$$

taking into account the circular symmetry of the rectangle. This equation gives

$$I_0 = - \frac{4 Z_s I}{Z_1} \quad \dots\dots\dots(8)$$

But it is known that, for a half wave symmetrical dipole,

$$Z_1 = 73.1 + j42.5 = 84.5 \angle 30^\circ \text{ in ohms } \dots(9)$$

whence, replacing the ratio I_0/I by ξ

$$\xi = \frac{I_0}{I} = 0.0474 Z_s \angle 150^\circ = \alpha + j\beta = |\xi| \angle \psi \quad \dots\dots\dots(10)$$

The mutual impedance $Z_s = R_s + jX_s = Z_s \angle \varphi_s$

is given by P. S. Carter.* Its relations are developed graphically in Fig. 2. With the aid of equation (10), curves of the complex ratio ξ (Fig. 3) may be constructed. The behaviour of the parasitic current I_0 may easily be studied in relation to current I . The quantity ξ plays an important part in the

* P. S. Carter, "Circuit relations in radiating systems and applications to antenna problems," *Proc. Inst. Radio Engrs*, 20, pp. 1004-41, June 1932.

Carter's relations for two half-wave dipoles parallel with one another and not displaced in the sense of their axes are written:

$$R_s = 30 \left\{ 2 \text{Ci}(S) - \text{Ci}[\sqrt{(S^2 + \pi^2)} + \pi] - \text{Ci}[\sqrt{(S^2 + \pi^2)} - \pi] \right\}$$

$$X_s = 30 \left\{ -2 \text{Si}(S) + \text{Si}[\sqrt{(S^2 + \pi^2)} + \pi] + \text{Si}[\sqrt{(S^2 + \pi^2)} - \pi] \right\}$$

both quantities in ohms, with

$$\text{Ci}(u) = - \int_u^\infty \frac{\cos x}{x} \cdot dx \quad \text{and} \quad \text{Si}(u) = \int_0^u \frac{\sin x}{x} \cdot dx$$

If tables in $\text{Ci}(u)$ (integral cosine) are not available, those for $\text{Cim}(u)$, the modified integral cosine, may be used, in which

$$\text{Cim}(u) = \int_0^u \frac{1 - \cos x}{x} \cdot dx = \log_e u + 0.5772 - \text{Ci}(u)$$

By substituting in the formula for R_s , one obtains:

$$R_s = 30 \left\{ -2 \text{Cim}(S) + \text{Cim}[\sqrt{(S^2 + \pi^2)} + \pi] + \text{Cim}[\sqrt{(S^2 + \pi^2)} - \pi] \right\}$$

in ohms; terms involving 0.5772 and log disappear.

Since in the problem under consideration an accuracy of 0.1 ohms is required for the values of R_s and X_s , it is necessary to calculate these values employing the Carter formulae, because diagrams published in ordinary literature do not give the required degree of accuracy.

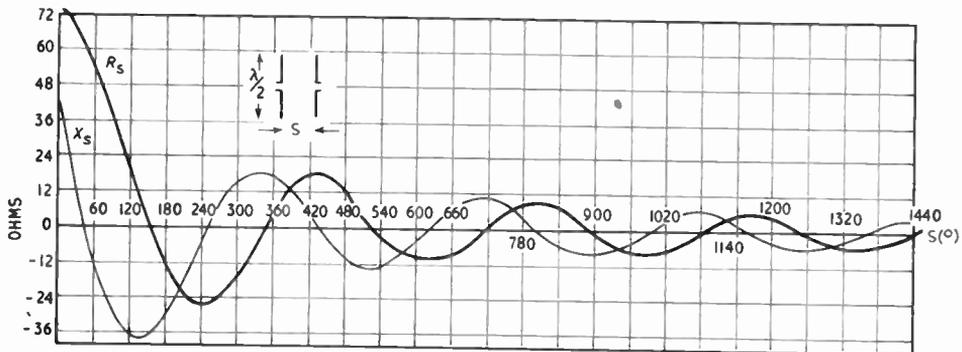


Fig. 2.—Variation of the mutual impedance $Z_s = R_s + jX_s$

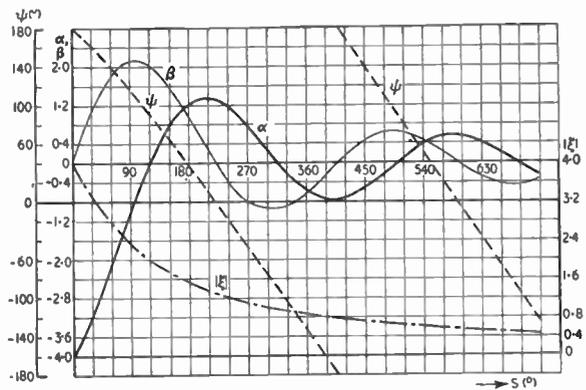


Fig. 3.—Parasitic current in terms of $I_0/I = \xi = \alpha + j\beta = |\xi| \angle \psi$.

formation of the radiation of the system. When $S \rightarrow 0$, $\xi \rightarrow -4$, and the radiation cancels out. When S increases, the influence of the parasite becomes weaker but always remains important (within range studied).

3. Radiated Field

In seeking expressions for the field radiated by the array using spherical co-ordinates (r, ν, φ) (Fig 4), we shall consider the field at a great distance, $r \gg s$.

Let P' be the projection of the point of observation $P(r, \nu, \varphi)$ on the plane of the rectangle (equatorial plane). To calculate the distance $(1P)$, the following trigonometric relations will be employed:

For the triangle $(1OP')$:
 $(1P')^2 = s^2 + (r \cos \varphi)^2 - 2s(r \cos \varphi) \cdot \cos(\delta' + \nu)$

For the rectangular triangle $(1P'P)$:
 $(1P)^2 = (1P')^2 + (P'P)^2$

$$= [s^2 + (r \cos \varphi)^2 - 2sr \cos \varphi \cdot \cos(\delta' + \nu)] + (r \sin \varphi)^2$$

$$= s^2 + r^2 - 2sr \cos \varphi \cdot \cos(\delta' + \nu)$$

Then, since $s^2 \ll r^2$,

$$(1P)^2 \cong r^2 [1 - 2 \frac{s}{r} \cos \varphi \cdot \cos(\delta' + \nu)]$$

From this it follows ($s/r \ll 1$):

$$(1P) \cong r [1 - \frac{s}{r} \cos \varphi \cdot \cos(\delta' + \nu)]$$

$$= r - s \cos \varphi \cdot \cos(\delta' + \nu)$$

Introducing the angle $\delta = \pi - \delta'$, we have

$$(1P) \cong r + s \cos \varphi \cdot \cos(\nu - \delta)$$

The corresponding electrical length is:

$$(1P) = R + S \cos \varphi \cdot \cos(\nu - \delta) \dots\dots(11)$$

with $R = 2\pi r/\lambda$, and $S = 2\pi s/\lambda$.

The distances $(1P)$, $(2P)$, $(3P)$ and $(4P)$ may be calculated in the same manner, giving:

$$\left. \begin{aligned} (1P) &= R + S \cos \varphi \cdot \cos(\nu - \delta) \\ (2P) &= R - S \cos \varphi \cdot \cos \nu \\ (3P) &= R - S \cos \varphi \cdot \cos(\nu - \delta) \\ (4P) &= R + S \cos \varphi \cdot \cos \nu \end{aligned} \right\} \dots\dots(12)$$

For a half-wave symmetrical dipole, the electric field of radiation is given by the well-known expression

$$j \frac{60}{r} I \frac{\cos(\frac{1}{2}\pi \sin \varphi)}{\cos \varphi} \angle -R$$

in the rationalized M.K.S. system of units, which will be used throughout this paper.

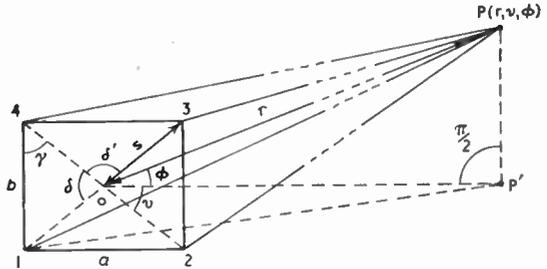
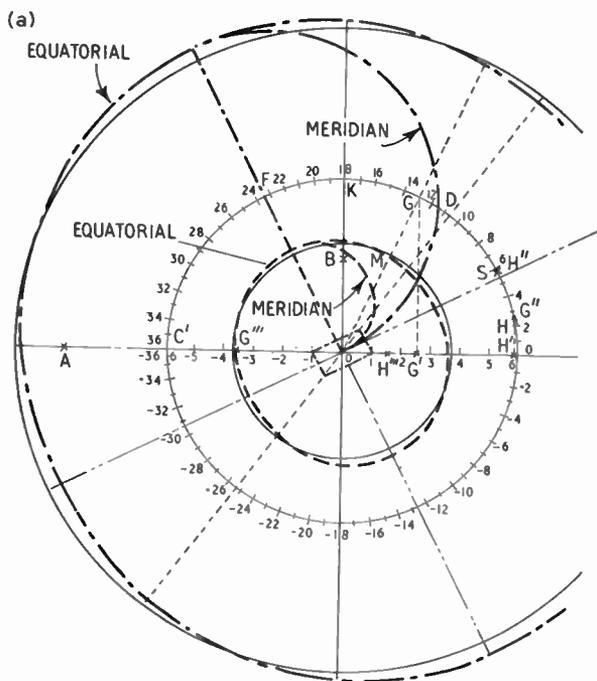


Fig. 4.—The radiated field of the array at a distant point P.

Applying the formula for each of the fed aerials, with the appropriate current and the part of the corresponding phase in accordance with the relations of eq. (12), it is found that the contribution to the field of each of the five aerials is given by:

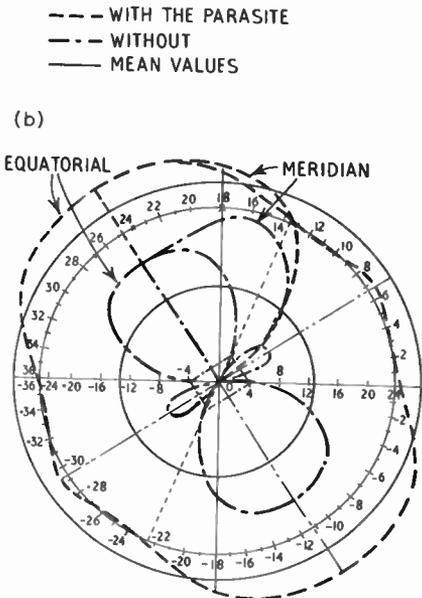
$$\left. \begin{aligned} E_0 &= j \frac{60}{r} \xi I \Phi \angle -R \\ E_1 &= j \frac{60}{r} I \Phi \angle -R - S \cos \varphi \cdot \cos(\nu - \delta) \\ E_2 &= j \frac{60}{r} I \Phi \angle -R + S \cos \varphi \cdot \cos \nu \\ E_3 &= j \frac{60}{r} I \Phi \angle -R + S \cos \varphi \cdot \cos(\nu - \delta) \\ E_4 &= j \frac{60}{r} I \Phi \angle -R - S \cos \varphi \cdot \cos \nu \end{aligned} \right\} (13)$$

where $I = I$, $I_0 = \xi I$, $\Phi = \frac{\cos(\frac{1}{2}\pi \sin \varphi)}{\cos \varphi}$



(a) $S=30^\circ$; $\zeta=2$; $\frac{1}{2}\alpha=-1.570$; $\frac{1}{2}\beta=0.561$; $\delta=53.2^\circ$;
 $\frac{1}{2}|f_m|=0.635$; $\frac{1}{2}|f_{0m}|=1.865$.

Fig. 5.—Radiation diagrams



(b) $S=120^\circ$; $\zeta=1.5$; $\frac{1}{2}\alpha=-0.0035$; $\frac{1}{2}\beta=1.005$;
 $\delta=67.4^\circ$; $\frac{1}{2}|f_m|=1.135$; $\frac{1}{2}|f_{0m}|=0.535$.

--- WITH THE PARASITE
 - - - WITHOUT
 — MEAN VALUES

and r is common to all the relations, since $s \ll r$.

It is easy to show that, in the exact expression for Φ , $\Phi \cong \cos \varphi$ may be substituted with a relative maximum error of about 17 per cent. for $\varphi=54^\circ$. Furthermore, the field being calculated at a great distance, the vectors of these five contributions are parallel to one another, and the total field at P is given by the sum:

$$E = \sum_{n=0}^4 E_n = \left\{ j \frac{60}{r} I \Phi \angle -R \right\} \cdot \left\{ \xi + \cos [S \cos \varphi \cos (v - \delta)] + \cos (S \cos \varphi \cos v) + \cos [S \cos \varphi \cos (v - \delta)] + \cos (S \cos \varphi \cos v) \right\}$$

or,

$$E = \left\{ j \frac{60}{r} I \Phi \angle -R \right\} \cdot \left\{ \xi + 2 \cos [S \cos \varphi \cos (v - \delta)] + 2 \cos (S \cos \varphi \cos v) \right\} \quad \dots \dots \dots (14)$$

$$\text{Writing } E = j \frac{60}{r} I f(v, \varphi) \angle -R \quad \dots \dots \dots (15)$$

it will be seen that the characteristic function of the radiation is expressed by:

$$f(v, \varphi) = [\xi + 2 \cos (S \cos v \cos \varphi) + 2 \cos (S \cos (v - \delta) \cos \varphi)] \Phi \quad \dots \dots \dots (16)$$

Since $\xi = \alpha + j\beta$, this expression may be written:

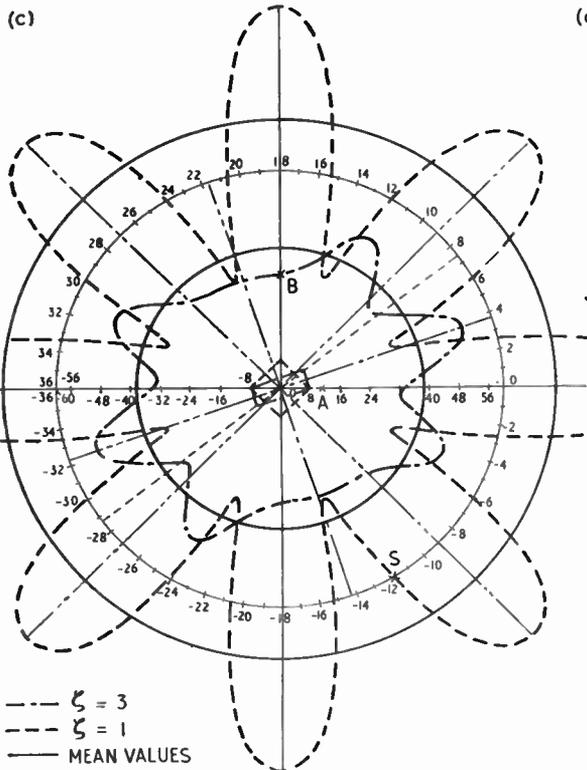
$$f(v, \varphi) = [\alpha + 2 \cos (S \cos v \cos \varphi) + 2 \cos (S \cos (v - \delta) \cos \varphi)] \Phi + j\beta \Phi$$

whence the modulus of the characteristic function is obtained:

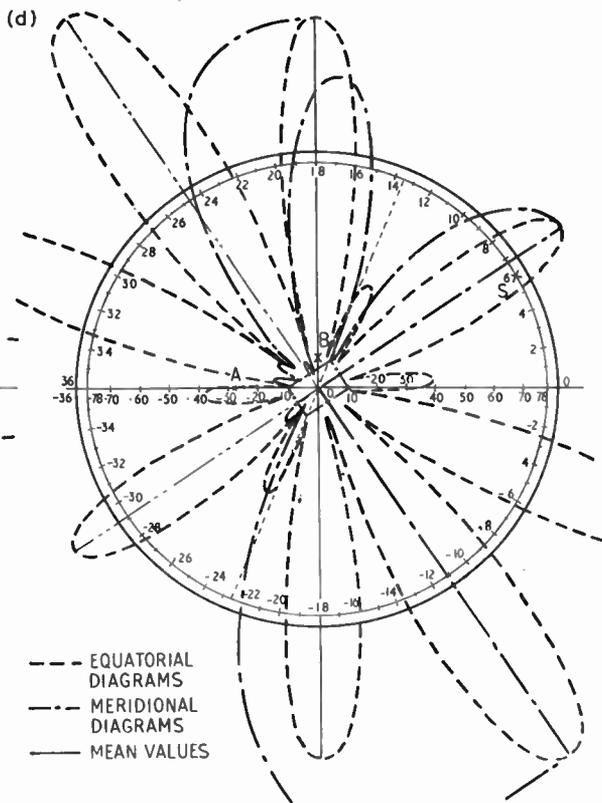
$$|f(v, \varphi)| = 2 \left[\left[\frac{\alpha}{2} + \cos (S \cos v \cos \varphi) + \cos (S \cos (v - \delta) \cos \varphi) \right]^2 + \left(\frac{\beta}{2} \right)^2 \right]^{\frac{1}{2}} \cdot \Phi \quad \dots \dots \dots (17)$$

The modulus of the field is then given by:

$$|E| = E = \frac{60}{r} I |f(v, \varphi)| \quad \dots \dots \dots (18)$$



(c) $S=300^\circ$; $\zeta=1$ and 3 ; $\frac{1}{2}\alpha=0.113$; $\frac{1}{2}\beta=-0.468$;
 $\delta=36.9^\circ$ ($\zeta=3$); $\frac{1}{2}|f_m|=1.230$ ($\zeta=1$);
 $\frac{1}{2}|f_m|=0.61$ ($\zeta=3$) (equatorial diagrams).



(d) $S=390^\circ$; $\zeta=1.5$; $\frac{1}{2}\alpha=-0.380$; $\frac{1}{2}\beta=-0.125$;
 $\delta=67.4^\circ$; $\frac{1}{2}|f_m|=1.040$.

The function $|f(v, \varphi)|$ has the sense of a reduced field, and decides the characteristic of the radiation. The sections of this surface in the equatorial plane (the plane of the rectangle), and in different meridional planes will give diagrams of equatorial and meridional radiation.

The expression of $|f(v, \varphi)|$ is obviously a function of S . It is equally a function of ζ , by the intermediary of the auxiliary variable δ (see Sect. 1). The influence of the parasite in the formation of the radiation is expressed by the presence of α and β in eqn. (17). By substituting in this equation $\alpha=\beta=0$, the characteristic function of the radiation in the absence of the parasite is obtained:

$$|f_0(v, \varphi)| = 2 |\cos(S \cos v \cos \varphi) + \cos(S \cos(v - \delta) \cos \varphi)| \cdot \Phi \dots (19)$$

To obtain the general equation of the equatorial diagrams, it is sufficient to make $\varphi=0$ in eqn. (17), giving:

$$|f(v, 0)| = 2 \left\{ \left[\frac{\alpha}{2} + \cos(S \cos v) + \cos[S \cos(v - \delta)] \right]^2 + \left(\frac{\beta}{2} \right)^2 \right\}^{\frac{1}{2}} \dots (20)$$

In the absence of the parasite, ($\alpha=\beta=0$) we should have:

$$|f_0(v, 0)| = 2 |\cos(S \cos v) + \cos[S \cos(v - \delta)]| \dots (21)$$

Each equatorial diagram is symmetrical with respect to the two axes of symmetry of the rectangle. It is therefore sufficient to restrict the calculation within the limits $\frac{1}{2}\delta \leq v \leq 90^\circ + \frac{1}{2}\delta$. A meridional diagram corresponding to $v=v_0$

is obtained by substituting $v=v_0$ in eqn. (17); its equation will be $|f(v_0, \varphi)|$. The diagram is symmetrical with respect to the equatorial plane and the calculation holds between the limits $0 \leq \varphi \leq 90^\circ$.

In Section 5, a graphical method is proposed for the plotting of radiation diagrams. Figs. 5 a-d have been traced by the aid of this method. It will be seen that the diagrams have a very variable form, in accordance with the variables S and ζ . For $S=30^\circ$ ($s=\lambda/12$) and $\zeta=2$ (Fig. 5a), almost circular diagrams are obtained. In the case of $S=120^\circ$ ($s=\lambda/3$) and $\zeta=1.5$ (Fig. 5b), we have an instance in which the presence of the parasite transforms a very directional equatorial diagram into another which is very much less so.

The case of $S=300^\circ$ ($s=5\lambda/6$), with $\zeta=1$ and $\zeta=3$ (Fig. 5c), gives another example of the influence of the form of the rectangle; equatorial diagrams are very directional for the square form, less so for $\zeta=3$. Finally, very directional diagrams can be obtained, for example, for $S=390^\circ$ ($s=13\lambda/12$) and $\zeta=1.5$ (Fig. 5d). Some meridional diagrams are also plotted.

4. Discussion on Equatorial Diagrams

Let us consider eqn. (20), which gives equatorial diagrams as a function of v . The function $|f(v, 0)|$ varies with the quantity:

$$o(v) = \left\{ \frac{1}{2}u + \cos(S \cos v) + \cos[S \cos(v - \delta)] \right\}^2$$

whence

$$\frac{do(v)}{dv} = 2S \left\{ \frac{1}{2}u + \cos(S \cos v) + \cos[S \cos(v - \delta)] \right\} \times \left\{ \sin(S \cos v) \sin v + \sin[S \cos(v - \delta)] \sin(v - \delta) \right\} \dots (22)$$

This first derivative cancels out and the field takes extreme values in the following cases:

(a) Firstly,

$$\frac{1}{2}u + \cos(S \cos v) + \cos[S \cos(v - \delta)] = 0 \dots (23)$$

If angles v exist satisfying this equation, $|f(v, 0)|$ takes the value $|\beta|$, which obviously constitutes the absolute minimum of the characteristic function (see eqn. 20).

It should be noted, however, that eqn. (23) does not always possess roots (in respect of v). This can be shown by attempting to resolve it graphically for the case of $S=30^\circ$ and $\zeta=2$. On the other hand, in the case of $S=390^\circ$ and $\zeta=1.5$, the graphical resolution carried out in

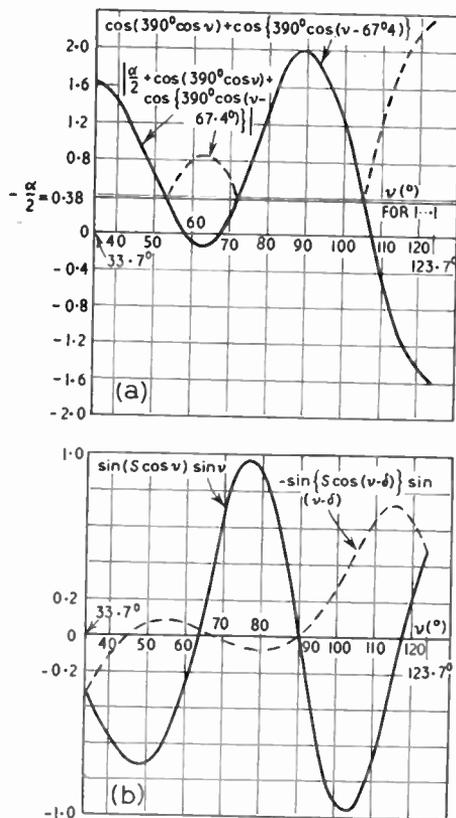


Fig. 6.—Examination of the maxima and minima of the field for $S=390^\circ$, $\zeta=1.5$.

Fig. 6a gives as roots: $v=53^\circ, 72^\circ, 106^\circ$ (for $\frac{1}{2}\delta \leq v \leq 90^\circ + \frac{1}{2}\delta$). Following these directions, $|f(v, 0)|$ takes the minimum value $|\beta|$ (see Fig. 5d).

To sum up, the value $|\beta|$ constitutes a lower limit to the function $|f(v, 0)|$, and this becomes effectively the absolute minimum of the function if eqn. (23) has roots with relation to v .

(b) Secondly,

$$\sin(S \cos v) \sin v + \sin[S \cos(v - \delta)] \sin(v - \delta) = 0 \dots (24)$$

This equation is obviously fulfilled for $v=\frac{1}{2}\delta$ and $v=90^\circ + \frac{1}{2}\delta$, i.e. following the direction of the axes of symmetry of the rectangle. The extreme corresponding values of the characteristic function are:

for $v=\frac{1}{2}\delta$

$$|f(\frac{1}{2}\delta, 0)| = 2 \left\{ \left[\frac{1}{2}u + 2 \cos(S \cos \frac{1}{2}\delta) \right]^2 + (\frac{1}{2}\beta)^2 \right\}^{\frac{1}{2}}$$

$$\text{or } v = 90^\circ + \frac{1}{2}\delta, \\ |(90^\circ + \frac{1}{2}\delta, 0)| = 2 \{ [\frac{1}{2}\alpha + 2 \cos(S \sin \frac{1}{2}\delta)]^2 + (\frac{1}{2}\beta)^2 \}^{\frac{1}{2}} \dots\dots\dots(25)$$

but apart from these two roots, eqn. (24) can have others. Let us seek, for example, the conditions under which the value $v=90^\circ$ is the root of eqn. (24). The equation is then written: $\sin(S \sin \delta) \cos \delta = 0 \dots\dots\dots(26)$

from this it may be deduced:

Either, $\cos \delta = 0$, then $\delta = 90^\circ$ (since $0 < \delta \leq 90^\circ$), which corresponds in the case of the square ($\zeta = 1$), for which, also taking account of the preceding roots, it is found that all the directions $v = k.45^\circ$ (k an integer), i.e. all the axes of symmetry of the square, are directions of the extreme values of the field. See, for example, the case of Fig. 5c.)

Or, $\sin(S \sin \delta) = 0$,
therefore, $S \sin \delta = k.180^\circ \dots\dots\dots(27)$

Here δ , the form of the rectangle, may for example be fixed and S sought. Let us take $\delta = 67.4^\circ$ ($\zeta = 1.5$):

we have $S = k. \frac{180^\circ}{0.923} = k.195^\circ$,

and for $k=2$, $S=390^\circ$. It may be verified from Fig. 5d ($S=390^\circ$, $\zeta=1.5$) that the field has a maximum for $v=90^\circ$.

The same line of reasoning could again be taken for any value of v , and the extreme field found in this direction, giving to S and ζ suitable values, obtained by a graphical resolution of eqn. (24).

By way of example, the graphical resolution of eqn. (24) in the case of $S=390^\circ$, $\zeta=1.5$ (Fig. 6b) has been given. It is there confirmed that the field takes extreme values following the directions:

$$v = \frac{1}{2}\delta = 33.7^\circ, 63^\circ, 90^\circ \text{ and } 90^\circ + \frac{1}{2}\delta = 123.7^\circ$$

which is in agreement with the diagram in Fig. 5d. To distinguish between a maximum and a minimum value of field, the graphical method is usually employed, rather than analytical calculations. On the other hand, the trace of the curve

$$|\frac{1}{2}\alpha + \cos(S \cos v) + \cos[S \cos(v - \delta)]|,$$

which may be used at the same time as an auxiliary for the outline of the equatorial diagram of radiation, suffices to give all

information on the position of the extremes of the field, and their character. This curve is traced for the case of $S=390^\circ$, $\zeta=1.5$ in Fig. 6a and establishes that the directions $v=33.7^\circ, 63^\circ, 90^\circ$ and 123.7° are directions of maximum field, whilst the directions $v=53^\circ, 72^\circ$ and 106° correspond to the absolute minimum $|\beta|$. (See (a) above.)

In order to compare with the array in the absence of the parasite, the expression $|f_0(v, 0)|$ in eqn. (21) must be considered. It can be easily claimed that the directions of the extreme field studied in (b) continue to exist, in spite of the fact that the character of an extreme can change. The influence of the parasite becomes perhaps more interesting where the minima of the field are concerned. Without the parasite, the absolute minima can be zero, whilst with the parasite minimum values of $|f(v, 0)|$ never fall below $|\beta|$ (in general, $|\beta| \neq 0$, Fig. 3), and are displaced in direction (Fig. 6a).

5. Graphical Constitution of the Diagrams

The equation of the equatorial diagrams (eqn. 20) suggests the following graphical method for the geometrical construction of the diagrams; this method is set out in detail, taking the example $S=30^\circ$, $\zeta=2$, as in Fig. 5a.

A circle is constructed as a base, graduated in 5-degree intervals for example by the graduations 0, 1, 2, 3, . . . The point "6" corresponds to $S=30^\circ$, and is marked on the figure. The diameter of the circle, C'C, is similarly graduated in 12 equidistant divisions from -6 to 6. The unit length of the diagram will be the radius OC of the circle. (The scales must, as usual, be suitably chosen.) Generally the graduations applied to this radius will be equal in number to that corresponding to the position of the point S.

This done, C'C is considered as one of the diagonals of the rectangle formed by the network; OC will serve as the origin for measuring the angle v . The second diagonal OD is drawn, also the axes of symmetry, OE and OF. Finally, point A is marked in its place such that $OA = \frac{1}{2}\alpha$ (A to the left of O when $\alpha < 0$), and B such that $OB = \frac{1}{2}|\beta|$.

Now, to find a point M on the diagram corresponding, for example, to the graduation 13 of the base circle ($v=65^\circ$), marked G on the diagram, G is projected on to the diameter C'C and the corresponding division is read on the projection G', or 2.54. The point G'' is marked on the base circle, corresponding to the same

division. The distance of G'' from the other diameter κκ is obviously the measure of the quantity cos (S cos v). This distance is carried over on AG'', taking into account its algebraic sign.

Finally, we return to G and move back to point H such that chord GH is equal to chord DC. We project to H', and read the corresponding graduation on the diameter c'c (that is, 5.84). The point H' of the same graduation is marked on the base circle. The distance of H' from the diameter κκ (which measures the quantity cos [S cos (v - δ)]) is carried algebraically into G''H''. The length H''B then measures |f(v, 0)|, as may be seen by reference to eqn. (20). This length is then carried in the direction OG to obtain the point M on the diagram.

The equatorial diagrams in Fig. 5 were traced using this method. As a graphical method it offers the possibility of following the diagram and of "tightening" the points where necessary. In addition, it is in general more convenient than calculation. The accuracy of the curve increases with the dimensions of the scale, and improves when S decreases.

The same construction gives equatorial diagrams in the absence of the parasite; it is sufficient, in accordance with eqn. (21) to eliminate points A and B and to take the algebraic sum of the distances of G'' and H'' from the diameter κκ, measured from the centre O. From the result, the influence of the parasite on the formation of the radiation is obtained: the parasite introduces the points A and B into the construction.

The construction also applies for meridional diagrams. It is sufficient to adapt it following the indications of the general equation (17). However, the geometrical construction then becomes less convenient, and calculation may be preferred.

It should be noted that the radiation-vector in Fig. 5 is of a length which measures $\frac{1}{2}|f|$ and not |f|, for reasons of convenience; this avoids the necessity of doubling the lengths OM, as would be required in eqn. (20). However, |f| may be obtained directly by measuring the lengths OM, with the half radius of the base circle taken as unity, instead of taking the radius itself as unity.

6. Mean Quadratic Value of the Field

To define the radiation in the equatorial plane, one introduces the mean quadratic value of the field in this plane, given by the relation :

$$E_m = \left[\frac{1}{2\pi} \int_0^{2\pi} E^2 dv \right]^{1/2} \dots\dots\dots(28)$$

E_m is therefore the radius of the circle possessing the same area as the surface, determined by the actual diagram of radiation in the equatorial plane.

To calculate E_m , the following expression is obtained from eqns. (18) and (20):

$$E^2 = \left(\frac{60}{r} I\right)^2 \cdot |f(v, 0)|^2 \\ = \left(\frac{60}{r} I\right)^2 \cdot \left[\alpha^2 + \beta^2 + 4\alpha \cos(S \cos v) + \right. \\ \left. + 4\alpha \cos[S \cos(v - \delta)] + \right. \\ \left. + 8 \cos(S \cos v) \cdot \cos[S \cos(v - \delta)] + \right. \\ \left. + 4 \cos^2(S \cos v) + 4 \cos^2[S \cos(v - \delta)] \right] \dots\dots(29)$$

This expression for E^2 must then be introduced into eqn. (28) and integrated. Integration of each of the seven terms contained within the square brackets of eqn. (29) gives the following results:

1st term: $\frac{1}{2\pi} \int_0^{2\pi} \alpha^2 dv = \frac{1}{2\pi} \alpha^2 \left[v \right]_0^{2\pi} = \alpha^2$
 2nd term: $\frac{1}{2\pi} \int_0^{2\pi} \beta^2 dv = \beta^2$
 3rd term: $\frac{1}{2\pi} \int_0^{2\pi} 4\alpha \cos(S \cos v) \cdot dv =$
 $= \frac{4\alpha}{\pi} \int_0^\pi \cos(S \cos v) \cdot dv$
 $= \frac{4\alpha}{\pi} \int_0^\pi \cos \left[S \sin \left(v - \frac{1}{2}\pi \right) \right] dv =$
 $= \frac{4\alpha}{\pi} \int_{-\frac{1}{2}\pi}^{+\frac{1}{2}\pi} \cos(S \sin v') dv'$

(where $v' = v - \frac{1}{2}\pi$)
 $= \frac{4\alpha}{\pi} \int_0^\pi \cos(S \sin v') dv' = 4\alpha J_0(S)$

(Since, from a known result of analysis*,

$$\frac{1}{\pi} \int_0^\pi \cos(x \sin v) \cdot dv = J_0(x) \dots\dots\dots(30)$$

where $J_0(x)$ denotes the Bessel function of the first type, of order zero and argument x.)

4th term: $\frac{1}{2\pi} \int_0^{2\pi} 4\alpha \cdot \cos[S \cos(v - \delta)] \cdot dv =$

* See, for example, A. Angot, "Complements de Mathématiques," page 369. (Published by *La Revue d'Optique*, Paris, 1949.)

$$= \frac{2\alpha}{\pi} \int_{-\delta}^{-\delta+2\pi} \cos(S \cos v') dv'$$

(where $v' = v - \delta$)

$$= \frac{2\alpha}{\pi} \int_0^{2\pi} \cos(S \cos v') dv' = 4\alpha J_0(S)$$

following the result of the 3rd term.

5th term: $\frac{1}{2\pi} \int_0^{2\pi} 8 \cos(S \cos v) \cdot \cos[S \cos(v - \delta)] \cdot dv$

$$= \frac{2}{\pi} \int_0^{2\pi} \left[\cos \{ S [\cos v + \cos(v - \delta)] \} + \cos \{ S [\cos v - \cos(v - \delta)] \} \right] dv$$

$$= \frac{2}{\pi} \int_0^{2\pi} \cos \{ 2S \cos \frac{1}{2}\delta \cdot \cos(v - \frac{1}{2}\delta) \} dv +$$

$$+ \frac{2}{\pi} \int_0^{2\pi} \cos \{ 2S \sin \frac{1}{2}\delta \cdot \sin(v - \frac{1}{2}\delta) \} dv$$

$$= \frac{4}{\pi} \int_0^{\pi} \cos(2S \cos \frac{1}{2}\delta \cdot \cos v') dv' +$$

$$+ \frac{4}{\pi} \int_0^{\pi} \cos(2S \sin \frac{1}{2}\delta \cdot \sin v') dv'$$

(where $v' = v - \frac{1}{2}\delta$)

$$= 4J_0(2S \cos \frac{1}{2}\delta) + 4J_0(2S \sin \frac{1}{2}\delta)$$

6th term: $\frac{1}{2\pi} \int_0^{2\pi} 4 \cos^2(S \cos v) dv =$

$$= \frac{1}{\pi} \int_0^{2\pi} [1 + \cos(2S \cos v)] dv$$

$$= \frac{1}{\pi} \left[v \right]_0^{2\pi} + \frac{1}{\pi} \int_0^{2\pi} \cos(2S \cos v) \cdot dv =$$

$$= 2 + 2J_0(2S)$$

7th term: $\frac{11}{2\pi} \int_0^{2\pi} 4 \cos^2 \{ S \cos(v - \delta) \} dv =$

$$= 2 + 2J_0(2S)$$

Introducing these values for the seven terms into eqn. (28), and making the following substitutions:

$$\alpha^2 + \beta^2 = |\xi|^2 \quad (\text{See Sect. 2}),$$

$2S \cos \frac{1}{2}\delta = A$, and $2S \sin \frac{1}{2}\delta = B$ (See Sect. 1), one obtains the following expression, where S , A and B are in radians:

$$E_m = \frac{60}{r} I [|\xi|^2 + 8\alpha J_0(S) + 4J_0(2S) + 4J_0(A) + 4J_0(B) + 4]^{\frac{1}{2}}, \quad \dots\dots(31)$$

Also, if $E_m = \frac{60}{r} I \cdot |f_m|$, $\dots\dots(32)$

then $|f_m|$ gives the mean quadratic value of the characteristic function of the radiation in the equatorial plane. From eqns. (31) and (32), this gives

$$|f_m| = [|\xi|^2 + 8\alpha J_0(S) + 4J_0(2S) + 4J_0(A) + 4J_0(B) + 4]^{\frac{1}{2}} \quad \dots\dots(33)$$

In the absence of the parasite ($\alpha = |\xi| = 0$), this will give:

$$|f_{0m}| = 2 [J_0(2S) + J_0(A) + J_0(B) + 1]^{\frac{1}{2}} \quad \dots\dots(34)$$

from which it follows that

$$|f_m| = [|\xi|^2 + 8\alpha J_0(S) + |f_{0m}|^2]^{\frac{1}{2}} \quad \dots\dots(35)$$

The mean quadratic value $|f_m|$ is a function of

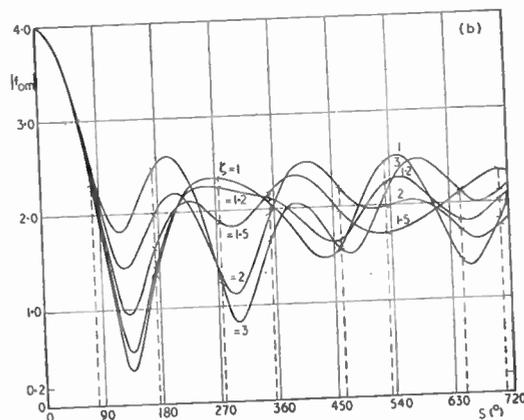
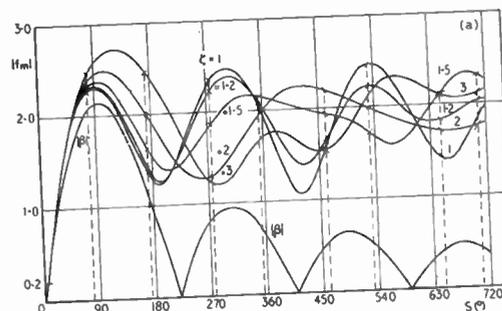


Fig. 7.—Showing the mean quadratic value of the field for various values of the parameter ζ . (a) with the parasite, (b) without the parasite.

S and of ζ . The form factor ζ is brought in only through the intermediary of A and B (see Sect. 1), and the case is similar for $|f_{0m}|$.

In Fig. 7a a network of curves for $|f_m|$ have been traced, with S as variable and ζ as a parameter.* A similar network of curves for $|f_{0m}|$ is shown in Fig. 7b. In comparing these two sets of curves, it may be seen that the influence of the parasite completely deforms the curves when S is sufficiently small (in the case of very strong coupling), whilst its influence is less marked, although not negligible, in the case where S is greater (during the interval under consideration).

The curves show an undulating form with a series of maximum and minimum points, displaced according to the value of the parameter ζ .

The two sets of curves for $|f_m|$ and $|f_{0m}|$ are linked by the property that, for similar values of the parameter ζ , the curves cut each other at definite values of the S abscissa, independently of the value of ζ . This is borne out by Fig. 7a, in which the small dashed points are segments of the curves for $|f_{0m}|$. This gives the result of eqn. (35); in that equation, where $|f_m| = |f_{0m}|$,

$$|\xi|^2 + 8\alpha J_0(S) = 0$$

and this condition is independent of ζ . It will therefore be seen that certain diagonal distances $2S$ exist, shown on Fig. 7a, for which the mean quadratic value of the field remains influenced by the presence of the parasite, and this is true for all forms of the rectangle.

Finally, the curves for $|f_m|$ can give a useful indication of the directional characteristic of the system. It will be recalled that the value $|\beta|$ constitutes a lower limit, or even the absolute minimum, for the characteristic function of the radiation (Sect. 4). If the curve for $|\beta|$ is traced with the curves $|f_m|$, as shown in Fig. 7a, the directivity will be most marked at the points where the distance between the two curves $|\beta|$ and $|f_m|$ is greatest. This accords well with the diagrams already shown in Section 3.

7. Input Impedance

The input impedance of each of the excited aerials, besides being of importance itself, may be used to calculate the gain of the system.

From Fig. 1, let Z_1 be the self impedance

* Each curve is indicated by a numeral giving the corresponding value of the parameter ζ .

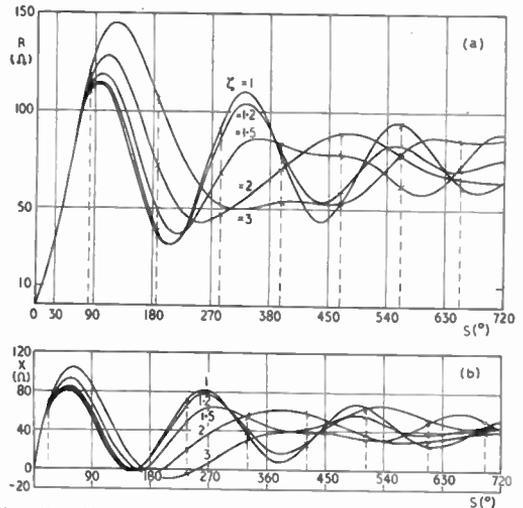


Fig. 8.—Curve showing the variation in the input impedance with the parasite for various values of ζ . (a) resistive part, (b) reactive part.

of one of the aerials, and let the mutual impedances between pairs of aerials be given as follows:

- Z_a , the mutual impedance between aerials (1) and (2),
- Z_b , the mutual impedance between aerials (1) and (4),
- Z_s , the mutual impedance between aerials (1) and (0), and
- Z_{23} , the mutual impedance between aerials (1) and (3).

Owing to the symmetry of the rectangle, it is not necessary to specify the other mutual impedances; for instance, the mutual impedance between aerials (2) and (3) will be Z_b , etc.

If V and I represent the voltage and the current fed to the centre of one of the active aerials, and the parasitic current is represented by I_0 , we have the classic relationships:

$$\left. \begin{aligned} \text{For an active aerial:} \\ V &= (Z_1 + Z_a + Z_b + Z_{23}) I + Z_s I_0 \\ \text{For the parasite:} \\ 0 &= Z_1 I_0 + 4 Z_s I \end{aligned} \right\} \dots\dots\dots(36)$$

From the second of these equations, it may be seen that

$$I_0 = -4Z_s I / Z_1,$$

so that, substituting in the first equation and putting

$$Z_0 = Z_1 + Z_a + Z_b + Z_{23} \dots\dots\dots(37)$$

the following relationship may be derived:

$$Z = \frac{V}{I} = Z_0 - \frac{4(Z_s)^2}{Z_1}, \dots\dots(38)$$

where Z is the input impedance of one of the aeri-als.

But it is known that, for a symmetrical half-wave dipole,

$$Z_1 = 73.1 + j42.5 = 84.5 \angle 30^\circ, \text{ in ohms,} \dots\dots(39)$$

therefore

$$\frac{-4(Z_s)^2}{Z_1} = 0.0474 (Z_s)^2 \angle 150^\circ,$$

which may be expressed as

$$Z_c = 0.0474 (Z_s)^2 \angle 150^\circ \dots\dots(40)$$

thus giving:

$$Z = Z_0 + Z_c \dots\dots(41)$$

The calculation of Z , as with that of Z_0 and Z_c , defined by the equations (37) and (40), depends finally on the mutual impedance, given by P. S. Carter (see Sect. 2). It should be noted that Z_0 represents the input impedance of one of the active aeri-als in the absence of the parasite.

The impedances Z and Z_0 are functions of S and of ζ ; however, the form of the rectangle only comes in by means of Z_a and Z_b (eqn. 37).

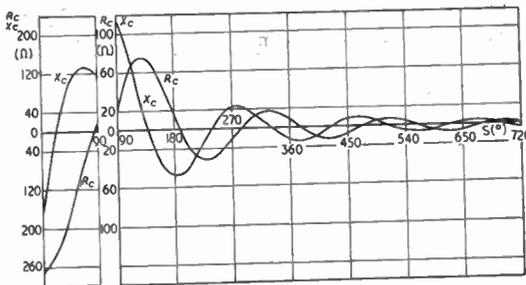


Fig. 10.—Showing the influence of the parasitic element on the input impedance ($Z_s = R_c + jX_c$).

The impedance Z_c , added to Z_0 to give Z , expresses the influence of the parasite on the input impedance and is independent of the form of the rectangle (eqn. 40).

Putting Z and Z_0 in the form

$$Z = R + jX, Z_0 = R_0 + jX_0 \dots\dots(42)$$

sets of curves may be traced for (R, X) and (R_0, X_0) as functions of S and with ζ as parameter (Figs. 8 and 9). To show more clearly the influence of the parasite, sets of curves are traced separately in Fig. 10 for the values (R_c, X_c), where $Z_c = R_c + jX_c$ $\dots\dots(43)$

As S approaches zero, the presence of the parasite cancels out the input impedance, and, at the same time, the radiation $|f_m|$ approaches zero. At the other extreme, where S approaches 720° , the parasite introduces into the input impedance a component of the order of 10 per cent. for R and 18 per cent. for X (these are purely indicative values).

On the sets of curves for (R, R_0) or (X, X_0), the same feature may be noted as for the intersections on the curves for $|f_m|$ and $|f_{0m}|$ (Sect. 6). That is, when $R = R_0$, or $X = X_0$, it follows that $R_c = 0$, or $X_c = 0$, by virtue of eqn. (41). This condition depends only on S and is independent of ζ (eqn. 40). There are therefore values of S for which the presence of the parasite has no influence on the values of R or X . The curves for R, R_0 and X, X_0 therefore intersect one another at points with the same abscissae S , determined by the condition $R_c = 0$ or $X_c = 0$, independent of the form of the rectangle. This is shown in Figs. 8 a and b, where one can read in addition the characteristic diagonal half-distances S .

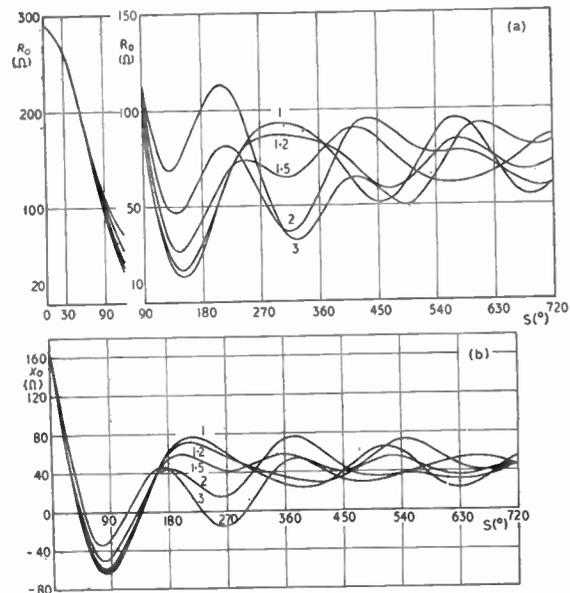


Fig. 9.—Curves showing the variation in the input impedance without the parasite for various values of ζ . (a) resistive part, (b) reactive part.

The corresponding gain $G(v, 0)$ with respect to the same array in the absence of the parasite is obtained from eqn. (53) by substituting $|f(v, 0)|$ for $|f_m|$, and $|f_0(v, 0)|$ for $|f_{0m}|$:

$$G_0(v, 0) = \left| \frac{f(v, 0)}{f_0(v, 0)} \right|^2 \cdot \frac{R_0}{R} \dots\dots(56)$$

All the expressions appearing in these two equations have already been calculated.

As an example, expressions are given below for the gains along the axes of symmetry of the rectangle. (See Sections 3 and 4 for expressions for $|f|$ and $|f_0|$).

$$G(\frac{1}{2}\delta, 0) = \frac{73 \cdot 1}{R} \left\{ \left[\frac{1}{2}\alpha + 2 \cos(S \cos \frac{1}{2}\delta) \right]^2 + (\frac{1}{2}\beta)^2 \right\}$$

$$G(90^\circ + \frac{1}{2}\delta, 0) = \dots\dots(57)$$

$$= \frac{73 \cdot 1}{R} \left\{ \left[\frac{1}{2}\alpha + 2 \cos(S \sin \frac{1}{2}\delta) \right]^2 + (\frac{1}{2}\beta)^2 \right\} \dots\dots(58)$$

$$G_0(\frac{1}{2}\delta, 0) =$$

$$= 0 \cdot 25 \frac{R_0}{R} \cdot \frac{\left[\frac{1}{2}\alpha + 2 \cos(S \cos \frac{1}{2}\delta) \right]^2 + (\frac{1}{2}\beta)^2}{\cos^2(S \cos \frac{1}{2}\delta)} \dots\dots(59)$$

$$G_0(90^\circ + \frac{1}{2}\delta, 0) =$$

$$= 0 \cdot 25 \frac{R_0}{R} \cdot \frac{\left[\frac{1}{2}\alpha + 2 \cos(S \sin \frac{1}{2}\delta) \right]^2 + (\frac{1}{2}\beta)^2}{\cos^2(S \sin \frac{1}{2}\delta)} \dots\dots(60)$$

For example, in the case where $S=390^\circ$ and $\zeta=1 \cdot 5$, it is found that:

$$G(\frac{1}{2}\delta=33 \cdot 7^\circ) = 1 \cdot 46 \text{ db, } G(90^\circ + \frac{1}{2}\delta) = 5 \cdot 5 \text{ db}$$

$$G_0(\frac{1}{2}\delta) = -2 \cdot 0 \text{ db and } G_0(90^\circ + \frac{1}{2}\delta) = 2 \cdot 1 \text{ db}$$

It may thus be stated that in certain cases and in certain favourable directions, the gain will be considerable, i.e. of the order of several decibels.

12. Conclusions

The analytical expressions for the principal values are somewhat complicated and cumbersome, but the use of curves renders their study more easy. The curves for the variation of these values show, in general, a wave form which is a function of the diagonal half-distance of the rectangle formed by the aerials, with successive maxima and minima which are displaced according to the parameter of the form of the rectangle.

The diagrams of equatorial radiation show a variety of forms, which may be interesting in application. The form of the rectangle has a considerable effect on the formation of the diagrams, and, in particular, it imposes a certain asymmetry on the radiation along the two axes of symmetry of the rectangle which does not exist in the case of the square form. The presence of the parasite also has a marked

influence on the formation of the radiation. For example, a very directive radiation diagram can be transformed by its presence into another, much less directive, diagram. On the other hand, the field, in the presence of the parasite, does not generally fall to zero along the directions of its absolute minima. In the case where S approaches zero, the radiation as is well known, cancels out.

The directions of the axes of symmetry of the rectangular array are always the direction of extreme field, and other directions of extreme field are also found. As explained in Section 6, Fig. 7a gives an indication of the directive properties of the system.

The array can give a mean equatorial gain over that of one of its elements, of which the absolute maximum is of the order of 1 db (neglecting the aerial losses; if these are taken into account, the maximum gain will be greater). In the unfavourable cases, which occur more frequently, there may be a loss of power.

The influence of the parasite from the point of view of the mean equatorial gain is expressed by calculating this gain referred to that of the same network in the absence of the parasite. Thus calculated, the gain may attain an absolute maximum of the order of 7 db. Setting aside the favourable cases, the gain in question is similarly, more often negative.

In certain cases, and in the favourable directions, the two relative gains, defined in Sect. 11, can have values of several decibels. The corresponding lobes present a width (at 3 db) which can be less than 30° or 20° . In the case of quarter-wave aerials, grounded in a perfectly conducting plane earth instead of symmetrical half-wave dipoles, the expression for input impedance must be divided by two, while those for the characteristic functions of radiation and for the relative gains remain unchanged (these last expressions only introduce ratios of resistance). Further, the expression "equatorial plane" must be changed to "horizontal plane."

Finally, it may be shown that the results for the relative gains can give an approximate indication in the case of aerials shorter than quarter-wave, grounded in a plane earth of infinite conductivity. This is on condition that all the aerials making up the array remain parallel with one another and not displaced in the vertical sense, and maintain the same common length.

. . . Radio Engineering Overseas

517.512.2:621.3.018.783:621.376

In the theory of non-linearity. E. HENZE. *Archiv der Elektrischen Übertragung*, 36, pp. 326-338, August 1956.

A general formula is drawn up for the characteristics of non-linear circuit elements. The characteristics of triodes are investigated with respect to the formation of harmonics and mixing. The known space-charge characteristic is dealt with briefly. With these characteristics the intermediate frequency amplitudes due to cross-modulation with an interfering signal and to undesired heterodyning are calculated and related to the normal intermediate-frequency amplitudes. These results are investigated with respect to their dependence on an applied bias, and thus on the operating point on the characteristic. The case of multigrid tubes is also discussed.

523.164.85:621.396.812.5.029.62

Meteoritic echoes observed simultaneously by back-scatter and forward scatter. D. W. R. MCKINLEY and A. G. MCNAMARA. *Canadian Journal of Physics*, 34, pp. 625-637, 1956.

Simultaneous observations of back-scatter and forward-scatter meteoric echoes have been made by means of a high power 33 Mc/s pulse transmitter at Ottawa, with identical receiving systems at Ottawa and at Scarborough, 337.8 km. distant. Two-way transmissions, employing a low-power transmitter at Scarborough, were also used to measure absolute time delays. The approximate position of each meteor was slotted from the observed time delays, which enabled corrections to be applied to the echo durations for variations in antenna patterns and other factors, and which also determined the forward-scatter angle, 2θ , for each meteor. In the majority of cases an enhancement was observed in the forward-scatter duration relative to the back-scatter duration. The data were divided into a short-duration or underdense group and a long-duration or overdense group. Assuming a theoretical forward-scatter enhancement proportional to $\sec^m \theta$, it was found that the exponent, m , was 1.73 for the underdense group and 1.13 for the overdense group.

523.164.85:621.396.812.5.029.55/62

Wave scattering and the effects of meteors on short and adjacent ultra-short waves. H. WISBAR. *Archiv der Elektrischen Übertragung*, 10, pp. 343-352, August 1956.

It is established that in a frequency band approximately 30 Mc/s wide above the limit frequency for grazing incidence a certain residual ionization favours the occurrence of scatter waves. The intensity of this ionization depends on the diurnal and seasonal patterns of the E-layer and F-layer concentrations. For higher frequencies the only reflections of scatter waves are those due to the "background effect", assumed through correlation to be directly related to the incidence of sporadic meteors. The continuous turbulence of the ionosphere adds to the reflecting power of the very minute ionization caused by meteoric dust. A contribution to the effect from a

A selection of abstracts from European and Commonwealth journals received in the Library of the Institution. 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.

steady, if weak, corpuscular radiation at the poles and the magnetic equator is not out of the question. In the course of the investigations two different cases are established, in which ionospheric scatter wave propagation is disturbed by inversions. Also described are details of the aurora effect in its influence on scatter wave reception. An attempt is finally made to give an explanation of the appearance of overlong meteoric echoes. The frequency dependence of meteoric echoes is discussed.

621.317.76

The theory and practice of a method for high accuracy frequency measurement. G. BECKER. *Archiv der Elektrischen Übertragung*, 10, pp. 315-325, August 1956.

A theoretical investigation of the accuracy attainable in measuring an unknown frequency against a known reference frequency by means of frequency multipliers, heterodyne equipment and electronic counters is followed by a comparison of some representative measuring results with the theoretical findings; data are thus obtained concerning the error of the measuring method. In the range 15 kc/s to 15 Mc/s the maximum measuring error is 1×10^{-9} with a measuring time of 100 sec. For favourably located frequencies the measuring error is lower with the same measuring time; for 100 kc/s, for instance, it is found to be not more than 1.4×10^{-11} on an average. Averaging methods are discussed with which measuring errors of a few parts of 10^{11} have been attained with the use of oscillatory filters already in measuring times of approximately 1 sec. The measuring results give information on the stability of crystal clock oscillators within seconds to hours.

621-52:621.315.2

An application of automation in the cable and wire making industry; the automatic control of rubber-insulated cable diameter. M. GLEITZ. *Onde Electrique*, 36, pp. 629-633, July 1956.

Describes a system designed to control during manufacturing the external diameter of a cable to specified tolerances, without the necessity for any manual action. Any departure of wire diameter from a specified value is expressed as a voltage which provides suitable rubber-feed regulation through a speed-variation gear control. The design of this control equipment necessitated special attention because of the very severe ambient conditions existing on wire-making machines. Results are satisfactory, but there is room for further improvements which could be

obtained from study of gauge-control systems, statistical considerations on perturbations, and loop-circuit stability.

621-52:621.37/8

Relations between automation and electronics. F. H. RAYMOND, *Onde Electrique*, 36, pp. 597-601, July 1956

The contribution made by electronics to automation is considered in two aspects: general concepts related to the idea of information, because an automatic machine or process makes use of energy and of information; technical means of transmitting information and of ensuring that the orders contained in the information are correctly executed.

621-52:621.37/8

Electronic controls and servomechanisms. R. LARGUIER. *Onde Electrique*, 36, pp. 586-596, July 1956.

The paper gives a well-illustrated description of the extension of electronic control application in industry. D.C. motors and rectifier tubes are the basic elements of electronic speed-variation systems. Requiring control signals of relatively low power, speed-variation gears of that nature provide ideal servo system control facilities. The author outlines how mechanical and electric techniques form an excellent combination towards the attainment of perfect automation: electronics providing improved means of application and greater operational flexibility, whereas mechanical methods guarantee perfect automaticity and accuracy. Such a combination results in improved efficiency and quality while bringing a large measure of simplification and economy.

621.37/9:656.25

Track circuits, automatic apparatus on the railway. J. WALTER. *Onde Electrique*, 36, pp. 606-616, July 1956.

To establish the presence or absence of a train or vehicle on a section of the track, the rails are made to provide an independent electric circuit. Using these track circuits, complete protection is given to trains working on the same line ("Automatic Block" system). Use of electronic apparatus recently by the S.N.C.F. has enabled the performance of track circuits to be improved by reducing their installation and maintenance costs. Improvements and additions will extend considerably automatic working on the railways. Electronic computers are envisaged which will be able to control points and signals in accordance with a complicated programme and which could therefore lead to the remote control of the trains themselves.

621.37/9:656.25

Lamouilly Railway Station: a prototype "press button" centre featuring complete electronic track-control circuitry. M. DUBOUDIN, *Onde Electrique*, 36, pp. 617-628, July 1956.

The Lamouilly station, on the 25,000 V 50 c/s electrified section of the French Railways is a prototype "push button" railway control centre, using electronic track control circuits of relatively simple construction. The system operates on normal (E.D.F.) line-supply; general economy, and reliability of the signalling system are specially taken into consideration.

586

621.385.23/33

Correlation coefficient of noise fluctuations in the potential minimum of a diode (triode). H. KOSMAHL. *Archiv der Elektrischen Übertragung*, 10, pp. 353-357, August 1956.

In discussing the noise problems in space-charge-limited discharge gaps it has been assumed that the fluctuations of the space-charge attenuated shot current are fully correlated with the fluctuations of the electron velocity and its equivalent potential, although no analytical proof has yet been offered for this assumption. Measurements of the induced grid noise current show, however, that these fluctuations must be considered as chiefly uncorrelated. The correlation coefficient between the fluctuations at the potential minimum at low frequencies is, therefore, exactly calculated for a single case of practical interest. On ideal diodes (triodes) the correlation coefficient lies between 0.65 and 0.75, and on practical diodes (triodes) is considerably smaller. The use of the correlation coefficient in calculating the induced grid noise current is briefly outlined.

621.396.5:621.396.43

Some possibilities of standardizing systems of radio relay links for under-developed countries. *Elektrotehniski Vestnik*, 24, pp. 189-193, July-August 1956.

Assuming that in under-developed countries 600-channel telephones systems are not indispensable, technical economic and other reasons are advanced which favour the use of frequencies of 1,700 to 2,300 Mc/s. On the basis of simplified functional schemes the author shows that there are great possibilities in using identical or similar sub-assemblies in radio devices for various relay systems in this frequency range. The discussion embodies: (1) Time-division multiplex p.p.m./a.m. systems with a transmission capacity of 24 telephone channels or several broadcast programmes; (2) Frequency-division multiplex f.m. systems carrying 60 or 120 telephone channels; (3) F.M. systems with a transmission capacity of 240 telephone channels or one 625-line television programme. The systems meet the recommendations of CCIR Study Group IX (Geneva, 1954).

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Microwave radio project of the trans-Canada telephone system. J. A. GROLEAU. *Engineering Journal of Canada*, 39, 1001-1009, 1040, August 1956.

Problems of the design and construction of the trans-Canada microwave radio system, planned for completion in 1958, are described. The project, which is to provide facilities for telecommunications and network television, makes use of the TD2 radio relay system. This operates in the 4000 Mc/s band, and has capacity for six radio channels in each direction. Each channel can handle approximately 600 telephone circuits, or a monochrome or colour video signal. Descriptions are given of the terminal and repeater equipment, and of the antenna system, which uses horn reflector antennae. Considerations affecting the selection of the route are detailed, and provisions made for the operation and maintenance of the system are also described.