The Journal of

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

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TIME TO READ

AN increasing number of journals and other periodicals cater wholly or in part for the attention of the radio and electronics engineer. Indeed, for those engineers whose mother tongue is English, and who strive to keep abreast of information published in Great Britain and abroad, it might truly be said that reading has become an occupational hazard of the professional engineer! Various forms of statistics have been produced to show that the average professional man may read anything between one and ten technical journals per month. On this premise, it may be assumed that whilst perhaps perusing all the journals published in his native country, the average engineer is not able to take account of work done elsewhere in the world.

English-speaking radio and electronics engineers are favoured in their literature, inasmuch as the greater part of technical information is published in the English language. Indeed, out of a world population of some 3,000 million people, over 250 million speak English as their native tongue and very many more millions use it as an auxiliary language.

There are, of course, some two thousand separate languages spoken throughout the world; whilst Chinese is reckoned to be spoken by about 600 million people, the language is divided into so many dialects which are mutually unintelligible, that Chinese is not so widely understood as English. English, French, Russian, Spanish and Chinese, in that order, are acknowledged to be the most important languages in the world, and it is in those five languages that the United Nations transact their business.

The English-speaking radio engineer has, of course, interest in technical publications in other languages, for example, German. More technical journals are being published in Japanese—the world's sixth most popular language—but it is interesting to note that an increasing number of journals published in Japanese and other languages now include English translations.

In order to meet the problem of at least perusing the maximum number of publications, some theories have been advanced on ways in which the individual may speed up his reading, for instance, by the publication of more précis or digests. It has been suggested that a quick scan of a journal can enable the reader to determine whether the subject is of sufficient interest to justify filing for subsequent reference, but such proposals ignore the library problem which a senior engineer will eventually have to face!

So far, these comments have only dealt with periodicals, and there still remains the additional time required to read new textbooks describing new work or, indeed, providing useful review of the state of a given art.

How best, therefore, to take advantage of the immense amount of literature available to the professional engineer is a problem which must be the concern of every professional body wishing to serve its members and further the desirable cause of securing the maximum dissemination of new information.

Our own Institution has made a useful approach to this problem in publishing in the *Journal* such items as "Radio Engineering Overseas"; some development of this idea might do much to help the average member to meet the problem of finding time to read. The task is formidable and a further contribution to its solution will be the handbook which the Institution has under preparation for publication, "Library Services and Technical Information for the Radio Engineer."

G. D. C.

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REPORT OF THE THIRTY-SECOND ANNUAL GENERAL MEETING

The Institution's Thirty-Second Annual General Meeting (the twenty-fourth since incorporation) was held at the London School of Hygiene and Tropical Medicine, Gower Street, London, W.C.1, on Wednesday, 27th November, 1957.

In the absence of the President, Mr. G. A. Marriott, who was indisposed, the Chair was taken by the Immediate Past-President, Rear-Admiral Sir Philip Clarke, who was supported by other officers of the Institution and members of the Council. Fifty-six corporate members had signed the Minute Book when the meeting opened at 6.5 p.m.

The Secretary read the notice convening the meeting which was published on page 465 of the September *Journal*.

1. To confirm the Minutes of the 31st Annual General Meeting held on October 31st, 1956

The Secretary stated that a report of the last Annual General Meeting was published on pages 587-589 of the November 1956 *Journal*. Admiral Clarke's proposal that these Minutes be signed as a correct record of the proceedings was approved unanimously.

2. To receive the Annual Report of the Council (published in the October *Journal*)

The Chairman asked Professor Emrys Williams, Vice-President of the Institution, to present the Annual Report of the Council for the year ended 31st March, 1957.

Professor Williams stated that he was pleased to have the opportunity of commenting on the work described in the Annual Report and the effect it would have on the future of the Institution. Since the conclusion of the year covered by the Report, the fourth post-war Convention had been held at Cambridge, and the measure of its success could be judged from enquiries which the Institution received for information regarding the next Convention. The Council's view, however, was that Conventions should only be held when there was a need for reviewing recent developments in radio engineering, and Professor Williams believed that this policy was responsible for much of the success of the Institution's Conventions. It was probable, therefore, that the Council would arrange the next Convention in 1959 and, as usual, it would be associated with a definite theme.

One point in the Annual Report to which Professor Williams particularly wished to draw the attention of members was the intention of the Council to establish within the Institution groups devoted to the various specialized branches of radio and electronic engineering. Such groups could be of great assistance in arranging for further papers for meetings and for publication in the *Journal*, as well as in helping the Council decide the theme of future Conventions.

Referring to the work of the Technical Committee, Professor Williams particularly mentioned its valuable work in the field of standardization through liaison with the Committees of the British Standards Institution, and through its latest series of reports on methods of specifying characteristics of electronic instruments.

Professor Williams suggested that the Education Committees of professional bodies performed great service in stimulating Universities and Technical Colleges to keep their curricula in pace with the times. The Brit.I.R.E. was fortunate in having senior members well able to anticipate future trends, thus helping to raise the standard of instruction in radio and electronic engineering. The Council particularly welcomed the co-operation which existed between the Institution and teaching bodies.

Regarding the Institution's own examination, which was set as a standard, Professor Williams said that although some reduction in the number of candidates had been expected, more than 1,000 applications a year were being received; he felt, however, that this number would be reduced as more degrees and diplomas were introduced having an adequate radio and electronics content. The work of the Membership Committee was, of course, complementary to the work of the Education and Examination Committee; during the year, the Membership Committee had considered nearly 1,000 proposals and the Council was appreciative of the care taken by the Committee in the consideration of each application.

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Finally, Professor Williams paid tribute to the work of the Committees of local sections in Great Britain and Overseas; he emphasized that through the Chairmen of local sections, who served as *ex officio* members of the Council, the opinions of members could be brought to the attention of the Council.

The Chairman's proposal that the 31st Annual Report of the Council be adopted was seconded by Mr. G. B. Ringham (Member) who, on behalf of the members present, congratulated the Council and Committees on their good work during the past year.

3. To elect the President

Admiral Clarke said that it gave him very great pleasure to propose that Mr. G. A. Marriott be re-elected President of the Institution for a second year. Mr. Marriott's long experience in the radio industry, together with the valuable advice and counsel which he gave on the Institution's problems were appreciated by all who had served with him during the past year. Admiral Clarke knew that all members would be sorry to learn that Mr. Marriott was in hospital. In a message expressing regret for his enforced absence Mr. Marriott had expressed a wish that the members be asked to help further in strengthening the membership of the Institution. Admiral Clarke felt that Mr. Marriott could be assured of every member's co-operation in improving still further the Institution's progress.

The motion to re-elect Mr. Marriott as President of the Institution was carried with acclamation.

4. To elect the Vice-Presidents

Proposing the re-election of the four Vice-Presidents, Admiral Clarke referred to the work of Mr. Leslie H. Paddle, the senior Vice-President, in actively promoting the Institution's work in Canada, and in helping members taking up appointments in that country and the U.S.A.

Particular appreciation was due to Mr. J. L. Thompson and to Professor E. E. Zepler who, in spite of a period of ill health, had continued to attend meetings of Council and Committees and to give every possible service to the Institution.

The activities of Professor Emrys Williams as Chairman of the South Wales Section were well known to members in that Section, and he also gave valuable help to the Institution through his service on the Professional Purposes Committee.

The motion was carried unanimously.

5. To elect the ordinary members of Council

The Council's nominations for the vacancies arising had been unopposed and the following were therefore elected to the Council for 1957-58:

Air Vice-Marshal C. P. Brown, C.B., C.B.E., D.F.C. (Member);
Colonel G. W. Raby, C.B.E. (Member);
Mr. S. J. H. Stevens, B.Sc.(Eng.), (Associate Member);
Mr. A. H. Whiteley, M.B.E. (Companion).

6. To elect the Honorary Treasurer.

Admiral Clarke stated that the Finance Committee members were always appreciative of the way in which Mr. G. A. Taylor tackled the burden of implementing the decisions of the Committee. The proposal that Mr. Taylor be re-elected Honorary Treasurer was carried unanimously.

7. To receive the Auditor's Report, Accounts and Balance Sheet for the year ended 31st March, 1957

After thanking the members for electing him for a fifth year of office, Mr. Taylor continued: "Members will realize, of course, that the Accounts published in the October *Journal* do not reflect any benefit from the new subscription rates which came into force on 1st April last. The position during the year will be very much helped by the increases made possible as a result of the Extraordinary General Meeting held in January.

"Members will have read in the Annual Report and in the November *Journal* of the continually increasing costs for paper, printing and postage. The Council regretted that the Postmaster-General was unable to meet some of the proposals made by the Parliamentary and Scientific Committee for allowing learned societies some facility for cheaper postage rates. The proceedings or journals of learned societies are not so well endowed with advertising as commercial publications, and heavy increases in postal charges therefore hit professional Institutions hard.

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"Regarding the Balance Sheet, members will note that it was possible to allocate a small surplus for the year to the Reserve Account. Monies received toward the acquisition of permanent premises for the Institution continue to be invested, and the Committee is grateful to all members who are supporting this project, and to the increasing number of companies in the British radio industry who are also making generous donations. I feel sure that the whole financial structure of the Institution will be more firmly based when a more suitable building has been acquired."

Mr. Taylor referred to the Current Liabilities, which represented forward or capital expenditure, and stated that it was this item which had always caused the Finance Committee the greatest trouble. He continued:—

"I am glad, therefore, to have this opportunity of paying tribute to our President for the way in which he has tackled this particular problem. Mr. Marriott has initiated an appeal to industry whereby we will acquire capital in the same way as similar Institutions have done in the past.

"It is opportune for me to mention that throughout the past year the Finance Committee had been greatly helped by the President and the Immediate Past President, who have attended every meeting of the Committee and made the subject of acquiring capital their main concern. I know that I speak on behalf of the members in thanking those Officers for their tremendous help, and it is with some satisfaction with the Institution's financial record that I beg to move that the Accounts be adopted."

The motion was seconded by Mr. R. N. Lord (Associate Member) and the Accounts and Balance Sheet for the year ended 31st March, 1957 were adopted unanimously.

8. To fix the Remuneration of the Auditors

Admiral Clarke stated that for many years the Institution had been well served by Gladstone, Jenkins & Company, who had always dealt most sympathetically with the question of Auditors' fees. As the Institution was growing it might not be fair to them, nor indeed to the Institution, arbitrarily to fix an audit fee at an Annual General Meeting. He proposed, therefore, that the remuneration be left to the discretion of the Council.

This proposal met with approval.

9. To appoint Solicitors

Admiral Clarke said that Messrs. Braund & Hill continued to look after the Institution's interests in all matters requiring legal opinion, and he formally moved their re-appointment as solicitors to the Institution. The motion was unanimously approved.

10. Awards to Premium and Prize Winners

Introducing this item Admiral Clarke said: "I know that Mr. Marriott was particularly looking forward to this part of the meeting. He has asked me to convey his congratulations to all the recipients, and it gives me much personal pleasure to present the awards on behalf of our President."

Admiral Clarke then presented Premiums for 1956 as follows:—

The Clerk Maxwell Premium to Dr. K. D. Froome.
The Heinrich Hertz Premium to Dr. A. G. Edwards.
The Brabazon Premium to Mr. K. E. Harris.
The Louis Sterling Premium to Dr. A. van Weel.
The Dr. Norman Partridge to Mr. H. J. Leak.
The Marconi Premium was received on behalf of Professor P. M. Honnell, a resident of the United States, by Mr. S. Austen Stigant.

The following Examination Prizes were awarded:—

The President's Prize to Mr. E. Senior.
The S. R. Walker Prize to Mr. L. Williams.
The Audio Frequency Engineering Prize to Mr. J. D. Smith.
The Mountbatten Medal to Mr. J. H. Masters.

11. Any other Business

The Secretary confirmed that notice of any other business had not been received. Before closing the meeting, however, Admiral Clarke welcomed a number of new members of the Institution and presented them with their certificates of membership.

The Chairman then declared the 32nd Annual General Meeting closed.

Admiral Clarke then opened the Annual General Meeting of Subscribers to the Brit.I.R.E. Benevolent Fund. A report of this meeting will be given in the January 1958 issue of the *Journal*. After the conclusion of the Annual General Meetings, Dr. A. van Weel gave a lecture on "Transmission Standards and Signal Distortion in Television and other Communication Systems."

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"S.A.R.A.H.": A U.H.F. (243 Mc/s) PULSE CODED AIR/SEA RESCUE SYSTEM*

by

D. Kerr †

SUMMARY

The simplification in construction and operation of the personal radio beacon which a pulsed system gives justifies the need for a special receiver in the search aircraft or vessel. A double pulse is used to (1) give maximum system sensitivity, (2) permit discrimination between beacons, (3) facilitate synchronization. Speech may be transmitted from the beacon by pulse frequency modulation. Reception from the search vessel is by a super-regenerative circuit. The search equipment can detect beacon pulses at a range of 90 statute miles at 10,000 ft. (145 km at 3,050 m). When mounted in a boat, double Yagi aerials are used giving a detection range of six miles (9·7 km).

1. Introduction

In order to design an effective radio beacon for air/sea rescue, consideration must be given to the conditions to be fulfilled to bring about a successful rescue. It is reasonable to suppose that the person to be rescued will be in a distraught condition and possibly physically incapacitated. Hence it would be useless to design a rescue system that requires co-operation from the person to be rescued such as manipulation of controls, or even the passage of clearly spoken messages.

Since some aircraft carry a crew of up to six persons, there may well be more than one person to be rescued each carrying a beacon and it is important that a number of separate transmissions on the same radio frequency do not confuse the search or rescue vessel.

The beacon should be capable of operating in any conditions, e.g. desert or arctic, on land and in the sea, after having been subject to the very low pressures and temperatures of high altitude, followed by complete immersion in the sea. The system employed must permit the rescue vessel to operate at night and in bad weather. It should also be remembered that to rescue a person one must actually reach him: it is not enough to fix his position.‡

2. Choice of Modulation Systems

It is important that the beacon is electronically as simple as possible. A radio beacon, consisting of a simple power oscillator emitting continuous waves, could be received on an ordinary v.h.f. or u.h.f. receiver but there would be certain reception problems. The maximum weight and volume of a battery a man can carry would limit the power output of this oscillator, and in order to detect it at a given range the bandwidth of the receiver used would have to be reduced until its sensitivity was sufficiently high. This bandwidth would then be small by comparison with the deviation of carrier frequency which occurs in a v.h.f. or u.h.f. oscillator due to the combined effects of temperature and the proximity of objects near the aerial. Thus this simple oscillator could not be used in conjunction with a normal crystal controlled receiver. (It could incidentally cause considerable interference on adjacent channels as its frequency varied.)

To overcome this effect of frequency variation the beacon transmitter might be crystal controlled. Overtone crystals are available up to about 60 Mc/s (and lately have become possible up to about 120 Mc/s) so that to radiate the

* Manuscript first received on 11th April 1957 and in final form on 6th November, 1957. (Paper No. 427.)

† Ultra Electric Ltd., Western Avenue, London, W.3.

U.D.C. No. 621.396.933.2

‡ See also G. W. Hosie, "An introduction to radio aids to air/sea rescue." *J.Brit.I.R.E.*, 17, pp. 481-488, September 1957.

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distress frequency of 243 Mc/s, a crystal oscillator would be followed by frequency multiplying stages, usually amounting to about four valves in all. These would necessarily be filamentary types, in order to keep the heater power consumption down to a minimum, and the resulting complex device would be rather remote from the basic necessity—an r.f. c.w. power oscillator coupled to an aerial.

However if the oscillator can emit short pulses its peak power can be raised for a given weight and volume of battery, thus achieving the same range figure with the wider bandwidth receiver now necessary. In addition the bandwidth of the receiver is now a larger fraction of frequency variations which will occur in a simple one-valve power oscillator and the beacon is more easily located by the receiver in the frequency spectrum. The very short bursts of oscillation would also have negligible interference effect on normal c.w. communications.

A special receiver will of course be necessary to receive the transmissions but the simplification of the beacon is so great that it was decided to develop a pulsed system.

3. Considerations determining Pulse Repetition Frequency and other Design Details

In general there are three phases involved in the rescue of a distressed person:

(1) detecting the beacon signal,
(2) homing towards it, and
(3) precisely locating the source.

Only the minimum amount of signal necessary to cover each phase of the rescue operation should be transmitted in order to keep the size of the battery as small as possible.

Considering the third phase first, the method of locating the beacon is the well-known one in which the aircraft finds the null in the polar diagram which exists immediately above the end of a vertical aerial (Fig. 1). This null can be considered an inverted cone to a reasonable approximation, the angle of the apex being 30 degrees. The duration of the null experienced by an aircraft will therefore be a function of its height and speed, and for a speed of 120 m.p.h. at 500 feet altitude, it will last about 1 second, during which time the aircraft will have travelled about 200 feet. If it is required to fix the position of the beacon to within 50 feet there will have to be at least four pulses from the transmitter during the period of the null. In practice, however, to make the observation of the null easy for an observer, the pulse repetition frequency requires to be rather higher than four per second.

During the second phase the aircraft homes on the beacon by taking bearings on the signal. An aircraft cannot alter its course very rapidly and it can be shown that frequent alterations are in fact unnecessary and that a correction to course once per minute would steer the aircraft towards the beacon. Thus during this phase it would be sufficient if the beacon emitted a burst of signal once per minute to enable the aircraft to take a new bearing.

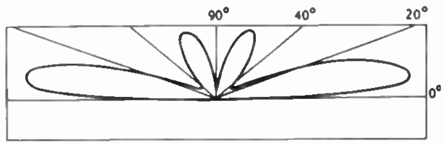

Fig. 1. Polar diagram of the vertical 0·62λ Sarah beacon aerial.

The aspect which however finally decided the pulse repetition frequency of the beacon was that of obtaining maximum radio range during the first search phase of the rescue operation when the aircraft has systematically to scan the area likely to contain the distressed person until the beacon signal is received. The distance at which this occurs depends on the system sensitivity, i.e. the effective radiated power of the transmitter and the receiver sensitivity. With a pulsed system of transmission, the best known method of detecting such signals is by means of a cathode-ray tube and there are two main ways of arranging the display. The time-base and the received signal can be synchronized to one another so that the pulse always appears at the same point on the tube as far as short term observation is concerned; an example of this is Rebecca.* Where there is no fixed synchronism, very

* "Rebecca" is the name for the interrogating end of an interogator/responder beacon system—Rebecca/Eureka. See, for example, K. A. Wood, "200 Mc/s radar interrogator beacon systems," *J. Instn Elect. Engrs*, **93**, Part IIIA, No. 2, pp. 481-5, 1946.

stable beacon and receiver time-base oscillators are used, as for example in Gee or Loran.†

The over-riding need for extreme simplicity and the restrictions on volume and weight in the personal equipment prohibit the use of either a responder beacon, or a transmitter with a highly stable pulse repetition frequency. The receiver time-base must therefore be triggered by the incoming signal to obtain synchronism.

If a transmitter emitting single pulses is considered there would be two simple ways of rendering these visible on the trace of the c.r.t. One way would be to trigger the time-base with each alternate pulse from the beacon, and have a time-base with a duration equal to twice the interval between the pulses from the beacon. The other would be to insert a delay line between the time-base trigger point and the signal deflection plates of the c.r.t. Thus each pulse arriving from the beacon first triggers the time-base and then a delayed version of it is displayed to the observer.

However, both these methods have severe drawbacks. It is most likely that the aircraft will commence its search outside the range of the beacon transmitter when the time-base will have no signals to trigger it. The receiver gain will be at maximum, however, and the time-base will be triggered by thermal agitation voltages at the receiver input.

In the first method, using a time-base equal to twice the interval between the pulses from the beacon, the chances of a signal pulse being displayed when the signal and thermal voltages are about the same amplitude will depend on the number of triggerings due to thermal noise, the duration of the time-base, and the number of pulses arriving from the beacon. Since the time-base duration is very long, random triggerings due to thermal agitation would rapidly diminish those due to signal and hence a large signal-to-noise ratio would have to be achieved before the triggering due to signal formed the majority of the time-base triggering. This high signal-to-noise ratio implies that the search aircraft would be closer to the beacon before its signal became apparent on the c.r.t.

The second method would place all the signals received at one point on the screen of the c.r.t. Thus any interference pulses, say from ignition systems, would also be displayed at the same place as a beacon signal together with thermal noise voltages in excess of the critical triggering value. The signal would therefore only be noticeable when it became very large or had a very noticeably different shape.

There is a further disadvantage associated with the first method. The simplest form of transmitter, a self-oscillating power amplifier, can be made to emit bursts of oscillation about 1 to 10 microseconds duration quite readily, but shorter or longer durations become progressively more difficult to achieve unless additional apparatus is used at the transmitter. Thus when the time-base duration is twice the interval between the pulses from the beacon (5 milliseconds) it will be of the order of 1,000 times the duration of the pulse from the beacon. If the time-base is a trace 50 millimetres long on the c.r.t., the pulse only appears as a fine spike of the order of 0·05 millimetres wide, which is not easily seen.

However, if the transmitter emits a closely spaced pair of pulses, a time-base whose duration is, say, just a little longer than the interval between the pair can be used at the receiver. The time-base is triggered by the first pulse of the pair and the second pulse is displayed somewhere along the time-base. The merit of this arrangement is that no matter how erratically or intermittently the time-base is triggered by the signal, when it is triggered there is bound to be displayed a pulse at the same point on the screen of the c.r.t. each time. Single pulses from interference sources, although they trigger the time-base, are not displayed as stationary pulses.

It can be shown that, by using pairs of pulses, the wanted signal has a much better chance of being displayed to the observer of the c.r.t. and thus the sensitivity of the system is effectively increased, without the expenditure of additional power at the transmitter.

If the beacon emits, say, 400 single pulses per second of 10 microseconds duration, then, in the

† "Gee" and "Loran" are hyperbolic navigation systems. See, for example, R. J. Dippy, "Gee: a radio navigational aid," *J. Instn Elect. Engrs.* 93, Part IIIA, No. 2, pp. 448-480; and J. A. Pierce, A. A. McKenzie and R. H. Woodward, "Loran—Long Range Navigation," M.I.T. Radiation Laboratory Series, Volume 4 (McGraw-Hill, New York, 1948).

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alternative pulse method, the time-base would need to be about 4,700 microseconds duration. Assuming that the thermal agitation voltages cause 400 random triggering pulses per second, then the chances of a beacon signal triggering the time base are*

$$W=\frac{1}{1+(n-W)\tau}$$

where W = probability of triggering time-base
n = number of beacons (1 beacon + interference pulses equivalent to 1 beacon = 2)
τ = ratio of duration of time-base to time interval between beacon pulses 4700 μsec/$(1/400\times10^{-6})=1{\cdot}88$

Hence $W=0{\cdot}23$.

A beacon with the same power consumption could be one emitting 200 pairs per second, say 200 microseconds between the pulses of the pair and 5,000 microseconds between the pairs, the pulses themselves still being 10 microseconds duration.

The time-base duration at the receiver now needs to be just in excess of 200 microseconds, say 300 microseconds. If we consider the signal competing for use of the time-base in the presence of 400 random triggerings per second as previously, then the probability of a beacon signal triggering the time-base is $W=0{\cdot}91$.

[In this case, $n=3=1$ beacon + twice relative number of interference pulses or 2 "beacons" $\tau=300/5000=0{\cdot}06$]

This device of transmitting pairs of pulses also improves the c.r.t. display since the time-base is now, say, 300 microseconds in duration, and as a trace 50 millimetres long on a c.r.t. a pulse of 10 microseconds duration would appear 1·6 millimetres wide, which is much more easily seen.

Since coding the transmissions into pairs of pulses allows the beacon to compete for use of the time-base on more favourable terms in the presence of thermal noise or interfering signals, when there are several beacons operating together it will allow them to use the time-base of the search vessel receiver simultaneously until the time-base is fully occupied. Referring to Fig. 2, if the intervals between the first and second pluses for beacon "A" is 150 microseconds, "B" 200 microseconds and "C" 100 microseconds, they will all appear on the c.r.t. at different points along the time-base and can thus be separately observed. A situation where there may be a crew of six persons all transmitting in close proximity on the same radio frequency can therefore be dealt with.

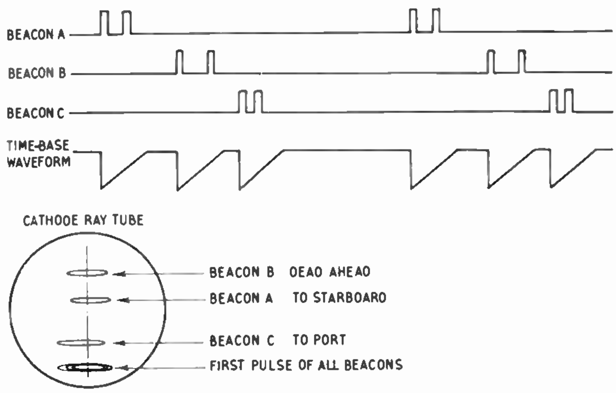

Fig. 2. Display of several beacons.

The parameters such as pulse duration, time interval between the pair, group repetition rate and the peak power of the transmitter are variable within certain bounds and the choice is made to obtain the maximum system sensitivity.

Tests were carried out to determine the efficiency of the parameters chosen. Under conditions where it is possible to detect pulses on a radar at a signal-to-noise ratio of −10 db they are detectable on Sarah to −2 db; Fig. 3 shows a graph of the ability of three observers to detect the presence of a signal on a Sarah receiver. The pulse was moved to one of four positions on the time-base at random, and the

* After A. Roberts. "Radar Beacons." page 110, M.I.T. Radiation Laboratory Series, Volume 3. (McGraw-Hill, New York, 1947.)

This formula was derived for the purposes of calculating the probability of getting a response from a responder beacon. The problem here is the same except that the response is observed at the responder end of the circuit and not the interrogator end. When used with the parameters stated for the single pulse beacon the answer given will not be exact due to the large value of τ.

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times taken by each observer to declare its position are plotted for various signal levels.

A measurement was made of the number of times the time-base was triggered by the incoming signal under varying signal-to-noise values. The time-base waveform was connected as one input to a coincidence gate and the signal waveform modulating the signal generator as the other input. Fig. 4 shows the number of coincidences recorded on a counter at various signal-to-noise ratios. At a signal-to-noise ratio of −2 db the number of beacon pulses effective at the receiver is 100 from a beacon transmitter having a p.r.f. of 192/sec.

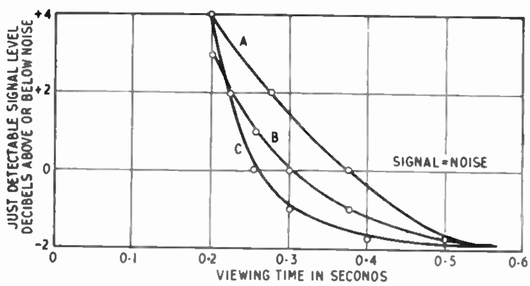

Fig. 3. Time taken by three observers to detect signals at various levels. A, B, C—three observers. Noise amplitude—2 mm. P.R.F.—200/sec. Pulse width—5 microsec. Cathode ray tube is type 3EC1.

The peak power transmitted is limited by the subminiature valve available for generating it, the volume and weight of the battery that can be carried, and the length of time the beacon must operate for after switch on. The voltage of the battery was therefore raised to the maximum the valve will withstand (450 volts). There is no merit in one pulse width over another in the range 1 to 10 microseconds, assuming the bandwidth of the receiver is adjusted accordingly. However, in the interest of using less of the frequency spectrum 5–10 microseconds was chosen and the separation of the pair is now adusted so that a pulse of 5–10 microseconds duration appears at near the optimum width (about 1 mm). The group repetition rate was raised until the consumption from the h.t. battery gave a life equal to the value decided by the operational requirement. These statements of course simplify the process.

The parameters decided on for the Sarah beacon are therefore as follows:—

Peak power—15 watts.

Group recurrence frequency—160 to 240 per second.

Pulse width—5–10 microseconds.

Pulse spacing—100–300 microseconds.

In combination with a search receiver having a sensitivity of 10 microvolts for a 2:1 signal-to-noise ratio, a beacon with the above parameters can be detected at a range of 90 statute miles by an aircraft at 10,000 feet altitude, or at a range of 6 miles by a motor launch with aerials at 20 feet. (See Sect. 12.)

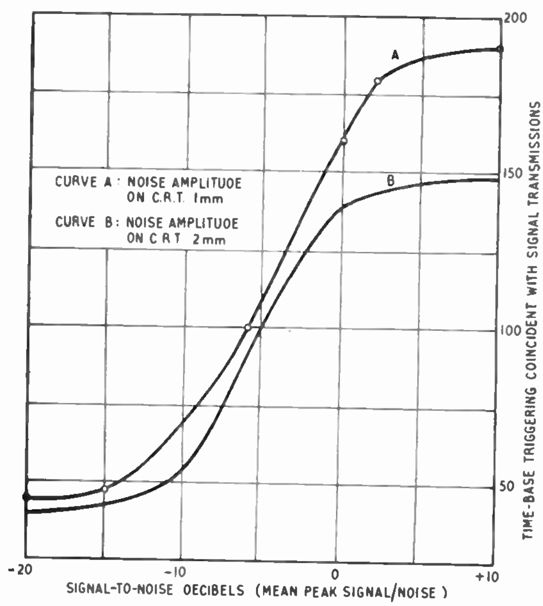

Fig. 4. Number of pulses triggering the search receiver at different signal-to-noise ratios. Beacon p.r.f.—192/sec. Pulse width—5 microsec. Averaging time—10 sec.

4. Radio Telephone Facility

The object so far has been to obtain the optimum transmission as a beacon and in so doing an h.t. battery of high voltage but low current capacity has been specified. If speech transmission is to be incorporated using the same battery it must also use a one-valve transmitter and this has been accomplished by using pulse frequency modulation.

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4.1. *Oscillator with Speech Transmitter*

The one-valve transmitter circuit is re-arranged as a self-quenching oscillator with a repetition rate of between 6 and 12 kc/s; modulation applied to the grid of this "squegging" power oscillator causes a variation of its repetition rate. Very little modulation power is required, and a carbon microphone could be in fact used without the need for amplifiers. Such a microphone cannot however be used as the transducer when receiving speech and a magnetic transducer of the moving coil type is employed. The output of the trans-ducer is amplified by a two-valve audio amplifier to modulate the power oscillator.

The number of pulses transmitted for beacon operation is 200 pairs per second or a total of 400 pulses per second, whereas on speech transmission a minimum of 6,000 pulses is required to transmit audio frequencies up to 3 kc/s. Thus the consumption from the h.t. battery would rise by a factor of 15 times, and to bring the consumption within the abilities of the battery the pulse width is therefore reduced to about 2 microseconds and the peak pulse power reduced to about half. By this means the h.t. consumption is kept down to about four or five times that on beacon transmission.

4.2. *Receiver*

The only practicable receiver for operation at 243 Mc/s having reasonable sensitivity with one r.f. valve is of the super-regenerative type. The power oscillator is caused to "squegg" at about 80 kc/s, in this case of course at a quite low power level. Output from this amplifier/detector is fed into the same two-valve audio amplifier previously used as a modulator to raise the power level enough for the transducer which now operates as a loudspeaker.

The system from beacon to search vessel receiver is p.f.m. whereas that from search vessel to beacon transmission is by amplitude modulated continuous waves. This may seem a little complex, but it is in fact consistent with the objective of keeping the beacon as simple as possible and allowing any complexity to be in the search vessel where it can be much more easily accommodated, in terms of weight, volume and power consumption. It also means that beacons cannot communicate with one another, which is in many respects an advantage since the power required for speech communica-tion is several times greater than that required for the more important navigational function.

5. Circuit Description of the Beacon

The valve used for the power oscillator is the sub-miniature EC70 triode in a self-quenching circuit in which the grid components are such as to give two bursts of oscillation in rapid succession, followed by a long resting period. The circuit of the oscillator is shown in Fig. 5.

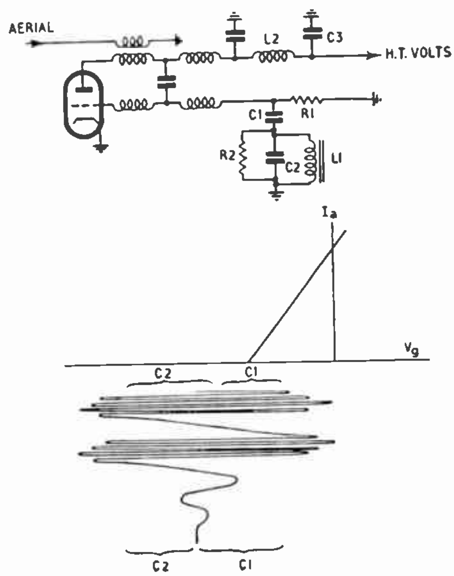

Fig. 5. Circuit of the Sarah beacon transmitter and the waveforms associated with its double-pulse operation.

When the valve oscillates, the capacitors C1 and C2 are charged by grid current. C1 is about five times the capacitance of C2 and the voltages developed across the capacitors are in this ratio, with C2 having the higher voltage. The voltages across C1 and C2 in series eventually cause the r.f. oscillation to cease. During this period of oscillation, which lasts from 5 to 10 microseconds, there will have been negligible rise of current in the inductance L1. After the r.f. oscillation has ceased, C2 dis-charges into L1 causing a reversal of the sign of the voltage across C1. The voltage on C1 will have fallen only a small amount during

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this time, since it has to discharge via the high resistance R1. The grid voltage is now the difference between the voltage across C1 and C2 instead of the sum and it then causes the valve again to conduct and burst into oscillation for a second time.

Again C1 and C2 are charged. Additional charge is put on C1 and C2 is re-charged. After the r.f. oscillation has ceased, C2 again discharges into L1 and the sign of the voltage across it reverses. However, the reversed voltage on C2 is not now enough when subtracted from the increased voltage on C1 to cause the valve to conduct, and thus no third oscillation takes place. The energy contained in C2 is therefore dissipated as a damped oscillation between C2 and the inductance L1. C1 discharges via R1 in series with R2 and L1 in parallel. When the voltage has fallen sufficiently the valve again conducts, oscillates, and the whole cycle repeats itself.

The resistance R2 controls the decrement of the tuned circuit C2 so that only two pulses are produced C1R1 principally determines the long interval (5,000 microseconds) and C2L1 the short time interval (100 to 300 microseconds). The duration of the pulse is determined by the effective capacitance of C1 and C2 in series, and the ratio of anode–cathode and grid–cathode capacitance of the valve, which control the grid drive and hence the grid current.

The rather high anode voltage of 450 is used in order to obtain the required r.f. power from the valve and it was initially found that cathode failures occurred with this high voltage. This proved to be due to the large current flowing prior to the valve oscillating and the inductance L2 was therefore inserted to limit the rate of rise of this current, since a large voltage drop occurs across it. The r.f. oscillation has therefore time to build up before the current has risen to a very high value. The capacitor C3 provides the current (200 mA) for the pulse, since the battery is a high-voltage, low-current source capable of delivering about 1 mA.

6. Mechanical Construction of the Beacon

The components making up the beacon are mounted on a small metal chassis (this does not include the grid circuit components R1 C1 R2 L1), the anode tuned circuit is wound on a nylon former and the remainder of the components are fitted into cavities in a nylon block. The whole is then placed into a mould, and polythene injected—thus the whole unit becomes a solid preventing any movement of components. Nylon is used as a matrix for the components to hold them in position during the moulding operation. This is necessary because in such a small mould it is difficult to find a point at which to feed in the polythene at 600 lb. per square inch, which does not displace the components. Any displacement might cause failure of the circuit at moulding, and lead to unpredictable frequency changes between the unmoulded and moulded conditions. Furthermore nylon will withstand the temperature of 190°C at which the polythene is injected.

The final unit containing the power oscillator is 3 in. × 1·18 in. × 1·1 in. and weighs 6·5 oz. (7·6 cm × 3·0 cm × 2·8 cm; 0·17 kg).

7. Aerial

The oscillator feeds r.f. power into a collapsible aerial 36 in. long and about half an inch in width, having an electrical length of 0·62λ at 243 Mc/s. This is used in preference to a quarter-wave element as with the beacon attached to the lobe of the life jacket it has no height worth mentioning apart from that due to its own length. The extra length therefore gains a little height and possesses also greater horizontal directivity (see Fig. 1). The aerial is made of steel tape similar to the familiar ruler; it is laminated in order to have the necessary strength to resist wind velocities up to about 30 knots, without collapsing, when the wind is bearing on its convex side. Four laminae of graded lengths are held together with metal clips, which encircle all four but are only attached to the outer laminae on the convex side. This permits the aerial to be rolled and fitted into a small cap since the laminae can now slide with respect to one another when bent into a curve.

8. Speech Unit

The speech unit (see Fig. 6) consists of a three-position switch, a transducer and a two-valve audio amplifier. These latter two are inoperative when the equipment is operating

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as a beacon. The switch is spring loaded to the central position in which the beacon is operative. The other two positions of the switch are PRESS TO TALK and PRESS TO LISTEN.

When the switch is turned to transmit speech, the code unit is disconnected from the grid circuit of the r.f. power oscillator and a normal R-C circuit is connected in place. The value of the time-constant is such as to cause

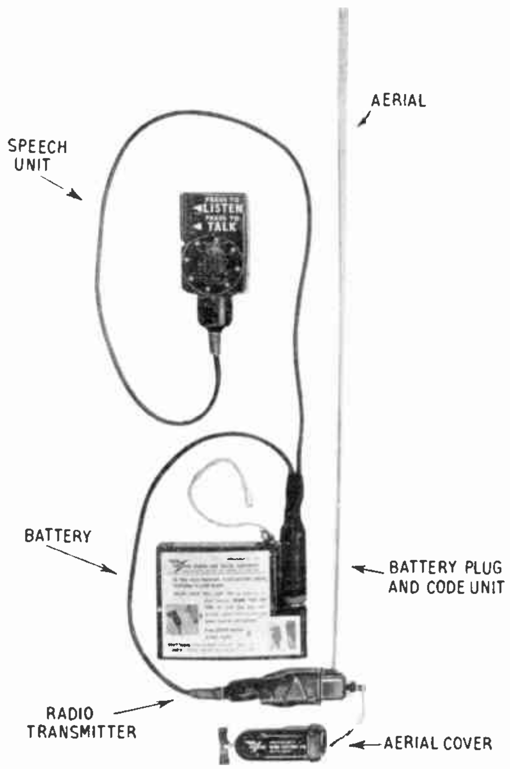

Fig. 6. Complete Sarah beacon.

the r.f. power oscillator to "squegg" at about 6 kc/s. The speech voltages from the transducer, amplified in the speech unit, are applied to the grid of the power oscillator causing pulse frequency modulation.

When the switch is turned to the position for receiving speech the code unit is again disconnected and an R-C circuit connected in its place, a resistance load also being connected in the anode circuit of the r.f. power oscillator. It thus becomes a super-regenerative detector, "squegging" at about 80 kc/s. The audio voltages developed across the detector load are amplified in the speech unit and fed to the transducer, which now functions as loudspeaker. The speech unit weighs 15 oz. and is 4·625 in. × 2·5 in. × 1·5 in. (0·425 kg; 11·8 cm × 6·4 cm × 3·8 cm).

9. Battery

The battery which weighs 32 oz. and has a volume of 30 in.^{3} (0·9 kg; 490 cm^3), consists of h.t. and l.t. sections. The length of time the beacon will operate is determined by the low tension battery. This is due to the nature of its discharge curve, in which there is a very sudden fall of voltage when the battery is exhausted. At this point the h.t. tension voltage is about 270 volts and the beacon would have continued operating with gradually falling power output down to an h.t. voltage of about 70 volts.

During beacon transmission the consumption from the 6·3 volts l.t. battery is 0·15 A and at 15°C the battery will last about 30 hours, having delivered 30 watt-hours. Consumption from the 450 volt h.t. battery is 1·5 mA and when the l.t. fails it will have delivered 20 watt-hours at 15°C. At a temperature of +5°C the battery will operate the beacon for 20 hours.

10. Search Vessel Equipment

One of the most useful rescue craft is a helicopter, in which space is particularly restricted so it was necessary for the special equipment to locate the Sarah beacon to be as small and light as possible. One of the great difficulties of miniaturization is disposal of the heat generated and the prevention of any parts from becoming very hot. The second aim is achieved by suitable circuit ratings while the disposal of the heat in Sarah is accomplished by building the transmitter/receiver in separate units, namely r.f. and i.f. circuits, time-base, display unit, transmitter, and power supply. The components for each unit are set in cavities in aluminium blocks, the high thermal conductivity of which ensures equality of temperature throughout a unit. This form of construction is also especially useful in providing good electrical screening and complete

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mechanical support for the r.f. and i.f. units thereby ensuring greater stability of the receiver. Details of the construction can be seen in Fig. 7.

The heat generated by the various units must be transferred to the outside of the case and so disposed of by convection and radiation to the

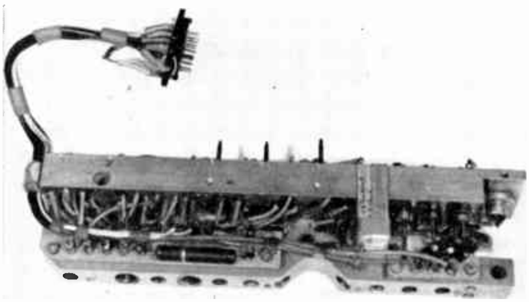

Fig. 7. R.f. and i.f. units of the search receiver

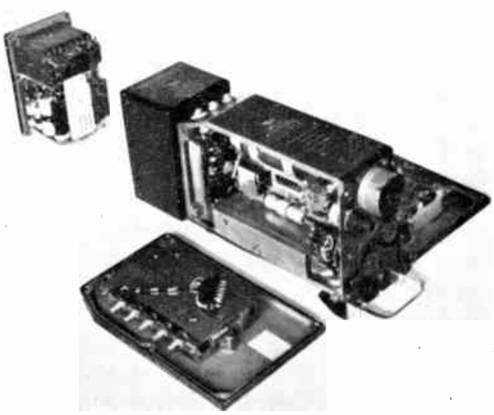

Fig. 8. Showing construction of the search transmitter/receiver equipment.

surroundings. The outer box of the transmitter/receiver is made in three parts (see Fig. 8). There is a central carcase carrying the cathode-ray tube and inter-unit wiring and the two side cheeks carry the r.f. and i.f. units and the time-base unit. These are bolted to the side cheeks and hence the heat they generate is conveyed by conduction to the outside surface of the box, no air convection internally being necessary. The transmitter is bolted to the base of the central carcase and disposes of its heat by the same method. The power unit is attached to the transmitter/receiver box which measures $10 \times 4 \times 6$ in. ($2{\cdot}5 \times 10{\cdot}2 \times 15{\cdot}2$ cm), and a total of 46 watts is dissipated leading to a temperature rise of 30°C above the ambient. When the side cheeks are screwed down the unit is sealed and is capable of operating up to an altitude of 25,000 feet (7,500 m).

The weights of the various units are as follows:—

R.F. and I.F. Unit	1 lb. 1 oz.
Time-base Unit	1 lb. 2 oz.
Display Unit and inter-unit wiring	4 lb. 14 oz.
Side Panels	1 lb. 10 oz.
Transmitter	15 oz.
Power Supply	5 lb. 6 oz.
Total (6·8 kg)	15 lb. 0 oz.

11. Circuit Description of the Search Equipment

11.1. *R.F. and I.F. Unit*

The r.f. and i.f. units make up a superheterodyne receiver having a four-valve r.f. unit and six-valve i.f. amplifier. The whole receiver is built in one block. The i.f. amplifier consists of four synchronously-tuned stages having a bandwidth of 800 kc/s at the −3 db points. This may seem excessive in order to resolve a 5–10 microseconds pulse but allowance must be made for the fact that movement of the beacon aerial causes changes in the carrier frequency. If the bare minimum of bandwidth were used this frequency drift would cause the apparent pulse shape to change, and since when homing towards the beacon one is comparing a pulse displayed to the left of the time-base with one to the right of the time base (see Fig. 2), any changes of pulse shape would tend to make this operation difficult. A further advantage of the wider bandwidth is that it permits the simultaneous display of beacons whose carrier frequency may differ from the nominal value.

The effects of this large bandwidth on system sensitivity is very slight. From Fig. 9* it can

* After J. L. Lawson and G. E. Uhlenbeck, "Threshold Signals," page 201, M.I.T. Radiation Laboratory Series, Vol. 24. (McGraw-Hill, New York, 1950.)

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be seen that loss of system sensitivity resulting when receiving a 10 microsecond pulse with 800 kc/s bandwidth is of the order of 1·5 db.

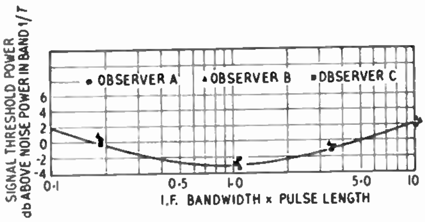

Fig. 9. Detection of pulses under conditions of reduced sensitivity due to excess bandwidth of i.f amplifier.

Pulse length—1 microsec.
Pulse on screen—1·7 mm.
Video bandwidth—10 Mc/s.
Signal presentation time—3 sec
P.R.F.—200/sec.
C.R.T. Screen—P1.

The r.f. section consists of a two-valve cascode amplifier, one mixer valve and one local oscillator. The cascode circuit gives a slight improvement in the receiver noise factor: with the sub-miniature valves available, it was found that a noise factor of 9 db could be obtained in an ordinary r.f. amplifier circuit while with the cascode 8 db was achieved. The more important benefit obtained from the cascode circuit is that second-channel rejection is greatly improved.

Measured in the laboratory, the receiver gives a sensitivity of 10 microvolts for a signal-to-noise ratio of 2:1 at the output.

During the search phase of the rescue operation, the receiver is tuned over a band of ±1·5 Mc/s. This is accomplished entirely electronically by means of a magnetic reactor, part of the local oscillator coil being wound on a ring of Ferroxcube, the degree of saturation of which is cyclicly varied by a sawtooth of current in a winding on an auxiliary magnetic circuit. For manual tuning this degree of magnetization is controlled by means of a potentiometer, adjustable by the operator. In order to ensure that the receiver is sweeping 1·5 Mc/s each side of 243 Mc/s, a crystal oscillator is incorporated which allows the centre of the sweep to be set at 243 Mc/s and checked at any time.

11.2. *Time-base Unit*

The time-base unit has four valves; signal amplifier, limiter, blocking oscillator and time-base amplifier. The pulses applied to the signal valve grid are positive-going with the object of reducing the amount of heat dissipated at the anode. For the same reason a blocking oscillator is used to generate the time-base waveform, as its anode dissipation is low and depends on the time-base loading.

The signal pulses at the anode of the signal amplifier are passed through a limiter before being used to trigger the time-base oscillator, as this improves the triggering of the blocking oscillator. It also ensures that all the pulses applied to the blocking oscillator are of the same amplitude and hence all have equal chances of triggering it, irrespective of their amplitude at the signal amplifier.

It was found that the signal-to-noise ratio at which a signal can be detected is affected by the stability of the display on the cathode-ray tube which may show small variations of the position of the displayed pulse. These variations arise through a.c. coupling to the deflection plates when the time-base is firing erratically due to thermal noise. To ensure fixity of origin of the time-base a d.c. restoring diode is necessary after the time-base amplifier. The same considerations also affect the signal plates except that here the d.c. restoring diode is connected to the grid of the signal amplifier. In the absence of this diode the displacement of signal at low signal-to-noise ratios is quite small. However, interference pulses are many thousands of times the amplitude of the desired signals and would drive the grid of the signal amplifier well into grid current. The resulting bias developed on the coupling capacitor would cause fluctuation of the gain and in bad cases would bias the wanted signal off the operative part of the grid base. The effect of the diode is therefore to enable the grid to recover very rapidly from a paralysing overload. It can be seen that this diode also ensures a continuity of signals to the time-base generator in the presence of overloading interference. Thus the nuisance value of the interfering pulses is only on account of their number and not on account of their amplitude as well.

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11.3. *Transmitter*

The other major unit is the transmitter block (Fig. 10) which allows the search aircraft or ship to reply to the beacon. The transmitter is tunable over the range 243 Mc/s $\pm$ 1·5 Mc/s, and during the homing phase of the rescue operation is tuned to the receiver frequency. The transmitter is set to emit pulses at a low power and tuned until these pulses reach maximum amplitude on the c.r.t. display, thus setting the transmitter to the same frequency as the beacon. The transmitter uses amplitude modulated continuous waves to communicate with the beacon.

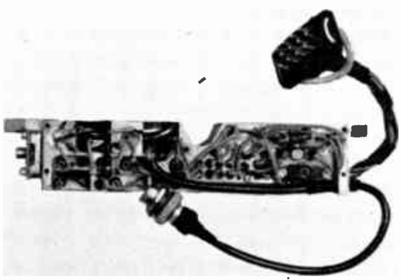

Fig. 10. The transmitter unit of the search equipment

The transmitter provides a further facility in that it can operate as a beacon itself. The search aircraft may have located a person in the sea 60 miles from the coast, whereas the range at which the boat to be used for the rescue can detect the signals is about 6 miles. The aircraft transmitter can be switched to "Beacon" and can come within radio range of the boat leaving the shore enabling the boat to home towards the aircraft until it comes within range of the beacon in the sea. Alternatively if they both switch their transmitters to "Beacon" they can home towards one another.

Thus the aircraft transmitter provides four facilities: transmit a.m. c.w., crystal check for the receiver, netting facility, and transmit beacon.

12. Boat Installation

It will be recalled that the aircraft fixes the position of the man in the sea by locating the null in the polar diagram of the beacon aerial vertically above the beacon. The search boat has therefore to be equipped with a directional aerial. This consists of two five-element Yagi aerials mounted at a height of about twenty-five feet above sea level and splayed at an angle of 30° giving the overlapping polar diagrams shown in Fig. 11. The boat therefore heads with the equisignal of the major lobes directed towards the beacon, the operator judging the nearness by the increasing strength of signal.

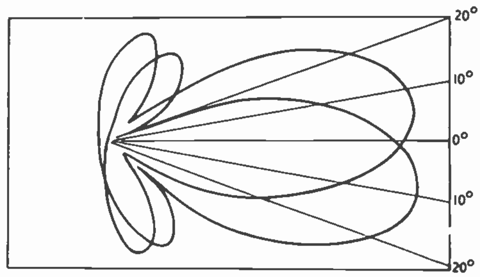

Fig. 11. Polar diagram of the double Yagi aerials used on the search boat.

Successful rescue must however be possible at night and under conditions of bad visibility and experience has shown that the boat can approach the beacon and pass within perhaps 10–20 feet to port or starboard, the crew obtaining a momentary view of it in the search-light beam. At this time the boat has very little seaway and hence manoeuvres rather slowly and in fact, with a man so close to the boat, careful movement is called for. The manoeuvring room required under these conditions exceeds the limit of visibility and the captain requires continuous information of the bearing of the beacon. This is not possible with Yagi aerials which only give precise information about the "dead ahead" bearing and for this additional facility an Adcock loop antenna is used on the boat.

During the approach to the beacon using the Yagi aerials the operator periodically switches in the loop aerial. A radio range of 6 miles is obtained with the Yagis and about 1 mile with the loop, thus giving an idea of the distance of the beacon. When the signal-to-noise ratio is good enough, the operator uses the loop aerial to give heading instructions to the helmsman.

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The ability of the Sarah system to discriminate between several beacons is useful in such circumstances since the operator can keep track of the bearings of a number of beacons with the loop aerial.

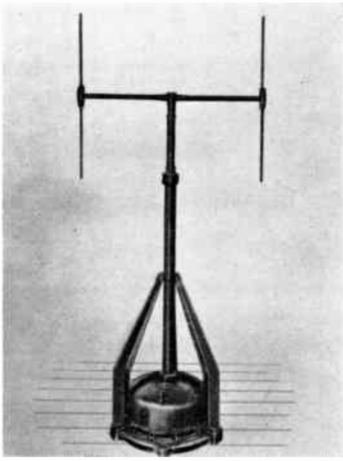

Fig. 12. The Adcock u.h.f. direction finding loop used on the search boat

The loop aerial which is shown in Fig. 12 is rotated by means of a servo system. The bearing of the beacon is ascertained by swinging the aerial to and fro and observing the signal amplitude on the c.r.t. The method is the same as for a normal df except that the display is visual instead of aural.

The loop installation has bearing repeaters for the helmsman and for the captain. When the set operator has ascertained the bearing of a beacon he can press a button to illuminate these latter two repeaters for reading.

13. Conclusion

Since it represents a person's last possible means of calling for help the beacon should be completely reliable and absolute simplicity of the electronics is vital if this is to be achieved. Moulding the circuitry of the beacon into a solid form prohibits any maintenance and failure of any part at the monthly routine checks is rectified by the complete replacement of one of the four basic parts of the beacon. The beacon is tested after transit under conditions equivalent to altitudes in the range from 60,000 feet to 12 feet below sea-level, at temperatures from $-40°$ to $+60°C$, and to an acceleration of 60g. Thus, it can follow, without failure, all the violent changes of environment to which its user may be subjected.

14. Acknowledgments

The author wishes to thank the manufacturers of this equipment, Messrs. Ultra Electric Ltd., for their kind permission to publish this paper.

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LOGICAL DESIGN OF A COMPUTER FOR BUSINESS USE*

by

R. J. Froggatt, B.Sc. (Eng.)†

A paper presented at the Convention on "Electronics in Automation" in Cambridge on 27th June 1957. In the Chair : Dr. A. D. Booth (Member).

SUMMARY

The paper describes the characteristics and logical design of the E.M.I. business machine which is a serial machine operating at a clock rate of 115 kc/s using a magnetic drum for storage. The machine also has provision for magnetic tape storage and additional drum storage can be provided if required.

1. Introduction

The machine to be described in this paper is a digital computer designed especially for use in business applications. It differs from the earlier mathematical machines in the amount of storage that can be provided; in the particular embodiment considered here a storage capacity of approximately a million binary digits is provided on the surface of a magnetic drum and further drums can be fitted as required. Magnetic tape decks can be fitted as required and any type of input or output equipment.

The following details refer to a specific machine but even with very different peripheral equipment there will be little change in the organization.

No attempt has been made to give complete details of the logical design of this computer. What has been done is to describe the more important parts of it but even in these some of the engineering necessities have been neglected such as detailed timing within digit periods.

2. General Arrangement

Figure 1 shows the general arrangement of the machine. The instruction code is of the two address type, so that an instruction such as addition takes the form

$$A + B \rightarrow B$$

that is, add the contents of location A to that of location B and place the sum in location B. The machine stores its information in serial form and the information from the two source locations flows to the arithmetic unit via two highways and back into store through a third.

The machine is single beat in that it obtains the next instruction to be performed while it is obeying the present one. Modification facilities exist so that the contents of a register designated in the instruction can be added to the instruction before it is obeyed. This means that two further highways must be provided, one to obtain the instruction and one for the modification.

As can be seen from the diagram any transfer of information to and from the various types of storage always takes place through the arithmetic unit. This is no drawback since the arithmetic unit is always free when an instruction has been performed. It does not contain in itself any accumulation or similar storage facilities that could hold information after an instruction is completed.

The word length in the machine is 36 binary digits and, apart from any special packing that might be necessary in a particular programme, a stored word can, in general, have one of three different significances in the machine. These can of course be distinguished only by a knowledge of the programme and where they are stored. They are:

(*a*) A word may represent an integral binary number expressed in the complements code, so that the most significant digit has sign significance. This is the normal representation for numeric working.

* Manuscript received 2nd May, 1957. (Paper No. 429.)

† E.M.I. Electronics Limited, Hayes, Middlesex.

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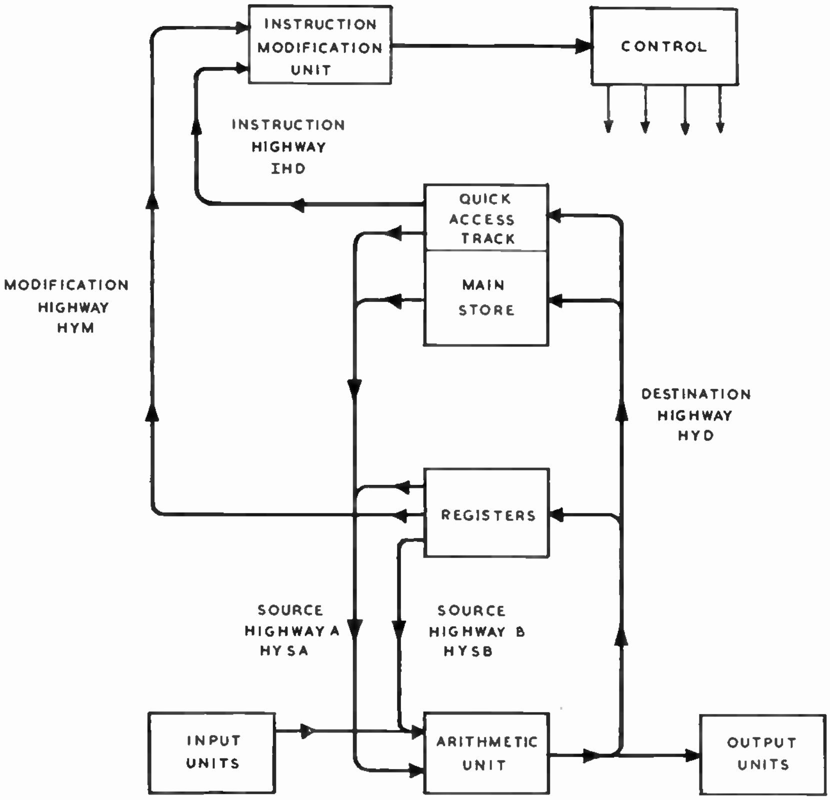

Fig. 1. General arrangement of the machine.

(*b*) A word may represent six characters, each expressed in a six bit code. This is usually used for alphabetic information which has no arithmetic operations performed on it. Since conversion from decimal or sterling numbers to binary code is provided at the input to the machine and the reverse on output, there is no need to use this form of representation for numerical data which has to be processed.

(*c*) A word may represent an instruction. Detailed descriptions of each instruction are given later but, in general, an instruction can be split up into the following parts:—

(i) 3 digits defining a modification register

(ii) 5 digits specifying a function

(iii) 6 digits specifying one address

(iv) 6 digits specifying another address

(v) Digits used for increasing the scope of (iv) or for various purposes specific to particular functions.

3. Storage

Storage inside the machine is provided in three separate ways: circulating registers, the quick access track and normal drum tracks. All of these use the surface of a magnetic drum for the storage of information.

3.1. *Circulating Registers*

A circulating register consists of a reading and a writing head spaced approximately 1 word apart on the surface of the drum, plus the associated amplifiers and other electronic equipment. Fig. 2 shows the general arrangement.

The drum, which is 8 in. in diameter, can store 64 words on one track and therefore the two heads are spaced approximately a 1/64th of a revolution apart. To allow for the delay in the arithmetic unit the distance is somewhat less than that corresponding to 1 word, a delay of $1\frac{3}{8}$ digits being added to the recirculating path plus the delay in the phase modulator ($\frac{1}{4}$ of a digit).

All information on the drum is recorded in phase modulation. In this a "1" is recorded as a positive pulse followed by a negative, and a "0" as a negative pulse followed by a positive pulse. The waveform is always balanced and therefore no d.c. coupling or restoring problems arise. The drum revolves at 3,000 rev/min making the clock rate approximately 115 kc/s.

As can be seen from the diagram the gates for both the source and destination highways are kept open by triggers which are set or unset by a transfer timing pulse (TTP) depending on the presence or absence of an output from a source or destination decoder (DRS or DRD). In the destination gating a changeover gate must be used to stop the circulating path when information is being fed in.

This gating arrangement removes any necessity for accurate timing and fast change-overs of the decoder lines which define which registers shall be used for sources of and destinations for information, and relies only on a set of common pulse services for this purpose.

Only seven registers are used for instruction modification purposes and a direct gating scheme is used without triggers since the decoder lines in this case need not change very quickly. Only the address information is modifiable (and the miscellaneous information at the end of some instructions) and any information occurring before this in a modification register is gated out in the instruction modification unit. The eighth modification register, which could be defined with the three modification digits is not realized physically. Its effective content is always zero.

As is shown on the diagram an output to the central monitor is provided from each register. This can be examined on a cathode-ray tube.

Fifty circulating registers are provided. Seven of these are designated for instruction

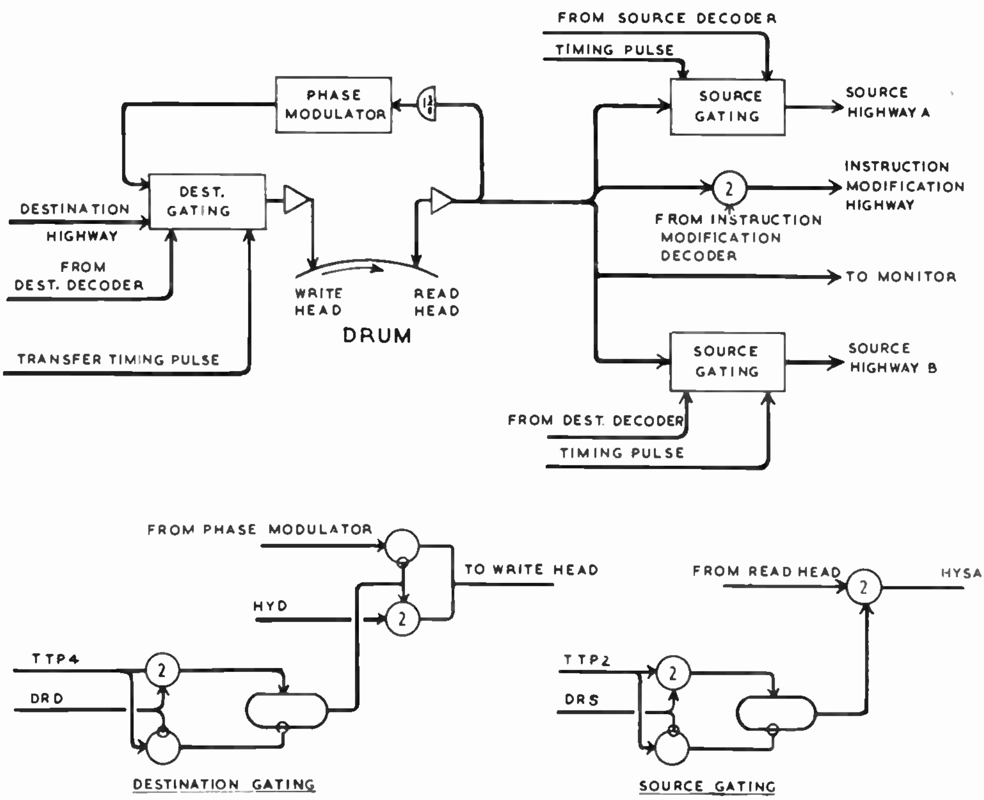

Fig. 2. Circulating register.

modification (41–47), one always receives the result of a collate instruction (40) and two (48 and 49) combine together to receive the product from multiplication or hold the dividend, and later the remainder on division. All these registers are available for normal use when they are not performing these specific functions.

3.2. *The Quick Access Track*

An instruction to be obeyed is obtained from the quick access track. This can be considered as having one read/write head and 63 reading heads; it is in fact split into two sections for ease of drum layout. Since 64 words are stored on a track, this means that, although access time is long for writing, it is immediate for reading. Since the quick access track is usually filled from another track on the drum, the long access on writing is unimportant as this is already involved in obtaining the information.

Apart from its use as the immediate source of instructions, this track can be used as a normal track (see Section 3.3.), with the added advantage of quick reading access. However this does reduce the number of instructions available without inter-track transfers and is used mostly for constants and the like stored with the programme on the main storage tracks.

3.3. *The Main Storage Tracks*

Approximately 24,000 words of storage are available on the main storage tracks of the drum. These are arranged in three groups and access to them is by means of head shifting mechanisms.

Two groups have mechanisms with eight heads each and capable of moving to eight positions, thus covering a total of 128 tracks between them. The third group has a mechanism with 16 heads and is capable of taking up 16 positions and therefore covers 256 tracks.

The first drum in any machine assembly has also to accommodate the circulating registers and quick access track. If further drum storage has to be provided these would not be duplicated and the capacity of a drum would be increased accordingly having about 64 tracks per inch of length.

The arrangement of the equipment for each head is simpler than for the circulating registers in that only one source highway (HYSA) is involved and there is no need for an instruction modification highway output. The circulation path does not of course exist.

The head shifting mechanisms are designed so that their various shifts are proportional to powers of two. Since part of the appropriate instructions gives the position of the head shifter in binary form, this allows for a direct drive from the instruction staticizer to the head shift amplifiers.

3.4. *Ancillary Tracks*

Various other tracks with fixed reading heads are provided. These are all recorded before the machine becomes operational and will not in general be changed.

(*a*) One track is a clock track used to provide a gating pulse during each digit period.

(*b*) Another track gives an output once per revolution of the drum and is used to define the position of the start of the first word (Word 0).

(*c*) A third track has recorded on it in binary form the number of each word. This occurs during the previous word so that it can be sought before the wanted word comes up.

(*d*) In order to start the computer some instructions must be built into it so that it can receive information and pack it into the correct places in store. 64 words of initial instructions are prerecorded on a further track and when the machine is first started or a new programme has to be fed in, the contents of this track are automatically fed to the quick access track and the first word used as the first instruction.

4. The Instruction Code

Table 1 gives a summary of the instruction code and the significance of the digits used in each instruction. The most complicated instructions are those concerned with peripheral units. These include the card readers and printer units.

Transfer of information to the arithmetic unit takes place via two highways. Information specified in instruction digits 10–15 (ID 10–15) uses one highway (B highway), that specified in ID 16 onwards uses the other (A highway). Only one destination highway is used. Since

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Table 1

Instruction Code

Digits		35 — 28	27 — 22	21 — 16	15 — 10	9	8 — 4	3	2 — 0
		c		*a*	*b*	Sp	Function	Sp	Mod
Stop				S	Condition for Stop		0		
Inter-Track Transfer		Source TRACK		Last Word	Next Instruction		1		
Read Input Card		New Card	Channel	Conversion	Destination Register		2		
Output		Print	Layout	Conversion	Source Register		3		
Register to Register	Add Subtract Transfer			Source Register	Destination Register		4 5 6		
Register to Register	Collate Multiply			Source Register	Source Register		7 8		
Register to Register	Divide			Source Register	Destination Register		9		
Shift	Left Right		Number of Shifts	Source Register	Destination Register		10 11		
Store to Register	Add Subtract Transfer	Source TRACK		WORD	Destination Register		12 13 14		
Store to Register	Collate	Source TRACK		WORD	Source Register		15		
Register to Store	Transfer	Destination TRACK		WORD	Source Register		16		
Store to Register	Block Transfer	Source TRACK		WORD	Destination Register		17		
Register to Store	Block Transfer	Destination TRACK		WORD	Source Register		18		
Transfer to Tape				Channel	Source Register		19		
Transfer from Tape				Channel	Destination Register		20		
Set Head Shift		TRACK					21		
Cumulative Multiplication				Source Register	Source Register		24		
Transfer to Dividend Reg.				Source Register			25		
Test	Zero Non-zero Positive Negative			Source Register	Next Instruction		28 29 30 31		

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this is a two address machine, the specification of a destination register on a two input operation also specifies a source feeding the B highway.

ID 0–2 specify the instruction modification register, the contents of which are added to the stored instruction before staticizing and using. If these digits have the value 0, nothing is in fact added; the remaining values correspond in order to registers 41 to 47.

The number contained ID 4–8 specify the function and the following notes are in order corresponding to the value of these digits.

For convenient reference, the remainder of the instruction is divided into three parts: *a* comprising ID 16–21, *b* comprising ID 10–15, and *c* ID 22 onwards.

Function 0—Stop

Cease operation and await manual restart.

This operation is conditional. If ID 16 is zero the stoppage is absolute. If ID 16 is 1 the machine will stop only if there is a 1 in any of the ID 10–15 and the corresponding switch on the monitor desk is also set to 1.

Function 1—Inter track transfer

Replace the contents of the quick access track by the contents of the track specified in *c*, starting at word 0 and continuing to the word specified in *a* leaving the rest of the quick access track unchanged.

In *b* is specified the number of the next instruction to be followed after making the transfer.

This is the only instruction in which transfers occur between tracks.

Function 2—Read card input

From the buffer store associated with the card reader specified by the "*c*" address (instruction digits 22–27) convert, in the manner "*m*", the "*n*" columns following those last read and transfer the resultant binary word to the register specified by the "*b*" address. If instruction digit 28 has the value 1 then, after the performance of the above instruction, any old information in the buffer store is destroyed and new information is to be fed in from the card at present in the sensing station of the associated card reader: the card in the sensing station is then changed.

"*m*" is given by the value of instruction digits 16 and 17, where 16 is the less significant digit and

if "*m*" = 00 (≡decimal value 0), there will be no conversion of the information from a column, i.e. the card punching is regarded as pure binary. By the addition of zeros to the most significant places the resultant binary word will contain 36 digits.

if "*m*" = 01 (≡decimal value 1), there will be a conversion of the decimal digits, represented by the column on the card, to produce a binary equivalent of 36 digits. The first column read will be regarded as the most significant decimal digit.

if "*m*" = 10 (≡decimal value 2), the information read from the card is treated as alphabetic information and each column is coded into six binary digits and stacked in sequence in a 36 bit binary word, the last column read being in the 6 least significant places. If less than 6 alphabetic characters are read there will be groups of 6 zeros (one group for each absent character) in the most significant places.

if "*m*" = 11 (≡decimal value 3), the information read from the card is treated as a sterling quantity and converted to the binary equivalent of the number of pence. The last column read will regarded as the pence column, the previous column the number of shillings (less than 10), the column before that as number of 10/– etc.

"*n*" is given by the value of instruction digits 18–21, where 18 is the least significant digit and

for binary punching, only one column may be read, i.e. $n = 1$;

for decimal, 1 to 11 columns, inclusive, may be read since $2^{35} = 34{,}359{,}738{,}368$;

for alphabet, 1 to 6 columns, inclusive, may be read;

for sterling, 1 to 12 columns, inclusive, may be read since 2^{35}d = £143,165,576 10 8.

Function 3—Output

Transfer the information in the "*b*" register to the output buffer, converting the binary information to the form "*m*" and store the "*n*"

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least significant resultant characters until a Function 3 instruction with instruction digit 28 of value 1 is received. The information transferred as a result of this last Function 3 instruction completes a line of print, these lines of print being printed out sequentially with the layout as specified by the "*c*" address (instruction digits 22–27) of this last Function 3 instruction.

"*m*" is given by the value of instruction digits 16 and 17 where 16 is the least significant digit and

if "*m*"=00 (≡decimal value 0, the transferred information, if any, is to be ignored and nothing is to be printed.

if "*m*"=01 (≡decimal value 1), convert the information to its decimal equivalent, each decimal character to be temporarily stored as a six place binary code.

if "*m*"=10 (≡decimal value 2), specifies no conversion of information. Each group of 6 digits of the 36 digit information is regarded as a code for an alphabetic character, the character represented by P_0 to P_5 being defined as the least significant character.

if "*m*"=11 (≡decimal value 3), regard the information as binary pence and convert to normal sterling representation, each sterling character to be temporarily stored as a six place binary code.

"*n*" is given by the value of instruction digits 18–21.

The layout digits occupy the digit positions 22–26 of the "*c*" address. These specify where the characters will be placed on the line and also details of the paper feed of the line printer.

Function 4—Register to register add

Add the contents of register *a* to the contents of register *b*, placing the sum in register *b*. The contents of register *a* remain unchanged after this operation.

Function 5—Register to register subtract

Subtract the contents of register *a* from the contents of register *b*, placing the difference in register *b*, the contents of register *a* remaining unchanged.

Function 6—Register to register transfer

Replace the contents of register *b* by those of register *a*, leaving register *a* unchanged.

Function 7—Register to register collate

Replace the contents of register 40 by a number having a 1 in each place in which the contents of registers *a* and *b* both have a 1.

Function 8—Register to register multiply

Multiply the contents of register *a* by the contents of register *b* and place the product in registers 48 and 49, the most significant half of the product being in register 49 and the least significant half in register 48.

Function 9—Register to register divide

Divide the double length number with the most significant half in register 49 and its least significant half in register 48 by the number in register *a*, placing the quotient in register *b*. The remainder is left in register 48.

Function 10—Left shift

Shift the contents of register *a* left (i.e. to a more significant position) by the number of places specified in *c* and replace the contents of register *b* with this result, leaving register *a* unchanged. If both *a* and *b* specify 50, a double length shift is performed on the combined contents of registers 48 and 49.

Function 11—Right shift

Shift the contents of register *a* right by the number of places specified in *c*, extending the sign digit, and replace the contents of register *b* with this result, leaving register *a* unchanged. If both *a* and *b* specify 50, a double length shift is performed on the combined contents of registers 48 and 49.

Function 12—Store to register add

Add the contents of word *a* of the track *c* of the store to the contents of register *b*, leaving *a* unchanged.

Function 13—Store to register subtract

Subtract the contents of word *a* of the track *c* of the store from the contents of register *b* leaving *a* unchanged.

Function 14—Store to register transfer

Replace the contents of register *b* with the contents of word *a* of the track *c* of the store.

Function 15—Store to register collate

Replace the contents of register 40 by a number having a 1 in each place in which the contents of register *b* and word *a* of track *c* both have a 1.

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Function 16—Register to store transfer

Replace the contents of word *a* of track *c* of the store with the contents of register *b*, leaving *b* unchanged.

Function 17—Store to register block transfer

Transfer up to eight words of track *c* to registers, placing word *a* into register *b* and continuing sequentially (($a+1$) to ($b+1$) etc.) until the value 7, 15, 23, 31, 39 or 47 is reached. The track remains unaltered after this operation.

Function 18—Register to store block transfer

Transfer to track *c* the contents of up to eight registers, placing the contents of register *b* in word *a* and continuing sequentially (($a+1$) to ($b+1$)) until the value 7, 15, 23, 31, 39 or 47 is reached. The registers remain unaltered after this operation.

Function 19—Transfer to tape store

Transfer to tape output channel *a* the contents of registers b, $b+1$ . . . etc. sequentially until the number of the register whose contents are transferred has the value 7, 15, 23, 31, 39 or 47 when the operation ceases. Since 8 words are normally transferred *b* will usually have the value 0, 8, 16, 24, 32 or 40. If instruction digit 22 of value 1 is present, the tape in output channel *a* needs to be changed.

Function 20—Transfer from tape store

Transfer the contents of the tape input channel *a* to registers b, $b+1$ . . . etc. sequentially until the number of the register receiving information has the value 7, 15, 23, 31, 39 or 47, when the operation ceases. Since 8 words are normally transferred, *b* will usually have the value 0, 8, 16, 24, 32 or 40. If instruction digit 22 of value 1 is present, the tape in input channel *a* needs to be changed.

Function 21—Set head shift

Set the head shift mechanism to the position specified in *c*.

Function 24—Cumulative multiplication

Multiply the contents of register *a* by the contents of register *b* and add the product to the contents of registers 48 and 49.

Function 25—Transfer dividend

Transfer the contents of register *a* to register 48 and extend the sign digit through register 49. This turns a single length number to a double length one and is used prior to division.

Function 28—Test zero

If the contents of register *a* are zero, proceed to the instruction in location *b* of the quick access track; if not, continue with the next instruction in series.

Function 29—Test non-zero

If the contents of the register *a* are zero, continue with the next instruction in series; if not, proceed to the instruction in location *b* of the quick access track.

Function 30—Test positive

If register *a* contains a non-negative number, proceed to the instruction in location *b* of the quick access track; if not, continue with the next instruction in series.

Function 31—Test negative

If register *a* contains a negative number, proceed to the instruction in location *b* of the quick access track; if not, continue with the next instruction in series.

5. Organization of Control

5.1. *Instruction Organization*

Figure 3 is a block diagram of the instruction organization. The sequence counter specifies which head must be used on the quick access track to obtain the next instruction. In normal operation, where instructions are taken in sequence, the head number is advanced by one every minor cycle (which is the time taken for one word to pass) apart from the first during an instruction. If an instruction takes only one minor cycle, there is no need to obtain information from a different head, as the rotation of the drum will bring the next instruction under the same head. Instructions which take longer than this entail following the next instruction round the drum.

The sequence counter has two halves so that it can compute not only the next head for normal sequence working but the head required for an instruction specified in a jump instruction.

The instruction flows to the instruction staticiser via an adder. This is inoperative during the first ten digits of the instruction (D 0 to D 9) as these are never modified. The first three digits are decoded and select the appropriate instruction modification register. The contents of the selected register then modify the rest of the instruction. Digits 10 to 15 are

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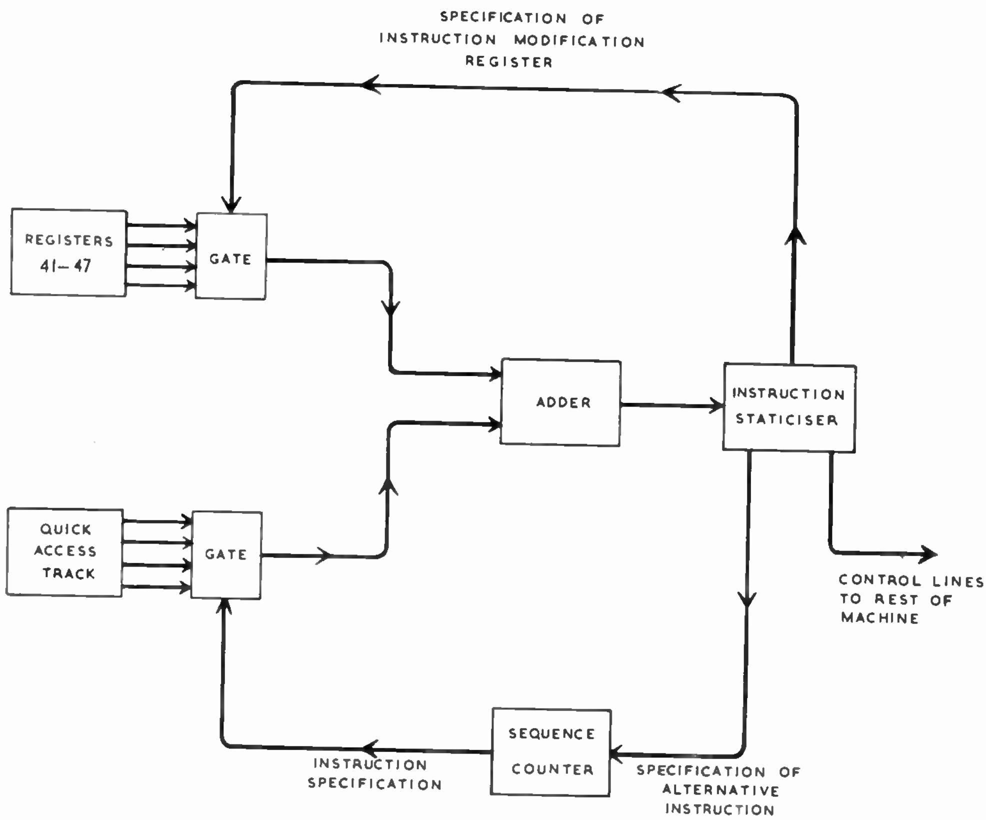

Fig. 3. Instruction organization.

passed to the sequence counter since, on some functions, these define the alternative instruction when jumping.

Figure 4 (*a*) shows the procedure adopted during an instruction in which no jump is involved. During "*A*" the sequence counter is advanced if the instruction being obeyed takes more than one minor cycle. At the end of this period the correct instruction is selected, during minor cycle *B*, and passed to the instruction staticizer, while the previous instruction is being obeyed. During *C* this instruction is then obeyed.

Figure 4 (*b*) shows the operation of the two halves of the sequence counter in a test function when a jump can occur. In the last minor cycle "*A*" of the previous instruction the sequence counter 1 defines the head on the quick access track from which the test instruction is obtained during period "*B*." Digits 10–15 are fed to sequence counter 2 to define the address of the instruction to be followed if the test is successful. During minor cycle *C*, the test is performed and depending on the result either sequence counter 1 or 2 specifies the next instruction which is set up during minor cycle *D* and obeyed in *E*. No instruction is performed during minor cycle *D*.

5.2. *Instruction Staticizer*

Figure 5 shows the three types of staticizers used in the instruction staticizer and Table 2 shows on which stages they are used. In (*a*) the appropriate digit pulse selects the correct digit from the modified instruction highway and sets the trigger. The trigger is turned off by the clear instruction staticizer pulse before the next instruction is sent.

In (*b*) in addition to the staticizing properties a changeover connection is provided which, in conjunction with the end element, allow the stage to function as a binary divider. This is used where a number of sequential addresses are required in one instruction for transferring blocks of words.

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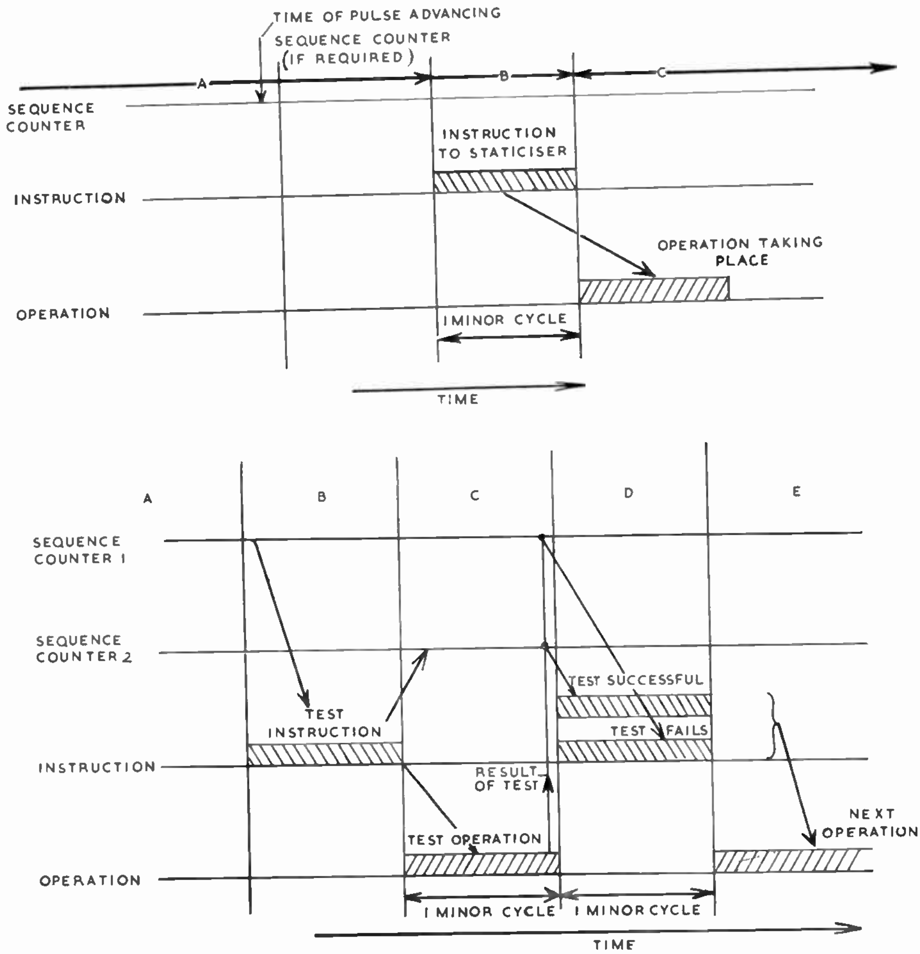

Fig. 4. (*a*) Normal instruction procedure.
(*b*) Instruction procedure with a test function.

In (*c*) the staticized information is redynamicized by the digit pulse *B*. This occurs in stages 16 to 21 which are redynamicized during digit periods 22 to 27. The output is used in the serial word comparison unit in which it is compared with the word numbers stored on drum (see Section 3.4(*d*)).

Table 2

Type	Used in stages
(*a*)	0–2, 4–8, 13–15, 28–30
(*b*)	10–12, 22–27
(*c*)	16–21

The outputs from IS 0–IS 2 go to the instruction modification decoding tree. Those from IS 4–IS 8 feed the function translator. This consists of a decoding tree, with a separate output for each function and a combining unit which combines these outputs to produce control lines for use in various parts of the machine.

IS 10–IS 15 feed the destination register decoding tree and their output is also used on function 0 to compare with the state of the switches on the monitor unit for determining whether the machine must halt. IS 10, 11 and 12 also feed a 3-gate for determining when a block transfer must be stopped.

The outputs from IS 16–21, apart from being dynamicized, feed the source register decoding

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tree, while those of IS 22 to IS 30 are used for selecting the track required, on functions involving this, including headshift. They also feed the peripheral units since these digits contain information for these on certain functions. The counting features of IS 22–IS 27 are used to determine the end of the shifting operations (functions 10 and 11).

All the outputs of the instruction staticizer are fed to lights on the monitor desk.

5.3. *Timing Control*

Figure 6 shows the basic timing chain for the machine. Assuming the machine is halted and that the machine is not to run at full speed, trigger T4 is set via input *A* and is then unset at the next DP 35 which in its turn sets trigger T3 since the full speed line is not energized. At the same time the first three digits of the instruction staticizer are cleared by CISA. T3 produces a pulse 3 digits long, RIP, which allows the instruction to go from the quick access track to the instruction staticizer. At the end of this period the remainder of the instruction staticizer is cleared, ready for the instruction, and T1 is set.

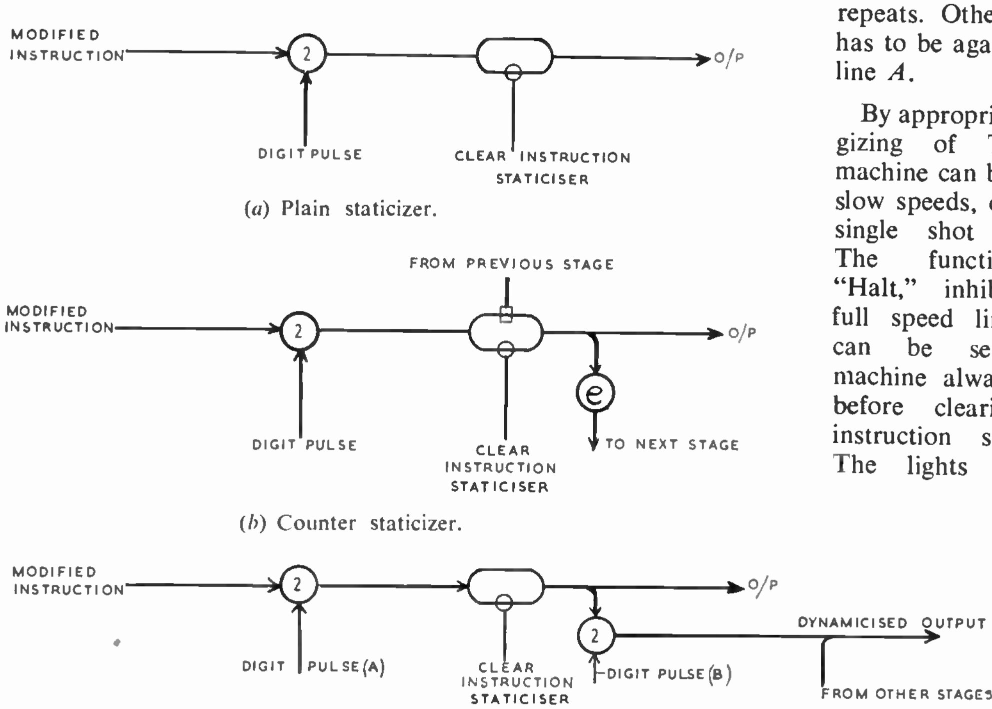
T1 is unset at DP31, at the end of the minor cycle before the one in which the operation can take place. In operations only using immediate access stores no delay is involved. In those which involve the track store, the unsetting of T1 must await the arrival of the correct word. This unsetting produces a pulse which controls the start of the operation in the various parts of the machine. At the same time trigger T2 is set.

This trigger T2 is unset at DP 35 in the last minor cycle of the operation. If the operation is only one minor cycle in duration this occurs four digits later than SOP. Otherwise it is delayed for the time the operation takes.

There are in fact two sets of pulses defining the start of the operation, SOPA and SOPB. The latter only occurs once in an operation, the former once every minor cycle during it. The unsetting of T2 stops the generation of SOPA and signifies to the machine the end of the operation.

If, during this cycle, the full speed line has been energized T3 is again set and the cycle repeats. Otherwise T4 has to be again set by line *A*.

By appropriate energizing of T4, the machine can be run at slow speeds, or under single shot control. The function 0, "Halt," inhibits the full speed line. As can be seen the machine always halts before clearing the instruction staticizer. The lights on the



(*a*) Plain staticizer.

(*b*) Counter staticizer.

(*c*) Staticizer redynamicizer.

Fig. 5. Units for instruction staticizer.

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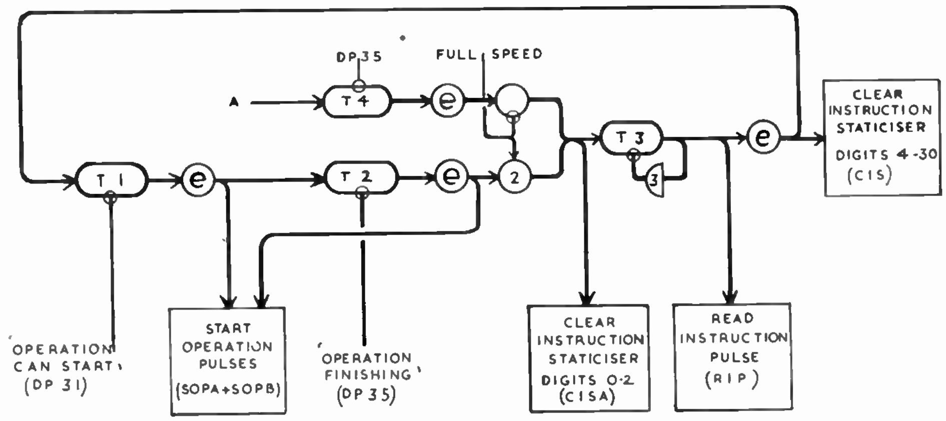

Fig. 6. Basic timing chain.

monitor desk therefore indicate the last instruction obeyed when the machine is stopped.

5.4. *Sequence Counter*

Figure 7 shows the arrangement of the sequence counter. The two counter staticizers are able to accept parallel inputs, which are fed by gates. At any one time depending on the state of the trigger fed by the alternative sequence pulse (ASP), the difference between the number specified in D 10 to D 15 of the instruction and the word number from the drum is fed to one or other of the counter staticizers and the output selected from the other one. When a jump is needed an ASP changes over the trigger and the quick access track decoding tree is fed from the other counter staticizer, which has just received the new instruction

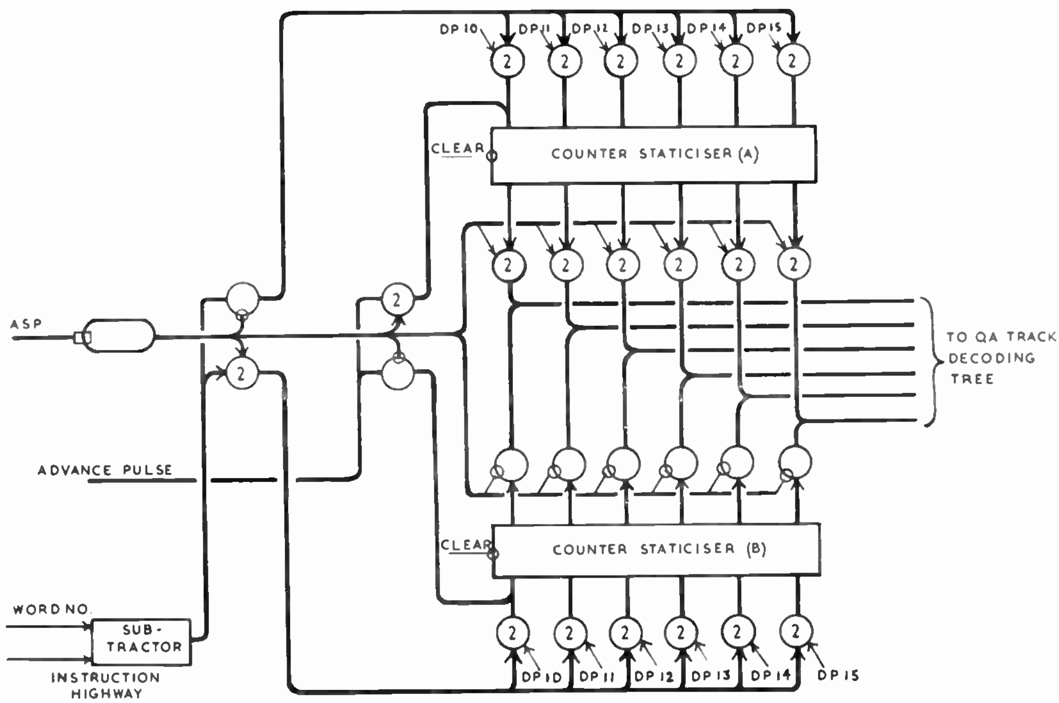

Fig. 7. Sequence counter.

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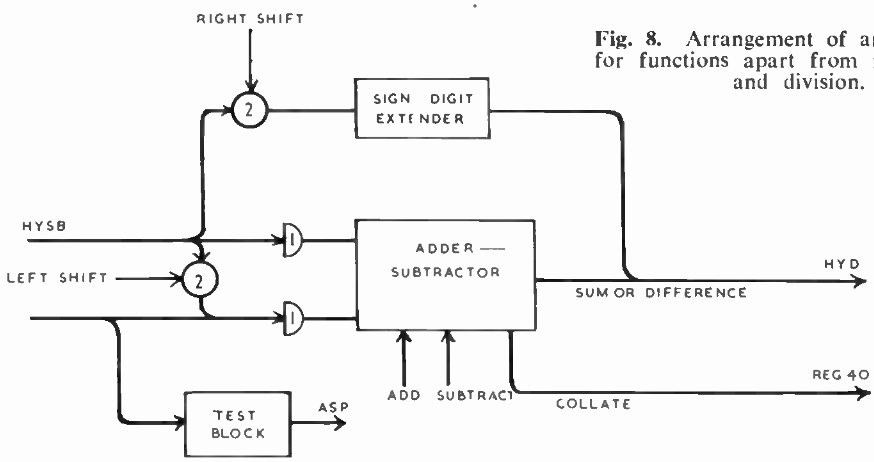

Fig. 8. Arrangement of arithmetic unit for functions apart from multiplication and division.

information. If this is not used immediately the advance pulse advances the count on the counter staticizer by "1." The advance pulse is effectively inhibited every time an instruction is fed to the instruction staticizer.

The counter staticizer whose output is not being used is cleared prior to receiving the information on a possible alternative instruction.

6. Arithmetic Unit

The following description of the arithmetic unit is divided into three sections. In the first the organization appropriate to operations other than multiplication and division is considered. These are covered in the second and third sections. In practice, of course, separate organizations are not provided, the changeover in function being performed with appropriate gating but, as in the rest of the descriptions, this and many details have been omitted for clarity.

6.1. *Operations other than Multiplication and Division* (Fig. 8)

The adder/subtractor can perform not only addition and subtraction but by putting in only one input, a transfer can be performed. The collate output (which is the logical AND) is also produced in this unit. It is the same as the carrys produced on addition.

Left shift is accomplished by adding the number to itself. The number comes via highway B and the gate passes it and also the other input to the adder.

There is an inherent delay in the adder subtractor unit, symbolized by the two delays shown. On right shift this is by-passed and the circulating path becomes one digit shorter. The sign digit extender makes the value of digit 35 the same as that of digit 34 after shifting so that sign information is preserved.

The test block, according to function, checks the value of digit 35 or whether there is a 1 in the number, and accordingly emits an ASP or not.

6.2. *Multiplication*

The arrangement of the unit for multiplication and division is shown in Fig. 9. It is derived from that described by Booth and Booth* with the addition of a further adder/subtractor which halves the operation time.

The sliding pulse (SP) occurs during DPO in its first operational cycle and then every 37 pulses for multiplication and 35 for division.

In multiplication, the multiplicand is shifted one place at a time to the left in the shifting register and successive digits of the multiplier are examined in the adder/subtractor control unit for multiplication with the aid of the sliding pulse. If the multiplier digit changes from a "0" to a "1" the multiplicand is subtracted from the accumulated partial products contained in registers 48 and 49, if from a "1" to a "0," it is added. Otherwise the number in the double length register remains unaltered.

* A. D. and K. H. V. Booth, "Automatic Digital Calculators, p. 44 et seq., 1st Edn. (Butterworths, London, 1953.)

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In the first minor cycle the multiplicand is passed from HYSB back to the register whence it came and also to the shifting register, which initially has a circulation time of 36 digits. In function 25 registers 48 and 49 are cleared (on function 9 they are not) during this minor cycle. The sign test unit tests the sign of the multiplicand and stores it, so that it can extend the single word length multiplicand to double word length.

At the start of the second minor cycle registers 48 and 49 circulate through the adder/subtractors. The multiplicand is subtracted or not according to the first multiplier digit. During this and subsequent minor cycles the multiplier circulates via HYSA, the adder/subtractor control unit for multiplication and HYD. A delay is now introduced into the recirculation path of the shifting register so that the total circulation time is 37 digits. The next digit of the multiplier is examined and the multiplicand is added to or subtracted from the product registers if required, the sign test unit providing the complement extension which is fed to the adder/subtractor which is not used for the multiplicand.

The digits of the multiplier are all examined in the adder/subtractor control unit for multiplication and when there is no change in digit beyond the working point the operation is stopped. This considerably reduces the time needed for multiplication with small multipliers and does necessitate, in a serial machine, shifting the multiplicand and not the multiplier and product to avoid shifting this latter into its correct phase.

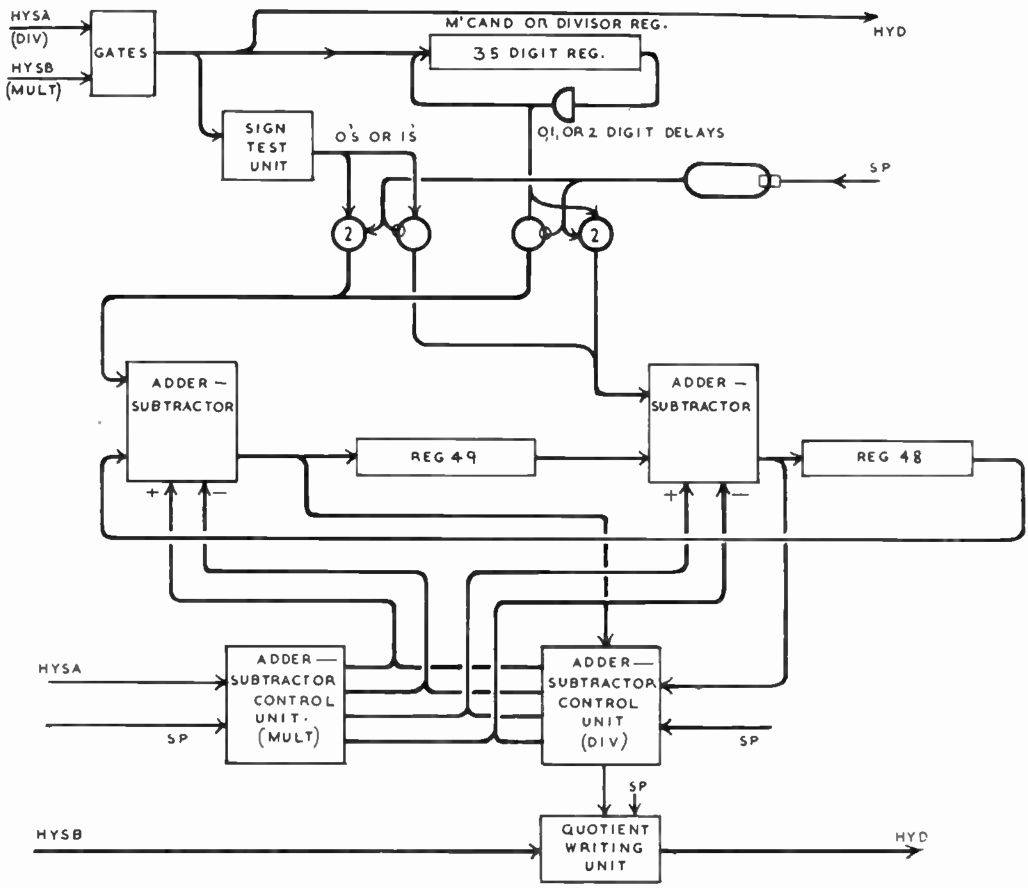

Fig. 9. Arithmetic unit: multiplier divider

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6.3. *Division*

The dividend is placed in the double length register and the divisor is stored in the circulating register where it is shifted one place at a time to the right. At each stage of the division the sign of the partial remainder is compared with that of the divisor. If these signs are the same the divisor is subtracted from the partial remainder and a "1" is recorded in the corresponding position of the quotient register; if the signs are different the divisor is added to the partial remainder and a "0" is recorded in the quotient register. The writing in the quotient register is phased so that the final stage of the division gives the penultimate quotient digit, the last quotient digit always being a "1."

In the first minor cycle of a division operation the divisor arrives along HSYA and passes the circulating register, the re-circulation delay of which is set at 1 digit. The sign of the divisor is tested by the adder/subtractor control unit for division which generates a series of 0's or 1's accordingly.

At the end of the first minor cycle the sign of the divisor and the dividend are compared and the appropriate adder/subtractor is set to add or subtract accordingly. At the beginning of the second minor cycle registers 48 and 49 circulate serially and the divisor is then added or subtracted by the adder/subtractor into the most significant end of the double length register so formed.

At the end of this circulation of the divisor the 1 digit delay in the divisor register is cut out (thus removing one of the sign digits of the divisor and giving the register an overall circulation delay of 35 digits), and a fresh addition or subtraction is begun in the other adder/subtractor with the divisor shifted one place to the right. Following each circulation the sign digit of the divisor is extended to the full length of the double length register by the sign test unit.

This procedure is performed 37 times, the divisor finally being added or subtracted into the least significant end of the double length register, which is left holding the remainder. During the course of the division the destination register, in which the quotient is assembled, is caused to circulate via HYSB, the bypass line, and HYD, an extra 1 digit delay being introduced into the bypass line to correct the path length. Each sign comparison made during the division causes the appropriate quotient digit to be written in the destination register by the quotient assembly unit which is also responsible for writing in the final "1." In this way 38 digits are written into the quotient register, the final two overwriting the first two. The time taken for a division is 37 minor cycles.

Function 9, division, is usually preceded by an instruction function 25, transfer to dividend register. This has the effect of extending the complement of a single word length number through a further register, and transferring them to registers 48 and 49, since the dividend is treated as being of double length. If a double length dividend exists there is no need for this instruction as each half will be transferred separately into registers 48 and 49.

7. Peripheral Units

The particular machine considered here is equipped with two punched card readers, a line printer and five magnetic tape units. There is no difficulty in adapting it to use a different number of these or other peripheral units as required.

The units considered previously have been realized physically largely with valve circuits, although germanium diodes are used in many places. The electronic equipment used in the units associated with the peripheral equipment employs mostly solid state components such as ferrite cores and transistors, valves being restricted to applications beyond the present capabilities of transistors.

7.1. *Punched Card Reading Unit*

The card readers, supplied by Messrs. Powers Samas, sense all holes in the punched card, at the same time, the output appearing as the pattern of energization on 720 output leads; 65 column cards are used each having 12 hole positions.

As explained in Section 3 under Function 2, there are four possible significancies in the punched pattern of a column. Except for the binary case where the pattern in a column is dynamicized directly into the least significant part of a word, the pattern is first translated into a six bit code, column by column when the programme demands Function 2. If the significance is alphabetic these are then passed to the machine in serial form with a maximum of six characters in a word.

If the information has decimal or sterling significance, as each column is converted to character representation it is passed to a convertor which translates the characters to the binary code which then go to the destination register demanded in the instruction.

7.2. *Line Printer Unit*

The line printer used is the Powers Samastronic which prints 300 lines/minute. The line has 140 printing positions but provision has been made for independent inputs to only 78 of them. The remaining ones may be used for providing duplicate information on the line. Various line spacings are controllable by the programme as are the disposition of the character printings relative to their order of arrival at the printer unit. Two webs of paper can be run through the printer at once with a measure of independence in their feeds.

The information which has to be printed is first stored in a buffer since a whole line has to be assembled before printing can commence. In order to save storage capacity the information is stored as it comes from the computer, together with the conversion instructions. The conversion takes place in the time taken for the paper to travel between the lines of print.

The converted information which is now in character code with six bits defining a character is passed to circulating registers which feed the printing mechanism via plugboxes. These plugboxes define the layout of the characters and five are available to the programme to cope with different layouts on a job. Different plugboxes can be fitted for different jobs if required.

7.3. *Tape Units*

Five tape decks are fitted to the machine but only three can be used at any one time. It is possible in this way to change tapes on the two machines not being used so that the computer is not held up while this is being done. Any tape deck can be used for recording or sending out information but during any one run of the tape only one of the functions will be performed.

The information is stored serially on the tape in 8-word blocks. These are transferred sequentially to or from the tape. Three tracks are provided on the tape for each direction of travel, one clock track, one marker to define the start of a block and the information track. After traversing the tape in one direction, it is automatically reversed. No provision has been made for searching for a particular block, except by reading out each block in sequence, since in any applications considered so far this has proved unnecessary.

The digit rate on the tape is 2 kc/s and comparatively long start/stop times are allowable for the application of the first machine. Other tape decks with higher digit rate and faster start/stop times can be fitted if needed.

Two 8-word buffers are provided between the tape deck and the computer. The usual interlocks to hold up transfers when these are either full or empty are provided.

8. Acknowledgments

The basic conception of this machine is due to Mr. R. T. Clayden, the engineer in charge of the project, and Mr. D. C. Hemy. The design is the result of the activities of many people in the team concerned with this equipment. The author has to thank the Directors of E.M.I. Electronics Ltd. for permission to publish the paper.

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INSTRUMENTATION FOR THE CONTROL OF PROCESS STREAMS IN SOME ATOMIC ENERGY PROJECTS*

by

H. Bisby, B.Sc., A.K.C.†

A paper presented at the Convention on "Electronics in Automation" in Cambridge on 28th June 1957. In the Chair: Dr. Denis Taylor (Member).

SUMMARY

Radiometric instrumentation has already proved valuable as an aid in the control of process schemes within the U.K. Atomic Energy Authority. Design features of plant instruments covering radioactivity assay by direct emission and absorption techniques are discussed with illustrations of recent instruments. In addition the part played by automatic sample-handling machines in plant assay laboratories is illustrated.

1. Introduction

The decade since World War II has seen a widespread development of analytical instrumentation applied to chemical plant operations. This has been conditioned by the need for increased product quality and productivity from a limited number of skilled operators and chemists, and conversely the urgent requirement for decreasing the degree of associated skill, compatible with efficient plant operation, so that a wider range of semi-skilled labour can be called upon.

Instrumentation in its broadest sense has already provided an answer in many commercial undertakings by:—

(*a*) producing contemporary "monitor" information on process behaviour in a form suitable for simple interpretation by semi-skilled operators responsible for continuity of operation;

(*b*) recording process content, both qualitative and quantitative, which might otherwise be obtained only by lengthy and tedious analysis of a formidable number of samples;

(*c*) reducing the labour involved in routine analysis of samples necessary for accounting purposes;

(*d*) making possible the application of direct automatic control from the "monitor" information.

From the initial stage of development of chemical plant programmes for atomic energy projects these benefits did not go unrecognized and instrumentation continues to carry considerable priority by virtue of two important factors. The first is that highly active and toxic materials are involved in the processes and, quite apart from the fact that initially there was no pool of labour with experience on this particular aspect of the work, it is extremely desirable that sample handling should be kept to a minimum. Secondly, the short interval between laboratory pilot plant operation and full-scale production imposes a need for diligent monitoring of these fundamentally new processes during the initial stages whilst operators are gaining experience.

These requirements for decreased skill from operators and minimum handling of radioactive and toxic materials contribute to the choice of "continuous-flow" operation of the processes involved wherever possible. With this choice the process streams can be wholly contained inside a biological shield to reduce the radiation and inhalation hazard to which operators and other workers would otherwise be exposed. Fig. 1 gives an impression of the scale of such a biological shield on the primary separation plant at the Windscale Works of the U.K.A.E.A. Industrial Group. The concrete walls of such a shield may be six feet thick and penetration by trained staff into certain parts of the enclosed cell is extremely limited and difficult once the process flow has been started. As with

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most chemical plant operations, process efficiency on atomic energy plants is conditioned by such conventional parameters as temperature, density, hydrostatic pressures rates of flow and pH values which are maintained by a system of monitoring and error feedback control. It will be appreciated however that this feature of cell construction imposed limitations on even the simplest instrumentation

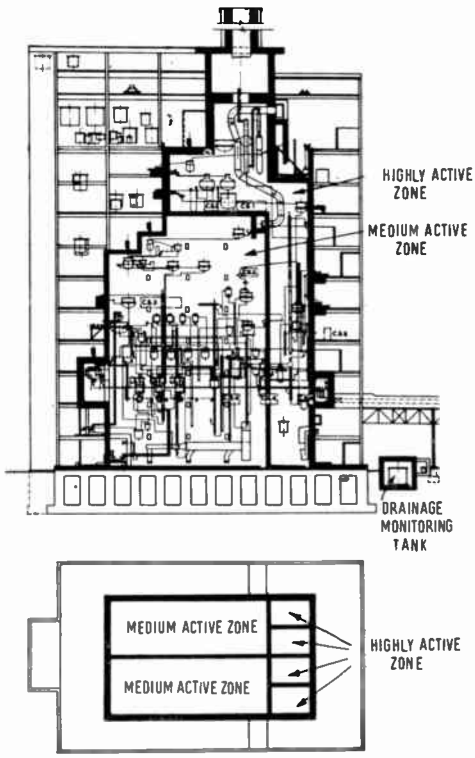

Fig. 1. Primary separation plant at Windscale Works

associated with these parameters particularly with regard to reliability. The use of more complicated radiometric instrumentation, with implied greater unreliability, may have been precluded altogether had not techniques been evolved whereby the access to instruments was made possible, or the instruments made capable of withdrawal from their monitoring positions, without disrupting the various radiation and toxic gas shields.

Control of a given product is normally made to depend on a specific characteristic which can be monitored with instruments disposed throughout the process stages. In atomic energy plants the characteristic chosen wherever possible, though not exclusively, is that property of the products to emit particulate or photon energy in the form of alpha, beta, gamma and neutron radiations, since radiometric assay can achieve a high degree of sensitivity. With the techniques used for measuring the emitted radiation, self-absorption by the process stream contents can introduce some complexity; on the other hand there are many examples in which the absorption of radiation from an external source is used to detect quantitative changes of product in a process stream.

2. Review of Instrumentation

Radiometric instrumentation as applied to plant processes may be considered in three convenient categories in each of which automatic methods have some part to play.

The first group comprises those instruments which monitor the radiation arising from the radioactive process streams. Their prime purpose is to present information on process behaviour in a form suitable for both interpretation by an operator and post-analysis. The type of radiation (α, β, γ, n) is usually defined by the product concerned and specific energy selection may be necessary. Again the type of radiation detector and its disposition relative to the process stream involves the consideration of such factors as the rate of particle (or photon) emission, the selectivity of the detector for a specific energy of radiation and the penetrative power of that and associated radiations. In cases where direct access to process streams is precluded either physically or by a lack of detector selectivity, automatic sampling techniques are involved. Taking all these factors into consideration, this type of monitor often results in complex and specialized engineering and electronics. This possibly contributes to the fact that these instruments have not been involved in any noteworthy application to automatic control. Included in this group, though often less complex, are the instrumentation schemes for process tracer techniques using radioactive isotopes.

The second group of instruments are those relying on the absorption of a specific type of radiation in its transmission through a product medium. The beta transmission and back-scatter gauges, the gamma and neutron transmission monitors are typical examples in which a suitable radioactive source is disposed with a fixed geometry relative to the process medium and the radiation detector. Thus any variation observed in the transmitted radiation intensity may be related to a variation in the process medium provided proper attention is paid to standardization of the detection system. The selection of a monotype monochromatic source reduces instrument complexity and, since the necessity for sampling is avoided where possible, this type of instrument may be relatively simple and has found more ready usage in automatic control systems.

The third group includes instruments which assist in routine sample analysis. These are generally designed for laboratory operation so that somewhat refined engineering is permissible for automatic sampling, measurement and recording to a degree of precision which is high compared to the former two groups of plant instruments. These instruments considerably reduce the amount of skilled labour which could be otherwise absorbed by routine work and find a wide variety of uses in research laboratories, in pilot plant development, and in the analytical services associated with large scale chemical plants.

Naturally, the Research and Industrial Groups of the Atomic Energy Authority employ instruments in these three categories covering an extensive number of applications in chemical plant operation, chemical engineering investigations, medical research, isotope tracer work, nuclear reactors and analytical chemistry. A comprehensive review of all these applications is beyond the scope of this paper; however a few of the most recent and novel instruments merit description.

3. Plant Instruments for Radioactive Assay

A radioactive element disintegrates by the spontaneous emission of nuclear particles (or photons) with a statistical disintegration rate (dN/dt) defined by the number of radioactive nuclei present (N) and the decay time constant (λ) of that element.

$$\frac{dN}{dt} = \lambda N = 4{\cdot}175 \times 10^{23} \frac{m}{AT} \text{ dis/sec} \quad \ldots\ldots\ldots(1)$$

where m gm = mass of material present

$$T \text{ sec} = \frac{0{\cdot}694}{\lambda} = \text{characteristic half-life}$$

$$A = \text{atomic weight}$$

The disintegration rate is observed by placing a radiation detector within the radiation flux such that a count-rate (dc/dt) is measured. This is related to dN/dt by an expression of the form:—

$$\frac{dc}{dt} = fa\,.\,fg\,.\,fe \cdot \frac{dN}{dt} + K \quad \ldots\ldots\ldots(2)$$

where the degradation factors fa, fg, fe take account of the absorption of radiation by the sample, the geometrical disposition which the detector bears to the sample and the efficiency of the detector for the particular radiation involved. Both (dc/dt) and K, the background count rate arising from the detector itself and other external radiation, show a statistical variation whose standard deviation is proportional to the square root of the count-rate under a given set of conditions. It will be seen that as $m \to 0$ the minimum change in (dc/dt) which can be observed with certainty increases with increasing background count rate, which must therefore be kept as small as possible to achieve the ultimate sensitivity in the measurement of m.

Combining expressions (1) and (2) and inserting arbitrary but typical values for a monitor of α-particle emission from plutonium ($A = 239$, $T = 2{\cdot}5 \times 10^4$ years) using a scintillation counter will serve to give the order of sensitivity attainable.

$$\frac{dc}{dt} = fa\,.\,fg\,.\,fe\,.\,4{\cdot}175 \times \frac{m}{AT} + K \text{ counts/sec} \quad \ldots\ldots\ldots(3)$$

The product $fa\,.\,fg\,.\,fe$ may be 0·1 and $(dc/dt)_{min} = 0{\cdot}05$ min. counts/sec. so that the minimum value of m discernible is $4{\cdot}42 \times 10^{-10}$ gm.

From expression (3) it is seen essential to design so that self absorption is small, the geometrical factor is high and the background low; also to choose a detector with a high detection efficiency. Equally important, these parameters once fixed must be constant if the

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ultimate degree of precision is to be maintained. These design principles are clearly illustrated by an α-monitor used at Windscale. The plutonium bearing liquor, also containing mixed fission products (β-γ emitters) is brought out from the main process lines by gravity feed to a solvent-aqueous separator. The aqueous feed flows into a subsequent small volume weir-reservoir whose surface is viewed for α-particle emission by a scintillation counter comprising a zinc sulphide screen and photomultiplier. Since the range of these α-particles in air is 4–5 cm, the zinc sulphide screen must be located as close as possible to the liquor surface and this also permits good geometry. However if this simple disposition were to be used, the background count rate generated by the effect of the γ-radiation on the photomultiplier valve would be high and the advantage gained would be entirely wasted. Fig. 2 shows the apparatus developed to resolve this difficulty. The scintillation screen is situated with constant geometry as near to the liquor surface as possible and the light photons are seen by the photomultiplier through a 6-in. light-guide which enables the photomultiplier to be positioned where γ-effects are rendered relatively insignificant. To prevent condensation on the zinc sulphide screen and on the α-source used for standardization, whose effect would be to absorb α-particles, air under pressure is warmed by passage through a small heat exchanger located in the scintillation counter unit and directed across the surface of the screen and standard source.

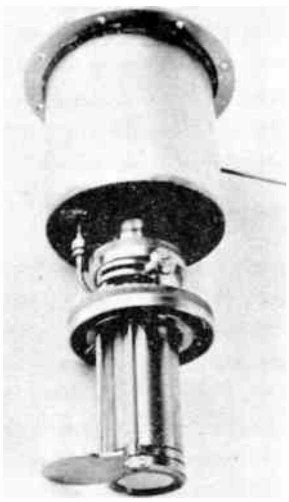

Fig. 2. An α-monitor for plutonium content.

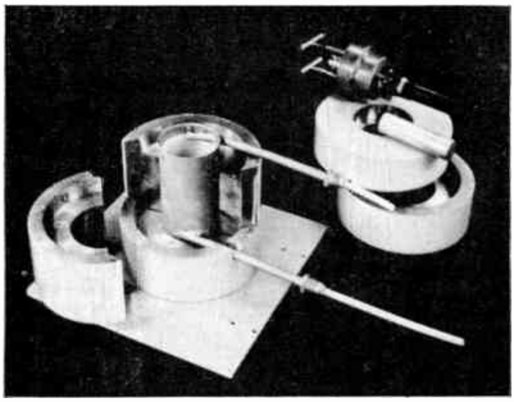

Fig. 3. A γ-monitor process instrument.

Another example is shown in Fig. 3 where the low γ-activity of a process stream made it necessary to sample a large bulk of liquor with as large a geometrical factor as possible to attain the demanded sensitivity. The process liquor is made to flow upwards through a helical coil to a set overflow height and the detector, in this case a Geiger counter, is mounted concentrically inside the cylinder formed by the coil. Again precautions are taken to reduce the background from external radiation by a heavy lead shield.

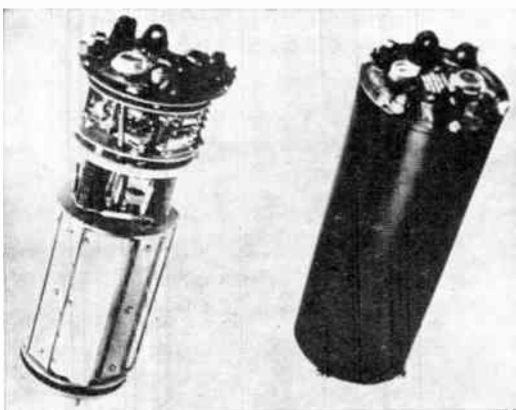

Fig. 4. A neutron counter (BF_3) probe.

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The instruments mentioned so far are basically monitors for record and checking purposes. A third example is one which could be applied to control of a process operation. The α-assay of plutonium in sealed tanks is not possible from outside, since the α-particles cannot penetrate the tank wall. It was reported[1] however that α-particles of the plutonium energy range produce a nuclear transformation in certain light elements which results in the emission of neutrons. This is extremely useful because neutron transmission through non-hydrogenous media is relatively good and therefore a neutron monitor located externally near a tank containing plutonium and a light element can be used for relative measurements of plutonium content. A BF_3 counter probe (Fig. 4) was designed to fit inside a 6-in NB pipe which is mounted through the biological shield to a position adjacent to the tank in question, an evaporator (Fig. 5).

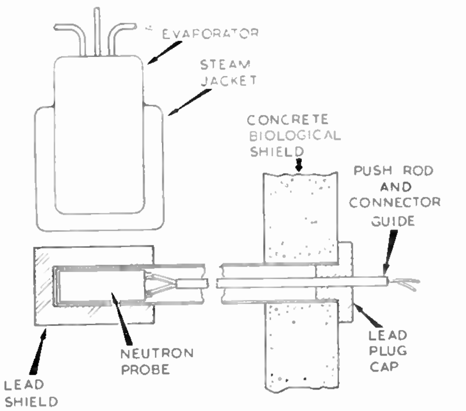

Fig. 5. Schematic of neutron counter location.

The normal operation is to charge the evaporator with dilute solution and evaporate until the bulk has been reduced by a fixed amount. This is repeated after the addition of more dilute solution and the final concentrate is discharged in two stages by applying air pressure to the vessel. The monitor record (Fig. 6) clearly shows these stages in the process cycle.

4. Radiometric Absorption Techniques

Two recent developments using the basic principles outlined in Section 2 show the versatility of the γ-ray absorption technique[2]

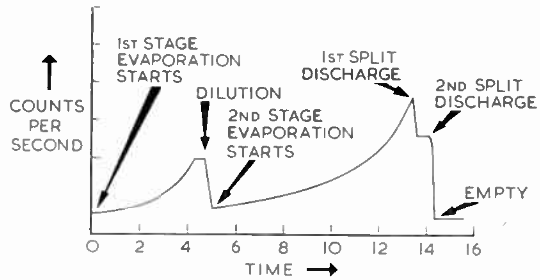

Fig. 6. Monitor record of evaporation process cycle.

when used to measure the density change of process media.

In uranium ore treatment plants, the control of the density of a mixture of milled ore and liquid ("pulp") is a matter of some importance during acid leaching and in transporting mineral ore. In a particular instance, the solid-to-liquid ratio of the pulp has to be maintained such that the density is $1{\cdot}5 \pm 0{\cdot}1$ to ensure efficient separation of uranium liquor from solid waste during filtration. The use of a γ-transmission gauge obviates the need for direct contact with the pulp or for process pipe line modification and Fig. 7 shows the gauge developed for this application. A similar system is now employed for the measurement of a uranium compound at high levels of concentration.

The radioactive source is placed on the opposite side of the process pipe to the ion-

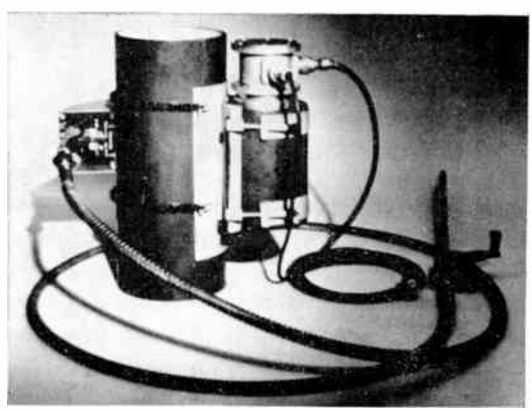

Fig. 7. A γ-transmission gauge for pulp density.

chamber detector, which is shielded from external and scattered radiation by a lead screen containing the ion-chamber aperture. The current generated in the ion chamber passes through a high value resistor and the voltage developed amplified to feed a recorder/controller. To achieve the greatest sensitivity to density changes the activity and energy of the γ-radiation must receive careful consideration[3] in each application.

The mass absorption coefficient for a given medium is energy dependent, being a combination of the Compton, photo-electric and pair-production absorption coefficients, decreasing rapidly with energy increase, reaching a minimum and then increasing slowly. The intensity of mono-energetic radiation after transmission through a combination of homogeneous media such as pipe walls and linings (grouped by the designation w) and the process medium (m) is expressed

$$I = I_0 B_m B_w \,.\, \exp[-(\mu\rho x)_m] \,.\, \exp[-(\mu\rho x)_w] \qquad \ldots\ldots\ldots(4)$$

when μ is the total mass absorption coefficient, ρ the density and x the thickness. B_m and B_w are terms introduced to account for γ-ray scattering.

The change in transmitted radiation for an incremental change in medium density may therefore be expressed

$$\Delta I = -(\mu x)_m \,.\, \Delta\rho_m \,.\, B_w B'_m I_0 \times \exp[-(\mu\rho x)_m] \exp[-(\mu\rho x)_w] \ldots\ldots\ldots(5)$$

If the pipe dimensions are fixed, as in the case of the pulp density monitor (6″ NB, ¼″ thick pipe walls, ¼″ rubber lining), such that $(\mu\rho x)_w \geq (\mu\rho x)_m$ it is worthwhile considering a γ-energy at which μ_w is a minimum.

I_0 is the source activity (disintegrations/sec) so that an expression similar to (3) can be formulated for the count-rate observed at a given medium density

$$\frac{dc}{dt} = fg \,.\, fe \,.\, I + K$$

$$\text{and } \Delta\left(\frac{dc}{dt}\right) = -fg \,.\, fe\,(\mu x)_m \Delta\rho_m B_w B''_m I_0 \times \exp[-(\mu\rho x)_m] \,.\, \exp[-(\mu\rho x)_w]$$

The selection of I_0 to give a demanded sensitivity is seen to depend on such factors as

(a) mass absorption coefficient of media
(b) source-detector geometry
(c) detector efficiency
(d) statistical deviation of background count
(e) γ-ray energy.

These factors were explored in the design of the pulp density gauge. The γ-energy of caesium 134 gave the optimum sensitivity for a fixed set of conditions (Table 1).

Table 1

Variation of Sensitivity with γ-energy

Source	Energy MeV	% change in count rate for given $\Delta\rho_m$
Tm170	0·08	96%
Cs134	0·6	86%
Co60	1·2	89%

A reduction in source intensity was achieved by using an ion chamber filled to 5·0 atmospheres with krypton which has an enhanced γ-detection efficiency (×15) over air at the same pressure. A precision of $1{\cdot}500 \pm 0{\cdot}004$ has been achieved using a relatively small source (50 mc) by consideration of these and other factors mentioned earlier.

From a practical point of view the Cs 134 source is ideal in that it exhibits a very slow decay ($T = 2{\cdot}3$ years) and the standardization on this account can be a very infrequent operation. In this example standardization is done by moving the source through a remote manual control from its "operate" position to a position where the ion chamber has a direct view of it through a second aperture in the lead shield equivalent to the absorption through the pipe direction at a pulp density of 1·5. In its final form the density gauge will control the addition of liquid to the mineral ore "cake."

5. Automatic Aids to Radiometric Analysis

There is inevitably a large amount of routine radiometric assay work in an atomic energy organization, most of which can be done conveniently and economically by automatic methods.

The basic form of these automatic machines comprises a mechanical movement which subjects each sample in turn to the radiometric monitor. The measurement is automatically controlled to give the desired precision after

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which the information is converted into a form suitable for recording or computation and the mechanical movement brought into action again. One example of the ingenuity of such a mechanical feed system[4] is shown in Fig. 8.

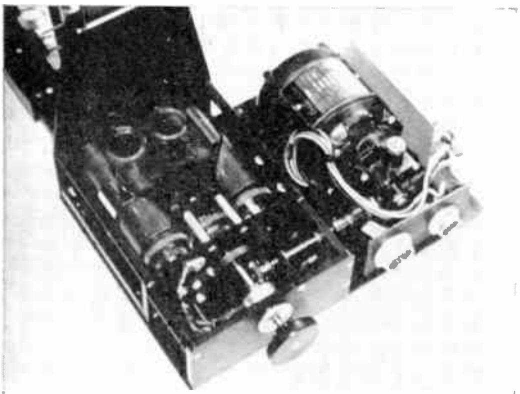

Fig. 8. Automatic sample-tray feed movement.

Two parallel cylinders each carrying a large pitch helical thread are rotated in opposite directions by the motor drive to translate the sample tray in a direction parallel to the axes of the cylinders. The direction of translation may be reversed by reversing the cylinder rotation.

A recent design (Fig. 9) shows a three-sample automatic turntable fitted to a slide which under operating conditions is pushed into the lead shield so that the sources are exposed in turn to an end-window β-counter surrounded by a cosmic cancellation screen of γ-counters. This

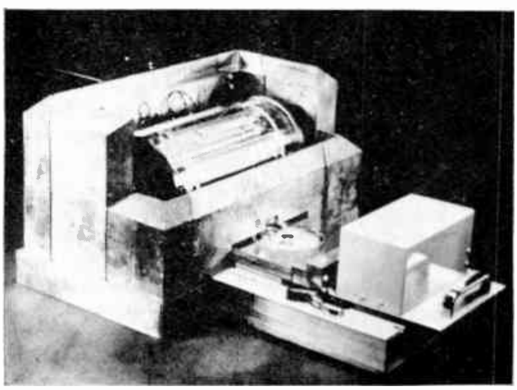

Fig. 9. Low background beta sample changer.

machine obviates the need to dismantle the lead shield after each sample measurement and being automatically controlled by the radio-activity measurement allows three sources of very low beta activity (time of measurement several hours) to be completed unattended. Fig. 10 shows a larger machine[5] capable of handling 50 samples. In a special application, the elution of an ion-exchange column produces a flow separation of radioactive rare earths from mixed fission products. A twin Geiger counter system (shown in their storage position) observes the ion column eluate as it falls into one of the sample holders. As each fraction appears, the activity in the eluate rises to a maximum and then falls. This information obtained by the Geiger counters controls a sequence of automatic operations, such as

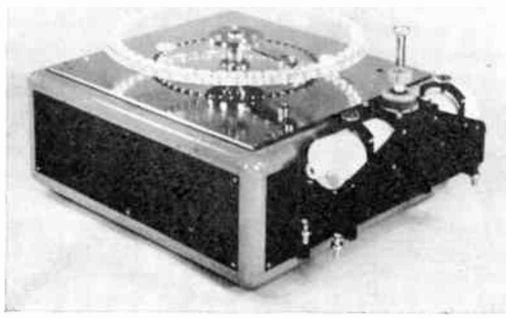

Fig. 10. Automatic rare earth separator.

lowering the turntable, rotating it through one position and raising it again, after each peak has been passed. Thereby physical separation of the rare earths is achieved.

6. Conclusion

The introduction of radiometric monitoring has reduced the need for frequent sample analysis in checking process efficiency and to some extent has simplified plant operation. Although there is a growing tendency towards the application of monitor information to direct automatic control, these methods have as yet been confined to simple operations only, and completely automatic control systems on a large scale are still some way in the future. The use of radiometric-automatic operations for the

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analysis of routine plant samples makes a substantial contribution to economy in analytical effort.

7. Acknowledgments

The author wishes to acknowledge the discussions with the various R. and D.B. and Instrument Sections of the Industrial Group, U.K.A.E.A. during the development of these instruments, which have at all times been helpful and encouraging.

The co-operation of the Automatics Group (Electronics Division), A.E.R.E., in allowing some of their work to be described is also acknowledged.

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ELECTRONICS AND AUTOMATION

Discussion on Session 3: Chemical and other Processes

Contributions made during the Discussion at this Session will be published early in 1957.

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DISCUSSION ON

"Detection of Pulse Signals in Noise: Trace-to-Trace Correlation in Visual Displays" *

Dr. Merrill I. Skolnik†: I have read with interest this paper by Professor Tucker, and find it, along with Mr. Griffiths' companion paper, to be an illuminating treatment of the problem of an operator integrating many pulses on a radar display. I would like to call attention to some unpublished work by J. I. Marcum‡ who treats analytically the improvement in signal-to-noise ratio to be expected from post-detection integration.

In this report Marcum derives the loss due to post-detection integration, assuming uniform weighting of the pulses and electronic (threshold) detection, rather than detection by an operator. An example of the integration loss computed by Marcum for a particular case may be found in a paper by Hall§ (Fig. 6). The integration loss is the loss referred to that which is theoretically achievable with pre-detection integration. It turns out to be less than the loss of 1·5 db/doubling as reported for operator integration on an A-scope.

I have observed that Marcum's theoretical results agree quite well with the experimental data presented in Tucker's paper for operator detection. I have taken the liberty to redraw in Fig. A the graph Fig. 1(c) of the paper. Curves A′ and B′ are slight rearrangements of curves A and B. They were drawn so as to yield a signal-to-noise ratio of 10 db for a single trace. That they were both redrawn to intersect the axis at 10 db is done only for convenience. Curve C′ is the improvement which would have been expected if the 1·5 db/doubling law were correct. The experimental results reported by Tucker show the improvement to be significantly better. Curve D is the maximum improvement which could be expected (3 db/doubling) with pre-detection integration.

To apply Marcum's calculations, the probability of false alarm should be known for a single trace. One can obtain the probability of a false alarm from the fact that the 10 db signal-to-noise ratio for a single trace

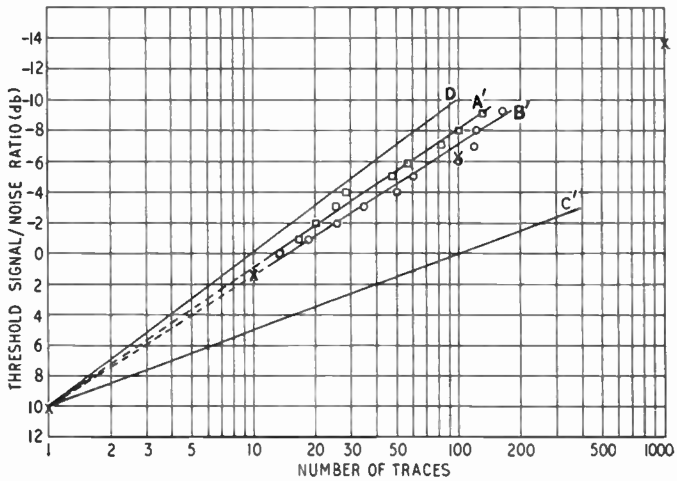

Fig. A.

corresponds to a 50 per cent. probability of detection. Then e^{10} = probability of false alarm = $10^{-1\cdot 35}$. The four points on the graph denoted by X's are taken from Marcum's report for a false alarm probability of 10^{-4}, the nearest value for which he has the computed data. They fit rather well to the experimental data and the slope agrees with the observed value of 2·2 db/doubling.

* D. G. Tucker, *J.Brit.I.R.E.*, 17, pp. 319-329, June 1957.

† Received 17th October 1957. Dr. Skolnik is a Staff Member, Lincoln Laboratory, Massachusetts Institute of Technology. Lincoln Laboratory is supported jointly by the United States Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

U.D.C. No. 621.396.963.3: 621.396.822

‡ J. I. Marcum, "A Statistical Theory of Target Detection by Pulsed Radar," The RAND Corporation Research Memorandum RM-754, 1st December 1947, and RM-753, 1st July 1948 (mathematical appendix). (The RAND Corporation, Santa Monica, Calif.)

§ W. M. Hall, "Prediction of pulse radar performance," *Proc. Inst. Radio Engrs*, 44, pp. 224-231, February 1956.

‖ J. L. Lawson and G. E. Uhlenbeck, "Threshold Signals." (McGraw Hill, New York, 1950.)

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I would tentatively conclude from the above that:

(1) The calculated improvement from post-detection integration agrees with the experimental data.

(2) The 1·5 db/doubling reported previously needs explanation as to why it does not meet the calculated improvement. Marcum recognized that the results reported by Lawson and Uhlenbeck[5] were not as good as expected and offered as an explanation the non-linear integration by cathode-ray tube and human operator losses. (RM-753, page 58.)

(3) The operators in Tucker's experiments seemed to have introduced little or no degradation.

(4) By extrapolating back to one trace the false alarm time of an operator on a single trace basis can be found. I am not sure, however, what value this latter result may be.

Acknowledgment is given to J. I. Marcum and the RAND Corporation for permission to quote results from the report cited.

Professor D. G. Tucker (*in reply*): Dr. Skolnik's contribution is both interesting and important. It is a great pity that Marcum's work, of which he makes use, has not been published, but he has very kindly had copies sent to me of the reports referred to, and these will be a great help to my colleagues and myself in our further research.

The idealized electronic integrator and the criteria of detection which Marcum's calculations assume, bear no obvious relationship to the side-by-side correlation effect which we have investigated, and the relatively close agreement of the results must therefore be mainly fortuitous. Marcum determines the probability of detection by supposing first that a time is chosen in which the probability of making a false detection is to be 0·5; that is to say, there is in this time to be only a 50 per cent. chance of a noise peak exceeding the bias level. This enables the bias level to be calculated, and then the probability of detection is determined as the probability that the peak value of signal-plus-noise will exceed the bias level during an interval of time called the detection time. This will normally be equal to the integration time. It is clear that this criterion assumes that it is the presence or absence of a signal that has to be decided. In the side-by-side correlation tests on the other hand, it was always known that the signal was present, and the matter to be decided was its position. However, no forced choice was imposed. Whether uncertainty as to the presence or absence of the signal would have made any difference to the results is not clear, but the effect would probably not have been very large, since no false judgments were in fact ever made by the observers. It would be difficult to make a theoretical comparison of the two systems, since an exact analysis of the side-by-side visual correlation effect can hardly be considered possible; psychological and physiological factors are involved which cannot at present be expressed quantitatively.

I would like to point out that an idealized integrator not unlike Marcum's was analysed by Kaplan, whose results were quoted in Mr. Griffiths's paper; they are considerably poorer than Marcum's, however. If Marcum's idealized integrator could be applied in practical form to an echo-ranging system, the improvement of threshold of 2·2 db/doubling which it would give would be a considerble improvement over the 1·5 db/doubling which, according to the available experimental evidence (as examined in my paper), is all that can be obtained from integration of the normal type, i.e. on cathode-ray tubes. The side-by-side visual presentation, which we showed to give 2·4 db/doubling, is not suitable for general application to scanning echo-ranging systems and an electronic integrator of equal efficiency would probably prove more useful.

It is desired to emphasize that none of the previously-published experimental work on integration which I reported in my paper specifies the objective integration characteristics (i.e. the law of brightness of cathode-ray-tube spot in relation to number and speed of pulses applied). My colleague, Mr. Griffiths, has therefore commenced an investigation of the effect on detection of true linear integration under precisely-specified conditions; and the results of this work may be expected to clarify the situation.

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ELECTRONICS AND PROCESS CONTROL SYSTEMS *

by

J. M. Keating, B.Sc.† and P. V. Slee, B.Sc.†

A paper presented at the Convention on "Electronics in Automation" in Cambridge on 28th June 1957. In the Chair: Dr. Denis Taylor (Member).

SUMMARY

A brief history of the development of process control and instrumentation up to existing conventional pneumatic and electronics systems is given and the use of miniaturization, graphic panels and console desks discussed. Two possible future systems of process control are described, one whereby the plant is programmed by punched card input, and the second whereby the plant performance is continuously analysed and monitored by computer. Problems concerning maintenance, safety, choice of components, and other items of importance to process control are discussed.

1. History of Development

Only in a few cases is chemical reaction encountered in the process plants in which crude oil is transformed into a large number of marketable products. The control of these plants thus depends basically upon the measurement of four variables, flow, level, temperature and pressure. These variables are measured and indicated or recorded by various types of instruments.

Even on the earliest of industrial plants, instruments, in some cases of the most primitive type were employed and in the oil industry these were limited to pressure gauges and local thermometers. Flow indicators took the form of glass boxes where the flow was visually observed and estimated. Levels in tanks were maintained by visual inspection and levels in closed vessels under pressure were measured by gauge glasses. These glasses are either inserted in the side of the vessel, or mounted externally and connected to the vessel by pipe connections. A plant operator was required to adjust the value of these measured variables by the opening or closing of appropriate plant valves in the particular plant circuit.

The earliest development therefore was naturally in the field of measurement, and rapid progress soon produced reliable industrial instruments to give local indication of the four variables.

This was of some assistance to the operator who had to perform the following functions to maintain constant plant variables:—

(*a*) Observe the measured value of the variable by reading the local indicator.

(*b*) Compare this value with the mentally stored desired value and obtain the value of error.

(*c*) Compute the change in controlling variable required to reduce error.

(*d*) Relate this change to a new valve position.

(*e*) Supply power to reposition the value.

The control loop for each plant variable was therefore closed by the human operator who supplied both the sensing ability and the output power of a control system. Even a medium sized plant contains a large number of such local loops and would therefore require a number of operators to maintain discontinuous control by scanning.

While this system was satisfactory where large tolerances and very slow disturbances were encountered, low capacity fast plants, with their resultant fast responses, soon created a demand for automatic control. Furthermore the economic aspect of this development also justified its introduction. By modifying basic measuring instruments with pneumatic components, such as nozzles flappers, relays and linkages, and supplying it with a source of pneumatic power, a monitored power output proportional to input was fed to the control valve which was modified to receive such an

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† British Petroleum Co. Ltd., Beaufort House, London, E.C.2.

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input. Thus automatic process control was introduced.

An automatic control system then consists of a device to measure the variable, a means of comparing this measured value with the desired value, some mechanism for creating an output (related to error) which is fed to a control valve to keep the measured and desired values correctly related, and in some cases equal to each other.

The advent of automatic control equipment has had a marked effect on the construction and operation of modern chemical plants. Some of the newer processes, involving as they do high temperatures, pressures and rates of flow, lead to extremely complicated interactions which would be very difficult, if not impossible, to control by the manual operation of valves.

In the past it was sufficient to measure and regulate the variables to a low degree of accuracy, but nowadays it has become more essential to maintain them within close limits. Control instruments have been developed to include this facility by detecting the rate and amplitude of changes and correct for these factors automatically. Each control instrument gives its full and undivided attention to its particular control loop. The result is that a large and fully controlled plant containing about 100 significant variables such as flow, level, etc., can be easily and efficiently handled by three or four operators.

In the early days instruments were locally mounted and scattered over a large area throughout the plant. As the size and complexity of process plants grew, so also did the number of instruments required for adequate measurement and control, and it became necessary to centralize the equipment in a control room to facilitate overall appreciation of plant conditions. Flow and pressure measurements, however, necessitated running long lengths of lines containing oil and gases, often at high temperatures and pressure, from the point of measurement into the control room. To obviate this on the grounds of safety, and overall instrument efficiency, the remote transmitter was developed. This device, which is located near the point of measurement, includes a transducer to convert the measurement to a pneumatic or electronic signal. The signal, which is directly proportional to the measured value, is fed to the controlling unit located in the control room, where it is used for continuous indicating recording and control as required. In addition alarm devices are fitted where necessary to inform the operator both visually and audibly if a condition arises which needs his attention. If the alarm condition causes the development of a dangerous condition and is not rectified within a certain time, control valves operate automatically so as to safeguard both plant and personnel. Standby generators and compressors are installed to safeguard against instrument air and power failures.

Control rooms however continued to grow in size until it became increasingly difficult for the operator to maintain efficient supervision of all his control instruments. To solve this problem indicators, recorders, and controllers were considerably reduced in size and graphic panels and console desks were introduced. On a graphic panel a diagrammatic picture of the plant is shown with the instruments inserted in appropriate positions. Thus a complete representation of the plant with actual control conditions is available to the operator.

More recent developments such as the in-line scanner[1], off-normal alarm systems, automatic data logging etc. have been produced for the specific purpose of presenting the operator with the maximum amount of information in a form which is easily assimilated, and to create records for accounting purposes and for the subsequent analysis of plant performance.

Instruments and automatic control have now become an integral part of process plant equipment and are incorporated and considered in the basic design of many modern installations which could not be operated without the assistance of this equipment.

Modern instruments are well engineered and very reliable as a result of 25 years of development and refinement. The first electronic process controller introduced in 1950 was almost a complete analogue of its pneumatic rival and did not make use of the many advantages at its disposal. Fortunately, later models have greatly improved with the result that the latest development has produced an electronic controller of no mean merit.

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2. The Computer as Master Controller

In considering further application of electronics in the chemical industry, a most probable suggestion would be in the form of computers in intimate contact with control of industrial plants as opposed to the normal use of computers for accounting, distribution and estimating purposes.[2]

As explained earlier, the object of plant control is to maintain the plant output as near as possible to a desired value. Plant with a conventionally designed control system depends entirely upon the human operator to achieve this end, but he is assisted by local loop controllers which maintain, independently, internal parameters. These parameters can be adjusted to values which are determined by previous knowledge, experience, or trial and error. In the absence of any input disturbances or changes in plant characteristics, the control system will maintain the plant output at the selected desired value.

Unfortunately, changes do occur in the input and plant characteristics, which require changes to be made in plant internal parameters, that is, local loop controller settings, necessitating continuous monitoring by the operator.

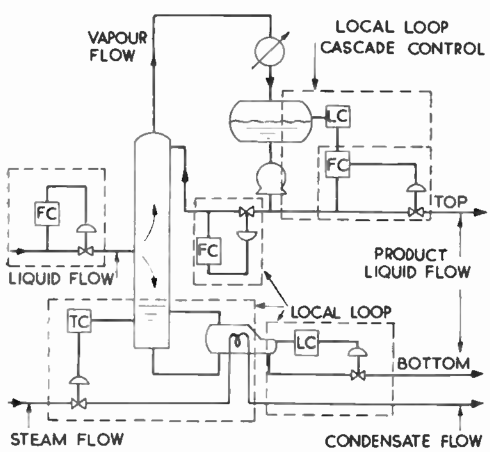

Fig. 1. Typical flow control set-up. Dotted lines indicate local loop.

A section of a plant is shown in Fig. 1. The dotted lines indicate the paths of the control loops and it can be seen that they embrace part of the plant. For example, the feed flow

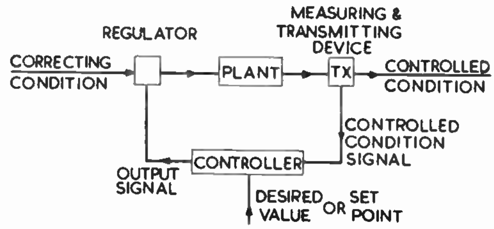

Fig. 2. Local loop—schematic diagram.

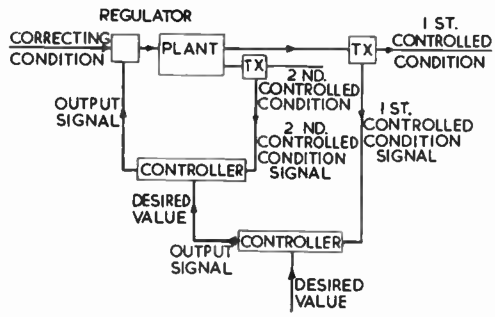

Fig. 3. Local loop—cascade control.

control loop has the downstream part of the line between the measuring point and the control valve, and the column pressure as part of its circuit. These components lumped together form the plant transfer function of the control loop. Figs. 2 and 3 show the schematic form of the control loops for single and cascade control. In the latter case the first controlled condition's path is the main control loop, and the inner loop attenuates the effect of secondary disturbances on the first controlled condition. The inner loop can be regarded as a noise eliminating system for the main control loop.

Each local control loop thus has its own plant transfer function, in most cases not predictable and often variable, which affects the final choice of controller settings during the lining-up period of the controller during commissioning. In most cases only the numerical value of the transfer function changes with the operation of the plant. Its form remains constant, and stability, which is usually achieved by trial and error, is given a fairly large phase margin. The local loop variables are not independent of each other, and considerable caution is to be exercised by the operator in altering the desired value of any variable to avoid plant oscillation, caused by interaction of the variables. For

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instance, if the feed flow controller in Fig. 1 were suddenly adjusted to a higher flow rate, i.e. a step function on the set point, although the loop response would eliminate the sharp front, the column would still receive a rapid increase in feed. This may instantaneously have a cooling effect and decrease the overhead vapour with a resultant decrease in liquid input to the top liquid collecting drum. The level controller associated with this vessel would then tend to reset the flow control to reduce the top product liquid flow. The increase in column feed would cause the column base liquid to cool and drop the temperature, which causes the base temperature controller to open up the steam valve to put more heat into the column base via the reboiler. This causes an increase in overhead vapour which is negative to the initial disturbance on the overhead system and thereby initiates an oscillation. The inherent regulation of the system ensures a damped oscillation but such conditions may have serious consequences if one or more of the variables contains danger limits. Phase margins are usually selected so that stability is sufficient to overcome the cycling tendencies, produced by rates of change of desired value and other disturbances most likely to be encountered in the particular plant.

We have now to consider replacing the operator by a master controller. While it is not possible at this juncture to predict the form of the master controller it will undoubtedly include the use of some sort of computer. If we replace the human operator by such a controller, in order to assimilate his actions the controller will be required to observe and analyse the plant input and output, analyse the nature of the disturbance and select suitable settings for the plant parameters.[3] One method of achieving this would be to feed the master controller with output information, input information and the current values of all the plant variables. The controller would also have to be preset with information of the particular plant characteristics. Fig. 4 indicates how the output of the master controller would be used to reset the local loop desired values as in the case of the human operator.

The problems facing the designer of such a control system appear formidable, at the present moment, but will no doubt be solved by study and research. The relationships between desirable products and tolerable byproducts from various raw materials has been fairly well established by chemical and market research over a considerable period of time, and no doubt facilities for applying this information, with the necessary periodic adjustments, could be built into the master controller with relatively little difficulty. The building-in of plant characteristics however, is a much more difficult problem since design of any plant is governed more by empirical methods and past experience rather than precise mathematical formulae, and plant characteristics can be obtained usually only after the plant has been commissioned.[3] The master controller would have to be sufficiently versatile to permit trial and error adjustments of the relationships between the variables during the commissioning period.

The question of stability, as mentioned previously, would have to be considered, and facilities for applying correct rates of change of desired values, in the correct order and with the proper time intervals, would have to be built in. This means stating, in mathematical terms, the action of the human operator who is motivated at the present time by instinct and past experience. Furthermore the failure of a plant component such as a pump, a valve etc. is inferred, in the first instance, by the human operator from observation of measured values, and is confirmed almost immediately by visual

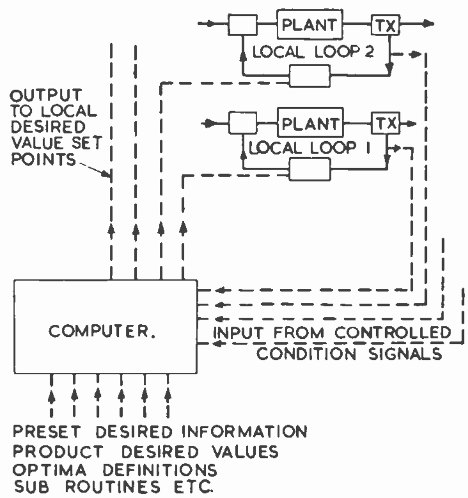

Fig. 4. Plant with local loops monitored by computer.

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inspection. From these observations corrective action is taken by the operator. The ability to perform these functions would have to be built in to ensure that even if corrective action cannot be achieved at least the breakdown may be localized to prevent further damage, and an alarm signal be initiated.

Since the master controller will be required to receive inputs from devices measuring the value of the variables, the necessity for reliable and accurate transducers becomes apparent. Such transducers would be required to convert from pneumatic to electric, or electric-to-electric states at different levels, either with an analogue or digital output, depending on the nature of the master controller's computing equipment. Whether the accuracy of an analogue computer would be sufficient for this purpose would have to be taken into consideration. Similarly the master controller's output would need to be matched to the local loop controller's desired value input.

Obviously the electronic process controller has the advantage over a pneumatic type in this case, if the master controller is an analogue type designed to accept the local loop controller's measuring unit output.

This system has the advantage of avoiding a plant shutdown in the event of a master controller failure. Under these circumstances the master controller could be cut out of circuit and the plant operated in the conventional manner by a human operator.

A second and more complicated use of a master controller[2] would be a system whereby the local loops were modified so that the plant variables were directly controlled from the output of the master controller as indicated in Fig. 5. With such a system a high speed computer could be employed to perform the duty of a master controller and at the same time scan the plant for changes in characteristic, continuously monitor the plant parameters, and by a parameter searching technique analyse the plant performance to obtain optimum parameter settings. Digital computers in conjunction with data reduction equipment and analogue computers have been applied to process plants for monitoring purposes and plant analysis,[4], but so far as is known, the applications have been confined to open loop indirect control.

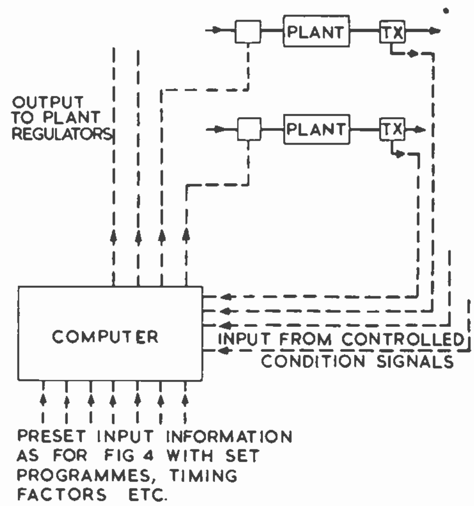

Fig. 5. Plant controlled by scanning computer.

In effect the master controller would act as the local controller in each loop by sampling the loop input in a pretermined sequence, the rate of scanning being preset by considering the response and importance of each loop. The output to each loop would remain constant during the scanning period and be readjusted during sampling.

If a computer, with a speed of response much greater than those of the local loops, is selected, then the computer is available for other work at the end of each scanning period.

The computer could be programmed in such a way that, during this period, a check of the plant transfer function of each loop could be carried out by one of the many popular present day techniques. In this manner any change in plant characteristics could be observed and local loop settings altered accordingly.

Again in this system as in the previous system all information concerning plant and process characteristics, control characteristics, economic details etc. would have to be fed into the computer at the commissioning stage, and subsequently altered as required.

The free period could also be used to employ a parameter searching controlled programme. By this means the effect of the variables on the trend of the output can be obtained, and successively repositioned, resulting eventually in optimization. Both economic and specification

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optimizations, and various combinations could be obtained in this manner if required.

The saving in capital on controllers for a large plant would probably offset the cost of the master controller.

3. Plant Controlled by Computer with Card Input

The object of this system of control is to ensure correct specification and maximum yield of plant output. The plant chosen for this example is one where the output specification might well vary during normal operation due to variation in the plant input.

A brief description of the process involved is given to facilitate appreciation of the problems facing the computer designer.

The feed is a binary mixture in liquid form, for example a mixture of propane and butane, or butane and isobutane, or alcohol and water. Mixtures of more than two components are more often encountered, but for the purpose of this description a pure binary will be used. The problem is to separate the mixtures to a given degree of overlap, i.e. contamination of one liquid with the other. Unfortunately absolute separation is not possible with this process, and optimum conditions are required to produce maximum separation. This is determined by the complexity of the plant.

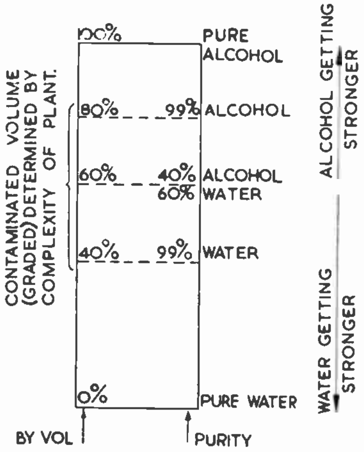

Fig. 6. Unit of feed of 40% alcohol and 60% water showing the degree of separation achieved by plant.

For a given plant operation the contamination of one component can be decreased at the expense of reducing the offtake of that component, and increasing the offtake and contamination of the second component. This can be pictured more clearly by considering Fig. 6. Assuming the feed to the plant contains 40 per cent. alcohol and 60 per cent. water and that the maximum separation for this particular plant is such that the contaminated volume below 99 per cent. purity is 40 per cent., then if we take a split at 70 per cent. the offtake of alcohol from the top of the column will be 30 per cent. but the composition or strength of the alcohol will be very much less than that from a lower offtake of say 22 per cent., that is split at 78 per cent. In the latter case the contamination of the water is increased since we have to put more alcohol with it.

Having taken into consideration the marketable value and demand of contaminated alcohol, referred to as the top product, together with those of the contaminated water, referred to as the bottom product, and other factors such as cost of operating, cost of feed stock, the following factors are determined:—

Feed composition (percentage of each component)
Degree of separation (plant operation)
Top product flow (offtake)
Top product contamination, composition, or quality
Bottom product offtake
Bottom product quality.

Once these factors are available, the plant parameters for this operation can be determined, and the plant can be brought on stream. As long as the parameters are maintained by the local loop controllers, the product will be on specification and the offtakes will be constant.

Unfortunately, the feed composition is liable to change due to deliberate or inadvertent operation of the feed supply system. When this happens, new parameters are required to maintain specification, and the offtakes must be changed to conform to the new feed composition. It often happens that the plant input varies continuously in this way, and the operator is hard put to guide the plant to maintain specification. He is often forced to accept a lower offtake with a varying quality under these conditions, with the result that the

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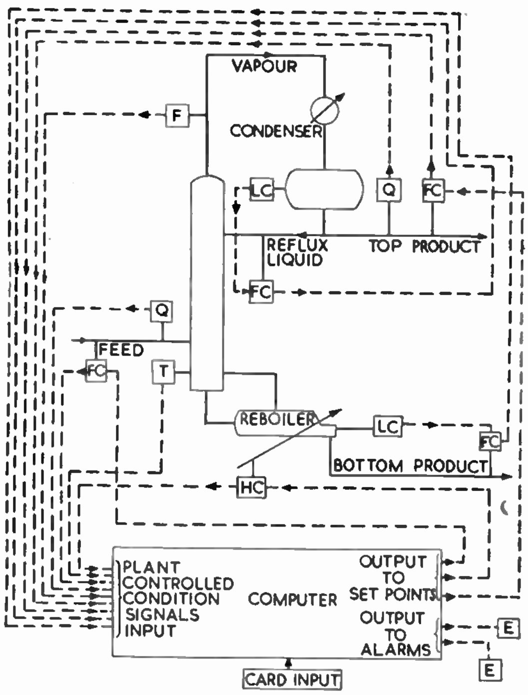
product has to be batch blended. This is a wasteful and uneconomic procedure.

Our requirements of the computer now become apparent. It must continuously monitor the output for specification and maintain it within limits by supervising the plant controllers, and it must also monitor the feed composition to calculate the new desired split and alter the top and bottom product offtakes accordingly.



F FLOW MEASURING & TRANSMITTING INSTRUMENT

FC FLOW MEASURING TRANSMITTING & CONTROLLING INSTRUMENT

HC HEAT (TEMPERATURE) MEASURING TRANSMITTING & CONTROLLING INSTRUMENT

E ERROR SOUNDING & INDICATING DEVICE

Q COMPOSITION MEASURING & TRANSMITTING INSTRUMENT

T TEMPERATURE MEASURING & TRANSMITTING INSTRUMENT

LC LEVEL MEASURING TRANSMITTING & CONTROLLING INSTRUMENT

Fig. 7. Plant for card input computer control.

The operation of the plant and computer is indicated in Figs. 7 and 8. Essentially the process consists of boiling off top product, condensing it, returning some of the condensate as reflux and sending the remainder to storage. Most of the bottom product, although absorbing heat, does not vaporize and passes straight through to storage. The reflux is necessary to provide a high degree of separation with a reasonably small size of plant.

Starting with the feed, its composition is transmitted to the computer, together with the feed rate from the feed flow controller and the top product desired limits from the card input. From this information the correct split is computed and a signal is fed to the top flow controller, thus adjusting the top product offtake. Since the top product offtake is now fixed, the bottom product offtake must be constant since these two offtakes must equal the input flow rate which is held constant by the feed flow controller. The bottom product offtake is adjusted automatically by means of the local loop, the reboiler level resetting the bottom product flow controller.

The top product composition is fed to the computer where it is compared with the top product desired composition limits, and the error, after translation, is fed to the set point of the reboiler heat input temperature controller, thus regulating the heat into the column. This process is a simple one, and the regulation of this one parameter is sufficient to control the top product specification. The computer can thus deal with input disturbances which, of course, is its main purpose.

The computer will further have to deal with plant start up, and limiting values of variables due to peaking during normal operation. It will also need to have cross checking facilities built in. Whilst it is not the purpose of this paper to produce a practical proposition, but rather to give some indication of the nature of applications which urgently need investigation, it is considered that Fig. 8 could be a possible form which the computer could take.

The estimated values are fed in from the card and are used for plant start up. These values are converted into a ramp function and fed directly to the set points of the controllers. This, of course, constitutes an open loop system and is precisely the same as a system employing a human operator. The plant gradually increases its throughput until the desired feed rate is approached. At this point the computer compares the actual feed rate with the desired feed rate, the actual top flow rate with the theoretically computed flow rate, and if these

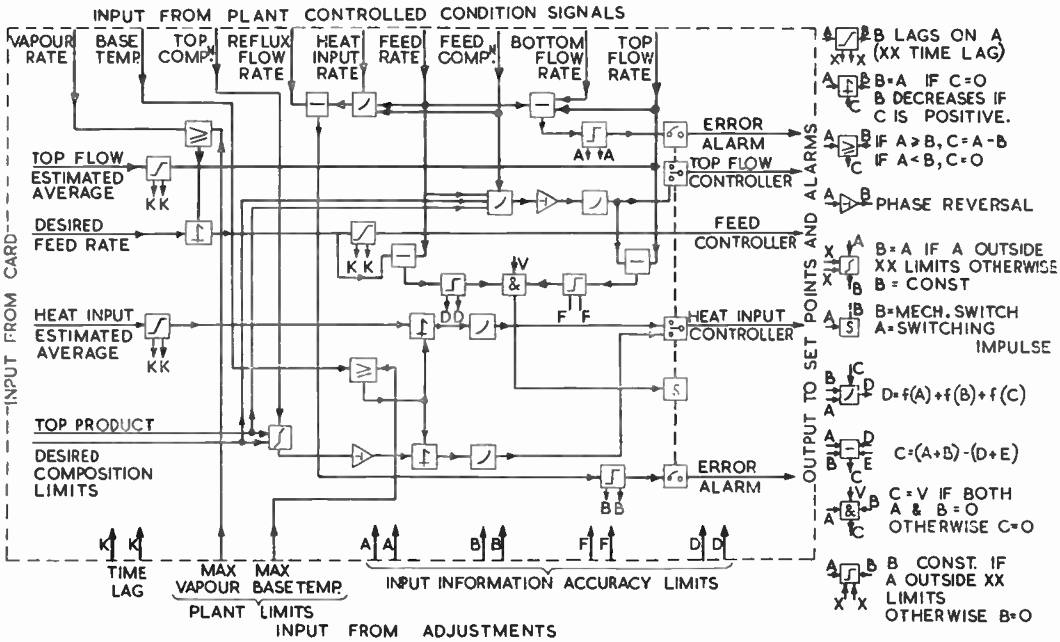


Fig. 8. Card input computer for plant control.

are within predetermined limits of each other, an AND circuit switches the computer's output set points from card estimated values, to the input from plant measured variables. Thus the switch is from open loop control to closed loop control, with the composition transmitters supplying feed back.

Although there can be several cross checks which would be made by the computer to ensure correct plant operation, only two examples of such checks are included in Fig. 8. One is a material balance check, that is, summing the two product outputs and equating them to the feed input; if an error exists outside the limits of normal instrument accuracy then an error alarm and indicator will be energized. The second concerns the operation of the plant whereby the actual reflux flow rate is compared with the theoretically computed flow rate which can be obtained from considering the feed rate, composition, and heat input rate. Again, an error alarm will be energized if the error is outside the normal accuracy limits.

As a safeguard against overloading the column, the computer must be able to prevent the vapour rate exceeding a maximum value. This it does by comparing a fixed input with the actual vapour rate, and the error, if positive, reduces the feed rate until the vapour rate has returned to a safe value. The second limit concerns the maximum base temperature. In a similar manner the temperature is limited by modifying the computer output to the heat input controller.

4. General Comments

Whilst accuracy of absolute values is not very important in most industrial applications, repeatability on the other hand is extremely important. It is readily understood that with any scanning or sampling system, that is, one in which a correction is made at discreet intervals of time, it is essential that constancy in successive corrective signals for a constant input be maintained for good control.

By their very nature electronic systems lend themselves to highly desirable features; these include:

Prevention of accidental operation by interlocking.

Automatic internal fault scanning and automatic replacement.

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Ability to sense and ignore intermittent false readings.

Testing the validity of readings with computed cross checks.

The design of industrial electronic devices needs to be considered in the light of the conditions under which they will be required to operate, and in this connection frequent liaison between user and designer is to be advocated. Equipment for use in the chemical industry might well employ such components as cryotrons, transistors, solid state circuits, static switching, passive elements etc., to reduce overall size and maintain voltages and currents to low values for safety reasons. (Intrinsically safe circuits are preferable to flameproofing.)

Technical labour is insufficiently skilled to deal with many of the elaborate and complex devices which are being produced at present and in this respect such features as expendable unit construction, simplicity, plug-in units, built-in testing facilities and logical checking techniques are highly desirable. Further points to be considered are standardized components, accessibility and easy removal of components, external transmitters subjected to weather and corrosive atmospheres and their need for robust construction.

At the present moment, the time efficiency of digital computers is far from satisfactory for the purposes described. A similar opinion is held with regard to analogue types, except perhaps those of the most simple form, and it is here reiterated that industrial controllers are simple analogues. It must be borne in mind that industrial equipment is expected to work a 24-hour day, continuously, throughout the "on stream" period of the plant, which may have a time efficiency of 98 per cent. and a stream period of 9-18 months. As computers become less complex, more reliable and not so expensive, such systems as have been described will be developed and will perhaps incorporate two computers, the second to act as a standby and carry out intermittent duties. Modern improved and reliable data transmission techniques permit a further possibility of one computer, with patch board input, to be used as a standby for a large number of individual plants or even of a few computers with one standby controlling a whole refinery by rapid selective scanning.

It is with possibilities of this nature in mind that a full study is being made by the authors and their colleagues to investigate the problems involved in such applications, and to search for new plant techniques which may become practical propositions as a direct result of the facilities afforded by new electronic developments.

5. Acknowledgments

The authors wish to thank the Chairman and Directors of the British Petroleum Company for permission to publish this paper. They would also like to thank their colleagues for their helpful suggestions and co-operation in preparing it.

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INSTITUTION NOTICES

OBITUARY

The Council has learned with regret of the deaths of the following members of the Institution, and has expressed sympathy with their relatives.

William Andrew Bryce, M.B.E. (Member), who died on October 4th, aged 58 years. Mr. Bryce served during the 1914-18 War as a signals instructor. After the war he founded his own business, W. Andrew Bryce & Co. Ltd., for the manufacture of mains transformers, chokes, etc.; his services in providing these components for the Armed Forces during the 1939-45 War were recognized by his appointment as a Member of the Most Excellent Order of the British Empire. He retired from business in 1946. Mr. Bryce was elected an Associate of the Institution in 1933 and was transferred to Associate Member in 1938 and to Member in 1944.

Hari Krishna Prashad Mago died on 18th August at the age of 26 years. Mr. Mago was employed by the Indian Corps of Electrical and Mechanical Engineers in a civilian capacity as a Technical Supervisor in Delhi. He registered as a Student of the Institution in 1953.

Whitworth Awards for Engineers

The Whitworth Foundation Awards offered for competition in 1959 will be as follows:—

Whitworth Fellowships.—Will not exceed three in number and are normally tenable for two years. They are valued at £500 a year, and may be supplemented by both dependents' and travelling allowances.

Six Prizes of £50 each.—Awarded to unsuccessful competitors whose work deserves recognition. To be employed in the furtherance of the competitors' engineering education.

Candidates must be British, and have an engineering qualification of university standard, or a Higher National Diploma or H.N.C. in Engineering, with at least two distinctions, together with practical engineering training of at least 104 weeks. Candidates will be required to write a thesis of 2,000-4,000 words, on a subject approved by the Ministry.

Further information should be sought from The Ministry of Education, F.E.I. (D), Curzon Street, London, W.1.

Visit to Western Germany

Considerable interest has been shown in the announcement in the September *Journal* about the proposal for a party of members to visit Western Germany in the summer of next year. More detailed plans are now being formulated, and any member who has not already notified the Secretary of his interest is invited to get in touch with the Institution.

Present plans are that the visit will probably take place in June, and that its duration, including travel to and from Germany, will be about ten days. The inclusive charge will be about £68, and ladies may also take part.

Norman W. V. Hayes Memorial Medal, 1957

Reference was made in the November issue of the *Journal* (p. 597) to the Norman W. V. Hayes Memorial Medal of the Institution of Radio Engineers, Australia, for which recommendations are made in alternate years by the Brit.I.R.E. and the I.R.E. of America.

This year, on the recommendation of the American body, the award has been made to Mr. B. F. C. Cooper, B.Sc., B.E., for his paper on "The Application of Transistors to A.M. Broadcast Receivers," which was published in the October 1956 issue of the *Proceedings of the I.R.E., Australia.* Mr. Cooper, who was born in England, is a Graduate of the University of Sydney in Science and Engineering, and is at present a member of the research staff, Radiophysics Laboratory of the Commonwealth Scientific and Industrial Research Organization.

Members will recall that Mr. Cooper's paper was in fact selected by the Programme and Papers Committee for re-printing in the *Brit.I.R.E. Journal* for February 1957, under the mutual arrangement between the Australian and British Institutions.

Completion of Volume

This issue completes Volume 17 of the *Journal.* An index to the Volume will be distributed with the January 1958 issue.

Members wishing to have their *Journals* bound by the Institution should send the complete set of issues and index to the Institution together with a remittance of 15s

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TECHNIQUES FOR USING COMPUTERS FOR OFFICE WORK*

by

E. A. Newman, B.Sc.† and M. A. Wright, B.Sc.(Eng.).†

A paper presented at the Convention on "Electronics in Automation" in Cambridge on 27th June 1957. In the Chair: Dr. A. D. Booth (Member).

SUMMARY

The paper discusses clerical work generally and points out why some clerical tasks involve more work in data processing than in calculation. A system for doing payroll in which a high speed computer does data marshalling as well as calculation and decision making is described. Application of this system to related tasks such as cost accounting is discussed. Mention is made of special equipment required and some consideration given to the economics of high-speed computer systems and the limitations of the above techniques.

1. Introduction

All recurrent clerical work involves both the collection of new data, and the keeping of information within the clerical organization.

This fact is easily recognized since if there were no new data, the clerical task could be done once and for all, and if no information were kept within the organization, there would be no means of knowing what to do with the new data. Even so, the fact is sometimes overlooked.

Before it can perform a clerical task a computer must store a large number of instructions. Also a large number of instructions must be stored when human beings carry out clerical tasks. For example, few people can learn to multiply or add without being taught or given a list of instructions to define every operation on every digit.

Many clerical tasks make extensive use of information recorded within the organization and the merging of new data with existing records is an important part of the work. This has to be done in present day manual systems and is often overlooked in such systems.

It would be possible to mechanize a very high proportion of all clerical work, provided use is made of apparatus which is technically possible to design, as well as that in existence. It is not at all certain however, that it would prove worthwhile.

In this paper, one class of clerical work is defined and a set of criteria are given from which the practicability and economy of computer mechanization of this class of work can be judged.

2. Classification of Clerical Work

Before discussing mechanization which is practical with existing apparatus and in order to give some idea of the limits of possibility, the following task is considered:

A regular customer telephones the following instructions to a garage storekeeper: "My car is not working. Send me a 2-in. bolt," and rings off without giving any further information. The "new data" that the customer has given is incomplete, but it contains more information than would at first appear, since the sound of the voice itself gives information. Under certain conditions a human store-keeper could carry out this clerical task and, with reasonable certainty, send the right bolt to the right man at the right address. The minimum conditions would be:—

(*a*) That the store-keeper could recognize the customer's voice.

(*b*) That the store-keeper had a record of

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the customer's name and address, and make of car (either in his brain or elsewhere).

(*c*) That the store-keeper stored the fact that when a human being makes two statements in a message, the statements are usually connected.

(*d*) That the store-keeper had a list of components which showed that this car contained only one kind of 2-in. bolt.

In this problem, there is probability but no certainty. The telephone conversation is new data—the remainder is record. By automatically measuring the amplitude of the electric current operating the telephone earpiece to 1 per cent. 10,000 times a second and feeding the result as a sequence of numbers, to a suitably programmed digital computer storing suitable records, the computer could decide what the problem was and make as good a guess at the answer as any human. However the computer might turn out to be very slow at the task, and the stored record would need to be very great.

Even though it would be possible to mechanize the handling of a series of telephone enquiries of this sort, it would be a very complex matter. Firstly, since the input information is not complete, the computer has to work on a basis of probability, not certainty. Secondly, since all kinds of knowledge might be needed to make a reasonable judgment, the storage capacity must be very large. Thirdly, if the new data is not "labelled" clearly, there is no easy criterion to enable a computer to judge what part of its vast stored information is relevant to the case.

A great many clerical tasks are very much more straightforward. The simplest type, the type with which this paper is mostly concerned has the following characteristics:—

(*a*) The new data and the existing records together make a complete set of data, and the task to be performed on them is defined within the organization without abiguity as a set of regulations, i.e. a programme of instructions.

(*b*) The task consists of a large number of small closely related jobs, which use a basically similar small programme of instructions and the recorded data for each job is not very large. The new data is mixed and might relate to any or all of the jobs, but it is labelled in a way closely defined in the instructions.

Examples of tasks of this sort are pay-roll work and cost accounting.*

This class of work, which we shall refer to as class A, is likely to contain as much calculation as any in the clerical field. But even so, the calculation element is apt to be a fairly small part of the total work. For example in a certain Civil Service pay-roll the new data consists of information about overtime, of change of work, changes of location of work, of changes in authorized deductions, and of changes in working pay or income tax conditions. Each item of new data can be labelled in a definite way. For example, if it refers to a change, the change can be given a code number and labelled with the name of the man to whom it applies and the number of the room in which he works. The programme of instructions is in large measure common to all employees—it adds up to about 5,000 instructions and the record for each employee is fairly small, about 200 decimal figures per man. The work can be said to consist of four parts, sorting the new data and merging it in with the records, applying the rules of the pay-roll, calculating and assembling results. The first of these involves considerable data manipulation and the second accounts for a very large number of instructions. For example, if a man is sick, whether he gets full pay, half pay or no pay depends on how his case fits in with a number of regulations. He may possibly qualify for some extra pay allowance: whether he does or not, depends on the circumstances of his case. Various other similar problems arise. The data to enable the right decisions to be made are available in the record or in the new data. The task of making decisions and marshalling data is a considerable one and takes up some 90 per cent. of the total effort when the pay-roll is performed manually. This proportion is borne out in machine time when it is carried out on a computer.

Even though the record for each man is quite

* "Wage Accounting by Electronic Computer." (H.M. Stationery Office, London, 1956.)

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small, the total amount of data in records for a large pay-roll is large. For example, the records for a 20,000 pay-roll would total 4,000,000 decimal characters. In some detailed studies it has been estimated that if the computer is to be profitably used on such work and if the original cost is of the order of £100,000 the processing rate must be such that the average access time to information in the records must be only a few tens of microseconds per character. A computer with a storage capacity of 4,000,000 characters and access to any character at random of, say, 20 μsec would cost a great deal more than £100,000.

In a clerical task of the kind we have called class A, only the programme and data for one separate job need be in the computer's high speed store at any one time. The remaining data and programme can be kept on cheaper stores with longer access time. This can be done without affecting the processing rate provided that the time spent in processing is sufficient to allow the data for the next job to be read in and the data from the last job written out. Serial stores based on the use of magnetic tape are inherently cheaper than parallel stores giving similar maximum transfer rate; but random access to data on serial stores may be very long. However, in class A clerical work, the work on the various jobs can be arranged in a specified sequence. Therefore if the records are kept on a serial store in the specified sequence the effective access time can be minimized.

A convenient way of defining the amount of processing on each block of data is to express it as the amount of data produced as intermediate results plus final results. For example, in multiplying two ten-digit numbers, 229 digits of intermediate results and 19 digits of final results may be produced. Thus in this case the ratio of results: input is 12·4 : 1.

In a typical pay-roll each man's record may comprise 200 characters. If 2,000 characters of intermediate and final results are produced, the computer will be occupied for 2000×20 μsec, i.e. for 40 msec assuming that the average time per character is 20 μsec. Thus no computer time will be wasted if the next record of 200 characters can be transferred to the computer during this 40 msec. This needs an average input transfer rate of 5,000 characters/second. Similar conditions apply to the output.

Appropriate parts of the new data have to be merged with each record before it is processed. Where the new data is precisely labelled it can be sorted* into the same order as the records and then a part of the new data can be fed into the main store of the machine at the same time as the record, to which it refers, becomes available.

3. The Broad Economics of Computer Application

It is never easy to tell whether any clerical task is suitable for computer application. However, if it is class A work, the above techniques will only prove satisfactory if the task satisfies, at least to some degree, the following conditions:—

(1) The programme of instructions needed to process each record is in large measure common to each record or is small and of nature such that the programme for processing each record can be merged with the record and fed into the computer as a block of record and a block of programme. Otherwise the storage required for programme will be as large as that needed for records, and will need a very large high speed store.

(2) The amount of processing is large, i.e. the ratio of intermediate and final results to input is large. Otherwise the tape must be capable of feeding information into the high speed store at high average rate, e.g. in our quoted example, if the ratio were unity, about 50,000 characters per second. (Although in more expensive machines this rate would need to be higher.)

(3) Most of the records are processed at each run of the record tape, otherwise the tape will have to operate too quickly.

Items (2) and (3) are to some measure interdependent. For example, if every record were processed, then it would be highly satisfactory

* D. W. Davies, "Sorting of data on an electronic computer," *Proc. Instn Elect. Engrs,* **103**, Part B, Supplement, pp. 87-93, 1956.

if, on average, every character in a record produced, say, 10 others. If each character used on a record produced on average 10,000 (a possible figure in scientific work) only one record in 1000 records need be used to be as satisfactory.

The figures quoted above depend on speed of tape, and price of computer. If a magnetic tape operated 10 times quicker, only a tenth as many records need be processed to be economic. This would also be true if the computer cost £10,000 instead of £100,000.

When there is a great deal of new data the task of converting new data to a form suitable for machine assimilation can be considerable, unless, as we postulated was the case in our "bolt" example, automatic conversion apparatus is available. However, our investigations indicate that when all the three conditions are satisfied, the computer will be an efficient tool, even when the problem of putting new data into new language is a major one. But if condition (2) is scarcely complied with, work done on converting new data into machine language can be the balancing factor.

3.1. *Pay-rolls*

In typical Civil Service pay-rolls all the conditions are fairly well met, and a machine fully employed on such work could pay very well. In pay-roll tasks where piece-work, plain time and bonus systems are involved, condition (2) is not well met. We think that the use of an automatic computer could probably pay on such work, but the expense of putting data into machine language becomes much more important. However, it has been calculated that the cost of converting all the output from a work clock into machine form, using a card punch and operator, is only equivalent to adding about £20 to the capital cost of the clock used for "clocking-in" (assuming that there is other work for the card punch and operator when not employed on this work).

3.2. *Cost Accounting*

Cost accounting tends to fall into two categories, the production of standard costs, in cases where the products of a factory do not change, and the production of actual job costs, where the products of a factory vary. In the latter case the selling price of an article may be based on an estimate of what it costs to make; computation of such a cost is similar to working out a wage in a piece-work shop. The article is given a "wage" made up of the summation of the man-hours, machine-hours, material, auxiliary man-hours and auxiliary capital cost for each part of the article. Standard costing is used, sometimes, to indicate change of efficiency.

Either of these tasks fits into the class of clerical work already discussed and precisely similar techniques can be applied. The authors have not studied the first in detail, but it would appear to satisfy the conditions rather well. The latter has been studied to some extent and it fits the conditions rather better than does the factory pay-roll problem.

Stores control and accountancy is a task which is in the same class provided that all goods are referred to by standard code names. It does not satisfy condition (3) at all well and this might make it difficult to mechanize cheaply.

3.3. *Sorting*

Sorting is an essential part of the technique of solving all these problems. Various methods have been developed which bring sorting into class A as a problem in its own right. In the methods so far developed, the sorting is done in several stages and at each stage the amount of processing is not very great, so that when large records are sorted, the processing ratio may not be much greater than unity. Consequently computers are not likely to be economic at sorting unless the input/output speed is very high. The only suitable medium for this input/output is magnetic tape and in the two major techniques* it is desirable to use at least four input/output units.

Some methods of sorting make use of the computer's internal store, instead of using magnetic tape. This can be done for several stages of processing depending on the size of the internal store. But if the data cannot all be stored on the internal store, then the magnetic tape has to be used, at least in the final stages of processing. Use of the internal store, in this way, relieves the input/output problem to some extent. However, if the

* D. W. Davies, *loc. cit.*

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internal store capacity is increased for this purpose, the cost of the computer becomes greater and the input/output problem becomes more acute.

Input/output units used for sorting need a quick start–stop time—how quick depends on the size of any immediate access buffer store and the number of tracks on the tape. But even 1 msec for every 500 characters of buffer store capacity would about halve the speed of a fast computer. In the magnetic tape type equipment required to store the record, the task is less difficult, a start–stop time some four times slower often being adequate; furthermore it would be practical in many jobs to have a much worse start–stop time than that.

3.4. *Index Problems*

Index problems can come into the same class under very special circumstances. For example, an index used to find insurance code numbers of people from their name and date of birth would be in this class if all names and dates were in correct and consistent form. However, in most index problems, condition (3) is not well satisfied, and usually, using existing equipment, a computer cannot be employed profitably.

In general, neither the stores nor the index problem is a class A problem. But they will be considered in some detail in order to show some of the limitations of the techniques we have discussed. The required item from store may be asked for in a number of ways. Although the data given in the request for the item may be complete, it will not contain a simple label (i.e. the address of the storage location) and much data processing may be needed to find the item. The problem of identifying the wanted store is very similar in kind, although not in magnitude, to translating from, say, French to English. Such work could be done on a digital computer and some investigation is being carried out. But it is a new technique, not yet fully developed.

In the index problem, the special feature is rather different in kind. In this case there is no guarantee that the new information is correct, and therefore, it may not exactly match the record; the problem is to find a most probable trace. To do this, it is necessary to keep a large record of the sort of errors which are likely to occur in the new data and the sort of differences between new data and index records which prove to be significant. If all the facts were known, and the record were sufficiently large, it would be possible to programme a computer to find a soundly based most probable solution. In practice the facts are not known, and to limit the size of store needed, only the most useful information about errors need be kept—although it is not known which will prove the most useful. A way to solve this problem is to programme digital computers to learn. This is quite possible, but good techniques for doing it are not yet fully developed.

4. Checking Procedures

In practice, any data processing organization mathematical or clerical, human or mechanized must include a reliable checking system. Checking mechanisms can be built into the machine, but such checks cannot make use of the nature of the problem being solved. However, it is possible to programme checks which use little computer time and which make use, in elegant fashion, of special properties of a problem, and therefore, are very effective. In general, once a computer has control of information, it is better to programme checks. However some built-in checks need very little equipment and enable simple errors to be detected at an early stage before much machine time has been wasted.

The problem of checking that data is correctly fed into a computer system and that the correct data is printed out is complex. Where the quantity of new data is large, there is a very strong case for automatic recording apparatus. In fact, there is probably a good case for this in any circumstances. Human beings make a great many more errors than do machines, and they are not nearly as good as machines at noticing the errors they have made. Thus there is danger in a mechanized system at all stages where human intervention occurs. A well known example of this is the need for verification of the work of card punch operators.

When processing of data is completed the final results become output. At this stage the computer no longer has control of the data

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manipulation so there should be special means of checking. This final checking can be accomplished only by re-reading the final record and this can be done conveniently at the writing stage by using a magnetic tape equipment with a reading station fitted after the writing station.

In a sample pay roll using inadequate programmed checks, a computer system has been found to pass no errors, while a human system running in parallel was making about one error in every 100 accounts.

One big danger in a computer system, using magnetic tape units capable of both being read from and written on under computer control, is the possibility that a fault in the computer might result in the destruction of vital data. This can be avoided if the machine is fitted with one tape unit which it can read from, but not write on.

5. The Assessment of Cost

The annual cost of a computer is easy to calculate, given the estimated life, maintenance and operating costs, interest rates, capital cost of the computer and an allowance for the effect of inflation. However, only the assumptions about capital cost and interest are simple. For example the life of a computer would be indefinite, provided there was no limit to maintenance costs, and there was no desire to replace it by a more modern machine. Once the annual cost has been decided and when one computer is fully loaded with one task, the total cost is easy to compute. In the case where a machine is fully occupied on a mixed group of tasks, the effective cost of the computer per hour can be found, and the time needed, and hence the cost for each task can be estimated. When the computer is utilized on several tasks, but is not fully utilized, estimating costs is more difficult.

It may be that a computer is comparatively slow, and therefore comparatively expensive, at certain parts of a clerical task. It might then pay to use a partially mechanized system, i.e. one with human intervention at certain points. It is not easy to compute the cost of such a system. It often involves dividing a task previously done by a man between a man and a machine. Since little is known about men as data processing machines, it is not possible accurately to assess how much of a man's time will be saved by taking part of a task from him.

In general the cost of a computer is not proportional to its speed. A very fast computer tends to cost little more than a medium speed one. It is therefore, obvious that the faster machine with its greater capacity for work is likely to be potentially more economic than the slower one. Thus, it is cheaper to share a fast machine between several tasks than to use a medium speed machine for each.

One question that sometimes gives trouble is how to balance ease of programming against cost or speed in a machine. If it is known what tasks are likely to be carried out on the machine, it is possible to estimate the time, and hence the cost, of programming the tasks. The capital value of the programme can therefore be found. In clerical work, where programmes are likely to be used for a very long time, ease of programming is of much less importance than in scientific work.

A vital factor, involved in the assessment of the likelihood of mechanization being economic, is the assessment of time taken. It is anticipated that even if a computer is fully occupied the cost of any task will not be reduced to less than, say, a quarter of the present cost. Since the computer cost is usually a large proportion of the total cost, an under-estimate of computer speed, and hence of computer cost, of five to one could very seriously affect the expected savings. Yet it is possible, even for an expert programmer after much study of a problem, to make errors greater than this. It is essential, if a good assessment is to be made, for expert programmers to study the task in very great detail. Even when, as a result of a detailed examination it is found that use of a computer would not pay the cost of the study is not wasted. For it is shown by experience that the study often enables the existing system to be improved, with resulting savings that more than balance the cost of the investigation.

6. Equipment

There may be a large class of tasks which, as was the case with the Ministry of Pensions and National Insurance index problem, do not

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fit condition (3) at all well. For such tasks, machines which could extract records from a file, or merge them in, according to a label, would be most valuable. The machine would be used to extract records for use in a digital computer, and to merge them back when modified. To be worth having, such a machine would have to cost a great deal less than a digital computer. The National Physical Laboratory has been considering the problem of the design of such a machine. A possible alternative to such a machine is a very high speed magnetic tape unit.

7. Acknowledgments

The work in connection with this paper has been carried out as part of the research programme of the National Physical Laboratory, and the paper is published by permission of the Director of the Laboratory.

DISCUSSION ON
"Office Machinery and Information Processing"

Contributions made at Session 1 of the Convention on "Electronics and Automation" in Cambridge on 27th June 1957. In the Chair : Dr. A. D. Booth (Member).

M. W. Gribble: In this session, there has been no mention of a computer for the real-time control of a system of process. Such a machine is being built by Ferranti Ltd. at Wythenshaw and, briefly, it is a plugged programme single address transistor computer, operating in the serial mode. It has special purpose input and output organs, and only a small working store. It receives its data mostly in the form of shaft rotations which are digitized by means of C.P. binary coded discs. The input unit thus consists of a disc selector, translator and serializer.

The output of the computer is used to provide the error to four hydraulically operated servomechanisms. An analogue, current for operating the hydraulic pilot valve, is obtained as follows: The error number is stored in an output register, which is actually an accumulator. According to the sign of the error, unity is either added to, or subtracted from the number in this accumulator until it is zero; and while it is not zero, a current of the correct sign is switched into the pilot valve. By making this current four times that which will produce maximum pressure difference in the pilot valve, four such valves may be operated at once on a time-sharing basis, and the time averaged current in each valve is accurately proportioned to the numerical value of the error.

The arithmetic unit has facilities for addition, subtraction, multiplication, shifting right and doubling, and the multiplier, which uses a speeded-up version of the short-cut method of Dr. A. D. Booth, is followed by automatic round-off.

Only ten words of storage are provided, four of these being the output buffer stores. The programme is stored on the plugboard, subroutines and constants are wired in, and the changing input data is read from the discs, so that the only store required is a small working one. The word length is 10 bits, and the machine will ultimately perform, in an average programme, 12,000 operations per second.

The circuitry is simple; altogether about 12 different types of plug-in package are used, but most of the computer is constructed from only two types of unit, a flip-flop storage element and a single type of logical gate.

The main advantages obtained by using transistors for a control computer are reliability, small size and low-power consumption. This computer contains about 900 transistors, and about twice that number of diodes. It consumes 10 watts of power, and in its final engineered version will occupy about a third of a cubic foot of space. To date, round about a million transistor hours have been run without a single component failure, and although there have been occasional faults, these have invariably been caused by bad connections and dry joints.

B. H. K. Willoughby: I should like to welcome Mr. St. Johnston's statement on the direct feeding of data from measuring instruments into a digital computer or data handling

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system. I feel that there is a distinct danger of this part of data processing systems being overlooked, or its importance underestimated, in this country at least. A great deal of effort is being expended in the U.S.A. on development in this field. This is encouraging, but it has already resulted in a large number of rival and incompatible recording and analysing systems.

The alternative means of obtaining experimental data for processing in digital computers are very extravagant in terms of time and cost. Familiar methods include the manual reading of analogue records, such as chart records and dial camera films, with some form of manual operation to convert the resulting numerical data to punched cord or punched tape. In the case of trials work, for instance, a very large proportion of the total effort required to record and analyse trial results is often concerned merely with the process of writing down or punching numbers previously recorded in some other form.

Miss Pamela Haddy: I have been carrying out some work with Dr. Bell in Birmingham University trying to make comparisons of the cost of carrying out certain tasks with an electronic computer, and of carrying out these tasks by other more conventional methods. Because it is so often considered for the use of electronic computers, we have been examining particularly the topic of payroll computation.

These cost comparisons are extremely difficult to carry out, and from scraps of information which we have gathered from different firms, we have found that the cost per head per week of computing a payroll can vary from about 5s. in one firm to a mere 8d. in another.

This has suggested to us that we are not really being given a clear impression of how much of the payroll computation is actually being accomplished by a machine. Even in some of the best-described computer applications, we are not told precisely at what stage the data is fed into the machine. For example, is the net earning figure being calculated from the gross figure, or is a more complicated set of items, such as basic hourly rate, number of hours worked at a basic rate, plus all the other more difficult items, being calculated? In other words, when we say that a computer is calculating a payroll, this can stand for any of a large variety of tasks actually being carried out.

If the feeding in of information and the printing of answers is so costly, it would seem to be desirable to increase the amount of computing which the machine does, for instance, on a payroll job. A recent attempt to give the machine starting and stopping hours of work of individual men, and leaving the machine to calculate the rest, would seem to be a move in this direction. Yet, General Electric and other American firms have found that it is more worth-while in computing payrolls to omit the complications of special piece-rate items and the like. From this I conclude that, in using computers for payroll work, it is desirable to feed in the information at the earliest possible stage, but to reduce the variety of payroll tasks with which the computer is to be faced.

I am doubtful if payroll work is really suited to computers, but it certainly provides a convenient, if not wholly adequate, way of making a rough decision as to whether the machine is economically justified.

Dr. A. D. Booth: Miss Haddy questions the applicability of "computers" to payroll work. I think that experts would agree that computers, as such, are not suitable and they would be unlikely to recommend them. The confusion lies between "computers" and "data processing machines": the former have limited input/output facilities and often limited long-term storage, the latter are adequately provided with both of these facilities. The data processing machines are of very recent origin and companies have frequently installed a computer in order to carry out pilot experiments. It would not be true to suggest that the technical experts and their superiors were unaware of the limitations of the equipment.

A. St. Johnston (*in reply*): I would like to agree wholeheartedly with Mr. Willoughby about avoiding time in manual conversion of trials data. My company has been associated with the trials analysis system installed in Australia, where a 403/WREDAC is the main computer, using magnetic tape as the main input and output. The Australians have developed a very elegant system where the raw data is available not only for quick look facilities but is also recorded directly electrically on magnetic tape

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for automatic conversion to digital form and thence for use in the computer.

We are also concerned with a 405 for the National Gas Turbine Establishment, where data will be taken into the computer directly using coded discs (1 part in 1024) rather in the manner mentioned by Mr. Gribble. This computer is capable of reading in up to 200 instruments directly in digital form. For this machine we have also developed a digital servo which uses a coded disc as the position measuring instrument of the system. In this instance the servos will drive XY point plotters which have been a special development for this contract. I would also like to add to Mr. Gribble's remarks concerning transistor reliability. We also are completing a small machine as a test vehicle for transistor circuitry and core storage. In this equipment the only transistor failures have been due to misplaced crocodile clips to which, unfortunately, transistors are rather more susceptible than thermonic valves.

For Miss Haddy I would add that we have been running a payroll of more than eight hundred employees on the 405 using magnetic film for over a year, and in this instance the data is punched straight off the clock cards onto paper tape, the machine carrying the job right through to the final payroll data which is handed to the man. I would agree, however, that payroll is not the most stimulating computer application, and in my opinion it is when computers bring greater managerial control that they are going to prove their true worth in business data processing.

E. A. Newman and M. A. Wright (*in reply*): We agree with Miss Haddy that payroll tasks vary greatly in complexity. In an extreme case employees are paid a fixed weekly wage, and the payroll can be worked out for a complete income tax year, changes in employees' tax code number being dealt with by exception. At the other extreme are examples in which any employee's pay depends on facts which change week by week, and which affect pay in a way governed by complicated rules.

We agree with Miss Haddy that the term "doing payroll" is vague, sometimes used to denote only that part of the payroll task involved in calculating net pay from gross, but at other times including the many other tasks involved in finding an employee's pay—such as gathering clock times, measuring work done, for sick pay, calculating rises, allowing for numerous variations and marshalling all such data. Since in some payrolls less than 10 per cent. of all the work is calculation—the rest being the application of rules and so on—the precise meaning given to the task "doing payroll" can greatly affect the estimated cost.

All the above is true whether the task is mechanized or not. When the task is mechanized comparisons of cost are even more difficult, for not only does the degree of mechanization vary widely in so-called fully mechanized systems, but so also does the efficiency of mechanization of the various stages.

We do not think that Miss Haddy is right in thinking in general that payroll is a poor subject for mechanization, or in suggesting that it is desirable to decrease the variety of payroll tasks, where a computer is to be used. We would say that although a very simple payroll is not suitable for mechanization, a complex one is, in general, a very good subject.

The reason that some practice has omitted complicated matters has either been that the complications occur so rarely that it is not worth keeping data about them on the main record, or that people have boggled at the complicated programming needed to cope with them. It is always very difficult to devise a detailed fool-proof system for doing complicated work, whether the system is manual or mechanical, and further, it is a task that no amount of interpretive programming or simple coding can really ease. Thus people are tempted to cope with complications by a manual system that already works.

However, by and large, the more complicated a payroll task is, the more its mechanization is potentially worth while, the exclusion of complicated parts leading to reduced efficiency. We would say that, in general, at the present stage of knowledge, office tasks that differ much in essence from payroll work are fundamentally less suitable subjects for mechanization. It may well be, however, that in practice such tasks are often done very inefficiently. Mechanization could then show a considerable saving, but not necessarily more having than would the introduction of a really efficient manual system.

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EXPERIMENTAL TELEVISION TRANSMISSIONS ON U.H.F.

EARLY in November the B.B.C. began an extensive series of test transmissions to collect propagation data relating to the u.h.f. bands (Bands IV and V) which were allocated to television at the International Radio Conference at Atlantic City, 1947, but are not so far used for this purpose.

Earlier tests employed beamed transmissions of square wave modulation instead of an omnidirectional array and a proper television signal. The information is thus insufficient to determine fully the suitability or otherwise of Bands IV and V for television broadcasting, and at the request of the Television Advisory Committee the B.B.C. decided earlier this year to embark on a more ambitious series of experiments using a high power transmitter and aerial and radiating full television signals, initially on 405 lines and later on 625 lines (C.C.I.R. standards). These tests have been planned by the B.B.C. in co-operation with the T.A.C. and the industry.

The B.B.C. has installed at the Crystal Palace a 10 kW peak-white v.h.f. vision transmitter and a 2½ kW carrier power sound transmitter manufactured by E.M.I. Electronics Ltd., the vision frequency being 654·25 Mc/s. The equipment is low-power modulated on both sound and vision channels and employs Eimac 3K50000LF klystrons in the final stages of both transmitters. These klystrons use three external cavity resonators and operate as linear amplifiers with a power gain of approximately 100. They are driven by a modulated amplifier stage operating with a cathode modulated circuit. The output of the transmitters is combined in a circuit of the filter bridge type constructed in rectangular section waveguide. The combined output is then conveyed to the aerial by an elliptical waveguide having dimensions of 12 in. × 6 in. The waveguide is made of 99·5% aluminium in 12 ft lengths, and expansion joints in the form of corrugated sleeves are provided at all changes of direction. At the top of the television mast the waveguide is transformed into a 5 in. concentric feeder to take power to the four driving points of the helical aerial, the pole supporting the aerial being arranged to form the outer of the concentric feeder.

The helical aerial made of ½ in. diameter copper rod comprises four bays, mounted one above the other on the same vertical axis, each having a linear height of five wavelengths. Each bay is fed at the centre, the helix being wound from the centre point of the bay in opposing directions around the supporting pole to cancel the vertical component of radiation. In the four bays there is a total of 48 turns, each turn being approximately two wavelengths long. The aerial is mounted at the summit of the Crystal Palace tower, the top of the 6½ in. diameter pole supporting the aerial being 707 ft above the ground, while the centre line of the aerial is 691 ft above the ground. The aerial has a power gain of 20 and after allowing for losses in the feeder and waveguide system, the effective radiated power of the vision signal is of the order of 125 kW peak-white in the horizontal plane. Provision is made for de-icing the aerial by electrical heating.

For several hours each day, the transmitter will radiate 405-line pictures which will be the same as those radiated by the Band I transmitter installed in the same building. Later on, the pictures on 625 lines will be produced at Lime Grove from flying spot telecine equipment and sent over a special coaxial cable to the Crystal Palace.

The tests on 405 lines will continue until about March 1958; for tests on 625 lines the programme will usually be different from that being radiated by the Band I transmitter, but at certain times duplicate copies of films scanned on the two systems will be radiated by the two transmitters simultaneously.

The B.B.C., the Radio Industry, the Post Office, the D.S.I.R., and the I.T.A. are organising comprehensive studies of the received pictures using both laboratory and commercially practicable receivers. The B.B.C. hopes to gain information from these tests on the problems which would be encountered were it decided to provide television services in the u.h.f. bands and the effects of a change of U.K. television standards for those bands to conform with those used on the continent. There is of course no intention of making any change in the 405-line standard used for B.B.C. television in Band I.

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. . . Radio Engineering Overseas

A selection of abstracts from European and Commonwealth journals received in the Library of the Institution. All papers are in the language of the country of origin of the journal unless otherwise stated. Members may borrow these journals under the usual conditions. The Institution regrets that translations cannot be supplied.

551.510.535

Solar tidal effects in the F_2-region of ionosphere over Delhi. C. S. RAGHAVENDRA RAO. *Indian Journal of Physics*, **32**, pp. 516-525, October 1957.

Ionospheric data collected at Delhi over the period 1946-55 have been analysed for these effects. The method developed by Martyn and extended by Mitra has been utilized for the purpose. The magnitude and phase of the drift velocities for the different seasons and the relative importance of the drift velocity are determined. While the seasonal velocities have been found to be of the order of 20, 18 and 33 km/hr. for summer, winter and equinox months, the ratio of the seasonal to semi-diurnal velocity has been obtained to be of the order of 1·5. This agrees well with the result obtained by Martyn.

The observed variations in N_m have been explained in terms of the phases of the drift velocities. The values of the attachment coefficient for the three seasons of the year have also been determined taking the tidal effects into consideration. These are found to agree fairly well with the recent results of Ratcliffe and others.

621-52:681.142

Principles of electronic simulation of automatic control systems. C. VAZACE. *Automatica si Electronica (Bucharest)*, **1**, No. 2, pp. 45-55, 1957.

The importance of analogue computers and their superiority over digital computers in solving automatic control problems is stressed. The distinction is pointed out between the two modes of application of the analogue machine: as a computer and as a simulator. A synoptic table presents the principal elements which make up an electronic circuit for analogue computation or for simulation. A series of examples show the use of these elements for the electronic computation or simulation of several linear and non-linear problems.

621.3.011.4

Non-linear capacitances. M. DRAGANESCU. *Automatica si Electronica (Bucharest)*, **1**, No. 2, pp. 61-65, 1957.

Several kinds of non-linear capacitances met in electronic circuitry are described. A general classification of these capacitances is given, making clear such notions as "static capacitance", "non-linear capacitance", "a.c. equivalent capacitance".

621.314.63

On the time-lag of semi-conductor diodes in pulse working, and their physical interpretation. W. HEINLEIN. *Archiv Der Elektrischen Ubertragung*, **11**, pp. 387-396, October 1957.

The common cause of capacitive blocking lag and inductive forward lag is shown to be the storage of charge in the semi-conductor regions outside the barrier (diffusion regions) of the *p-n* junction. The quantity of stored charge is calculated and a measuring method devised for the case of very large diffusion regions. The time-lag of the reverse resistance depends on the quantity of stored charge, and its decay. The stored charge disappears, partly by recombination, partly by returning into the circuit as reverse current. Numerous measurements on germanium crystal diodes with very large diffusion regions, confirm the theoretical concepts. The time-lag of the forward conductance is based on the increase of the conductance of the diffusion regions with increasing charge storage. In the case of very large diffusion regions the inductive forward time-constant equals the effective life-time of the charge carriers which is borne out by measurements on various germanium diodes.

621.315:621.396.5:621.3.029.65.

Cables and radio paths at microwave frequencies. O. ZINKE. *Nachrichtentechnische Zeitschrift*, **10**, pp. 425-430, September 1957.

The paper discusses the possibilities of using "single-wire" transmission lines in the u.h.f. and decimetric wavebands. The attenuation per km and the radial extension of the field around the wire are derived in an explicit form for the following types of single-wire transmission lines: 1. Sommerfeld line (metallic wire), 2. Harms-Goubau line (metallic wire with dielectric coating), 3. Helical line, 4. Helical line with dielectric coating. Specific attenuation values of 0·3 to 0·6 neper/km and field radii of approx. 30 to 100 cm can be achieved with insulated helical lines of 10 to 15 mm diameter or Harms-Goubau lines of 15 to 25 mm diameter in the frequency range of approx. 100 to 1,000 Mc/s ($\lambda = 0{\cdot}3$ to 3m). At frequencies higher than 1,000 Mc/s as well as at frequencies below 100 Mc/s the diameter of single-wire lines has to be chosen considerably larger. Tests with single-wire lines are recommended in this suitable frequency range in order to gain experience as far as the mutual coupling between lines on the same supports is concerned.

621.317.353.1:621.396,5:621.375.376.3

The calculation of distortion factors and noise due to non-linearities in multi-channel f.m. radio links for cases with various types of distortion. H. MARKO. *Nachrichtentechnische Zeitschrift*, **10**, pp. 450-457, September 1957.

The non-linear distortions occurring in multi-channel f.m. radio links are discussed. The requirements for the signal-to-noise ratio in the reference system are first derived on the basis of the C.C.I.F. recommendations. After a general review of the various important types of distortion, the static and dynamic distortion factors for the different types of distortion are calculated for the case of sine-wave modulation.

621.373.431.1

Analysis of cathode-coupled free running multivibrator. D. C. SARKAR. *Indian Journal of Physics*, **32**, pp. 431-439, August 1957.

An analysis of the relaxation period of free running cathode-coupled multivibrator is made, and the method of finding different electrode potentials at different instants is shown. The theoretical values obtained have been compared with the experimental data.

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621.375.133

Wide-band amplifiers with positive feed-back M. Birnbaum. *Automatica si Electronica (Bucharest)*, **1**, No. 2, pp. 66-71, 1957.

Two amplifier circuits with positive feed-back, known in the literature, are analysed. A two-stage amplifier with positive feed-back and cathode output is considered, making a comparison between its optimal possible performance and the performance of a two-stage RC amplifier. A two-stage amplifier with positive feed-back and anode output is also analysed, showing the conditions for optimal performance. The limitations in the use of these amplifying circuits are also considered.

621.375.3

Computing elements of magnetic amplifiers. S. Sapira. *Electrotechnica (Bucharest)*, **5**, pp. 246-251, August 1957.

A graphic-analytical method for calculating magnetic amplifiers is displayed. The magnetizing curves were experimentally traced for several premagnetization regimes. Diagrams for rapid calculation are given.

621.375.326

Simple design of ferromagnetic series resonance circuits. J. Antal and A. König. *Periodica Polytechnica (Budapest)*, **1**, No. 1, pp. 89-100, 1957.

The series resonance circuit with ferromagnetic core is treated. It is shown that such a circuit can be used, not only as a non-linear network with two stable states, but also as a simple a.c. stabilizer. Design procedures are given by the aid of a graphical construction for the unloaded as well as for the loaded cases.

621.376:538.112

The magnetic ring modulator and demodulator. K. Klinkhammer. *Nachrichtentechnische Zeitschrift*, **10**, pp. 436-438, September 1957.

A magnetic ring modulator can be derived from the diode ring modulator by analogy. The magnetic modulator has the advantage of a certain power gain and it can easily be matched to the rest of the circuit by means of a suitable choice of the number of turns. One disadvantage is the frequency response of the equivalent circuit of this ring modulator. Practical results are given.

621.385

A further group of papers read at the International Congress on Hyperfrequency Valves, held in Paris in June 1956 has been published in *L'Onde Electrique*, (Vol. **37**, No. 10. October 1957). The papers include:—

Triode power amplifiers for 4,000 Mc/s. G. Andrieux. pp. 777-780.

The measurement of group delay in triode amplifiers at 4,000 Mc/s. J. P. M. Gieles. pp. 781-788.

Some aspects of build-up characteristics of pulsed magnetrons. J. Baker, R. Dehn, E. Kettlewell. pp. 789-794.

A variable frequency magnetron. J. Lazzeri. pp. 795-803.

A review of the performance of magnetrons operating at low magnetic field. T. M. Goss, R. G. Robertshaw, J. R. Tew, and W. E. Willshaw. pp. 804-813.

An approximate method of calculating the propagation constants in delay lines in the presence of a beam of electrons. L. N. Lochakon and M. F. Stelmakh. pp. 814-818.

Plasma wavelength in low signal travelling-wave tubes. J. Labus and R. Liebscher. pp. 819-823.

Non-linear theory of the travelling-wave tube. L. A. Wainstein. pp. 824-830.

Large-signal travelling-wave amplifiers. E. Rowe. pp. 831-842.

Phase velocity in helical wave-guides. B. Valtersson. pp. 843-849.

A theoretical study of propagation along tape ladder lines. P. N. Butcher. pp. 850-862.

On the coupling impedance of tape structures. P. N. Butcher. pp. 863-877.

Backward-wave oscillators. H. R. Johnson. pp. 878-879.

621.392.4

Methods for frequency synthesis of passive linear two-terminal networks. J. Helsztynski. *Rozprawy Elektrotechniczne, Warsaw*, **3**, No. 3, pp. 299-327, 1957.

More important methods for the frequency synthesis of passive linear two-terminal networks constructed from lumped elements are discussed. The synthesis is carried out on the basis of a given function of impedance or admittance satisfying conditions of physical realizability, i.e. on the basis of a given rational real positive function.

621.396.5

A microwave link system with frequency modulation for 120 telephone channels in the frequency band 1700 to 2300 Mc/s. J. Holzwarth, H. Bosse, G. Colani, and E. Seibt. *Nachrichtentechnische Zeitschrift*, **10**, p.p. 485-493, October 1957.

The telephone channels are carrier-frequency modulated in the base band 6 to 552 kc/s. The C.C.I.F. recommendations for the noise power in a 2500 km reference circuit can be met for all 120 channels. The transmitter output is approx. 5 W and the maximum frequency deviation is approx. ± 700 kc/s.

621.396.677.43

The behaviour of two rhombic aerials placed inside one another. W. Kronjager and K. Vogt. *Nachrichtentechnische Zeitschrift*, **10**, pp. 494-496, October 1957.

Measurement of the coupling factor, the matching and the gain of two rhombic aerials placed inside one another show that the quality of the inner aerial is not affected by the outer.

621.397.611.2:523.841.3

An application of television for the discovery of variable stars. J. Borgman. *Philips Technical Review*, **19**, pp. 140-142, October 1957.

The apparatus consists essentially of a flying-spot scanner arranged so as to scan simultaneously two photographs of the same region of the sky. The signals from two photo-multipliers are subtracted, the difference signal serving as the picture signal for a television display tube. When the two plates are identical the picture signal remains zero, with nothing to be seen on the screen. When the plates differ at a certain point, due to the presence of a variable star, that point appears lighter or darker than its surroundings on the screen. The instrument allows more rapid investigation than is possible by microscopic methods, and offers a much better chance of detecting variable stars. Mention is made of other possible uses of the instrument.

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