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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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THE BRITISH RADIO INDUSTRY

(On November 25th, 1952, H.R.H. The Duke of Edinburgh, K.G., gave an Address at the Annual Dinner of the Radio Industry Council.)

The President and Secretary represented the Institution at the 1952 Annual Dinner of the Radio Industry Council. Speaking as the guest of honour, His Royal Highness The Duke of Edinburgh first expressed his appreciation of being elected an Honorary Member of the Institution.*

After paying tribute to British pioneers, including Sir Oliver Lodge and Sir Ambrose Fleming, His Royal Highness made the following points.

Through radio communication and navigation and with electronic detection and weapon control, the whole art of war has been revolutionized and there is a continued demand for new and better equipment. "Even the Post Office, which might easily have become too well satisfied with itself, still remembers that if one parent was Rowland Hill, the other is certainly Dollis Hill!

"Industrial electronics can also play an enormous part in almost every other industry, particularly by improved production methods, including control, inspection and safeguarding production processes. But electronic devices will not be readily accepted if they are only a little better than existing systems. They must be far and away better before industry generally will think it worth while to go over to them."

In referring to domestic apparatus, His Royal Highness stated: "It is sometimes forgotten that Britain had the first television service in the world and that the present transmitters are the most powerful in the world, covering 78 per cent. of the population of the British Isles.

"Radio and television have gone beyond the stage of being amusing and entertaining novelties. Where the instantaneous connection of the radio telephone has become an established feature in the political life of the Commonwealth, so too can radio and television play their part in the cultural field to cement the ties of Commonwealth and Empire. We should look forward to the day when the member countries of the Commonwealth can receive each other's programmes as easily as they can tune in to their own domestic stations.

"The future holds almost unlimited possibilities for radio and electronics. In the relations of the people of the Commonwealth, in industry, in the home, in defence, and as an increasing part of Great Britain's export trade, the radio industry is a growing factor in the nation's economy. But it cannot play its proper part if there is not a big enough entry of properly qualified people. It is a highly skilled industry and it needs highly skilled people. It is a very grave matter that there are not enough qualified radio or electronics engineers and physicists coming from the universities and technical colleges to meet the industry's requirements."

Other speakers included Lord Cherwell, F.R.S., who emphasized the increasing importance of electronics in atomic research and development.

Those present included a large number of distinguished guests representative of H.M. Government, the Services, Government Departments, the B.B.C. and the learned institutions.

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* See *J.Brit.I.R.E.*, **11**, October 1951, p. 413.

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NOTICES

Mr. H. W. Shipton

Mr. H. W. Shipton (Associate Member), who will be well known to members as an author of papers in the *Journal* on electroencephalographic subjects, will be the British representative on the International Committee on Standards of the World Federation of E.E.G. Societies. The Committee is to meet during 1953 at the Iowa Psychopathic Hospital in the United States.

Regulations for Controlling Television Interference

The Postmaster-General has laid regulations before Parliament which will enable him to ensure that suppression devices are fitted to the ignition systems of new cars, motor cycles, motor boats, etc., which radiate sufficient energy to interfere seriously with television reception. The Regulations have been made on advice received from an Advisory Committee set up under the Wireless Telegraphy Act 1949.

Members of the Committee, who represented the motoring organizations, the radio and motor industries, and the motoring public, were agreed on the requirements prescribed in the regulations which apply only to new vehicles sold after July 1953, and assemblers and importers of motor vehicles, etc., will be required to ensure that the interference radiated from their products is below a certain amount specified in the Regulations. The Post Office will collaborate with manufacturers of ignition apparatus in advising on how the requirements can be satisfied and in making necessary tests.

For the present the Postmaster-General will continue to rely on the voluntary collaboration of owners of vehicles already in use; the usual cost of fitting suppression components to ignition systems is about 2s. 6d. A very detailed account of the whole problem was given in the paper by Mr. E. M. Lee (Member), published in the November issue of the *Journal*.

The requirements laid down in the Regulations are that the electromagnetic energy radiated at any frequency between 40 and 70 Mc/s in any direction from the apparatus under test should not exceed 50 μV/m at any distance not less than 33 ft. The Schedule accompanying the regulations lays down that the measuring apparatus shall be a calibrated radio receiver of the superhetrodyne type, fed by a dipole aerial through balanced screened cable and comprising radio-frequency amplifier, frequency charger, intermediate frequency amplifier and output valve-voltmeter. Attenuators, calibrated in decibels, are to be provided in the input circuits of both R.F. and I.F. amplifiers.

The Schedule specifies the frequency setting accuracy, the field strength sensitivity and accuracy, overload characteristics, and frequency characteristics of the R.F. amplifier, as well as the rejection characteristics against spurious image frequency and intermediate frequency signals.

Radio Component Show, 1953

The Tenth Annual Private Exhibition of British Components, Valves and Test Gear for the Radio, Electronics and Telecommunications Industries will be held in the Great Hall, Grosvenor House, Park Lane, London, W.1, during the period Tuesday, April 14th, to Thursday, April 16th, 1953. It will be open daily from 10 a.m. to 6 p.m. (5 p.m. on Wednesday, 15th); admission will be by invitation only.

It is understood that over 100 firms are participating, and the R.E.C.M.F. is extending a particular welcome to overseas enquirers.

Glass Industries Exhibition

What is believed to be the first national exhibition devoted solely to the British Glass Industry, and of interest to all users of glass in its industrial and domestic forms, will take place at the New Horticultural Hall, Westminster, London, S.W.1, on May 11th-16th, 1953. In addition to the finished products of all kinds, the exhibition will include plant, machinery, raw materials, and demonstrations of glass-blowing and other processes involved in the industry.

Liege International Fair

The Fifth Liege Fair, to be held from April 25th to May 10th, 1953, will have features of particular interest to radio and electronics engineers. The Fair normally features exhibits relating to Mining, Metallurgy, Mechanical Engineering, and Industrial Electricity, but in addition to ordinary ranges of exhibits, there will be five specialized features, one of which will be "Electronics in Industry." A comprehensive show is to be arranged under the broad headings of tubes and amplifiers, measurement and control, microwave techniques, applied electronics (H.F. heating, radar and computers), and components.

ON OPTIMUM RELATIONS BETWEEN CIRCUIT ELEMENTS AND LOGICAL SYMBOLS IN THE DESIGN OF ELECTRONIC CALCULATORS*

by

Andrew D. Booth, D.Sc., Ph.D.†

A Paper presented before the London Section of the Institution on November 5th, 1952

SUMMARY

The paper deals first with the main units required in a high-speed calculator, this treatment being functional rather than engineering in character and designed to familiarize readers with the detailed discussion to follow. Some typical examples of units of a calculator are next examined and possible means of representing such units in terms of logical symbols discussed. The means by which such logical symbols can be transformed into engineering details are then considered, and it is shown that certain types of logical unit lead to great complexity of real circuit equivalents, whilst other types of symbol adapt themselves particularly well to engineering realities. The paper concludes with a description of a suggested logical notation for computer elements which is such that a small number of basic standard "building blocks" can be combined together to form units of any desired functional complexity with some assurance that the resulting whole will operate in a reliable manner.

1. Introduction

Before coming to the main subject of this paper, it is necessary to give a brief explanation of the nature of a modern high-speed electronic calculator, and to make clear the meaning of certain terms which will constantly occur during the main part of the paper.

In the first place, it can be stated generally that the advent of electronics, and especially the pulse techniques developed for radar, has made possible the design and construction of units capable of performing the operations of ordinary arithmetic. Specifically, numbers of high digital accuracy (from 6 to 12 decimal places) can now be added or subtracted in times as small as 10 microseconds and multiplied in not much more than 100 microseconds. A computor, then, is assumed to have amongst its units one which is capable of performing some or all of the above operations: this will be referred to as the "Arithmetic Unit."

Modern electrical desk calculators, of the usual proprietary types, can perform the operation of addition in about ½ second and those of multiplication and division in from 5 to 10 seconds. An analysis of a number of large-scale computing schedules shows that a human operator, using one of the above electric machines, occupies his time in about the following proportions:

Actual machine use:	10%
Setting up machine:	20%
Writing down results:	50%
Deciding on next step:	20%

It thus appears that, if the human operator is retained, the use of electronic techniques for doing the arithmetical part of a computing sequence can result in a maximum saving in time of only 10 per cent, a very poor reward for the expense and complexity of an electronic calculator.

This gloomy picture is improved, however, if it can be shown that the intermediary of the human operator with pencil and paper can be removed; this is the case. The human operator can be replaced by an electronic device which orders the operations of the arithmetic unit in the required sequence, and at speeds comparable or superior to those attained by the latter, such a device being known by the generic name of "Control." Furthermore, it has now been shown possible to store information in several ways[1, 2, 3] each having the property that the operations of "writing" and "reading" can be performed at speeds comparable with those attained in the arithmetic and control units. These storage devices are commonly called "Memory."

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* Manuscript received September 17th, 1952.

† Director, Birkbeck College Electronic Computer Project.

U.D.C. No. 681.142.

Finally, it is necessary that a human operator should be able to supply the machine with instructions and with data, and that the machine should be capable of communicating the results of its operation to the outside world. The organs having these functions are generally referred to as "Input/Output" and physically take the form of a teletype or a punched card installation.

If it should be argued that the human operator will limit the machine speed just as if he were operating directly upon the arithmetic unit alone, it should be pointed out that a machine of the type under discussion is *never* used on problems which would only take a few minutes by ordinary means of calculation, and that no *really significant* large-scale problem has yet been found which does not involve the iterative processes necessary for the efficient use of an electronic machine.

2. The Mode of Operation

Most existing digital computers represent numbers by the presence or absence of pulses on given lines. Clearly the most suitable scale of notation for such a device is binary, in which only the digits 0 and 1 occur. This has the advantage that no use has to be made of amplitude discrimination as would be the case if decimal notation were used, and it is doubtful if a satisfactory multi-level signal computer could be constructed at the present time.

When decimal operation is absolutely necessary, numerous means are available for reducing it to an effectively binary operation. For example:

(*a*) Each digit can be represented by a single output on one of 10 wires.

(*b*) Each digit can be represented by its binary code on four wires.

(*c*) Each digit can be represented by a temporal sequence of pulses on a single wire.

to mention only a few alternatives.

Again, the whole machine can be constructed in two distinct ways:

(1) All digits of a number may be available simultaneously.

(2) Digits of a number may become available in temporal sequence starting from the most, or least, significant.

If the machine operates on the first plan it is usually referred to as "parallel" and if on the second, as "serial."

In general, neither the scale of notation of the numbers used in a machine, nor the mode of operation of the machine as a whole, need have any basic effect on the logical structure of the engineering details. The discussion, which is to follow, was based originally on a serial binary machine, but the resulting elements have been applied, since their development, to both parallel and decimal types of machine with equal success.

3. Existing Logical Symbols and Elements

If it is assumed that a calculating machine operates from "pulses", there is a clear necessity for some means of controlling such entities. (The word "pulse" is here used in a very general sense to mean any voltage, or current which changes value at some time in its existence).

The simplest control element is generally accepted to be the "2 gate"; this is shown, diagrammatically, in Fig. 1.

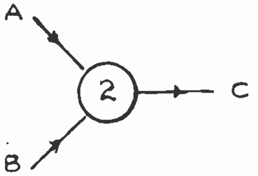

Fig. 1.—Diagrammatic representation of a "2 gate."

Here an input A is controlled by a second input B so as to give an output C only if both A and B are present. It will be shown later that this logical element is eminently suitable for simplicity of engineering in a number of ways.

Many computer designers have made use of more complex elements than the simple one mentioned above. Fig. 2 shows a selection of those to be found in the literature:

(*a*) Is usually called a "not" element since an output is produced at C if an input exists at A but *not* at B. Any input at B inhibits absolutely the output at C.

(*b*) Is a gate having m inputs $A_1 \ldots A_m$ which produces an output at C if at least n of these are simultaneously operated (*any* combination of n, A_r's will suffice). A natural extension of this element allows inhibition of C by various combinations of the A_r's.

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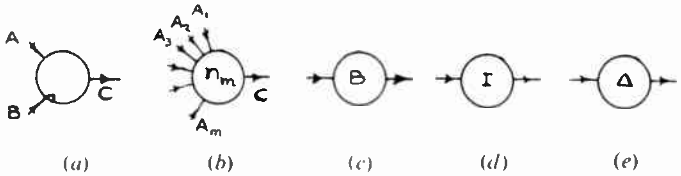


Fig. 2.—Examples of more complex gate circuits.

(*c*) Is a buffer element having the property of isolating the input from the output.

(*d*) Is an inversion element which reverses the sense of any pulse incident upon it.

(*e*) Is a delay element which produces an output at a pre-arranged time after it receives an input.

Before commenting on these elements, it is interesting to see how they are used in the design of an actual computer component. In Fig. 3 is shown the logical diagram of an adder. It is assumed that two binary numbers are incident upon A and B respectively. These numbers are in serial form so that the digits are represented by voltage pulses separated by equal intervals of time τ. The required rules of combination are given in Table 1, where C is the carry which may have resulted from a previous stage of the addition process.

Table 1

A	B	C	Sum	Carry
0	0	0	0	0
1	0	0	1	0
0	1	0	1	0
0	0	1	1	0
1	1	0	0	1
0	1	1	0	1
1	0	1	0	1
1	1	1	1	1

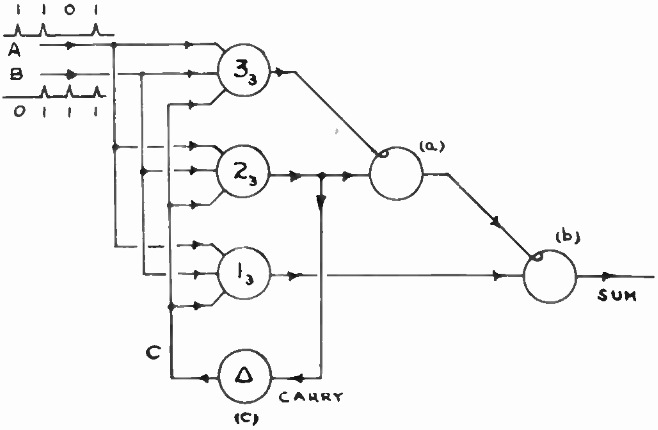


Fig. 3.—Logical diagram of an adder.

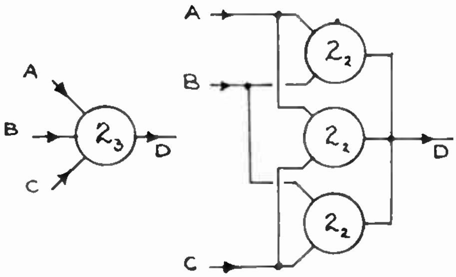


Fig. 4.—Diagrammatic representation of a 2_3 gate.

In the first place it is clear from Fig. 3 that if no input exists on A, B or C, no output whatever will be produced. If either A, B or C separately are in receipt of an input the 1_3 gate will emit an output but not 2_3 or 3_3; the output from 1_3 will thus pass unhindered through the inhibitor (*b*) and emerge as a sum digit 1, as required by entries 2-4 of Table 1. When any *pair* of inputs A, B, C are simultaneously in receipt of pulses both 2_3 and 1_3 will emit outputs. The output from 2_3 will pass unhindered through inhibitor (*a*) and operate inhibitor (*b*), thus preventing the emergence of the sum digit, 1, from 1_3. At the same time, a carry digit will pass from the output of 2_3 to the delay element (*c*) which will, in turn, produce an output at a suitable time for the next inputs at A and B. Finally, if A, B and C are *all* in receipt of inputs, 3_3, 2_3 and 1_3 will all emit outputs. That from 2_3 will produce a subsequent carry, via (*c*), as before; however, its passage through (*a*) will be inhibited by the output from 3_3 and, in consequence, (*b*) will transmit the sum digit pulse from 1_3.

The elegance of this logical circuit makes clear the reason for the historical suggestion of n_m gate units and it is unfortunate that no simple means exists for engineering the general case. As an example, Fig. 4 shows the complexity necessary for the actual construction of the 2_3 gate of Fig. 3. It is seen that each of the possible combinations AB, BC, CA, has to be provided with a separate 2_2 gate and the outputs from these gates connected in parallel.

The only cases allowing really simple engineering are n_n and n_1 and since these are immediately constructible from the 2_2 elements, which will be described later, it is not proposed to consider them separately.

4. A Suggested Set of Basic Computer Units

Now that some indication of the existing types of logical element has been given, it is proposed to indicate, very briefly, the set of units which has been found most suitable for the work of the Birkbeck College Computer Laboratory. It must be borne in mind that the machines to which this symbolism has been applied are, intentionally, not in the highest speed range and thus they permit the use of certain circuit devices which may not be possible in very much faster apparatus. On the other hand, careful consideration seems to suggest that only slight modification would be necessary in order to meet the highest speed requirements at present possible.

The basic units suggested are:

(1) The single digit store—often a flip-flop.

(2) The buffer isolator.

(3) The inverter/amplifier.

(4) The 2_2 gate.

Three computers have now been constructed using only these elements, and it seems clear that, apart from special circuitry required by the memory device, they are a sufficient set.

5. Some Engineering Details

A long paper might be written concerning the design of single digit storage devices—existing circuits range from flip-flops to two-state oscillators in the field of valves, and from high remanence magnetic devices to ferro-electric capacitors in the more advanced designs. Whatever machine is envisaged, however, it seems probable that at least some flip-flop circuits will have to be included. A reliable design is shown in Fig. 5, the circuit being so conventional as to require no detailed description; it is worth remarking, however, on the large value of the cathode resistor which tends to even out valve variation by negative feed back. A further point to be noted is the absence of "speed up" capacitors in the anode/grid circuits; these have been found to produce instability in computer applications.

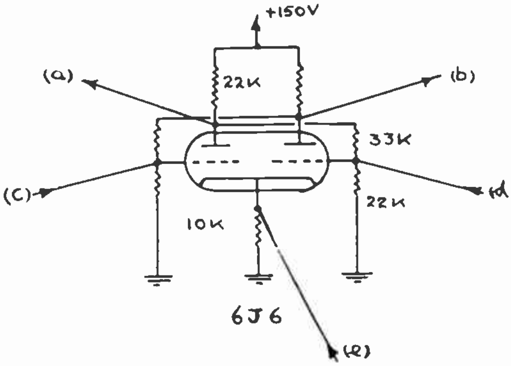
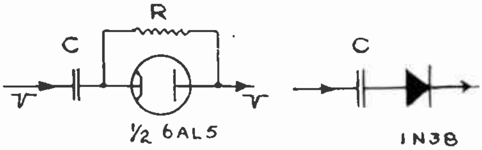


Fig. 5.—Circuit of a "flip-flop" suitable for use as a single digit store.



(a) (b)

Fig. 6.—Circuits of buffer isolators, (a) using a thermionic diode, (b) using a germanium or selenium diode.

A suggested buffer isolator is shown in Fig. 6. In this circuit the capacitor, C, and resistor, R, may be omitted if the d.c. levels of the input and output lines are suitably matched. When this is not the case, the time constant R.C must be chosen to suit the pulse repetition rate for which the device is designed. When a germanium or selenium diode is used instead of the valve, R may usually be omitted since the reverse resistance of these devices is often relatively low.

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The design of inverter stages again depends largely upon the repetition rate at which they are to be used. In the range up to 50 kc/s, the circuits of Fig. 7 have been found suitable.

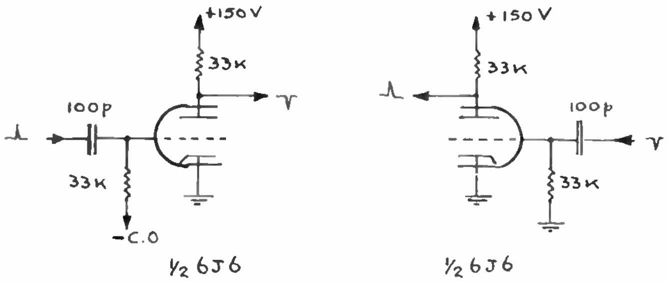


Fig. 7.—Inverter circuits.

A very large number of circuits have been suggested for the 2_2 gate, and a typical variant using diode elements is given in Fig. 8. In this circuit $R_K \ll R_A$, so that the normal voltage at C is determined by the divider action of R_K and R_A.

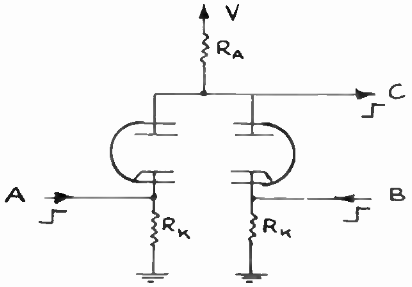


Fig. 8.—Circuit of a 2_2 gate.

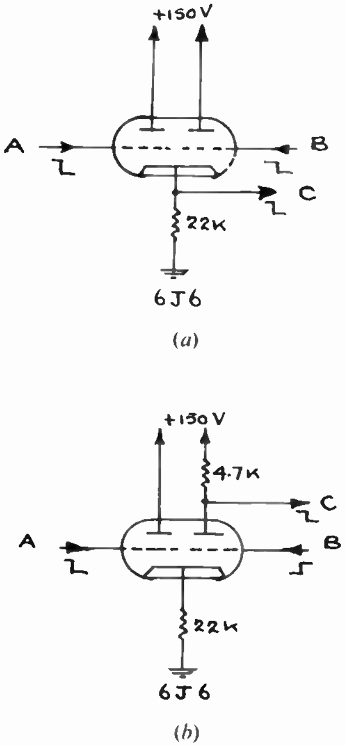
If the potential at *either* A *or* B is raised, the output at C only rises from $R_K . V/2R_A$ to $R_K . V/R_A$, whilst if *both* A and B have positive voltages applied to them the output voltage at C can in principle rise to V. An obvious variant allows the gate to be used for negative input voltages. The disadvantage of circuits of this type lies in the fact that, for fast operations, A and B have to be driven from sources having a low impedance and this, in general, involves the interposition of cathode follower stages.

The types of 2_2 gate favoured in the writer's laboratory are shown in Fig. 9.

In the first, two cathode followers feed a common load; if either grid voltage falls separately only a very small output occurs at C, but when both grid voltages fall, the voltage at C drops to the higher of the two. The second circuit requires *one* positive-going gate voltage, at B, and an output at C can then be produced only when A goes low and B high at the same time. A considerable advantage arises from the fact that no break-through occurs at C when A and B are operated separately.

Both of the above circuits have the advantage of high impedance inputs and both can be immediately extended to the construction of n_n and n_1 gates.

In the design of an extended computing system, A and B can be connected directly to the outputs of flip-flops or of amplifiers and so long as units of the same type are used throughout no voltage level difficulties arise.



(a)

(b)

Fig. 9.—Circuits of other forms of 2_2 gate.

6. Logical Symbols

To conclude this paper, it is proposed to describe a notation for the basic units of a computer which has been found to simplify the preparation of both wiring and service drawings.

In the past, it has been usual to represent, for logical purposes at least, the various gates, buffers and delays used in a computer by means of the symbols given above in Fig. 2. An additional symbol, shown in Fig. 10, was used to represent the flip-flop unit of Fig. 5, corresponding outputs and inputs being labelled identically in both figures.

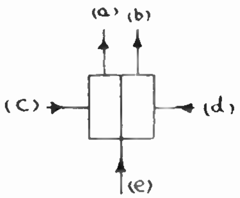
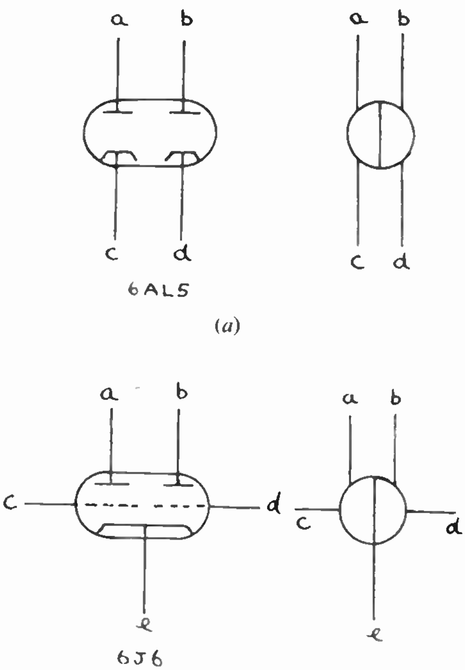


Fig. 10.—A logical symbol for the flip-flop unit shown in Fig. 5.

Numerous disadvantages result from the use of this notation, since, for example, the flip-flop unit of Fig. 10 requires accurate drawing if the result is to look presentable; the logical symbols of Fig. 2 give no idea of the number of valves involved in the engineered version of the unit, and the units cannot easily be made to correspond in position to the valves of a real chassis.

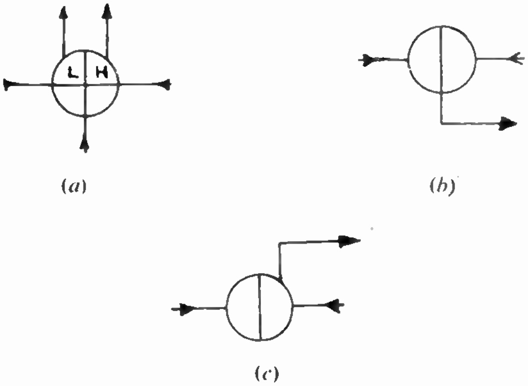
To overcome these difficulties, and at the same time to represent the standard units previously envisaged, the notation of Fig. 11 was evolved. In the Birkbeck College Computers, at least, the only valves used are miniature double diodes and double triodes, and this at once suggests the idea of representing a full envelope by a circle divided, as in (*a*), (*b*) by a vertical diameter. The various input and output points for 6AL5 and 6J6 types are shown in the figures, anodes, cathodes, and grids appearing in their natural positions on the shorthand diagram. The next stage of complexity is to insert detail into the logical elements: in Fig. 12 are shown the symbols used to represent the complete units previously described. Thus, Fig. 12 (*a*) represents the flip-flop of Fig. 5, the letters L. H. being inserted in such a manner as to indicate which anode is at low and which at high potential when the element is in its unexcited state. Fig. 12(*b*) represents the cathode output 2_2 gate shown in detail in Fig. 9(*a*), and similarly Fig. 12(*c*) gives the representation of the anode output 2_2 gate of Fig. 9(*b*).



(*a*)

(*b*)

Fig. 11.—Basic examples of the author's system of logical symbols.



(*a*) (*b*)

(*c*)

Fig. 12.—Development of the symbols of Fig. 11.

In a like manner the buffer diode element of Fig. 6(*a*) can be represented by the notation of Fig. 11(*a*), and the inversion elements of Fig. 7 by the triode representation of Fig. 11(*b*), with suitable pulse sense indications at the grid and anode points of the latter. The delay element, if engineered in the form of a mono-stable multivibrator, can be represented by the notation of Fig. 13, in which the actual circuit wiring is immediately suggested by the logical diagram.

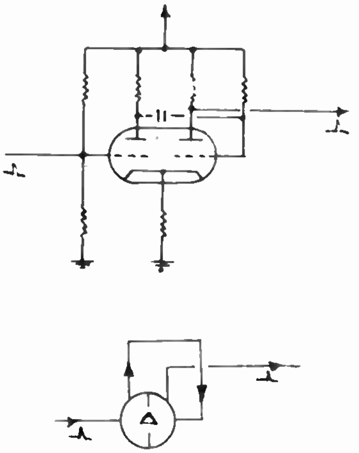


Fig. 13.—Circuit diagram and logical symbol of a monostable multivibrator used as a delay element.

It is not profitable to go into the finer details of the actual circuits used in a particular computer, since these will inevitably vary extensively in any other laboratory. Enough has been said, however, to show how the notation is built up and to indicate its convenience.

To conclude, Fig. 14 shows a complete chassis of the A.P.E.(X).C. computer represented in the above notation. The unit chosen is a 6-stage binary counter of conventional type, having pre-setting facilities from a set of external flip-flop counter elements, the small (*c*) indicating that speed up capacitors are added to the circuits of Fig. 5. (This practice is no longer used). Valves 7, 8, 9, 10, 11 and 12 are the usual double diode buffer units, whose detailed circuit is shown in Fig. 15. Valve 13 provides a pair of inverter amplifiers, the left-hand section providing an output indication from the

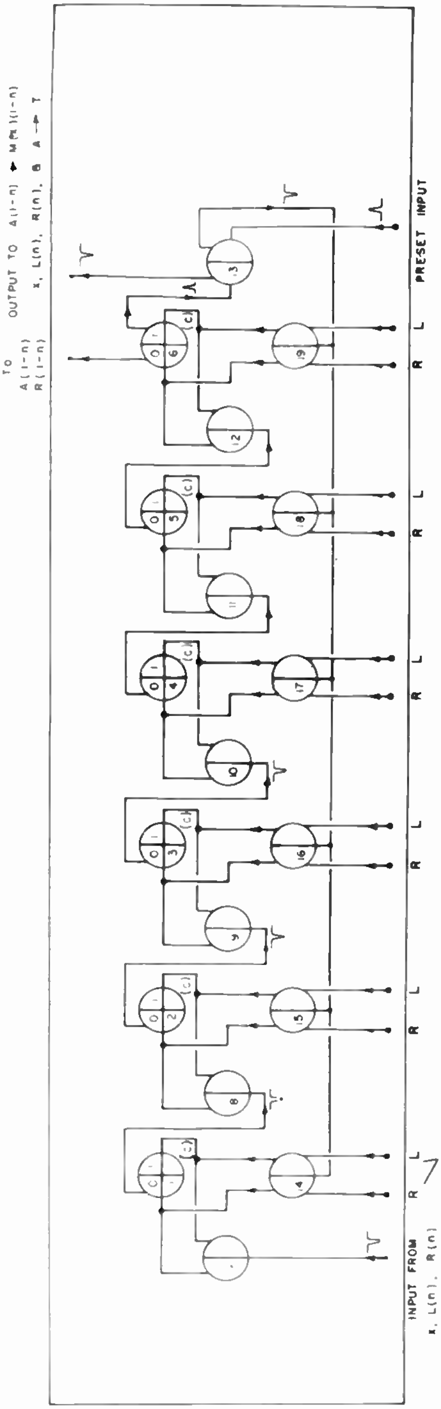


Fig. 14.—Complete chassis diagram of a 6-stage binary counter of A.P.E.(X)C. computer using the author's logical symbols.

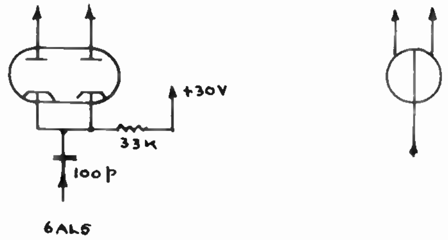


Fig. 15.—Circuit and logical symbol of a double diode buffer unit.

final counter stage, and the right-hand section a high impedance input for the pre-setting pulse. Valves 14, 15, 16, 17, 18 and 19 are standard register shift interposers of the type described elsewhere by the author, the detailed circuit being shown in Fig. 16.

The diagram of Fig. 14, in its original form, provides then:

(*a*) A full-sized drawing of the actual chassis showing each valve base, to enable the chassis to be punched.

(*b*) A logical diagram for use in fault finding.

(*c*) To a wireman who has memorized the conventions of Figs. 15, 16, etc., a layout from which he can build the circuit.

It is perhaps worthy of remark finally that, using the notation described, the complete design of a computer was carried out in 3 days and involved only 10 detail sheets apart from the standard units.

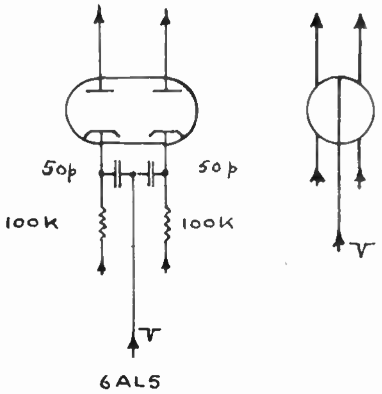


Fig. 16.—Circuit and logical symbol of a standard register shift interposer.

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THE USE OF RADIO IN THE NAVIGATION AND OPERATION OF CIVIL AIRCRAFT*

by

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SUMMARY

This paper reviews the current use of radio in meeting the operational requirements of civil aviation. Systems of navigation and communication for landing, traffic control and en-route communication and navigation are described in sufficient technical detail to enable their functions and capabilities to be appreciated, but the general purpose of the paper is to indicate the contributions made by radio to the solution of operational problems.

Mention is made of V.H.F. telephony and long range H.F. air to ground working in the communication field and of GCA, ILS, and M.F. and V.H.F. radio ranges and DME, in their respective relations to approach and landing, and short-range navigation. Of the position-fixing systems, Gee, Loran, Decca and Consol are described.

The use of radio point-to-point services for administration purposes is described and also the functions of international and national administrative bodies in relation to civil aviation. The future philosophy of air traffic control, in which radio will play a vital part, is described.

1. Introduction

In the early days of civil aviation, aircraft in flight were almost completely isolated from the ground and the successful completion of a passage depended on the unaided navigational skill and flying ability of the pilot and on good weather.

It was soon realized that to be a *commercial* proposition air travel must be independent of time of day and weather, at least to the same extent as sea transport, and it was natural to turn to the almost equally new art of radio for help in navigation and communication.

Before the recent war this aid was confined mainly to radio-telegraphy communication with main airports and position fixing by direction finding from ground stations. Blind approach to landing by Lorenz or similar systems was also in use but traffic control on the ground and in the immediate vicinity of airfields was still mainly by light or other visual signals.

With traffic densities obtaining in 1939, these methods were already becoming inadequate and it later became obvious that after the war they would certainly not suffice to control the passage of large numbers of aircraft on congested air routes, and in and out of main airports. In particular, it was seen that a position-fixing system which did not require the active co-operation of two or three ground stations (as in the case of ground D/F) would be essential if the system were not to fail due to overloading and if gross errors were not to be introduced in the case of high-speed aircraft by the length of time necessary to obtain a fix.

The late war greatly increased experience of handling large numbers of aircraft and enormously enhanced the arts of communication and navigation, and the air transport industry found itself in 1945 with a wide choice of aids to the efficient handling of air traffic. Indeed, this very profusion of techniques has led in the past few years to a great deal of uncertainty as to the best methods to be adopted and has called for a great deal of work on the practical and theoretical evaluation of the various systems and considerable international discussion to enable some uniformity of practice to be arrived at.

The basic philosophy of the art of aircraft navigation and control hinges largely on the fact that the aeroplane, although in many ways like a ship, and amenable to similar systems of navigation, differs in one vital respect from all other forms of transport—it cannot be stopped or appreciably slowed down in poor visibility or heavy traffic. This means that the consequences of collision cannot be mitigated by

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reducing speed and also that the only way of delaying an aircraft's arrival at a given point (such as a terminal airport) is to resort to "holding" which involves flying to some predetermined location out of the area of general traffic and there flying some roughly circular course until the journey can be resumed. This involves heavy wastage of fuel and time and makes undesirable inroads on the pilot's endurance and the customer's patience. It is thus very desirable that any system should enable an aircraft to be so navigated and controlled that its passage approximates as nearly as possible to a straight line from take-off to landing.

The relatively high speed of modern aircraft coupled with this desire to avoid delay and at the same time to satisfy the paramount requirements of safety has made it necessary to adopt specialized systems of navigation and communication. Position fixing must be rapid and communication must be clear, immediate and operable with the least possible diversion of attention from the main duties of the user.

These requirements, desirable at all times, become mandatory during approach and landing when both position data and communication must be available directly to the pilot, who alone can take the action necessary for the safety of the aircraft. The heavy mental and physical burden placed on the pilot at these times imposes severe restrictions on the methods adopted for position and direction indication. No method which involves any removal of the pilot's hands from the controls or more than a mental appreciation of data presented by the minimum number of directly calibrated instruments will be of any use during landing. The data presented by the aid must also represent the aircraft's position and direction *at the time of indication* if it is to be of any real use. It is also desirable that the data be presented not in the form of statements of fact (which still leave the pilot to decide what action to take) but in the form of instructions such as "fly left" or "fly higher," etc. Information of this type is also a step in the direction of completely automatic landing as it is in a suitable form for feeding directly into some sort of automatic pilot.

In addition to short-distance communication and navigational aids, there are also requirements for long-distance navigation aids and air-ground communication and also for a network of short- and long-distance point-to-point circuits for control and administrative use. These latter are, of course, in many cases wire circuits, but there is a large number of radio links.

The imminent use of jet aircraft with higher speeds and relatively inefficient operation at low altitudes is also presenting new approach and landing problems and the whole philosophy of the art is tending towards completely automatic operation.

2. The General Problem

The problem of air traffic control and navigation can be stated by considering the basic conditions in which any aircraft will find itself when operating. These are:—

(1) On the ground, between loading point and take-off position or between landing and unloading point.

(2) In flight, in the immediate vicinity of the airfield—immediately after take-off or before landing.

(3) In a control zone—that is, in an area of high traffic density due to convergence of traffic on to an airport, or taking up position to commence the landing process.

(4) En-route, that is, in flight during passage in regions of comparatively low traffic density. This latter condition may be of long or short duration (for instance on an Atlantic crossing it will be several hours) or may not obtain at all (for example in some areas of the U.S.A. or Europe and in the U.K. the aircraft may not pass out of a controlled area at all).

Each of these conditions gives rise to certain requirements for communication and navigation and in addition means are needed for passing to the selected destination the expected arrival time of the aircraft and other relevant information and also for passing service messages in connection with the normal business of the airline operating company.

Having now stated the general problem, we can pass on to a brief review of the present means to hand for meeting the requirements.

3. Short-Distance Ground/Air Communication

This service embraces communication for control of aircraft (and vehicle) movements on airfields and in control zones while in flight.

The basic requirements of the service are that it shall be simple to operate, immediate in action (i.e. no tuning procedure shall need to precede the passing of a message) and its range shall as far as possible be restricted so that it will not interfere with traffic in other areas.

These requirements are at present met by a technique developed during the late war, namely, by V.H.F. telephony. By international agreement the band 118-132 Mc/s is allocated to the service and the band is divided into 140 channels spaced 100 kc/s apart. The airborne equipment is usually remotely controlled, channels being pre-set and selected by simple rotary switch or push buttons, and the A.G.C. requirements are very stringent to permit reception in widely varying field strengths without distortion or adjustment of gain by the pilot.

A considerable number of sets are available for aircraft use, all of which are crystal controlled, giving instant communication. Some of these sets enable any one of the 140 channels to be selected at will, but the majority of the types readily available in Europe enable only a few pre-set channels to be obtained in the air (varying from 2 to 23 according to the equipment). Transmitter powers vary from about ½ to 30 W, the bulk being in the 5 to 8 W range.

On the ground it is usual to use one single-channel transmitter and one receiver for each channel required at a particular point. This is due to the fact that the loading on any ground station channel is usually too high to enable increased equipment utilization to be obtained by switching channels on one set of equipment. Transmitter powers vary from 10 W for local working to 50 or 100 W for longer distance service.

A year or two ago, when the above allocation of frequencies was ratified, there were no sets available in Europe capable of working at will on every allocatable channel, while there were in service a considerable number of almost new equipments giving four, six or more channels up to 23, and in order to avoid rendering these sets obsolete in an uneconomically short time, an interim arrangement was made whereby a maximum of 19 pre-arranged frequencies were to be sufficient for aircraft flying internationally. This enables full V.H.F. operation to be available to any aircraft carrying one or at the most two of a number of readily available equipments. (In this connection it is worth while noting that although the development of multichannel V.H.F. was a little more advanced in the U.S.A. than in Europe, the Americans have not been faced with the problem of obsoleting existing V.H.F. equipment as it had not been put into service to anything like the same extent as over this side of the Atlantic—a great deal of local control having been carried out on H.F. or M.F.)

These 19 channels are allocated in blocks of up to five for specific services such as aerodrome control, approach control, area control, etc., and there is one universal emergency channel which is guarded by all ground stations. This enables any aircraft in difficulties to have the use of a lightly loaded channel and also (most important in a short-range system) obviates the need for an aircraft to know the frequency on which the nearest ground station is listening. This is a particular advantage in the case of an aircraft lost in bad weather when the pilot may not know which *is* the nearest ground station.

The channels for a particular service are allocated between ground stations on a geographical basis to minimize the risk of interference between adjacent stations. This problem cannot be completely solved due to the possibility of interference by high-flying aircraft, which may be heard on the ground at distances of up to several hundred miles depending on altitude. V.H.F. working is, however, substantially immune from the random very long distance interference experienced on H.F. due to sky wave and the trouble can be minimized by limiting the power of all transmitters to the minimum essential for reliable operation at the distances required for the various services.

Where a comprehensive V.H.F. system is operating it is now possible for an aircraft to be in reliable contact with the airfield controller at all times both on the ground and in the air and also with the approach or area control as required. The functions of the various control organizations will be enlarged on later.

3.1. *Area Coverage by V.H.F.*

In congested areas such as the U.K. or Western Europe, where there must be a great deal of air traffic crossing main air routes, it is necessary to control aircraft over areas larger than the local or approach zones pertaining to particular airports and the need arises for a control authority responsible for a fairly wide

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area to be able to speak directly to aircraft anywhere in that area. This can perhaps be better understood if we refer to a concrete example such as the U.K.

The U.K. and certain sea areas surrounding it are divided up into a number of adjoining Flight Information Regions each under the supervision of an Air Traffic Control Centre. In conditions of poor visibility all aircraft in passage in any Region are under the direct supervision of one or more controllers stationed at the appropriate A.T.C. These controllers may thus want to speak to aircraft anywhere in quite a large area, some parts of which would be out of V.H.F. range of any single station situated in the area. The problem thus arises of choosing the means of communication. Shall we use M.F. which is reliable at all distances but has a small capacity for R/T channels and is also liable to cause long-range interference—or shall we use H.F. which is liable to give poor results at low ranges coupled with random long-range interference—or can some system of extending the coverage of V.H.F. be adopted.

It is this latter method which was chosen by the M.C.A. and is now in operation in the Southern F.I.R. The method adopted is that proposed by Mr. Brinkley when he was at the Home Office and involves the use of transmitting and receiving stations strategically distributed over the area to be served and having a transmitter and a receiver tuned to each channel at each station.[1] The receiver outputs for each channel are all taken together to the A.T.C. and all transmitters on any channel are modulated in unison from the A.T.C. The interconnections are by carrier telephony over land lines.

The transmitters on any channel are all accurately controlled on slightly different frequencies such that while the frequency of no transmitter falls outside the pass-band of the airborne equipment, the heterodynes between carriers, and the more complex intermodulation products, do not fall within the audio band width of either ground or air receivers.

It is proposed to apply this system to all F.I.R.'s in the U.K. and there has also been considerable interest shown in Western Europe, so that eventually we may expect V.H.F. communication to be possible anywhere within the European area. The Americans propose to achieve the same result by a system which is integrated with their short-range navigation system which will be dealt with later.

Having thus briefly reviewed short-range communication we may now pass on to considering approach and landing aids.

4. Approach and Landing Aids

4.1. *The Problem*

For the purposes of this section, we will assume that the aircraft has found its way to within a few miles of the airfield at which it is proposed to land, and it is found that the sky is almost completely obscured by cloud, the base of which is below the 1,500 or so feet at which it is usual to commence the run-in to land. This weather may also be accompanied by rain, snow or fog but in any case some sort of landing aid will be required. The pilot will already be aware of the height and location of any obstructions in the vicinity of the airfield and will have been told from the ground the correction to set on his barometric altimeter to allow for the pressure in that area and also the weather conditions and range of visibility at ground level so that he may know when he may expect to see the runway or its lighting and be prepared to counteract the drift due to wind across his line of flight.

In order to appreciate the psychological factor which is of such great importance in blind landing it will be well to visualize the conditions in which the pilot finds himself.

In conditions other than fog (which is usually accompanied by fairly calm air) the aircraft will be pitching and yawing to an extent dependent on its size and the degree of turbulence of the air and some degree of concentration will be needed to hold a steady course. Secondly, in continuous cloud, fog, very heavy rain or snow, nothing will be visible outside (probably not even the wing-tip lights) and the aircraft will appear to be flying into a blank wall varying from pale, luminous grey to black depending on weather and state of the light. In rain, the windscreen will be covered with streaks of driven water, and snow will be seen as white streaks rushing by the windows from a blank wall seemingly a few yards ahead. There will be no outside indication of the attitude of the aircraft and the pilot will have to concentrate on his gyro-controlled instruments to keep the aircraft in proper flying attitude and restrain any impulse to look outside in the hope of seeing something helpful. Finally, the aircraft will be comparatively close to the ground

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and the pilot feels safer when he has plenty of air around him, just as the ship's captain feels safer in deep water than in shoal.

All these adversities the experienced airline pilot will take in his stride, but such circumstances always engender in even the most phlegmatic pilot a disinclination to be distracted more than strictly necessary from the business of flying his aircraft.

On the purely practical side we have to satisfy the requirement of setting down an aircraft flying at a speed of about 90 m.p.h. on a runway about 300 feet wide. This speed present two problems, one, that it is a fair velocity at which to attempt to set down a large mass of machinery on a small target, and the other is that, aerodynamically, this is rather a *low* speed at which the aircraft is not so agile as at normal flying speeds. Consequently the landing aid must so guide the aircraft that by the time the pilot is able to take over for a visual landing it is so positioned that no violent manœuvre is needed to make safe contact with the runway.

This examination of the problem shows that there are three basic requirements to be met—firstly, the system shall be accurate enough to ensure that the aircraft is correctly positioned both horizontally and vertically at the moment of first visual contact. Secondly, the minimum effort shall be required of the pilot to operate and interpret the system, and, thirdly, the system shall be such that the pilot has complete confidence in it. This latter point will be completely met if it is possible to arrange for the pilot to be able to monitor the action of the aid by some independent checking system. As we shall see, this latter condition can be satisfied by currently available facilities.

4.2. *Current Landing Aids*

There are currently developed quite a number of landing aids based on various techniques but it is proposed to deal only with the two which are likely to come into general use. These are GCA (Radar ground-controlled approach) and ILS (Instrument landing system). This latter is now internationally adopted as the standard landing aid with the former as a secondary facility. Coupled with either of these systems it is necessary (for full control of the airspace round the field) to have a surveillance radar system capable of searching an area stretching for a considerable distance all round the airfield in order to build up a general picture of the traffic situation. This surveillance radar is normally an integral part of the GCA system, to which it is essential for operational reasons as we shall see. The two parts of the GCA system are now known as PAR (precision approach radar) and SRE (Surveillance radar element).

The two landing systems differ radically in that in GCA all the data are collected and presented *by ground apparatus to ground operators*, while in ILS the reference signals are generated on the ground but the data are derived and presented to the pilot by apparatus in the aircraft. In the one, the pilot acts entirely on instructions from the ground while in the other he acts on information provided by instruments in the aircraft.

4.2.1. GCA

There are several GCA systems in existence—two principal American systems (Bendix and Gilfillan) and, recently, a British system developed by Standard Telephones and Cables. All these systems are basically the same, differing mainly in the mode of presentation of the data and the number of operators required. It is proposed to give here a brief description of the Bendix GCA whose basic principles are representative of GCA technique.

Taking the surveillance radar first, this consists of a normal search radar system operating on 2880 Mc/s, with a peak power of 200 kW and a pulse duration of ½ microsec. This radar searches the air space round the field for a distance of 30 miles up to 5,000 ft. at one sweep every 2 seconds. Data is displayed on two 12-in. P.P.I. tubes in 4 ranges—6, 10, 20, 30 miles. Accuracy is ±1·5 deg. in azimuth and ±3 per cent. of the range scale in use. Resolution is such that two aircraft at the same range can be distinguished provided their bearings differ by 7·5 deg. or more. The aerial system is mounted on a 70-ft. tower suitably located on the aerodrome while the apparatus and displays are located usually in the aerodrome control building.

Coupled with the SRE we have the height finder. This consists of a radar system operating on 9,150 Mc/s, with a peak power of 45 kW and a pulse of ½ microsec derived from the same source as the SRE. This radar has an aerial (mounted on a tower separate from the SRE) which scans over a vertical sector extending over a narrow arc in azimuth, at a rate of 1 sweep per second. This aerial can be rotated manually to any bearing required, and covers a radius of 20 miles up to 12,000 ft. The height-finding operation is carried out as follows. The operator selects on the Surveillance P.P.I. the spot representing the aircraft whose height he wishes to determine and rotates a hair-line to cut this spot. This automatically rotates the height-finder aerial to the correct bearing. The height-finder display is another 12-in. tube showing a portion of an expanded P.P.I. display and is calibrated horizontally in range and vertically in height. On this tube, when the aerial is correctly trained, will appear a spot at a range exactly corresponding to that shown on the SRE P.P.I. for the aircraft selected. A cursor on the height display is now moved to cut the spot and height will then be indicated on a scale beside the display. The height finder will determine elevations to an accuracy of ±500 ft.

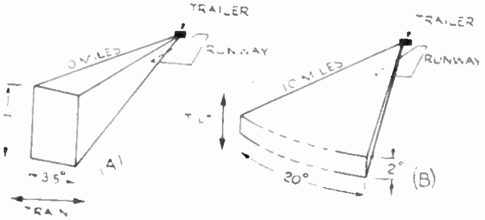


Fig. 1.—*GCA Precision element coverage.*
(*a*) *Elevation* (*b*) *Azimuth*

With this equipment the Airfield Controller can form a clear picture of the distribution of aircraft in his area, and can pass appropriate instructions to any one of them which will enable the pilot to take up a position suitable for starting his run-in. From this time onwards, he will be in the hands of the Talk-down or GCA Controller who works with data from the Precision Radar (PAR). As soon as the GCA Controller has established V.H.F. radio contact with the aircraft he will instruct the pilot not to acknowledge any further messages, which means, of course, that the pilot can concentrate on flying the machine in accordance with instructions given him by the Controller.

The Precision element consists of two radar systems giving azimuth, elevation and range with relation to the optimum position of contact with

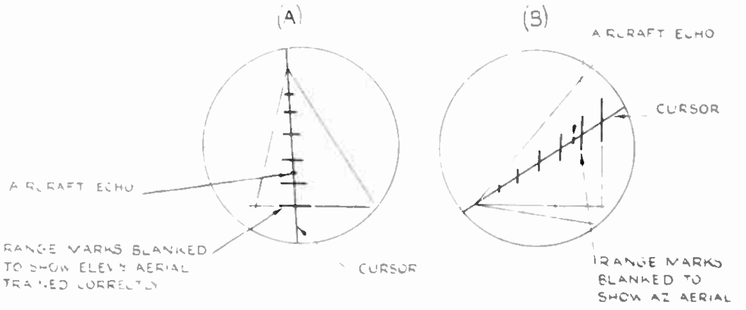


Fig. 2.—*GCA precision presentations.*
(*a*) *Azimuth* (*b*) *Elevation*

the runway (Fig. 1). The aerials and apparatus for these radars are housed in a mobile trailer which can be placed alongside the runway required (usually on some prepared hard-standing). The azimuth and elevation radars operate with powers of 45 kW and ½ microsec pulses on 9,040 and 9,010 Mc/s respectively. Accuracies are of the order of azimuth 0·2 deg., elevation 0·1 deg. and range 300 ft. This means that at 1 mile variations of 10 ft. in elevation and 20 ft. in azimuth can be detected.

These two radars each have 12-in. expanded partial P.P.I. displays which are wedge-shaped in nature starting from a point of origin corresponding to the optimum point of contact with the runway (Figs. 2 and 3). In each case the sweep corresponding to the salient factor (either elevation or azimuth) is considerably expanded for accuracy of reading. Both displays have one range of 6 miles only. The azimuth display shows azimuth horizontally and range vertically while the elevation shows range horizontally and elevation vertically. Each display carries electrically-generated range marks every mile. Operating over each display is a cursor which can be moved by the operator to track the spot

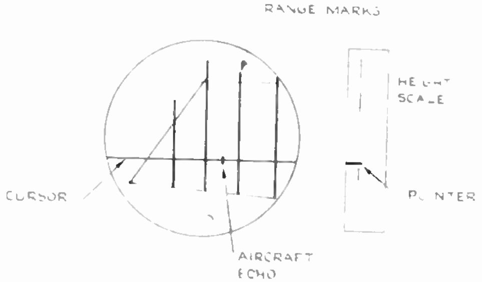


Fig. 3.—*GCA height-finder presentation* corresponding to the aircraft. The movement of each of these cursors is electrically transmitted to the Position Deviation Indicator which will be described later.

The aerial of the Azimuth radar scans over a sector of 20 deg. in azimuth at a rate of 2 sweeps per second, and the whole aerial system can be tilted vertically so that it can always be directed at the aircraft. The Elevation aerial scans over a 7-deg. angle vertically and can be trained bodily in azimuth so that it can be kept directed at the aircraft. In the case of the Azimuth aerial the tilting operation is carried out by the Elevation Operator and vice versa. The range marks on the Azimuth display are blanked out except for a small distance on either side of the direction in which the Elevation aerial is trained in azimuth and a similar effect is produced on the Elevation display. This enables each operator to keep the other's aerial directed correctly. In practice, each operator simply keeps his cursor on the aircraft echo and, in so doing, relays to the Position Deviation Indicator information on the position of the aircraft with respect to the correct line of approach.

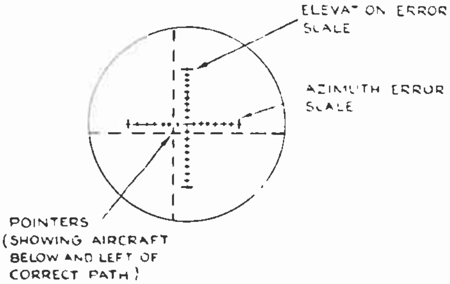


Fig. 4.—GCA position deviation indicator

The PDI consists basically of a translucent dome which has horizontal and vertical scales which cross at the centre of the dome. The horizontal scale is graduated in feet either side of correct path while the vertical scale is calibrated in feet above or below the correct path (Fig. 4). The positions of the Azimuth and Elevation cursors are relayed to two needles whose shadows are cast on the dome to give the effect of two lines which will cross at the centres of the two scales when the aircraft is on the correct path. Any deviation of the aircraft from the correct path, will be tracked by the precision operators and will be indicated by a movement of the corresponding shadow. The information thus given can be relayed to the pilot by the GCA Controller who will be in constant V.H.F. contact with the aircraft.

The GCA Controller also has a repeated display of the Surveillance Radar PPI so that he can have at hand a general picture of the traffic in the immediate vicinity of the airfield.

It will be seen from the foregoing brief description, that with no more equipment in the aircraft than the normal communication facilities it is possible to guide an aircraft in to land in any conditions where the pilot is able to take over for a visual landing at a height of 100-200 ft.

It will also be appreciated that, since all the data is in the hands of the GCA Controller, if the system is to work successfully the pilot must have complete confidence in the accuracy of the equipment and the ability of the Controller. This is best achieved by constant practice during normal weather, and pilots are encouraged to make dummy GCA landings at every opportunity.

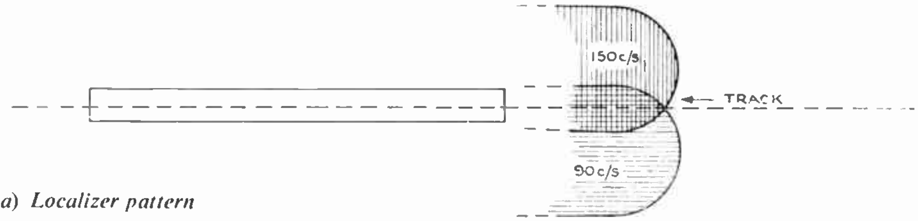
It is generally agreed that, by using duplicate precision displays and two Controllers handling alternate aircraft, it should be possible to handle at the same time up to three aircraft on the approach path spaced at two-mile intervals. This will demand close co-operation with the Controller using the surveillance radar and feeding aircraft to the GCA Controllers to ensure that aircraft arrive at precisely the right position to start their approach at exactly the right time.

4.2.2. ILS

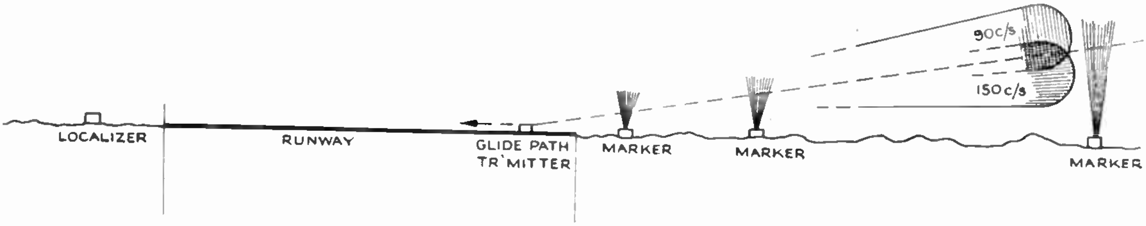
The second system we have to consider provides accuracies of the same order as GCA but the position data is presented to the pilot. It needs equipment on the ground but no co-operation by ground personnel and also special equipment in the aircraft which GCA does not, of course, require.

It is worth noting that the use of this system together with GCA gives us the facilities for cross checking of performance which we noted as desirable earlier in this section. It will readily be seen that a pilot making an ILS landing can be monitored by GCA and can get the GCA Controller's comments on his deviation from the correct path over the radio. The reverse also holds good. The use of the two systems together also provides an additional safeguard should either fail during the approach.

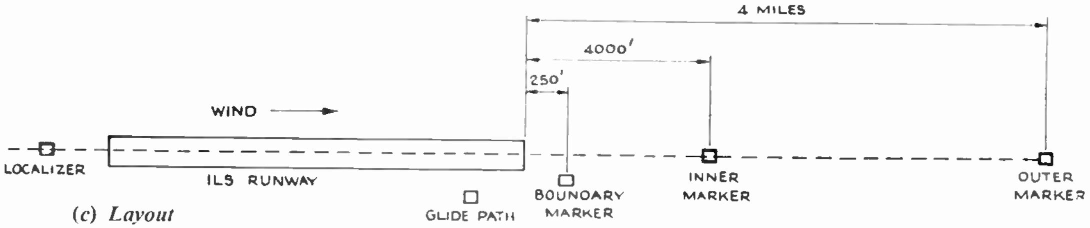
ILS operates on the same principles as the



(*a*) *Localizer pattern*



(*b*) *Glide path and marker patterns*



(*c*) *Layout*

Fig. 5.—Instrument landing system

Lorenz or SBA systems from which it differs only in minor details of technique. In considering the operation of ILS we will assume, as we did in the case of GCA, that the aircraft has arrived by some means at a point suitable for commencement of its run-in to land.

The ILS system employs three elements, each of which requires a separate receiver in the aircraft and a transmitter, or transmitters, on the ground (Fig. 5). The first element, known as the "localizer," provides a course which will guide the aircraft laterally on a line running down the centre of the runway (Fig. 5*a*). It comprises a transmitter and aerial system located about 750 ft. beyond the "stop" end of the runway. The device radiates two separate amplitude modulated carriers, one modulated at 90 c/s and the other at 150 c/s. The aerial systems radiating these signals have radiation patterns such that an aeroplane flying down the intersection of the pattern (which coincides with the centre line of the runway) will receive equally strong 90 and 150 c/s signals. These signals are rectified in the localizer receiver and applied to what is in effect a centre zero meter whose movement causes a white vertical wire to move over the face of the ILS instrument on the instrument panel of the aircraft. The system is so arranged that the wire moves in the direction in which the pilot is to steer to correct his course. The relative amplitudes of the 90 and 150 c/s signals and the symmetry of the patterns of the aerials are controlled to close limits so that the system provides an accurate guide to the correct heading of the aircraft. The relative positions of the patterns are always arranged so that when the aircraft faces the localizer from the approach end of the runway, the 150 c/s pattern is on the right.

The localizer operates on frequencies between 108 and 112 Mc/s and its radiation is horizontally polarized. The coverage provided ensures satisfactory operation up to 2,000 ft. at 25 miles from the optimum point of contact, over a 20-deg. sector centred on the on-course line. Adequate cover is also given up to 17 miles at 2,000 ft. in all other directions and up to 1,000 ft. anywhere over the landing area. The amount of deflection of the instrument for a given course deviation can be pre-set on the aircraft equipment and a normal setting is full scale for 3 deg. deviation in either direction. Facilities are also provided for modulating the localizer with speech without interrupting the course facilities so that it can be used as a communication channel with the aircraft. Each localizer also radiates a 2- or 3-letter morse identification signal about once every 10 seconds which can be heard on an audio channel on the receiver from which the 90- and 150-c/s signals have been removed.

The second element provided is the "glide path" which gives the pilot vertical guidance to make his descent at the optimum angle for good contact and safe approach (Fig. 5*b*). The glide path system consists of another transmitter and aerial system providing two intersecting patterns again modulated with 90 and 150 c/s tones, so arranged that the equisignal line follows the preferred descent path which can be adjusted over a range of 2-4 deg to the horizontal. measured from the point of contact. The path is actually so arranged that it passes 20 ft. above the point of contact.

The glide path operates on frequencies between 328·6 and 335·4 Mc/s and requires a separate receiver in the aircraft. The rectified d.c. outputs due to the tones are fed to a horizontal pointer on the same instrument as is used for the localizer, and this pointer moves down when the aircraft is above the glide path. The system is always arranged so that the 150 cycle pattern is below the glide path. Glide path range is about 10 miles over an 8-deg. sector in azimuth and the transmitter is located beside the runway at the approach end.

It will now be seen that by keeping the two pointers crossed in the middle of the instrument face, the pilot can keep a correct course both in azimuth and elevation. Also the instrument can be placed so that it can be seen at the same time as the other blind-flying instruments and it provides, as they do, information of the simplest type, such as—"fly higher," "fly to the right," etc.

Having now provided the pilot with course and angle of descent guidance, we have to provide some information on his progress along the approach path, so that he can adjust engine speed and trim correctly for the different stages in the landing. This data is provided by three "marker beacons" located along the approach path (Fig. 5*c*). These beacons each consist of an amplitude modulated transmitter with an aerial system projecting signals vertically into the descent path. The first or "outer" marker is situated about 4 miles from the approach end of the runway, the second or "middle" marker is about 3,000-4,000 ft. from the runway and the "inner" about 250 ft. from the threshold. The "outer" is modulated at 400 c/s keyed two dashes per second (and indicates the point for commencement of the descent); the "middle" is modulated at 1,300 c/s, keyed with alternate dots and dashes; and the "inner" is modulated 3,000 c/s, keyed at six dots per second. These signals, which are on 75 Mc/s, are received on a third receiver in the aircraft and the pilot can identify them either by their morse coding or by three lights which are operated through filters to flash when the appropriate signal is received. The patterns of the aerials are such that their signals will be heard by an aircraft travelling on the glide path at 90-100 m.p.h. for times varying from 6 sec for the outer marker to 3 sec for the inner.

It will be seen that by the three elements now mentioned, ILS provides the pilot with the guidance he needs to make a landing in poor visibility. The system is further safeguarded by extensive monitoring equipment on the ground which detects failure or deviation from the required standard of any element and also by small warning flags on the ILS indicator in the aircraft, which appear should the signal level fall below that needed for reliable operation.

It should be noted that it is still advisable to use surveillance radar with ILS in order to make sure that aircraft do not enter the landing path at dangerously close intervals. Both GCA and ILS provide comparable landing aids and both have certain merits and shortcomings, but ILS is now adopted by international agreement as the primary aid for main airports. There are, however, considerable advantages in having GCA available as an alternative or as a monitoring system as has been mentioned previously. In particular GCA, operating with very narrow beams, in not so susceptible to site error as ILS.

The ILS system is of American origin but British equipment is now developed—the airborne equipment by Standard Telephones and Cables and the ground equipment by Pye.

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5. Short Range Navigational Aids

So far, we have not concerned ourselves with the means by which the pilot may arrive with certainty at the correct position for either commencing to land or waiting his turn for landing. In this section, therefore, in considering this point, we shall review those navigation aids whose basic function is to help the pilot arrive at a given position rather than to find with accuracy his present position. In practice, as we shall see, it is not possible to make such a neat distinction between the types of navigational aids since some of the short distance aids are capable of giving accurate fixes with reasonable ease over considerable distances, and some of the long distance aids are able to give (or can be adapted to give) directional guidance to considerable accuracy and at a speed adequate for flight in congested areas. However, these points will be enlarged on later.

5.1. *Ground Radar and V.H.F. D/F*

If the pilot is able to get to within 10-20 miles of the airfield (which is quite practicable even if flying by dead reckoning) the aircraft can be picked up by surveillance radar and courses to fly can then be passed by V.H.F. radio to the pilot. Using this method, of course, the pilot can be told of his actual position at any time.

An alternative system is to use ground-based V.H.F. D/F, of which there are now several types made in the U.K., which give direct and instantaneous indication of the bearing of the aircraft from the station, thus eliminating the need to transmit a special continuous signal for D/F. For a *fix* obviously at least two suitably situated D/F stations must take bearing but courses to steer can be given by one station if located near enough to the destination. The two systems which come to mind as examples of this technique are the one made by S.T.C. which has cathode ray tube presentation and that made by Marconi which has scale-and-pointer presentation. Both these systems will give virtually instantaneous bearing to accuracies of the order of 1-4 deg. on any normal aircraft V.H.F. transmitter within line-of-sight range. Both systems have remote presentation so that the aerial system may be located at a more suitable site than is usually available within the airfield boundary.

5.2. *M.F. Beacons and Radio Compass*

Neither of the systems so far mentioned requires special equipment in the aircraft and they are, therefore, very suitable for handling small machines with the minimum of equipment. Since both systems require individual attention by operators on the ground to each aircraft, they are very prone to overloading and therefore other methods have been devised for use in aircraft which can carry the necessary equipment.

The first of these systems we shall consider is also perhaps the oldest and involves the use of a low power M.F. omni-directional transmitter or beacon suitably sited on the ground, and a radio compass in the aircraft. The radio compass is a sensitive narrow-band communication receiver usually operating over a 100-1,750 kc/s frequency range and provided with a rotatable loop aerial (Fig. 6). This aerial is so controlled by circuits in the receiver, that it will automatically align itself on any transmitter to which the receiver is tuned. The position of the loop is relayed to a remote indicator visible to the pilot which has a pointer moving over a 360-deg. scale. This pointer will always indicate the true direction of the ground station relative to the fore and aft line of the aircraft, sense determination being automatic.

The principles of operation of the radio compass, like those of ground automatic D/F have been widely known for many years and it is not proposed to recapitulate them here, but it is worth noting that the provision of a very narrow I.F. bandwidth gives considerable improvement in performance by reducing the obscuring of bearing by noise and interference from other stations. Equipment is now available whose bandwidth can be reduced at will to 100 c/s.

It will be seen that the radio compass can be used in a number of ways. It can be used to "home" on a given beacon by keeping the pointer on zero, or it can be used to obtain a fix by rapidly taking bearings on two or more suitably placed beacons and plotting the results. This latter process can be speeded up considerably by the use of two radio compasses and these are often carried in large aircraft. In some cases, also, a dual indicator is used which has two pointers on one scale. With a dual compass it is possible easily to fly on a course directly from one beacon to another by keeping the pointers one on 0 deg. and one on 180 deg., or to fly exactly between two beacons on a course normal to the line joining them, by keeping the two pointers at equal angles either side of zero (or 180 deg. when flying *away* from the beacons). With the radio compass passage over a beacon is fairly accurately indicated by a sudden reversal of the direction of the pointer.

Radio beacons radiate M.C.W. signals with modulation keyed with morse identification and the type recommended for use with ILS and similar systems gives reliable radio compass operation up to 10 miles. In this application the beacon is used as a guide to get the aircraft suitably placed for approach to land or as a holding point for aircraft waiting their turn. If larger range is required suitably located broadcast stations can be used—long wave stations providing good bearings up to several hundred miles. The sort of accuracy to be expected from a radio compass *in actual practice* is about ±2 deg although the apparatus is fundamentally capable of better accuracies and many bearings of ½-1 deg accuracy will be obtained.

There are many radio compasses available in the U.S.A. and Europe, and several of these employ loop aerials which can be "suppressed" or sunk level with the skin of the aircraft to reduce drag. This is an important feature for use with high-speed aircraft.

6. Medium-Range or "En-Route" Communication and Navigation

This section deals with en-route navigation over medium distances; the techniques may be said generally to apply to the control of aircraft within continental boundaries where stations for guidance and communication may be established at frequent intervals.

Here we shall deal with a number of systems whose functions overlap those dealt with in the previous section in that they can be used in the later stages of a flight for navigating the aircraft into position for approach and landing.

These systems form the basis for the latest philosophy of aircraft control which is based on the allocation of discrete paths for each aircraft (in accordance with its route and capabilities) and the adherence of the aircraft to those paths throughout its flight.

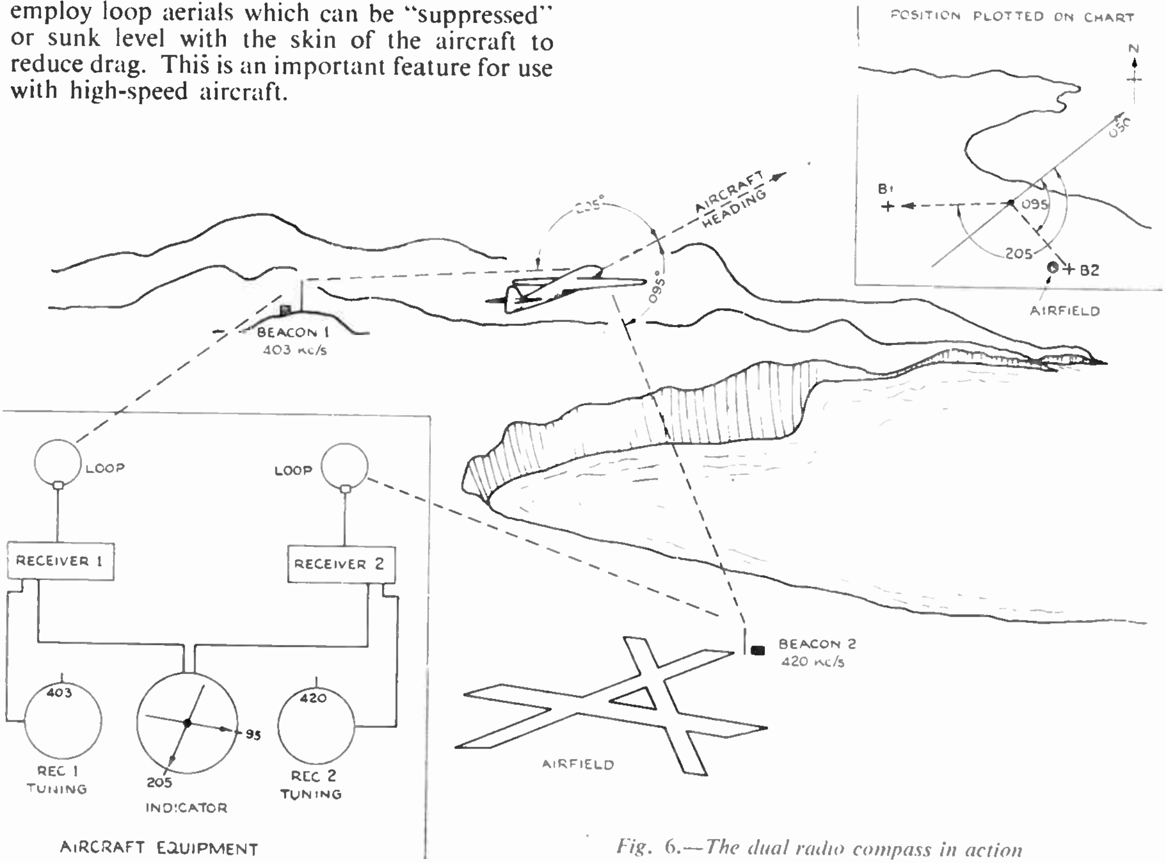

Fig. 6.—The dual radio compass in action

The devices fall naturally into two types—those that provide guidance over only two or four pre-determined courses and those that enable the pilot to fly any selected course at will.

6.1. *Four-Course M.F. Ranges*

The operation of this system can be best understood if we visualize a conventional Adcock aerial system of dimensions suitable for M.F. operation. The centre aerial is fed with a signal somewhere in the 200-400 kc/s range and this provides an omni-directional signal. The remaining aerials are paired in the usual manner and the pairs are fed in succession with a keyed carrier on a frequency differing from that on the centre aerial by some 1,000 c/s. One pair is keyed with the morse character "A" and the other with the character "N." These characters are complementary and if the elements are correctly timed in position and duration, they can be made to "interlock." This feature is illustrated in Fig. 7 and is used as follows. Let us call the aerial pairs "A" and "N" in accordance with the signals they radiate. In accordance with the well-known Adcock polar diagram each pair will produce a figure-of-eight pattern in azimuth orientated in the plane of the pair concerned. We thus have in quick succession, two figure-of-eight patterns at right angles. Beats between the signals from the pairs and that from the centre aerial will cause an audio note to be heard by a suitable receiver in the aircraft and this note will be keyed with predominantly "A" or "N" signals according to the position of the aircraft in azimuth. (If it is in the area where the field of the "N" pair predominates the "N" signal will appear and vice-versa.)

Now it will be seen that at four directions in azimuth (corresponding to the bisectors of the angles between planes of the two pairs) the "A" and "N" signals will be equal in strength and, by virtue of the "interlocking" characteristic in time mentioned earlier, the result will be a steady signal of about 1,000c/s in the pilot's headphones. Any deviation from these courses will cause "A" or "N" signals to appear. Thus the pilot can fly by this means on four definite courses towards or away from the range station. So far we have assumed these courses to be mutually at right angles but the angles between all the courses can be adjusted over a wide range by adjusting the amplitude and phase relationships of the signals in the aerials. The whole pattern can of course be orientated in any desired direction during erection by suitably placing the aerials.

The radio range requires in the aircraft no more than a communication receiver covering the frequencies of the ranges to be flown. It is also helpful, however, to carry a V.H.F. Marker Beacon receiver for reception of the "Z" marker beacons used to indicate the moment of passage over the range station which is difficult to identify otherwise.

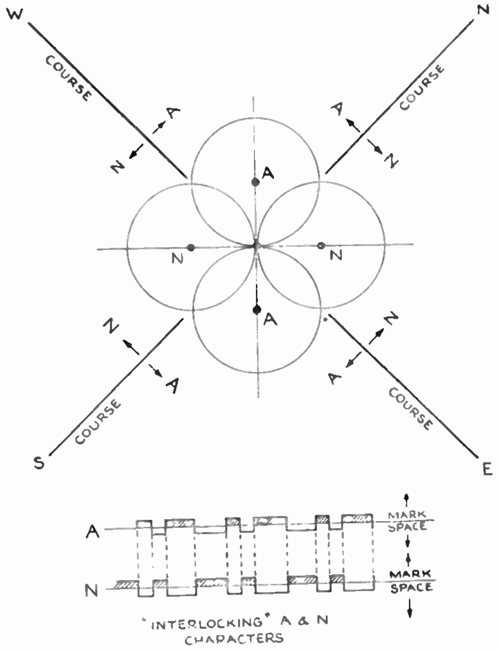

Fig. 7.—Four-course M.F. range

The four-course M.F. range has been in use for many years in the U.S.A. and forms the basic aid for the "airways" system of traffic routing. In this system definite paths between major traffic centres are established and marked by chains of radio ranges. The pilot, in flying from "A" to "B" has thus simply to pick up the appropriate "leg" of the local range on taking departure from "A" and, by tuning in to the successive ranges on the route he can be guided all the way to "B." Intersecting chains of ranges are also provided so that a pilot having to fly for a certain distance along one airway, can turn off at a suitable point by tuning into the first range station in the other chain and turning off along the intersecting "leg."

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It is also possible to use the range stations to transmit weather and other information by amplitude modulating the centre aerial signal with speech and providing an optional filter in the receiver to cut out the 1,000 c/s range signal.

Salient points along the range "legs" such as turning points, emergency fields, etc., are also often indicated by "airways" marker beacons on the range frequency or on V.H.F. keyed with signals coded according to the information to be conveyed.

The M.F. range system is still in wide use in the U.S.A. and a limited number of similarly marked "airways" have recently been put into service in the U.K. but the whole system is now rendered obsolescent in the U.S.A. in favour of a system based on the V.H.F. Omni-directional Range which will be described later. (It should be noted here, that the U.K. and some other European countries have disagreed with this decision, which is based on a system developed in the U.S.A., and have proposed alternative systems which will be dealt with later).

6.2. *V.H.F. Ranges*

The move to the use of V.H.F. for radio ranges is conditioned mainly by their decreased liability to disruption by static, but both M.F. and V.H.F. four-course ranges suffer from the drawback of ambiguity. This can clearly be seen if we consider a four-course range whose legs are respectively NSE and W and let the plane of the A aerial pair be NW-SE and that of the N pair be NE-SW.

Now, an aircraft flying in a *northerly* direction *towards* the range station will have A on the starboard side and N on the port side. This is, however, equally true if the aircraft is flying in a *westerly* direction *away* from the station. These ambiguities can, of course, be resolved by a rough knowledge of the aircraft's position and heading and by taking radio compass bearings, but still the range does not provide by itself complete information about the aircraft's relative direction.

6.2.1. Two-Course Visual-Aural Range

The visual-aural V.H.F. range is an attempt to overcome this difficulty and, as its name implies, is intended to provide visual indication of two courses pointing in opposite directions along the airway. It is not proposed to go into the technique of this system in detail as it represents only an interim device which is already obsolescent. In principle, however, it involves a receiver and a centre zero instrument (the latter can be the same as used for the ILS localizer as the operating signals are the same). The ground station lays down two overlapping patterns modulated respectively with 90 and 150 c/s and the equi-signal zone of these patterns lies along the airway (Fig. 8). Thus the course can be flown by keeping the instrument centred.

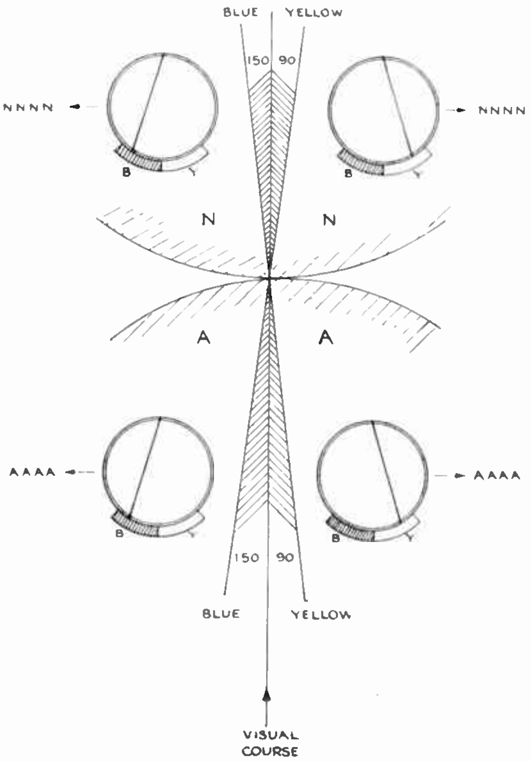

Fig. 8.—Two-course V.H.F. visual-aural range Indicator positions and audio output shown for aircraft in four positions

On the face of the instrument are two coloured sectors which meet opposite the end of the pointer when in its centre position. The right hand sector is coloured yellow and corresponds to the 90 c/s signal and the left is coloured blue and corresponds to the 150 c/s.

The ranges in the U.S.A. are so set up that on North-South airways the yellow sector is to the east of the range and to the south on East-West airways.

It is possible to fly along the range by keeping the instrument centred, and also to tell which side of the course the aircraft is on, by the colour to

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which the needle points but, to take the example of a North-South range, the pilot also wants to know whether he is North or South of the station. This problem is solved by laying down another signal which produces the Morse character of "N" in the Pilot's headphones when he is to the North of the station and "A" when he is to the South. A similar arrangement holds for East-West ranges. Thus, by noting the pointer position in conjunction with the Morse character heard, the pilot can readily determine whether he is East of the airway and South of the range station—or what—and can thus roughly determine his position. All he has to know to avoid ambiguity completely is which way the aircraft is facing, which is not asking a great deal.

At some airports which form the terminals of a chain of ranges, the last range station is sometimes used as an ILS localizer, in which case it is so arranged that the "N" signal prevails while the aircraft is on the far side of the range from the airport and the "A" signal between the range and the runway.

6.2.2. The Omni-Directional V.H.F. Range (VOR).

We now come to consider the second type of range mentioned in the opening paragraph of this section—namely, that which enables the pilot to fly any course he may select with reference to the station. This facility is not the exclusive property of the V.H.F. omni-range; it can also be obtained with some of the primarily long range navigational systems, but these will be dealt with later.

VOR has been the subject of great controversy both in the U.S.A. and Europe and although a great deal of time and money has been spent in the U.S.A. on the evaluation of its performance and accuracy, the data is still not regarded as complete by many authorities, and work is now also going on in the U.K. with the aid of range stations lent by the U.S.A.

The V.H.F. omni-range station works usually between 112 and 118 Mc/s and radiates a rotating field pattern so that a receiver situated at any point around the station will receive a signal amplitude modulated at a frequency corresponding to the rate of rotation, which is about 30 c/s. At the same time the station radiates an omni-directional signal on the same radio frequency, and this carrier is amplitude modulated at 10 kc/s (actually 9,960 c/s). Thus, the receiver is producing two audio signals, one of 30 c/s and one of 10 kc/s. The 10 kc/s signal is frequency modulated by a signal of exactly the same frequency as that produced by the rotating pattern and phase-locked to it, so that an aircraft in a position due magnetic north from the station would receive both 30 c/s signals exactly in phase. It will now be seen that at other positions round the station the phase difference between the signals due to the rotating pattern and that due to the reference signal will vary through 360 deg. according to the bearing of the aircraft with respect to magnetic north. Thus all we have to do to determine the bearing is to recover the 30 c/s reference signal from the 10 kc/s sub-carrier and compare its phase with that of the signal due to the rotating pattern.

The rotating pattern can be produced either by feeding an Adcock system from a spinning goniometer or by using a rotating directional aerial system. In either case the correct phase relation between the rotating pattern and the reference signals is ensured by mechanically coupling the 30 c/s generator to the mechanism producing the rotating pattern. In an attempt to avoid the more prolific causes of site error the aerial system is horizontally polarized and therefore requires a separate aerial in the aircraft from the vertically polarized one used for V.H.F. communication.

In its simplest form the airborne equipment comprises a normal A.M. V.H.F. receiver with provision for recovering the 30 c/s frequency modulation from the sub-carrier and a phase meter for comparing the phase of the variable signal with the reference tone.

To examine the method of operation a little more closely, let us take the case of an aircraft on a magnetic bearing of 045 deg. from the range station, and let the direction of rotation of the pattern be such that the variable phase signal lags 45 deg. on the reference phase at this point (Fig. 9). If we can now measure the phase difference between these two signals in the aircraft, we shall be able to indicate to the pilot that he is on the bearing already stated from the station. This can be done by means of a calibrated phase shifter to adjust the phase of the reference signal and some sort of indicator to show the correct adjustment. Since quadrature is easier to indicate accurately than phase coincidence the phase shifter is usually arranged so that for a given indicated setting it actually produces a signal 90 deg. in advance of the

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indicated angle. Thus, when the phase shifter is set to 45 deg. it feeds into the quadrature detector (a phase sensitive rectifier system feeding a centre zero meter) a signal which is 90 deg. in advance of the variable phase signal which is also fed to the detector. Under these conditions the meter will indicate a balance.

It will now be seen that to take a bearing from the range station it is necessary only to rotate the phase shifter until the meter is centred and read off the bearing from the scale of the phase shifter. It is also possible to fly along any chosen radial bearing by altering the course of the aircraft to keep the instrument centred.

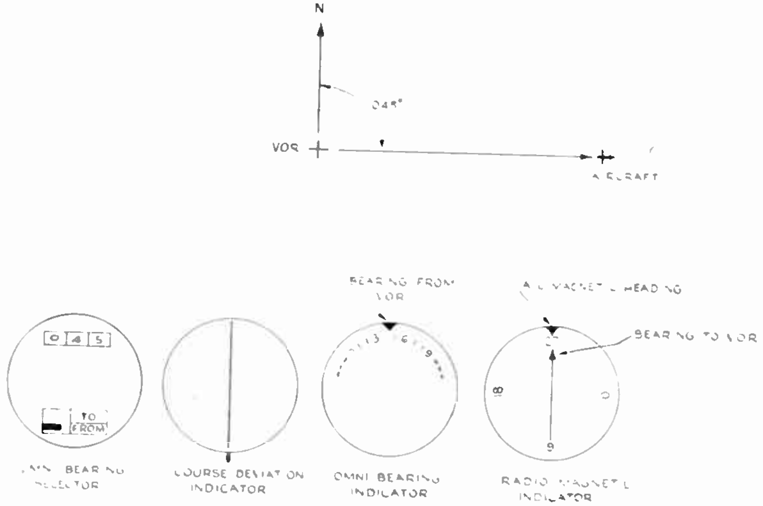

Fig. 9.—VOR aircraft instrument readings
(For aircraft 045 *deg. from VOR and heading* 270 *deg.)*

With this simple system there is ambiguity due to the fact that the detector will only indicate quadrature. Therefore, there will be two settings of the phase shifter at which balance will be given (one at the correct setting and the other when the reference signal *lags* 90 deg. on the variable signal). Thus, the bearing may be 045 deg. from the station or its reciprocal 225 deg. This difficulty is soon resolved. The reference phase output from the phase shifter can be advanced a further 90 deg. by a fixed phase shifting circuit and again compared with the variable phase in a simple phase comparison circuit. This circuit operates a subsidiary indicator which is deflected one way if the two signals are in phase and the other if they are in anti-phase. There is no need for accuracy here, as we merely have to indicate two widely differing conditions.

As an example, let us assume that we have the same conditions as before and have set the phase shifter to 045 deg. This produces a signal 90 deg. advanced on the variable signal. If this signal is advanced in phase another 90 deg., and compared again with the variable signal they will be in phase opposition. This will deflect the ambiguity indicator in one direction which we label "FROM," indicating that the bearing we have determined is the bearing *from* the station, which is the information the V.H.F. omni-range is intended to give. If we rotate the phase shifter to 225 deg. we again get a balance on our main instrument but the two signals in our subsidiary phase comparator are now in phase and the indicator will be deflected in the opposite direction which is labelled "TO." This indicates the course to set if we want to fly *to* the station along the radial selected. This eliminates the need for the pilot to compute mentally reciprocal bearings and also helps to prevent errors due to wrong interpretation of the instrument.

The "to-from" indicator is usually incorporated in the Radial Selector which can with advantage have "veeder-counter" type of presentation enabling the radial to be indicated directly in figures. The course-deviation indicator can also be the same instrument as is used for the ILS localizer.

One advantage of the VOR system over the radio compass is that it is not "heading sensitive," that is, it will indicate the bearing of the aircraft from a given point directly, no matter in what direction the machine may be pointing at the time.

The airborne VOR equipment can also be made to give direct indications without the use of the manual radial selector by using the signals produced by the phase comparator to rotate a similar phase shifter through a servo system. The moving element will be rotated until it takes up a position corresponding to the bearing from the range station, which will then be indicated on a dial attached to the moving element. In this case the ambiguous indication is avoided by making the setting corresponding to the reciprocal course an unstable condition of the servo

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system which will prevent the instrument stopping on this point.

If "heading sensitive" indications are required from the VOR equipment, this can be arranged by feeding the omni-bearing information used by the instrument just mentioned to another instrument where it moves a pointer over a rotating 360-deg. scale controlled from the remote aircraft's indicating compass. Since the scale will rotate according to the aircraft's magnetic heading an additional facility is now provided by a fixed pointer against which the scale rotates, giving indication of the aircraft's heading with respect to magnetic North on the same instrument. The *moving* pointer shows bearing *to* the station.

In addition to the navigational information which the station provides, the VOR omnidirectional aerial signal is modulated by Morse identity coding and also by speech for weather information, etc. These can be heard on the audio output of the receiver, from which the navigational signals have been removed, without interruption of the navigational facility

It is perhaps worth while reviewing the equipment involved in a modern VOR airborne installation and the facilities it provides. A typical American installation comprises a receiver working on all the 100-kc/s channels from 108 to 135 Mc/s. In this range it can receive ILS localizer (108-112), V.H.F. Two-Course Range (108-110), VOR (112-118), and V.H.F. Communication (118-132). The circuits for operating the displays for each service are automatically switched in as the frequency is selected. Two aerials are needed—one vertically polarized for communication and the other horizontally for navigation. Instruments in a full installation will be cross-pointer Course Deviation Indicator (for ILS, Two-Course Range and VOR), Omni-Bearing Selector (for use with Course Deviation Indicator for accurate flying of radial courses), Omni-Bearing Indicator (for direct indication of bearings from range stations) and Radio Magnetic Indicator (for heading-sensitive bearings on VOR). This latter instrument often has a second pointer which can be operated by a radio compass. With the addition of a Glide Path Receiver (to operate the horizontal needle of the Course Deviation Indicator) and a Marker Beacon Receiver (both of which need an additional aerial each) the equipment provides complete ILS facilities as well.

It will be seen from the foregoing description that the VOR system, which is claimed to give accuracies of ± 2 deg. up to ranges of 100 miles (line of sight) and up to vertical angles of at least 40 deg. from the aerial system, provides a very useful system of short-range navigation. Reports on experimental installations in the U.S.A. have made it appear, however, that the system is prone to site error to an extent which may make it difficult to find suitable sites in all cases and, while experiments still continue, opinion in the U.K. is reserved on the question of its adoption as the standard short-range aid and we have dissented from the international agreement on its adoption.

6.2.3. The R-Theta System of Position Fixing

As a natural sequel to our brief review of VOR it is worth considering the R-Theta system of position fixing of which VOR forms a part.

We have a method, in VOR, of determining bearing from a fixed point in terms independent of the heading and attitude of the aircraft. If we could now measure our distance from the point we could define the geographical position of the aircraft in terms of polar co-ordinates with reference to a known point (the site of VOR beacon).

DME (Distance Measuring Equipment) is intended to give this distance information.

DME comprises basically a ground transponder beacon, which, when interrogated by a suitable aircraft equipment, provides a response enabling the distance of the interrogater from the beacon to be determined in the aircraft by measurement of the interval between radiation of the interrogation and receipt of the response. This technique is of course familiar through its use in radar transponder beacons, but in the case of DME the technique is a little more elaborate in that the presentation is in the form of a direct reading on a dial calibrated in miles and pulse coding is used with R.F. channel selection to make available a considerable number of independent channels. DME is intended to give line-of-sight coverage up to 200 miles and each beacon is to be capable of responding to simultaneous interrogation by up to 50 aircraft. Accuracy predicted for the British equipment under development by Ferranti is ± ½ mile, or 3 per cent. (whichever is the greater).

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It is intended that there shall be 10 interrogation frequencies spaced 2·5 Mc/s apart between 963·5 and 986 Mc/s (these are interrogation channels 1 to 10) and 10 reply channels at the same spacing between 1,188·5 and 1,211·0 Mc/s (these are reply channels 00 to 90). The use of every combination of interrogation and reply frequency gives 100 DME channels which are numbered 1 (reply channel 00, and interrogation channel 1) to 100 (reply channel 90, interrogation channel 10).

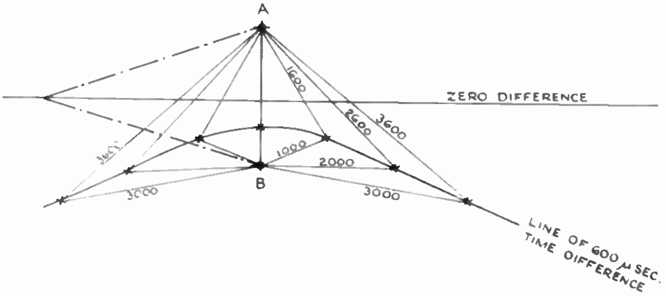

Fig. 10.—*Hyperbolic system, showing generation of line of constant* 600 μsec *transmission time difference from two stations A, B. Zero difference line right-bisector of base-line*

In order to increase protection from interference between channels the interrogation and reply signals consist of double 2·5-microsec pulses with 10 different separations. The pulses are spaced from 14 to 77 microsec in multiples of 7 and interrogation and response spacings are paired to make 10 "modes" from "A" (interrogation 14, response 77) to "J" (interrogation 77, response 14). Each DME channel is paired with a different mode, so chosen that adjacent channels differ in mode as much as possible. (Thus, DME channel 1 (reply 00, interrogation 1) has mode A, and channel 2 (reply 00, interrogation 2) has mode D, etc.)

It has been further proposed that each beacon should radiate an identification signal consisting of three letters. These letters would be displayed visually to the pilot and would be transmitted in a binary code. One code element would be transmitted by a pulse 10·5 microsec after the second pulse of the DME reply and the other by a pulse 24·5 microsec after the second pulse.

There is still a considerable amount of work to be done in reaching universal agreement on the details of DME operation (such as identification) and work is still being done in the U.S.A. on the evaluation of DME performance. It will be seen, however, that if the system fulfills expectations a single-site installation consisting of a VOR and a DME equipment will give complete instantaneous fixing service to all aircraft within a radius of 100 to 200 miles in any direction. The information will moreover be in simple terms—range and bearing from a known point.

6.2.4. Gee

This section would not be complete without mention of the Gee system of navigation which was devised in this country during the late war and was the primary medium distance position-fixing system for the European area from 1942 onwards.[2]

Gee belongs to that group of navigations aids known as "hyperbolic" systems because (in common with Loran and Decca, which will be described later), it provides a series of intersecting position lines which are hyperbolæ with foci corresponding to the positions of the stations of the system, and it is worth considering for a moment the basic principle of this type of system.

It will be clear that if we take two points on the ground and measure accurately the distance from our aircraft to each of the points we can fix its position in one of two places (one on each side of the line joining to two ground reference points). If we know which side of this line we are, we can resolve this ambiguity, or we can provide another reference point so placed that any position corresponding to a particular set of three distances is unique.

Now, in order to measure the actual distances from the aircraft to the reference points by radio, we shall have to use some sort of interrogator responder combination as in DME and this is done in the case of "Shoran" (an accurate system of position fixing used in the U.S.A. for aerial survey work and checking of less accurate systems, such as VOR stations).

If we decide not to use this system but to employ continuously radiating ground stations (which have the great advantage that they can be used by any number of aircraft without saturation) we can no longer determine the *actual distance* to each station by measuring the time of travel of a pulse over the double journey between aircraft and station. We can, however, measure the *difference in distance* from the aircraft to each of two stations by noting the difference in arrival time of pulses sent out simultaneously from each station (Fig. 10). It can be shown that if we plot the locus of a point, the difference of whose distances from two stations is constant, that this will be a hyperbola with the two stations as foci. The line corresponding to no difference in distance will of course be a straight line, the right bisector of the line joining the two stations (Figs. 11*c* and 12).

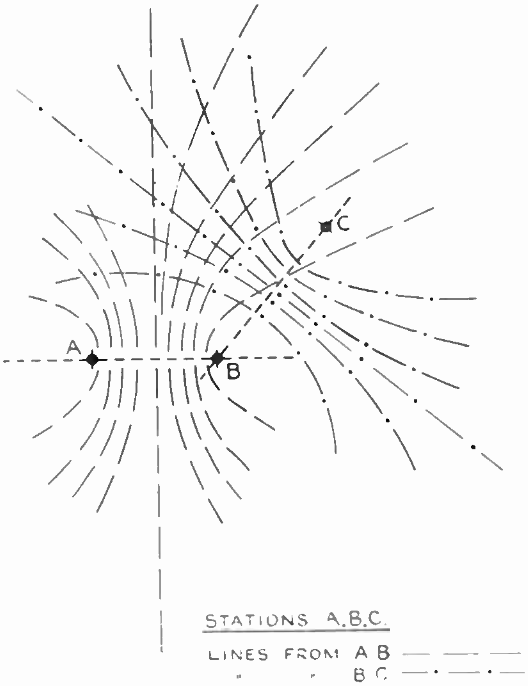

Fig. 11.—Intersecting position lines for any hyperbolic system: Gee, Loran or Decca

Gee operates on this basic principle. A Gee pair capable of producing a set of position lines consists of a "master" station radiating 6 microsec pulses. These pulses are received by the aircraft and they also trigger the other or "slave" station (which is situated about 70 miles away), causing it to radiate pulses which are also picked up by the aircraft. Thus, the aircraft will receive two pulses at different times, one of which will arrive at a time corresponding to the distance from the master to the aircraft and the other corresponding to that from the slave to the aircraft plus the distance from master to slave.

Gee stations operate on frequencies of 20-85 Mc/s with powers of 300 kW peak and the aircraft equipment comprises a receiver for this band and a cathode ray display enabling the spacing between the arrival times of the master and slave pulses to be measured.

The data from this pair will give a family of hyperbolic position lines spaced apart at intervals corresponding to the accuracy with which the time difference can be determined. In the case of Gee this can be said to be about 1/10 of the pulse width or 0·6 microsec. From this information we can deduce information about the accuracy and coverage of the pair. Firstly, as the hyperbolæ diverge as the distance increases the absolute accuracy will fall with distance although remaining almost a constant percentage of range. It varies from about 100 yards on the base-line joining the two stations to about 5 miles at 450 miles range. Secondly, if we progress in azimuth round the pair we see that at angles near the extension of the base-line the least change of timing we can measure corresponds to a large variation in azimuth and can, therefore, introduce large errors in the locating of our position lines. In practice the accurate coverage of a Gee pair is about 120 deg. centred about the right-bisector of the base-line.

It will thus be seen that to obtain complete 360-deg. coverage with accurate position lines we need three slave stations distributed at 120-deg. intervals and each about 70 miles from the master. The position lines generated by these three pairs will also cut at angles sufficiently obtuse to give accurate and unambiguous fixes at short and medium distances from the chain but the angle of cut will become too acute for accurate fixes at distances great compared with the base line length. This will result in the radial accuracy of the fix being low and in fact this accuracy varies approximately inversely as the square of the distance from the chain while the position line accuracy decreases only as a direct function of distance. The only way to improve this accuracy at distance is to increase the base line, or to use pairs of stations so placed that the hyperbolæ cut more nearly at right angles. This cannot be achieved by the four station system mentioned above.

The general trend of the foregoing reasoning applies to all hyperbolic systems and should be borne in mind when considering the other, longer distance, systems.

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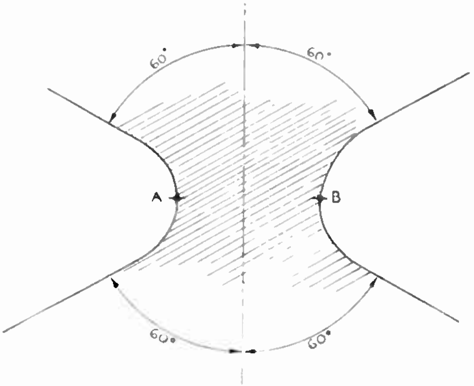

Fig. 12.—Gee, Decca or Loran coverage from single pair A, B

There are at the moment, seven Gee chains in operation in the U.K. and Western Europe. These are the Scotland, Eastern, Southern and South Western in the U.K. and the Rheims, Loire and Carcassonne on the Continent. Between them, these chains give coverage of much of the U.K., France and Western Germany at 5,000 ft.

It is worth noting that Gee is immune from errors due to night effect (being exclusively a ground wave system) and choice of the sites is not at all critical. This latter attribute is true of all "wide aperture" systems versus "one site" systems, such as VOR. Against this, Gee is not a direct-reading device and the operations to obtain a fix take about a minute. On the other hand, however, the hyperbolæ can be used as track guides by simply holding a course which causes the time difference for any pair of stations to remain constant.

6.2.5. A Gee Track Guide System

A system proposed by Cossor to utilize the above facility would provide a device giving coverage over a limited azimuth comparable in number of radial tracks with VOR, but probably capable of greater accuracy and much less subject to site error.

Suppose we place on either side of the airfield, or other point to which we wish to lay down tracks, a master and slave Gee station about 10 miles apart and so disposed that the right bisector of the base line lies in the required direction of approach and passes over the required point. It can be shown that in these circumstances the hyperbolic position lines may be regarded as straight lines radiating from the centre of the base line for all distances greater than three times the length of the base line. Working from the known resolution of the system we also see that there will be about thirty readily distinguishable tracks disposed in the 60 deg. either side of the right bisector where the accuracy is acceptable. These can be said to correspond to some of the radials of a VOR station. It can further be shown that seven of these tracks (the right bisector and three tracks each side) will also pass within 1½ miles of the centre of the base line. This is close enough to place the aircraft using them in a suitable position for GCA or ILS landing. The separation between these seven tracks would be about 4 deg.

Since each line corresponds to a definite time difference between master and slave pulses it would be easy to make the pulse spacing operate a centre zero meter through suitable circuits which would give a left-right indication for deviations from the chosen course. This presentation is suitable for pilot operation, and overall accuracy of course (including stability of equipment and aircraft handling) should be better than ±¾ deg. Using transmitters of 1 kW peak power the range should vary from 50 miles at 1,000 ft. to 145 miles at 10,000 ft. with the station aerials at ground level. With the station aerials at 300 ft. cover should be 75 miles at 1,000 ft. to 165 miles at 10,000 ft.

7. Long Distance Communication

Long range communication between ground and air is currently carried out by H.F. C.W. telegraphy on frequencies between 2 and 18 Mc/s. Manual Morse is used and aircraft transmitters range in power up to 150 W. Most aircraft transmitters are crystal controlled on up to 10 pre-set channels and most aircraft receivers are continuously tunable. Ground equipment is of the conventional type used for long distance H.F. communication with transmitters and receivers on different sites and controlled remotely. The aircraft station is usually worked by a wireless operator.

Air-ground ranges of up to about 1,000 miles are required and the provision of an efficient aircraft aerial present some problems. The trailing aerial, much used in the past, is falling into disuse with the increasing speed of aircraft in favour of fixed aerials running from a mast near the nose to the tail fin. These aerials vary in length from 40-80 ft. according to the size of the machine and usually have to be fairly heavily loaded at the lower frequencies with consequent loss of radiated power.

The advent of jet aircraft has made even the drag imposed by fixed aerials unacceptable and much work has been done on completely suppressed H.F. aerials. This technique usually takes the form of excitation of some large part of the aircraft structure, and brings in its trail new problems of decreased radiation efficiency and limited frequency range.

Static interference is a serious problem at H.F., especially precipitation static due to the passage of the machine through electrically charged rain or snow. This type of interference is very common and can be extremely serious. A great deal of work has been done on its suppression and the cure involves such things as wick dischargers at points of the machine known to accumulate high charges and also large diameter insulated covering for the whole of the aerial system. The wick dischargers consist of lengths of stranded semi-conducting material fastened to the trailing edges of the wings and other such points to dissipate gradually the accumulated charge.

In order to simplify long-distance communication a requirement has arisen for a high-power R/T equipment with 20 to 30 crystal-controlled channels suitable for operation by any member of the aircrew. It is also possible that single side-band working may eventually be adopted to save channel space and also to reduce weight and power consumption of the aircraft set. There seem to be considerable snags in the adoption of long-distance R/T working as distinct from W/T, the main ones being the need for more bandwidth per channel which would be a heavy tax on the narrow band allotted to aircraft working and also the lower interference and noise levels that can be tolerated in R/T working.

The use of radio teletype or facsimile for ground-to-air transmission of weather reports and other data which may be required for use some time after receipt has also been suggested. Such a system would obviate laborious copying of dictation-speed messages by aircrew.

It is also possible that the need for very long-range working may eventually be obviated by providing multi-channel long range point-to-point radio links with relay and drop-out facilities at strategic points along major world air routes, so that at any time on a long flight the actual air-ground link would be comparatively short.

8. Long-Distance Navigational Aids

Long-distance aids need not be suitable for pilot operation, they are mainly for the navigator and consequently the requirements governing speed of operation and type of presentation are not so stringent. Of the three we shall review here, two (Loran and Decca) are hyperbolic systems, while the third (Consol) is a radial position line system. All are in current use.

8.1. *Loran*

Loran is similar in principle to Gee but operates on frequencies of the order of 2 Mc/s and consequently has considerably greater range under some conditions.[3] Daytime ranges of up to 700 miles over water are obtained, but this is reduced to 100 to 250 miles over land. At night, sky wave operation increases ranges to 1,000-1,400 miles. Sky wave operation gives some errors due to variable transmission times, but these decrease with distance and serve in some measure to cancel the increasing geometric errors. The altitude of the aircraft has very little influence on Loran range, and even over land by day little increase will be found above 1,000 ft.

Due to its limitation over land, Loran is primarily an aid for navigation over large sea areas and consequently its stations are usually disposed as long chains of three or more along major sea coasts. Each chain has its "master" which triggers the other stations.

Loran transmits much longer pulses than Gee due to the necessity to conserve channel space on the lower frequencies. Pulses are of the order of 100 kW peak and 50 microsec duration with a P.R.F. of the order of 25 per second. Adjacent stations operate on the same P.R.F. which differs slightly from the other pairs in the chain so that with five or six stations in one chain the navigator can pick out the pair he requires by synchronizing the time base of his C.R.T. display to the desired P.R.F. All stations except the end one are double as they each form a part of adjacent pairs.

As an example, the North Atlantic is covered by five stations distributed along the east coast of the U.S.A., Nova Scotia and Newfoundland together with a chain of three between Newfoundland, Labrador and Greenland and another three between Iceland, the Faeroes and the Hebrides. These stations form a total of eight pairs and give the navigator three, four or five sets of position lines according to his location.

It is not possible, without considerable duplication of equipment, to obtain two position lines simultaneously (as with Gee) due to the difference in P.R.F. between the pairs and consequently a Loran fix takes longer than with Gee.

Loran accuracy is subject to all the restrictions already discussed which are applicable to all hyperbolic systems. Using a three-station chain, average errors in the ground-wave region range from about 300 yards at short distances up to 1 mile at 700 miles. On sky-wave, errors at distances from 300 to 1,400 miles range from 1½ to 8 miles.

The Loran pulse is considerably rounded and consequently the measuring technique involves adjusting the amplitude of the two pulses to be as similar as possible and then matching by superimposition. This becomes difficult if the pulses are considerably distorted by sky-wave transmission and contributes to the inaccuracy on sky-wave operation which is further complicated by the need to apply corrections before using the charts, which are computed for ground-wave working. In normal working, time intervals can be determined to within about 1 microsec.

It is worth noting that although the band used by Loran is subject to heavy noise and interference in most parts of the world this has surprisingly little effect on its utility, as Loran signals can be read through interference of much greater amplitude.

8.2. *"SS" Loran*

In an attempt to utilize the great night-time sky-wave range of Loran to increase the base-line the "SS" or Sky-wave Synchronized system was evolved. This uses sky-wave to transmit the synchronizing pulses from Master to slave stations and enables spacing to be increased up to the limit of sky-wave coverage.

The ideal station siting for this system is with four stations at the corners of a square. Useful coverage extends over nearly the whole area of this square, which might be up to 1 million square miles. The accuracy, as controlled by angle of cut and spacing of the position lines, is highest at the centre of the square but at no place are the errors due to this factor likely to exceed 1¾ miles. Due to the use of sky-wave for both synchronizing and transmission paths, errors due to variations in height of the reflecting layer may reach 8 microsecs, causing an error of the order of 1 mile at the centre of the area. A further random error due to unpredictable excursions in the path length caused by ionospheric storms may lead to errors of 5 miles or so but these do not usually occur more than about 1 per cent. of the time.

Serviceability is surprisingly good, averaging over 95 per cent. of the night hours except when the reflection points are in the auroral zone.

8.3. *L.F. Loran*

A system of Loran has been devised which operates on frequencies of the order of 200 kc/s and has a coverage of the same order as the sky-wave range of Standard Loran irrespective of time of day. The pulse width is increased to 300 microsec, to economize in channel space and for other reasons, and timing is consequently less accurate than Standard Loran, being about 4 microsec. This error is mitigated by the improved accuracy due to the longer base line. Due to the fact that the signal does not penetrate the E layer, the long train of sky waves which make pulse identification difficult with Standard Loran are not present and due to the long pulse length the E reflections overlap the ground wave and most of the energy arrives in a single pulse.

The band width required for a chain is 20 kc/s and P.R.F. selection would enable 16 chains to be operated on one R.F. channel. About 12 chains would cover the major part of the globe.

A system of cycle matching (or comparison of the phase of the R.F. signals) has been devised for both synchronization and interval measurement which gives accuracies of 1/10 microsec and correspondingly increased accuracy of fix.

8.4. *Decca*

Decca is a hyperbolic system operating on L.F., but differs from the other systems so far described in that its stations radiate continuous waves.[4]

The basic principle of operation can be appreciated if we consider the case of two stations separated by 50 to 60 miles. If we radiate signals locked in frequency and phase from each of these stations, the relative phase of

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the two signals as received at any point around the stations will depend on the relative path distances between the point and each of the stations. Position lines corresponding to constant path differences will be hyperbolic.

Consider the base line between the two stations and assume that the phase relationship between the master and slave station is so adjusted that there is phase coincidence at the master station. As we progress along the base line towards the slave we shall pass through points of phase-coincidence at half-wavelength intervals, and extending from these points in each direction roughly normal to the base line will be hyperbolic position lines of phase-coincidence. It is also obvious, of course, that between these lines, there is an infinite family of hyperbolæ corresponding to other constant phase relationships. If we have in the aircraft a phase meter enabling us to read off these phase differences we can establish our position on any one of these sets of lines. It will also be seen that if there are a number of lines of phase-coincidence we shall only be able to say that we are on any one of the lines between any two adjacent such lines which correspond to the phase difference we have measured. Thus, in the basic system there is a high degree of ambiguity.

If we consider the practical application of this system we see that it will not be practicable to radiate on the same frequency from each station as we shall not be able to tell which signal comes from which station. This difficulty can be overcome by radiating two signals on different but simply related frequencies (such as 90 and 120 kc/s). We can receive these signals on two receivers, and by multiplying one by four and the other by three we can produce common frequencies of 360 kc/s whose phases we can compare. The process of reception and conversion to the comparison frequency must be achieved without disturbing the phase relationship between the two signals, but this is quite practicable with modern technique. A little consideration will also show that the position line spacing is a function of the *comparison* frequency. Thus the hyperbolæ of phase-coincidence, for instance, will be separated on the base line by distances of half a wavelength at 360 kc/s which is 430 metres. It will also be seen that the higher we make the comparison frequency the greater will be phase change for a given change of position and consequently the greater the sensitivity of the system (and also the greater the ambiguity because the number of "lanes" bounded by position lines of similar phase will be increased.)

The Decca systems in operation work on the above basic principle and each chain usually consists of a master and three slave stations giving approximately 360 deg. azimuth cover. Frequencies used are of the order already mentioned and siting of the stations is not critical. Phase comparisons are carried out on a separate meter for each slave station, the meters having 360-deg. scales. Position fixing is carried out using special charts over-printed with hyperbolæ corresponding to the various pairs in the chain. Transmitters of the order of 1-2 kW are used feeding simple vertical aerials with heavy top loading.

It will be seen that in operation, as the aircraft moves to and from over the phase pattern the pointers on the meters will rotate continuously to and fro in sympathy. As the meters are provided with counters to indicate the number of revolutions of the main pointer, if each meter is set up to the number of complete revolutions, corresponding to the initial position of the aircraft its subsequent position can be read off at any time from the meters, as these will have revolved in sympathy with the number of lanes crossed (which will be indicated on the counters) and the exact position in the lanes will be indicated by the main pointers. This feature has valuable application in connection with various forms of track and position recording devices which are now being developed.

The accuracy of position line indication in any lane varies from about ± 10 yards on the base line of any pair to about 100 yards at 200 miles. Accuracy of fix may be rather worse than this, depending on the angle of cut of the position lines used, as in other hyperbolic systems. It is clear though, that Decca is an extremely accurate system up to about 300 miles. The system is subject to considerable errors at distances where the sky-wave is appreciable and work still remains to be done on the long-range aspect. It appears, however, that useful results may probably be obtained on long ranges.

Using narrow-band receivers the system has a remarkably high degree of protection from interference although it is not so good in this respect as the pulse systems.

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Much work has been done on the solution of the ambiguity problem, and the systems of "lane identification" produced depend basically on the laying down of a very coarse pattern (between each pair of stations) which has no ambiguity and at the same time sufficient discrimination for an indicator to show which lane the observer is in at the time of transmission of the lane-identification signals.

There are several Decca chains in operation in the U.K. and on the Continent, a typical one being Sidmouth (Master), Bournemouth (Red Slave) and Helston (Green Slave).

8.5. *Consol*

Consol is a M.F. C.W. system which lays down a series of radiating position lines similar to VOR except that the service area of a station is confined to two opposite sectors 120 deg. wide. Only one station is required for a set of position lines and two for a fix, as distinct from Gee, Decca and Loran.

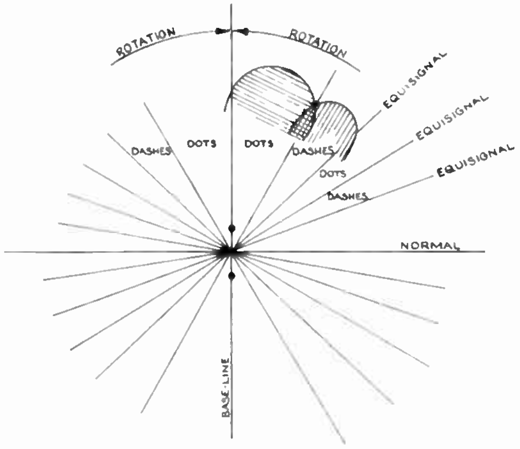

Fig. 13.—Consol radiation patterns

The station consists of a transmitter feeding three vertical aerials about 300 ft. high situated at equal intervals along a line about 3-4 miles long which forms the base-line of the station. The signals to these aerials are so phased and keyed that two overlapping patterns of narrow lobes are set up. These lobes are of equal strength and shape and one pattern is keyed with dots and the other with dashes (Fig. 13). The keying characteristics interlock so that along the equisignal line, where adjacent lobes overlap, a continuous signal will be heard. The phase of the inputs to the aerials is altered in synchronism with the keying speed so that these equisignal lines rotate in such a manner that during the keying cycle each line moves to take up eventually the same position as the one next to it. The lines on one side of the station move in one direction and those on the other side in the opposite direction. At the end of a cycle the patterns revert to their original positions. Each keying and rotation cycle is preceded by the call-sign and a long dash followed by a break to act as a warning to the navigator to start his observation.

Now, if we assume that an aircraft is situated at some point in one of the 24 sectors set up by the station and has a C.W. receiver tuned to the station, the operator will hear the identification signal followed by, say, a succession of dots which will fade into a steady tone as the equisignal line passes the aircraft's position. After the equisignal dashes will appear until the cycle finishes.

It will thus be seen that the angular position of the equisignal line when it passes the aircraft can be determined by counting the characters heard before and after the steady signal, as their number is fixed and their spacing is locked to the rotation speed of the pattern. Tables are available which show the bearings corresponding to different counts for each station.

It will be seen that there is ambiguity in the system but this can easily be resolved by taking a radio compass bearing of the station which will identify the sector, after which the precise radial position in the sector can be determined from the tables.

Daytime ranges of Consol are of the order of 700 miles over land, and 1,000 miles over sea. At night the range may be expected to increase considerably but errors due to sky-wave will be found as with the other long-range systems. These errors will, however, be negligible along the right bisector of the base line, which is useful should it be desired to use a station as a long-range single-track guide.

Accuracy of Consol under normal conditions is at best about 0·2 deg. and at worst 0·5 deg. near the right bisector of the base line, deteriorating to 0·4-1·0 deg. towards the 60-deg. limit of coverage either side of the normal. Speed of fix is dependent on the length of the Consol cycle

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which varies from 40-120 seconds. In general 3-5 minutes should be sufficient to get a fix from two stations.

The system has the advantage that it requires no special equipment in the aircraft and siting is not critical.

There are at present Consol stations at Bushmills (N. Ireland) on 266 kc/s with a 40-second cycle, Stavanger (Norway) on 319 kc/s and a 120-second cycle, Plonéis (France) on 257 kc/s with a 40-second cycle, Lugo (Spain) on 303 kc/s and Seville (Spain) on 311 kc/s both with 120-second cycles.

These stations give position-fixing coverage over the North Sea and all the western sea coasts of Europe down to the south of Spain and also considerable areas of the Atlantic, including the waters west of the British Isles for several hundred miles, the Azores and Iceland (Fig. 14).

9. Administrative Communication

This comprises the world-wide network known as the "Aeronautical Fixed Telecommunications Service."

Civil aviation to-day is a highly organized affair and the flight of an aircraft is subject to all manner of local and international controls and regulations. There is also a comprehensive meteorological information service on an international basis and extensive rescue services in case of accident. Liaison with the air force authorities in various countries must also be provided for reasons of national security and to prevent accidents due to service aircraft becoming entangled with civil aircraft.

All this requires a very extensive administrative machine and, when coupled with the private requirements of airlines for communication with their aircraft and agencies, the total demand for practically world-wide communication channels of high capacity, is surprisingly large. A further complication is the high speed of transmission and distribution required for messages connected with aircraft movements. These messages must be received and distributed to numerous addressees while an aircraft is in transit and the system must have sufficient capacity to deal with heavy message traffic in abnormal conditions (such as in the case of missing aircraft) without disrupting the handling of normal aircraft movement messages.

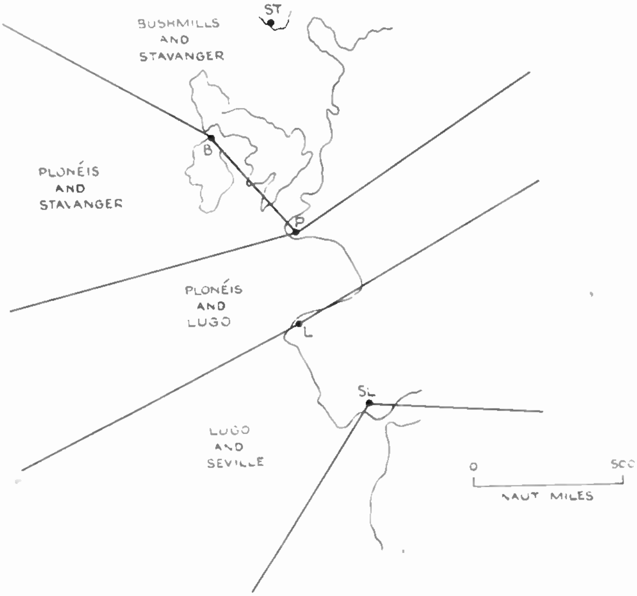

Fig. 14.—Consol station coverage

In order to appreciate the scope of the communication service needed, let us consider a generalized aircraft operating system. The area under a particular administration will be divided up into a number of adjoining Control Areas in each of which will be a number of Control Zones embracing the air space for a specified distance round an airport or group of airports. The clearance of traffic into Control Zones is the responsibility of the appropriate ATC but air traffic control within the Zones is carried out by Approach Control. Control of traffic into aerodromes within a Control Zone is the responsibility of Aerodrome Control and where there are a number of important airfields in a Control Zone, traffic for each may be handled by a separate Approach Control. Aircraft will be under varying degrees of control from these ground authorities according to weather conditions and the rules of the local administration, but the system will always be designed so that air traffic movements are carried out with the minimum of delay and without risk of collision or other accident.

Area, Approach and Aerodrome Control Centres in a given Control Area, are usually connected by a multiplicity of wire circuits, as the distances involved are comparatively short, and

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the same hold good for Area Control interconnection between Areas under the same administration, but if we consider international and long-distance flying we come into a field of communication where radio has an increasing application. The main headings under which international aviation point-to-point working falls are:

Aircraft Movements
Meteorological Services
Service Messages
Commercial Traffic

Let us consider these in turn.

9.1. *Aircraft Movements*

If an aircraft requires to fly from A to B the captain must, in general, file with Aerodrome Control a Flight Plan which will be transmitted to the Area Control authority having jurisdiction over that aerodrome.

This Flight Plan is a comprehensive document and contains the following information:

Aircraft identification
Flight number (as used by operating companies)
Type of aircraft
Name of Captain
Aerodrome of departure
Proposed time of departure
Cruising altitude and route
Point of first intended landing
Proposed airspeed at cruising altitude
Total estimated time to arrival over destination
Amount of fuel on board
Estimated time to reach "point of no return"
Radio frequencies to be used
Navigational and instrument landing facilities carried
Number of persons on board
Alternative aerodromes to intended destination
Any other information added by ATC.

ATC will issue a Flight-Plan Clearance to the aerodrome of departure which will contain brief instructions of route and altitudes to be flown and will indicate the geographical point to which the clearance is valid and also the latest time of departure for which the clearance holds. The point to which clearance is valid is usually some point within or on the borders of the next Control Area for which the aircraft is destined.

It is the responsibility of the ATC issuing clearance to transmit the flight plan to all ATCs through whose areas the aircraft will pass including that of final destination. The information contained in the Flight Plan Clearance is appended to the Flight Plan as transmitted.

When the aircraft actually departs, a Departure Message is originated at the aerodrome of departure and passed to the appropriate ATC which relays it to all other ATCs concerned. This message must find its way to the aerodrome of intended first landing and also to any alternate fields specified in the plan well in advance of the actual time of arrival of the aircraft.

Flight plans may be changed while an aircraft is in transit either at the request of the aircraft, or by any ATC having jurisdiction over the machine at the time. If this takes place the relevant information must be again relayed to all interested ATCs for transmission to any aerodromes affected.

When the aircraft lands an Arrival Message is immediately originated and sent to all relevent authorities; this holds good whether the aircraft lands at one of the airfields designated on the Flight Plan or returns to its departure field or lands at some other field. This action is essential for if an aircraft's arrival is not reported before the fuel specified on its Flight Plan is due to be exhausted it is assumed to be in distress and if it is not in radio contact with any ground station, news of it is sought from all points at which it may have been visible, between the position of last radio contact and its destination. This procedure calls into action a widespread organization of coastguards, police, air force units, D/F stations and rescue organizations as well as necessitating the notification of all ATCs concerned.

It will thus be seen that the normal routine flight of a single aircraft involves quite a volume of communication, sometimes over long distances. This traffic is considerably multiplied for non-routine flights for which special clearances may have to be requested from the destination before Flight Plan Clearance can be issued.

9.2. *Meterological Services*

Since aviation is now a truly world-wide affair, the need for rapid and accurate weather information covering considerable areas is greatly increased. Besides area weather forecasts of conventional nature, aircraft operation demands an almost "on-tap" service of information about present weather at distant points and present weather along specified routes and expected weather at specified points for periods of an hour or so to several hours ahead. In addition, data peculiar to aircraft operation is needed about cloud height and formation, ice formation levels and wind speed and direction at various altitudes.

In order to provide this service there is a considerable traffic, over the international network, of "on request" information about actual weather and tendencies and also many main national airports and telecommunication centres pick up and re-broadcast continually weather-data collected from similar broadcasts going on all over the world.

The volume of this traffic is such that it may, at main centres, amount to 30 per cent. of the total circuit time.

9.3. *Service Messages*

These mainly concern such things as airfield and radio aid serviceability and the passing of urgent notices for inclusion in the briefing of aircrews. Such messages are passed between distant ATCs by radio telephone or teletype and constitute an appreciable volume of the daily traffic.

9.4. *Commercial Traffic*

This mainly involves messages between airline operating companies and their aircraft crews, messages connected with aircraft maintenance, reservations and messages for passengers. Many of these messages are handled by the public telephone or telegraph system but when this system is inadequate they are carried on the aviation radio network.

The traffic detailed under the general headings above, has attained a formidable (and increasing) volume and is of such a character that it cannot be saved up and transmitted at high speed like normal commercial traffic. Most of it is required to be received within a few minutes of its origination and a great deal of it falls into the "question and answer" category. This means it can in general be handled only by manual Morse or teletype operation and consequently the channel capacity in words per day is low.

A further complication is that many international airports are not situated near large centres of population and consequently have to be served by communication facilities specially laid on for their use.

This has led to a great many of the long-haul routes being served entirely by radio links specially installed for aviation purposes. An interesting example of this is that the London telecommunication centre operated by the M.C.A. is continually in direct contact with some 30 other centres, some as far away as Newfoundland and Pakistan.

In this way, since the war, a vast world-wide radio network has been evolved which at present is operated in different ways and by a wide variety of authorities. For instance, in the U.K. all traffic is handled by the M.C.A. In the U.S.A. official traffic is handled by the C.A.A. while the airlines own and operate their own radio networks for handling service messages. On the Continent the air radio services are mainly operated by the Posts and Telegraphs or by the Government aviation authorities, but the American airlines own (or hire) and operate an extensive system of line and radio networks in Europe.

In South America and in countries in the Near and Far East where the governments do not provide service adequate for safe and expeditious handling of modern air transport, radio systems are operated by a miscellany of air lines and semi-official British or American bodies such as Air Inc. in South America and International Aeradio in the Near and Far East.

It is the intention eventually to set up by international agreement a world-wide radio network of main and subsidiary communication centres providing complete broadcast and relay facilities to all airports and providing universal radio contact along agreed major world air routes.

10. National and International Administration of Air Radio Services

Services within the various countries are operated by various bodies according to the laws of the country concerned. In the U.K. the Ministry of Civil Aviation is the responsible agency and in the U.S.A. it is the Civil Aeronautics Administration (C.A.A.). All air radio services use the frequency bands allotted to them by international agreement through the International Telecommunications Union, which body allocates frequencies for all radio services.

On an international basis, civil air radio is regulated by agreement through I.C.A.O. (The International Civil Aviation Organisation). This body, which has its headquarters in Montreal, came into being at the end of the recent war to standardize procedure and equipment for the whole field of civil air operations. The need for such a body is obvious if one considers that after the war, aviation, which prior to 1939 had been a local or at most a regional affair was, by 1943, global in scope and some standardization of regulations, facilities and procedure was essential in the interests of efficiency, safety and economy.

In no field of air operation was this need more pressing than in radio where the widest diversity of practices existed between the various major aircraft-operating countries. In order to avoid breakdown of operation on the one hand and the carrying of a prohibitive number of different radio equipments and navigational aids on the other it was essential to try to standardize on the communication and navigation facilities at least at all airports handling international traffic.

Members of I.C.A.O. (or so-called contracting States) include most of the principal States of the world. I.C.A.O. is divided into a number of Divisions, according to the sphere of aircraft operation covered and there are a number of Regional sub-committees to deal with affairs affecting particular world areas.

I.C.A.O. has done a great deal of useful work since its inception and in the communications sphere in particular a very substantial degree of agreement has been reached and a considerable programme to implement the world-wide radio coverage scheme has been initiated.

11. Miscellaneous Aids

11.1. *The Radio Altimeter*

The barometric altimeter suffers from the defect that if set to read the actual altitude while the aircraft is on the ground at a given point it will read altitude correctly over other points only if the pressure at sea level at those points is the same as that at the original point. Moreover it will only read altitude above sea level in any case—it will not indicate altitude above the ground. This defect is mitigated in practice by telling the pilot the pressure at sea level at the place at which he wishes to know his altitude and if he also knows the altitude of the terrain above sea level he can form an accurate estimate of his ground clearance.

In an attempt to overcome these defects the radio altimeter was devised. This device measures the height of the aircraft above the nearest ground by determining the time for a radio signal to pass from the aircraft to the ground and be reflected back again.

The altimeter operates by radiating from a small dipole on one wing a signal varied sinusoidally between 420 and 460 Mc/s at 120 c/s. This signal is reflected from the ground and is picked up by a receiving aerial on the other wing. The received signal is compared in frequency with the signal passed direct from transmitter to receiver and it will be seen that due to the length of time taken for the reflected signal to make the double journey its frequency as received (which will be the same as when it was sent, of course) will not be the same as that of the signal now being radiated by the transmitter.

The audio frequency generated in the receiver by this difference is directly proportional to the altitude. It is averaged over a number of cycles of the sweep frequency and applied to a meter which is calibrated in feet of altitude.

The equipment has two ranges: 0-4,000 ft. and 0-400 ft. Error on a properly set up equipment should not exceed 5 ft. plus 5 per cent. of altitude for the low range and 50 ft. plus 5 per cent. for the high range.

11.2. *The Radar Altimeter*

This is a device intended mainly for high altitude work and is suitable for checking terrain clearance over mountains and at other times when substantial clearance is required.

It consists essentially of a simple radar set with a low power transmitter and uses the same aerials as the radio altimeter. It has two ranges presented on a C.R.T. display with a circular time-base and a scale of 0-4 (for 0-4,000 and 0-40,000 ft.) is marked on the tube face. The low range can be used as a vernier for the high range if required.

Both these altimeters are suitable for pilot use.

11.3. *Radar Cloud and Collision Warning*

In bad visibility the pilot of an aircraft not flying under radar surveillance from the ground has little or no warning of converging aircraft or proximity to high ground. It has further been known for some years that cloud formations of the cumulo-nimbus type are very dangerous to aircraft. They contain ascending and descending air currents of terrific velocity (sometimes reaching 30,000 ft. per minute) and several aircraft have been lost by flying unawares at night into such clouds.

It has been known for some time that these clouds can be detected at considerable ranges by centimetric radar which also, of course, give warning of other aircraft and dangerous high ground.

E. K. Cole are currently developing such a radar which operates on 3 centimetres and has a scanning system stabilized for aircraft roll and pitch.[5] This radar has been found to detect tropical cumuliform clouds of dangerous size at distances up to 40 miles and to give range of the order of 14 miles against large aircraft. Terrain clearance is also indicated with adequate accuracy.

Apart from the fact that 14 miles warning is barely adequate for very fast aircraft approaching head-on this equipment should prove a very useful aid. It is currently being purchased in small quantities for fitting to new British high-speed civil aircraft.

11. Future Prospects for Air Traffic Control

The volume of air traffic in the most congested areas has now loaded the present system of control to, and in some cases beyond, saturation point.

Future developments depend very much on the aid which can be given by radio techniques and considerable thought has been devoted to the problem both in this country and the U.S.A.

The most comprehensive document so far produced on the subject is the work of the Radio Technical Commission for Aeronautics and is embodied in the report of R.T.C.A. Sub-Committee 31. This report covers a scheme to embrace both civil and national defence aviation in an overall system of control and is estimated to cost ultimately 1,113 million dollars. The report contains a great deal of highly controversial matter and a body called the Air Navigation Development Board (A.N.D.B.) was set up in the U.S.A. in January 1949 to handle all investigations and developments for the implementation of a system such as that described by SC-31.

In the U.K. the M.C.A. has set up a planning group to examine the proposals of the report and also a working party known as the Air Traffic Control Development Staff, which is charged with the preparation of a long-term plan for a common system of air traffic control for the U.K. and Commonwealth.

It is by now generally conceded that traffic handling can best be expedited with safety by confining aircraft to definite routes and controlling closely their passage along them. This would make sure that each aircraft was allotted sufficient air space for safety and also that each would arrive at the right point at the right time for feeding without delay into the landing procedure.

To implement this system successfully means that aircraft must have adequate means of flying accurately on the track allocated to them and that there must be a comprehensive surveillance system enabling the whole length of each airway to be monitored with positive identification of each aircraft in order to control its rate of progress along the allocated track.

In this system each aircraft would be allocated a discrete three dimensional air-space about 5 miles square by 1,000 ft. high. This is fairly straightforward on an airway, but when we come to turning and crossing points and approach and landing areas the problem of separation becomes much more complicated especially as each aircraft must have not only its present space allocated but space must be reserved for its next evolution. It is also obviously not possible to confine all private, charter and military aircraft to airways, and provision must be made for off-airways flying and supervision.

The system as proposed calls for much more supervision than at present and considerably more passage of information and instructions between air and ground. To meet this by increasing the ground personnel would not be the answer as it would become increasingly difficult to ensure sufficient liaison between the controllers to prevent the issuing of conflicting clearances. Also the traffic capacity of the present V.H.F. R/T channels would be quite inadequate. This latter factor has a particular bearing on approach and landing control. If the rate of landing is to be increased to one aircraft every 1½ minutes, as is envisaged by the scheme, it would not be possible to pass by R/T the necessary messages in such a short space of time—the best that could be done would probably be one every 3-4 minutes due to limitation by this factor alone. The system also calls for a continuous and accurate direct reading track guidance system.

The SC-31 proposals envisage the establishment of private-line communication with each aircraft using some sort of symbolic display actuated by push buttons for the passing of instructions (to replace the R/T method) and also automatic transmission actuated by interrogators in the ground to establish aircraft identity, height, speed, etc., on a continuous basis. Several proposals are made to effect this service and in general involve multiplexing of the channels for this purpose on the existing VOR communication channels or on alternate 100 kc/s channels of the V.H.F. R/T system.

On the ground there would be displays showing the situation continuously to the controllers and a comprehensive system of computors and interlocks would be called for to assist in the issue of flight plans and to prevent the issue of dangerous clearances.

For the track guide systems SC-31 proposes the VOR/DME combination with an R/Theta computor to enable automatic flying of courses other than radials. It is at present questionable whether the accuracy of VOR (in view of its susceptibility to site error) is going to be adequate for this purpose and it seems probable that some such systems as Gee or Decca with their greater accuracy, and freedom from site error, would be more likely to meet the need, if suitable attachments for direct reading of courses are perfected.

In the field of immediate action towards the ultimate plan the C.A.A. in the States are already well ahead with the replacement of M.F. ranges with VOR on the airways.

In the U.K. the M.C.A. Airways System is now in being, using M.F. radio ranges.[6] This system provides lanes for all the main international traffic as follows:—Green Airway 1 serves the Atlantic-Shannon-London route and is being extended from London eastward to Brussels. Amber 1 covers Daventry-Dunsfold, Dieppe-Paris. Amber 2: Paris-Abbeville-Maidstone-Brookmans Park-Daventry. Blue 1: Woburn-Watford-Crowborough. Red 1: Dunsfold-Maidstone-Amsterdam. Red 2: Woodley-Epsom-Ashford. Red 1 is being extended via Hurn towards the Channel Islands and Amber 1 is being extended via Manchester and Liverpool to Prestwick. Three further Airways will complete the system. Green 2: Dublin-Liverpool/Manchester-Ottringham-North West Europe. Red 3: Liverpool/Manchester-Isle of Man-Belfast. Blue 2: Belfast-Prestwick.

The whole philosophy of the proposed ultimate system of control is very controversial and it is perhaps open to question whether the reliability of machines and electronics attainable in the next few years will in fact enable the close spacing and automatic control to be realized in practice.

Whatever the outcome may be, however, it is clear that progress in air transport in the future will be as closely dependent on advances in radio technique as it has been in the past.

13. References and Bibliography

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7. Stallibrass, C. W., "Navigational and Air Traffic Control Problems of Civil Aviation." *J.Brit.I.R.E.*, **12**, Jan. 1952, pp. 3-22.
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APPLICANTS FOR MEMBERSHIP

New proposals were considered by the Membership Committee at a meeting held on November 26th, 1952, as follows: 19 proposals for direct election to Graduateship or higher grade of membership and 19 proposals for transfer to Graduateship or higher grade of membership. In addition 39 applications for Studentship registration were considered. This list also contains the names of two applicants who have subsequently agreed to accept a lower grade than that 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.

Direct Election to Full Member

BENHAM, Cedric Minett, B.Sc., D.I.C. *Towcester, Northants.*

Direct Election to Associate Member

BURTON, Alan Roger Kenneth, B.Sc. *Newton Abbot, Devon.*

COLLINS, John Ivor. *Aberdeen.*

KARNIK, Vinayak Ramchandra, M.Sc. *Bangalore, India.*

NARAYANAN, Kalandy, Squadron Leader, I.A.F. *Kozhikode, S. India.*

WALTON, Frederick Leonard, Flight Lieutenant, R.A.F. *Portsmouth.*

Transfer from Associate to Associate Member

BRICKWOOD, Ronald, Flight Lieutenant, R.A.F. *Fife.*

GRANT, James Philip. *Plymouth, Devon.*

Transfer from Graduate to Associate Member

DONOVAN, Timothy Denis. *Marazion, Cornwall.*

FELLOWS, Horace. *Wolverhampton, Staffordshire.*

Direct Election to Associate

BARTLETT, Sidney Cyril. *Little Munden, Hertfordshire.*
BOULTON, Thomas Albert. *Havant, Hants.*

CURTIS, George Loos. *Karachi.*

STEWART, John Patton. *Lydd, Kent.*

Direct Election to Graduate

CAWTHRAW, Maurice John, B.Sc. *Mitcham, Surrey.*

FAULKNER, Harold John. *Stockport, Cheshire.*

NARAYAN, S. Shankar, B.Sc., Pilot Officer, I.A.F. *Bangalore, India.*

PRINS, Aurele Gerald Edward. *London, S.W.1.*

VOWLES, Hugh Herbert. *Portishead, Somerset.*

Transfer from Student to Graduate

BELLARE, Chandrakant Vasudeo, B.Sc. *Bombay.*
BUTTERY, Peter Joseph. *New Malden, Surrey.*

DEWAN, Lakhpat Raj, B.A. *Saurashtra, India.*

GASKING, Alan James Francis, B.Sc. *London, N.15.*
GOVINDARAGHAVAN, Dorasiwamy, B.Sc. *Calicut, S. India.*
GUNDU RAO, G. S., B.Sc. *Bombay.*

MASILLAMANI, Joseph Jeyapalan, B.Sc. *Bombay.*
MATTEI, Rodolfo. *London, N.8.*
MOTHERSOLE, Peter Leonard. *Calne, Wiltshire.*

OLLINGTON, David Reginald, D.F.H.(Hons.). *Stafford.*

SOMANATHAN, C. S., B.Sc. *Bombay.*
SURI, S. K., B.A., M.Sc. *Delhi.*
SZKUTNICKI, Zbigniew Ryszard. *Mitcham, Surrey.*

WILLIAMS, Peter Brundall. *London, N.19.*

Studentship Registrations

AHMAD, Anwar. *London, W.2.*
ARTHUR, Alasdair Vosper. *Broadstairs, Kent.*
AYLWARD, Patrick. *Kilkenny, Eire.*

BARROW, Ross Percy. *Germiston, South Africa.*
BASCH, Ernest Frederic. *Haifa, Israel.*
BHARDWAJ, Jagdish. *Mhow, India.*

DALTON, Vincent. *Glasgow.*
DHAVALE, Prabhakar Shreepad, B.Sc. *Poona, India.*
DIXON, Clive Haughton. *Cambridge.*

FERBABDES, Antonio Taurino, B.Sc. *London, W.8.*

GIBBS, Ian Grenville. *Lingfield, Surrey.*
GLEDHILL, Arthur Robert. *High Wycombe, Bucks.*
GRICE, Charles John. *Great Yarmouth, Norfolk.*
GUNASEKERA, W. A. *Homagama, Ceylon.*

JOOSTEN, Johan Gerhard. *Christchurch, New Zealand.*
JOSHI, Ramchandra Balkrishna, B.Sc. *Bombay.*

KHAN, Mohammad Saadullah, B.A. *Rawalpindi, Pakistan.*
KRISHNANANDHA, Ramiah. *Coimbatore, S. India.*

LAGU, Madhuswdan Purushottam. *Bombay.*
LAGU, Sadashiv Purushottam. *Bombay.*

MAHAJAN, Raj Kumar. *Delhi.*
MALLALIEU, John Gaston Hugh. *London, S.E.27.*
MARKEY, Eugene F. *London, N.7.*
MILES, Ronald Boyce. *Lydd, Kent.*

NARANG, Prem Nath. *Delhi.*

PARIKH, Kanaiyalal Jivanlal, B.Sc. *Bombay.*
PETHE, Vasant Avadhut, M.Sc. *Bombay.*
PRASAD, Ram Jatan. *Bombay.*

REHMAN, Saif-ur. *London, W.2.*
RITCHIE, Robert. *Cromarty, Scotland.*

SARASWAT, Ishwari Prasad, B.Sc. *New Delhi.*
SATYANARAYANA, Ramu, M.Sc. *Banaras, India.*
SHAKDHER, Madhusudhan Lal. *New Delhi.*
SRIVASTAVA, D. P. *London, W.C.2.*

TANTSETTHI, Prasit. *Warwick.*
TIWARI, Madhukar Eknath. *Bombay.*

WIERSTRA, Marten Klaas. *Oegstgeest, Holland.*

YASIN, Mohammad. *London, W.2.*

ZANGER, Chaim Heinrich. *Haifa, Israel.*

Correction: In the list of Applicants for Membership published on page 576 of the November *Journal*, the 5th entry under the heading "Direct Election to Associate" *should read:*

SHAH, Saleemulla, Captain, Pakistan Army. *London, W.5.*

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