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SPACE RESEARCH

THIS *Journal* contains reports on projects which only a few years ago were regarded as science fiction, but are now matters of international importance. Indeed the question discussed may possibly be the key question of the age as determining the scientific future of Britain, the Commonwealth and the European countries.

It is clear that an increasing number of people in science and Parliament are intuitively convinced that a space activity is a worthwhile thing even at the high cost which goes with it, which should not be under-stated or laughed off. The difficulty has been to find cogent commercial arguments. Radio provides one such, the communication satellite.

The Commonwealth should be indebted to Mr. W. A. S. Butement, Chief Scientist of the Australian Supply Ministry, for so strongly emphasizing this aspect while on a recent visit to Britain and for having forcefully expressed the view-point that a country which does not have communication satellites of its own is likely to find itself out of the long distance communication market altogether Surely such a situation cannot be contemplated by Great Britain, who is not only by heritage and tradition a natural leader in communications but is really committed to this position as head of the Commonwealth. Indeed, for this reason and others, it would appear that a British space programme ought to be thought of in terms of a Commonwealth undertaking rather than an insular one. European co-operation must also be considered.

The editorial in the last issue of the *Journal** gave information on how the Department of Scientific and Industrial Research is already committed to a space research programme. In that instance, however, the programme is limited and will not involve a project of the size suggested by Professor Hawthorne in his recent address to the Parliamentary and Scientific Committee.

Present arguments on the comparative costs of using missiles in a space research programme need to be considered against technical and even commercial facts. Such detail might best be sifted by a committee consisting of Government, industrial, and scientific representatives working in consultation perhaps with similar committees in other countries of the Commonwealth. The whole venture will, of course, involve Government support. It could, therefore, well justify the appointment of a permanent British Committee reporting to the Minister for Science.

As is evident from the reports, much apprehension is felt on the score of cost when this is compared with allocations for other scientific purposes. But would it not be appropriate to view these costs rather in comparison with our defence budgets?

The fact that radio is so heavily involved in any space programme prompts the following suggestion. Should not the next Institution Convention be organized under the title "The Significance of Space Research Projects to Radio Engineering".

L. H. B.

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* "Justifying the cost of research," *J. Brit.I.R.E.*, **20**, page 401, June 1960.

COMMUNICATIONS AND A BRITISH SPACE PROJECT

A discussion on Space Research was held by the Parliamentary and Scientific Committee on 12th April, at which the Institution was instrumental in sponsoring a contribution dealing with instrumentation and electronics. The opening contribution was made by **Sir Edward Bullard, F.R.S.,** who said that the discussion would largely centre on the national benefits which might be expected to be gained from a British satellite project.

Sir Edward pointed out that the present British effort consisted of two parts : "Skylark" rockets, suitably instrumented,* were being fired in Australia and had been extremely successful. In the course of the next year it was hoped to fire something of the order of fourteen rockets for scientific purposes. The expenditure on the "Skylark" programme was probably between £100,000 and £150,000. The second part of the present space effort involved collaboration with the Americans, using the "Scout" rocket, which was designed to put up a satellite at small cost. In this instance, Britain was paying for the instruments and the cost of visits to America.

Sir Edward thought these programmes could well continue. They were fairly expensive programmes in relation to the ordinary academic scientific research—of the same order of magnitude as the whole of D.S.I.R.'s grant to universities for everything but nuclear science. He continued : "At the next level we could use 'Blue Streak' to fire our own satellites putting somewhere between 1,000 lb. and a ton into orbit, which is comparable to Russian achievements and more than the Americans have done. 'Blue Streak' happens to be extremely well suited to this purpose. We would have to adapt 'Black Knight', or make a completely new second stage. We are doing a design study of this, the results of which are not yet available. The cost is expected to be of the order of £4 million a year for several years to do the necessary development work and then start a firing programme, which is an expenditure which is large compared to any expenditure we are at present making on academic science. I feel a little doubtful that the purely scientific aspects justify this expenditure. A yet more expensive scheme for European co-operation in an entirely non-military satellite programme has been proposed, with an expenditure of £20 million a year. My firm feeling is that the scientific importance of the results would not justify that.

"Other considerations that have to be taken into account are, first of all, the stimulus which this kind of work gives to various branches of engineering, secondly, civilian projects of practical utility, particularly the communication satellite, which is technically feasible and may well be competitive in cost with other means of communication. The other justification would be military."

Professor W. R. Hawthorne, C.B.E., F.R.S., of the Engineering Laboratories of Cambridge University said he was in favour of spending £100 million to £200 million over the next ten years on launching space satellites and probes because of the benefits it would bring to British engineering and economy. The areas of advance were likely to be in control, communication and power as well as in structures and mechanical engineering and he continued : "In order to control space vehicles new types of controllers may have to be developed. At present we are in the era of the programme control, that is, a control which is designed for a system whose rules of behaviour are known in advance. The conditions in which a space vehicle will have to work are such that it may not be possible during the design of the control to predict the best way of controlling the vehicle. In fact the control may have to work out its best plan of action as it goes along. Adaptive rather than programmed control systems are being studied for space vehicles. When their engineering is understood and developed, their value to industry and particularly to process industries will be enormous.

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* See, for instance, K. Burrows, "A rocket-borne magnetometer," *J. Brit.I.R.E.*, **19**, pp. 769-776, December 1959.

"To send messages over the great distance of space we need to be able to detect weak signals in a background of noise. It is possible to develop transmitters and receivers of much greater precision than hitherto, particularly with respect to frequency control, which will solve this special problem of communication. The engineers who have learned how to do it will be able to design instruments and equipment for radio and for measurement which industry will find invaluable in the next decade.

"The engineering problems of space exploration are themselves important," said Professor Hawthorne. "The newer and more difficult the problem, the more important the skill with which it is formulated and the wider the range of alternatives searched for in its solution. It is in these conditions that the greatest amount of *innovation* occurs. By *innovation* I do not mean just a new idea but a new idea put into practice. The putting into practice is the part from which we learn the most.

"If this country does not support a serious space project there will be two consequences. We shall reduce the number of innovations which we shall develop, innovations which may be of material advantage to our industry as a whole. Secondly, if we blank off a new technology or let it filter slowly through some foreign country, we shall reduce the resources of skill and experience upon which our designers can draw. Even if our future space projects turned out badly and were bare repetitions of American and Russian efforts, we should still ensure that our industry was not left barren of the stimulus and experience of space technology. The difference between a developed and an under-developed country is partly due to the fact that there is a limit to the value of vicarious experience in engineering.

"The education of our young engineers would benefit greatly from a space project. It is important that their early experience in problem solving should be in an environment which fosters innovation. This may explain why out of the 400 engineering graduates who left Cambridge in the last two years (excluding 80 serving officers) over 150 have gone into industries such as electronics, aircraft, advanced mechanical engineering and the chemical industries. Seventy have gone into civil engineering design offices where they come to grips with problems much sooner than in some industries. Only two went into the railways and shipbuilding. I generally advise undergraduates to go where fresh problems are being tackled energetically, for their own good. It would be sad to have to advise some of the more able to go elsewhere if they are interested in the engineering problems for which space projects provide the most fruitful field of endeavour today."

The military possibilities of space projects were discussed by **Sir Robert Cockburn** of the Ministry of Aviation, who said that a wide range of possible applications had been discussed in the American and British press. These included the use of satellites as navigational beacons, for surveying, for interception, reconnaissance and communication.

Discussing the first of these, he said that a satellite well above the earth's atmosphere—several hundred miles up—would maintain an almost invariant orbit for many years. By radiating a stable high frequency transmission it could provide a world-wide all-weather navigation system with an accuracy of the order of one mile or better. Such a system could provide an international standard available to all nations.

Sir Robert pointed out that a satellite orbiting a few hundred miles above the earth could permit optical surveillance of the entire world. Apart from the obvious military uses of such a reconnaissance satellite, meteorological surveillance of cloud cover could improve long term weather forecasting.

The final contribution was by **Dr. Denis Taylor, M.Sc.** (Member) who said that a satellite constituted effectively a small but elaborately equipped laboratory for the measurement of a great many physical parameters, and a telemetering equipment for the transmission of the measured data back to the earth.

"As satellites are relatively small and the number of measurements required relatively large, a great deal of micro-miniaturization of electronic equipment is necessarily involved. The development of these techniques could prove of considerable value in the field of military electronics, particularly since it requires the highest possible reliability with the equipment subject to extreme environmental conditions. Concentrated research on these topics, as would be required in support of a British space research programme, would naturally produce new techniques capable of being exploited in other fields. Undoubtedly some civil applications would result, but it is fairly definite that the majority of applications would result in the military fields, for example radar, communications, navigational equipment for aircraft, etc.

"Space Research involving the setting up of artificial satellites around the earth is likely to play an important part in future round-the-world telephone, radio and television communication. Already the Americans have put experimental communication satellites into orbit, but it is doubtful if their results will be made available to Britain. Hence, if Britain is to remain a key power in the long-distance communications business, it can be argued that we should be considering this new possibility. Basically the system proposed is that the satellite should carry radio repeaters to act as relay transmitters of the ultra-short wave radio signals. Such communication systems would not be subject to the limitations of the currently employed short-wave radio circuits and would be capable of transmitting greater amounts of information."

Dr. Taylor considered that satellite communication systems would be employed for point-to-point radio relaying for military and civilian purposes, and might ultimately be used to provide a world-wide radio and television service as well. Assuming the availability of a suitable launching device it could be shown that the cost of a satellite relay system was competitive with other means of relaying wide-band information. He concluded: "For this reason it is attracting a great deal of interest in America. It is recommended that we in Britain should be similarly interested."

In the informal discussion which followed, the general consensus of opinion was that the improvement which could be achieved in communications was a worthwhile reason for embarking on a British space project. A plea was made for the association of the Commonwealth countries in the project: both their financial support and their contributions in knowledge, personnel and facilities to the scientific effort necessary in space research would be of immense value.

An address on a similar theme was given to the Commonwealth Press Union on 13th June by **Mr. J. R. Brinkley** (Member) who said that engineers were now on the threshold of the third great phase in long distance communication. The first phase was the development of the summarine telegraph cables, which took place at the end of the nineteenth century—some eighty years ago. The second great phase was the development of the short-wave beam system, which took place in the 1920's. This new development made possible many new circuits and opened up the possibility of telegraph and telephone circuits to the many countries to which one cannot, for reasons of geography, lay submarine cables. The immense expansion of world trade and of air transport had now stimulated the demand for communications beyond the capabilities of the present two media and only a third great phase of expansion similar to the first two could produce the kind of answer that is needed.

In the present known state of the telecommunications art, Mr. Brinkley saw only two solutions: the laying of modern high quality submarine cables; and the development of communication via space.

There were now thirty-four high-grade circuits available twenty-four hours per day between Britain and North America and these were the forerunner of many more transatlantic cables taking many more circuits and providing much cheaper circuits. In ten years he believed there would be hundreds and in twenty years' time, thousands.

Mr. Brinkley continued: "But submarine cable will not solve all the problems: the production and laying of tens of thousands of miles of such cable is a major undertaking, costing great sums of money and taking up much time. Moreover, many of the territories to be reached are inland, with no modern trunk routes connecting them to the sea. The only other medium which offers itself is communication via space and there are three possibilities:

communication via the moon;
communication via a passive satellite;
communication via an active satellite."

Using the Jodrell Bank telescope with some quite modest, though specially designed equipment, signals returning from the moon had improved in the short span of eighteen months from an unintelligible noise to quite good intelligibility. During this period, the first attempts to analyse the bandwidth and circuit capacity of the moon as a communication circuit had been made with a good deal of success and he was in no doubt that practical circuits via the moon were feasible now and would, in the space of a few years, become economic.

Quite recently the U.S. Navy had established a permanent moon circuit between Maryland and Hawaii carrying four simultaneous teleprinter channels and also capable of excellent picture transmission. The circuits were reported to be of a high degree of reliability: they were open for some six hours per day, and were free from fading and impervious to magnetic storms and sunspots.

Moon circuits had two disadvantages. The first was present high cost but this would fall rapidly in the future. The second was that the times during which the circuits were open and closed each day varied cyclicly round the clock throughout the lunar month. The cyclic time variation was a drawback, but did not offset the fact that the circuit availability was completely predictable, the fading slight and the frequency possibilities vast: capacity for a million teleprinter circuits could, if need be, be provided.

Even greater dividends could be expected from transmissions via passive and active satellites. In this case the future held the prospect of hundreds of high grade telephone circuits and television circuits over world-wide routes twenty-four hours per day. Electronic development was not the controlling factor, with the passive balloon reflector which required electronics on the ground only. A study carried out by Mr. Brinkley's company had shown that an active relay equipment to be carried in a space vehicle was currently practicable and one design proposed required only a single valve, would be powered from solar cells, and have a life of one to two years. The equipment would weigh about 100 lb. and could easily be launched by a missile such as the "Blue Streak".

Such satellites would bring undreamed of improvements in world-wide communication and the electronic techniques were known in Britain now. But if Britain was to play its traditional part in the third phase of telecommunications expansion as it had in the first two phases—it was necessary that we learn the art of satellite launching, for the establishment and control of the space circuits would be in the hands of those countries competent in this art. Mr. Brinkley hoped that the Press would use its authority to ensure that the Commonwealth took a leading rôle in space communications.

POSTSCRIPT

The contents of this month's editorial and the article "Communications and a British Space Project" were referred to at a meeting of the General Council of the Institution held on 13th July. Council unanimously resolved that a 1961 Convention Committee should be set up at once, comprising representatives of all Standing Committees including the Specialized Group Committees.

The main terms of reference of the Committee will be to make recommendations to the Council regarding the holding of a residential Convention during the summer of next year at a British University and to draw up a detailed programme on the general theme of "Communications and Space Research."

INSTITUTION NOTICES

Obituary

Air Marshal Sir Raymund George Hart, K.B.E., C.B., M.C. (Member) died on July 16th at the age of 61 years.

Sir Raymund, who joined the Royal Flying Corps in 1918 and was decorated for gallantry during the First World War, had a distinguished service career of over 40 years; he was in fact the last R.F.C. pilot on the active list. He took a leading part in the application of radar for ground and airborne use in the R.A.F. and subsequently held important staff appointments at the Air Ministry; immediately prior to his retirement he was Controller of Engineering and Equipment. In 1958 he was appointed Director of the Radio Industry Council. A biography giving a fuller account of his career was published in the October 1959 *Journal*.

Members will recall that Sir Raymund took part in the inaugural meeting of the Institution's Radar and Navigational Aids Group last October, when he gave an address entitled "A Historical Survey of Radio and Radar Aids to Aircraft Navigation" (published in last month's *Journal*). An address he gave at the 1954 Convention discussed some of the other applications of electronics in the R.A.F. Air Marshal Hart was an active supporter of the Institution's work, particularly in aspects affecting members in the R.A.F. He was elected a Member of the Institution in 1957.

His death was caused by a shock received whilst adjusting an electric lawn mower at his home. The General Secretary represented the President and Officers of the Institution at the funeral at Aston Rowant on 20th July.

Leslie Charles Munn (Associate Member), who died in January aged 41, had been with the British Broadcasting Corporation for over 20 years. He commenced his professional career as a youth-in-training with the engineering department of the General Post Office, and subsequently held appointments with the Western Electric Company and the British Thomson Houston Company. During the war he served in the R.A.F. with the rank of Squadron Leader, and he returned to the B.B.C. in 1946 as a senior research engineer. Mr. Munn was elected an Associate Member in 1952.

William Edward Corlett (Graduate) died on 6th May as a result of a motor accident. Born in Pietermaritzburg, South Africa, in 1926, Mr. Corlett was educated in Durban and was a ground station radio operator in East Africa from 1944 to 1946. He then joined British Overseas Airways Corporation as a radio officer, subsequently becoming Navigation Officer with the Britannia and Comet Fleets. He was elected a Graduate of the Institution in September 1953 following success in the Examination. Mr. Corlett's wife also died at the same time, and they are survived by their son aged eight years.

"Aviation Electronics and its Industrial Applications"

On 7th October next the South Western Section of the Institution is organizing a Convention at the Bristol College of Science and Technology, having the above theme. The Convention is planned to explore the application of developments in electronics made by and for the aircraft industry which could be of benefit to other industries. A small exhibition will be held in conjunction with the Convention.

There is still opportunity for members able to contribute to this Convention to offer papers, and further details may be obtained from Mr. W. C. Henshaw, Hon. Secretary, South Western Section, c/o The School of Management Studies, Unity Street, Bristol, 1.

Symposium on New Components

The Programme and Papers Committee is arranging a two-day Symposium on New Components, to be held in London on 26th and 27th October. A series of short papers discussing new component development will be presented, as well as a group of papers dealing with reliability aspects. Planning is nearly completed but the Committee can still consider offers of papers. Further details will be announced shortly.

Correction

In the editorial to the June *Journal* (page 401) the fourth sentence of the final paragraph *should read*: In Great Britain there is now an expenditure of over **£300 million** a year. . . .

The Work of the British Standards Institution in relation to the Radio and Electronics Industry †

by

H. A. R. BINNEY, C.B., B.SC.(ENG.) ‡

A paper read before a meeting of the Institution in London on 7th April 1960.

In the Chair: Mr. G. A. Marriott (Immediate Past President).

Summary: In the newer technologies such as electronics and telecommunications much is being done, through standards techniques, to establish good order in engineering practice. The application of standards is described at the three levels: national, international and in the individual company. The growing importance of working to international specifications is fostered by the International Electrotechnical Commission and other international organizations and the way in which these bodies function is dealt with briefly. The interplay of national and international requirements is discussed in some current standards projects covering: terminology, dimensional interchangeability, safety, methods of test, specifications for components and radio-interference suppression. The paper concludes with a general review of the international standards scene.

1. Introduction

The radio and electronics industry produces an immense assortment of products—equipments, instruments, components—ranging from hearing aids and pocket-size radio receivers and the miniature components inside them, up to control systems for industrial plants, radio transmitters, guided missiles and so on. For such an industry, expanding rapidly both in scope of activities and in technical development, a programme of standards might appear to the uninitiated to be somewhat premature. That, of course, would be an entirely mistaken view.

It is broadly true to say that standards were late in being applied in Western industrialization, much too late to avoid some very costly differences of practice. We began with craft standards, the Craft Guilds of the Middle Ages had their standards: then later, as the Industrial Revolution progressed, standards developed in some branches of industry. But it was not until this century that industrial standards of broad national application emerged and there were not many of these until after the first World War. In the meantime, differing habits and practices had become set and so much more difficult to unify. While this is true of national standards, it applies even more to international standards. Fortunately, the newer technologies, like electronics, have learned a lesson from this and it is heartening to note the great volume of work towards good order by established standards in the field of electronics, and not least in the international sphere through the work of the International Electrotechnical Commission.

2. National, International and Company Standards

There are three distinct levels of standards, the national, the international and the company standard, and each has its place in our industrial life. The national standard, the British Standard, is the basis from which we have to commence. It should aim to provide a sufficient but not excessive range of commodities to meet the general need with a quality and performance to satisfy those general requirements. It should

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† Manuscript received 16th March 1960. (Paper No. 564.)

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visualize the need for revision to take account of progress and to meet changing requirements. In drawing up such a standard, attention has to be paid to the popular usage at home, but weeding out should be done to eradicate unnecessary diversity, and there must be a readiness to modify practices so that the standard may be acceptable overseas. It is perhaps a hard truth that a standard which treads on nobody's toes is usually scarcely worth printing. There is thus a need for willingness by industry to adjust in the general national interest in order that the national standard may be the best possible and that it should not be so delayed in preparation that this country forfeits an initiative.

More will be said later on the developing role of international standards but the work in the field of international standards is increasing at a very great pace. This development is very much a product of the past decade only so that it tends to be catching up on some people unawares. Whether we like it or not, much of the international trade of the future will be based upon the international standards now being developed at a greatly increasing rate. Industry has therefore to pay very close attention to those international standards which affect their business both as regards imports and exports.

At the third level of the company standard, it seems an obvious home truth to say that every individual firm should have a vigorous standards policy within its own organization. There is now a growing tendency to set up more formal machinery than hitherto within a manufacturing unit or group of units to deal with this matter, i.e. by the establishment of a standards department. This, in turn, has led to the training and appointment of "standards engineers" and the B.S.I., with its responsibilities under its Royal Charter for encouraging the adoption of standardization and simplification practices, has become more active in recent years in aiding the work in the application of standards. The activities which the B.S.I. has sponsored in this connection have included the organization of periodic conferences of Standards Engineers, in conjunction with the Institution of Production Engineers, the support of corresponding work by the British Productivity Council and, for example, the publication recently of a booklet (P.D. 3542) "The Operation of a Company Standards Department."

The form which any standards department in a company should take will, of course, be largely dependent upon the type of manufacturing organization concerned but its objective is to provide for economy and simplification of effort at all levels. Simplification for designers—by specifying standard parts and fittings the time of designers, draughtsmen and other creative personnel can be husbanded for more original and effective work. Simplification of production—by concentrating the main production on the ranges and types which are most in demand, we lower unit costs. Simplification of stocks—by this we not only reduce costs but enable deliveries to be made more quickly and replacement parts to be secured more easily. Simplification of ordering—by providing standard specifications of performance, construction and methods of test for materials, parts and equipment, we provide reference data which save an enormous amount of time. These and other related things lead to greater simplification in administration generally, to simplification of correspondence and quotation, and to a variety of similar benefits which can accrue to management itself by relegating to the field of routine those problems which can be signposted and settled for routine treatment in day-to-day administration.

The French call time and motion study "rationalization" of work. Standardization is in some ways the rationalization of products and procedures and is no less important.

The fact that one firm's end product is another firm's raw material emphasizes the need for joint discussions between all parties concerned when drawing up standards. If every "user" were to consult every "supplier," however, in connection with every company standard, the situation would be utterly uneconomic. If, on the other hand, accredited representatives of the various interests concerned consult together with a view to drawing up a standard which will embrace the requirements for a large section of industry, considerable economic benefits immediately accrue to all who need to work to standards, either as suppliers or users.

3. Co-operation between B.S.I. and Radio Industry Organizations

This is where the B.S.I. has its role, one which is well understood in your industry. As far as trade associations are concerned, I know there is full awareness of the value of co-operation between the Electronic Engineering Association, the British Radio Equipment Manufacturers' Association, the British Radio Valve Manufacturers' Association and the Radio and Electronic Component Manufacturers' Federation. This co-operation takes place in various ways: by the setting-up of joint Committees, by discussions in committees formed jointly by Industry and the British Government Departments concerned with the Armed Services, and by full participation in the work of the B.S.I.

The draft standards prepared by the B.S.I. Committees dealing with "electronics" and "telecommunications" are widely circulated throughout the industry, and there can be few radio engineers who have not had some contact with these documents at one stage or another of their preparation.

The position of the electronics industry is high in the list of United Kingdom exporting industries and this has to a large extent been made possible by the existence of international agreements on standards. Many of these standards, e.g. frequency bands, signal characteristics and other standards affecting international telecommunications, are laid down by Government-sponsored organizations such as the International Telecommunications Union and its Consultative Committees (the C.C.I.R. and C.C.I.T.T.) and by the European Broadcasting Union. In the main, however, these bodies deal with standards which are the concern of public administrations, leaving a vast field of standards for use in the private sector of international trade to be dealt with by other bodies. Participation in the activities of these other bodies is a very important part of the work of the B.S.I. In the older sections of the electrical industry there have been British Standards for many years, and in many cases it is only recently that corresponding international standards have "caught up." For instance, the B.S.I. specification for electricity meters, B.S. 37, first published in 1907, has since then been revised many times but the corresponding specification issued by the International Electrotechnical Commission (I.E.C.) was first issued in 1931. In the electronics field, on the other hand, the preparation of British Standards and of corresponding international standards by the I.E.C. have to a large extent progressed together and the somewhat slow rate of publication of British Standards in this field can be accounted for by the fact that the man-power available in industry for this sort of work has at the same time been engaged in the consideration of the draft I.E.C. specifications. Furthermore, international agreement takes longer to secure than national agreement and, if the British Standards are to take account of the international recommendations, the work tends to proceed at the rate set by the international activity. At the present time this activity is considerable.

4. Standards and Trade

In the electronics field, as in others, much of the international trade of the future will be based technically on these internationally agreed standards. The B.S.I. Committees dealing with these standards pay very close attention to the I.E.C. work and they are in full agreement with the views of the B.S.I. Export Panel, composed of top-level persons in our industrial and commercial life, who a year or two ago issued a memorandum of which the following is an extract:

> "... the Export Panel think it essential that this country should participate actively and with the best possible representation in the Committees of I.S.O. [that is, the International Standards Organization] and I.E.C. Unless we do so we cannot expect the internationally agreed recommendations to take proper account of the views of British Industry and British exporters.
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> "The Panel has asked B.S.I. officials to ensure that the machinery, through B.S.I. Committees, for consideration of international standard problems, for reaching agreement on the U.K. viewpoint and for briefing the delegates to international meetings is adequate and effective. While the B.S.I can help in this way with the organization, it is for industry to provide the drive and authority to establish forward-looking policies and to carry them through."

Then again the Export Panel have also said:

> "Difficult issues will arise in deciding if, or how far, we should modify accepted British

practice and techniques in order to secure, or to fall into line with, an internationally agreed specification, or again in order to follow the specifications of important overseas markets. Clearly, this must depend on the merits of the individual case. The Export Panel think, however, that there are probably many more instances than is realized where we should be prepared to bring our standards substantially into line with internationally agreed specifications, or with practices widely accepted overseas. For many branches of industry the Panel believe that we shall improve our competitive position in international markets for price, quality and service if we do this, and if we are careful to ensure that the British specification is not more elaborate or rigorous than sound techniques require."

5. International Standards

In the radio and electronics field, the most important of the bodies dealing with international standards (or rather, international recommendations on which national standards may be based) is the International Electrotechnical Commission, which has already been mentioned. This is a world-wide organization, founded in 1904, the headquarters being in Geneva. It has National Committees in 33 countries (including the U.S.S.R. and the People's Republic of China); the British National Committee operates under the aegis of the B.S.I. Of the 50-odd Technical Committees of the I.E.C., about a dozen deal exclusively with radio, electronics and allied subjects. Under the Technical Committees there are numerous sub-committees and Working Groups, about eight of which are scheduled to meet in New Delhi next November. The work of all these "electronics" committees is under the supervision of an Advisory Committee on Electronics and Telecommunications, which reports to the Committee of Action, a body which is in effect the main policy forum of the I.E.C.

Another international body interesting itself in electronic apparatus of the types used by the general public (e.g. radio and television receivers, tape recorders, radiograms) is the International Commission on Rules for the Approval of Electrical Equipment (happily abbreviated to the C.E.E.). This body draws its members from European countries only, these members being the organizations responsible in the various countries for testing electrical apparatus for approval purposes, approval being based primarily on safety considerations. The C.E.E. works in very close liaison with the I.E.C. and this collaboration goes to the extent that in some cases the rules are issued as a joint I.E.C./C.E.E. publication, e.g. safety rules for radio and television receivers and similar apparatus.

Although not dealing specifically with electrical or electronic subjects, reference must be made to the International Organization for Standardization (I.S.O.); its membership is world-wide, and the headquarters are in the same building which houses the Central Office of the I.E.C. in Geneva. The I.E.C. is nominally the Electrical Division of I.S.O. but for all practical purposes it is entirely autonomous. The I.S.O. deals with many subjects of general interest to most branches of industry, ranging from screw threads to drawing office practice, from boilers to nuclear energy and so on; and British industry participates in this very big and growing work through the B.S.I.

6. Standards in Radio and Electronics

Having now outlined the machinery available for drawing up national and international standards, I will draw attention to a few projects as examples of a wide field of activity. This activity is directed mainly by the Telecommunication Industry Standards Committee of the B.S.I., which was set up in 1952 when the "electronics" group of committees was hived off from the Electrical Industry Standards Committee. This step was taken because of the rapid growth of the electronics industry, and was influenced by the fact that this section of industry had its own well-organized structure of trade associations under the Radio Industry Council. It was, of course, realized that there is no hard and fast line of demarcation between the electrical and electronics industries and in some cases an arbitrary decision had to be taken as to whether a particular committee should remain under the Electrical Industry Standards Committee or should go over to the Telecommunication Industry Standards Committee. For example, it might be thought that the subject of radio interference (or rather its suppression) obviously qualified the committee dealing with it for membership of the electronics group of committees. It was decided, however, that, as the interference was caused by the products of the electrical industry (to the annoyance of users of products of the electronics industry), it would be desirable to leave the committee in the Electrical group, thereby emphasizing to the electrical industry its responsibility in the matter. Mercury-arc rectifiers provide another example. These devices are undoubtedly electronic in nature but they are made and used by the electrical industry and the mercury-arc rectifier committee has remained under the wing of the Electrical Industry Standards Committee. If there is any doubt or argument about allocation of a particular subject to either the Electrical or the Telecommunication groups, the matter is referred to a special Steering Committee for decision.

Under the Telecommunication Industry Standards Committee there are 13 Technical Committees, which, between them, have at present about 50 sub-committees and panels.

6.1. *Terminology and Symbols*

One of the first subjects which most committees have to consider is that of terminology and symbols and the first Technical Committee set up under the aegis of the Telecommunication Committee was that on "Nomenclature and Symbols." This committee has over the past few years been very active in connection with the revision of B.S. 204, Glossary of Terms used in Telecommunications, and this work has now been completed. It was unfortunately seriously delayed at one stage due to the death of Mr. L. H. Bainbridge-Bell, who I am sure was well-known to many members of the Brit.I.R.E. and who, at the time of his death, was secretary to the committee, or rather series of sub-committees and panels engaged on the revision. This was not, however, the only reason why the work has taken so long. Every endeavour has been made to keep the new glossary in line with the corresponding glossary currently in preparation by the I.E.C. as part of the second edition of the International Electrotechnical Vocabulary and the I.E.C. has, in its turn, endeavoured to keep in step with the corresponding work of the Consultative Committees of the International Telecommunications Union. This three-way co-ordination has been a somewhat slow process but would no doubt have been less effective were it not for the fact that the B.S.I. Committee working on the revision of B.S. 204 has been responsible for the secretariat work in connection with the corresponding I.E.C. glossary. In all this work we have received a tremendous amount of help from representatives of the Post Office and I am glad of this opportunity to express our thanks.

The B.S.I. publication on graphical symbols for telecommunications, B.S. 530, is also under revision. Here again, the latest international recommendations are being carefully studied and at the same time an endeavour is being made to co-ordinate the telecommunications and electronics symbols with those used in general electrical engineering, the latter being at present given in B.S. 108. It is proposed to combine the two standards into a single volume and the work—a long-term project—is being done by a committee set up jointly by the Electrical and the Telecommunication Industry Standards Committees.

6.2. *Dimensional Standards*

Dimensional standardization perhaps finds its most important example in the field of valve bases and holders. The Committee dealing with this subject has devoted a great amount of study to the problems of gauging and of the precise conversion of inch dimensions into millimetres and vice versa. In both these problems we have had considerable assistance from the National Physical Laboratory. The main object of the exercise is, of course, to ensure compatibility between the valve base and the corresponding holder and the work is done in close relationship with that of the I.E.C. on the same subject. Other examples of dimensional standardization at present under consideration relate to transistors, printed wiring, r.f. cables and waveguides.

One of the main difficulties often met with when discussing dimensional standardization internationally is that of lining up a series of sizes in inches with a corresponding series of sizes in metric units. If the series of sizes in, say, millimetres is drawn up on the basis of "preferred numbers," the sizes when converted into inches involve odd fractions which may not be acceptable to British industry. This is a problem which is receiving a good deal of attention by the I.S.O. but in the electronics field the problem has not yet arisen to any great extent, since it has been accepted that the basic dimensions shall be those of the country in which the particular article, e.g. a valve base or r.f. cable, originated, the corresponding dimensions in the other system of units being derived by precise conversion.

6.3. *Safety*

Safety requirements have received considerable attention, both nationally and internationally. Safety rules for radio and television receivers and like equipment have been issued as a joint I.E.C./C.E.E. publication and the corresponding B.S.I. publication, B.S. 415, was revised a year or two ago and is substantially in agreement with the international document.

6.4. *Test Methods*

While the safety requirements for radio and television transmitters and receivers have been under consideration so also are the methods of test for their performance. The standardization of testing techniques has always been an important part of the function of the B.S.I., since agreement on these techniques is usually necessary before attempting to prescribe the criteria to define quality or performance. An essential element in the standardization of electronic components such as capacitors and resistors is therefore the basic testing procedure for determining the climatic and durability characteristics of the components. This testing procedure is given in B.S. 2011 and the tests are graded so as to enable suitable functional characteristics to be prescribed (in separate specifications) for components for the widest possible range of applications, for use in domestic radio and television receivers at one end of the range, up to high-grade professional equipment and equipment for use by the Services. For the latter applications in particular, a very high degree of robustness and reliability under widely different climatic conditions is necessary; hence the importance attached to the basic testing techniques. The Services are represented on the B.S.I. Committee dealing with these basic techniques and this same committee provides technical advice to the B.S.I. which acts as Secretariat for the corresponding I.E.C. Committee. Both Industry and the Services are therefore very closely in touch with the international work in this field and it is to be expected that B.S. 2011 and I.E.C. Publication 68, both of which are currently under revision, will be kept closely in line with each other.

Before leaving the subject of methods of test, I would mention that attention is now being focussed to an increasing extent on methods for measuring the electrical characteristics of radio valves and transistors. Whether the characteristics themselves can ever be standardized is an open question; the development of new applications of electronics brings in its train the development of valves and transistors having special characteristics. In theory this development could run wild and it is to keep a check on this that the Services maintain their list of preferred types of valves, outside which designers of Services' equipment should not go unless absolutely necessary. This rein on the use of valves is, of course, put on in the interests of ease of maintenance rather than to stop the legitimate development of new types of valve. Guidance on the use of valves is given in a British Standard Code of Practice and a corresponding Code on the use of semi-conductor devices is under consideration.

6.5. *Components*

The standards for electronic components, some of which have been published but most of which are still to be completed, are in two parts. Part I prescribes limits for the performance characteristics, the test for checking the limits being made in accordance with B.S. 2011, while Part II lists the preferred sizes and ratings. It is here, in Part II, that "simplification" comes into the picture. The listed sizes and ratings will be fairly numerous—too much so, some may say—but in a field which embraces components for such a wide range of applications it might well be that the "preferred" items would be ignored if the list were unduly restrictive. In practice, simplification is carried a stage further in the Company Standards of the manufacturing firms which are "users" in this context. At the same time, the preferred lists in the British Standards do help to limit the number of sizes and ratings that the component manufacturers are called upon to supply.

6.6. *Radio-interference Suppression*

British Standards were published some years ago for the limits of interference (B.S. 800), for the equipment for the measurement of interference (B.S. 727), and for components for use in suppression devices (B.S. 613). There are also British Standard Codes of Practice dealing with the general principles of suppression and with the particular problems of suppression of the interference caused by motor vehicles, electro-medical and industrial h.f. equipment and equipment on board ship. All this work is done in close collaboration with the Committee on Radio Interference of the I.E.E., which latter committee acts in an advisory capacity to the Government on interference matters. The B.S.I. has the somewhat heavy task of acting as Secretariat for the Special International Committee on Radio Interference (C.I.S.P.R.), a body composed of representatives of the I.E.C., the European Broadcasting Union and about half a dozen international organizations interested in the problem of interference, either as producers of the interference or as producers of signals or programmes exposed to interference. The C.I.S P.R. maintains liaison with the C.C.I.R. but the latter body, being of governmental status, prefers not to take up formal membership of C.I.S.P.R.

Apart from the reports of its Plenary Meetings, held about every three years, the C.I.S.P.R. has not yet published any official documents but it will shortly publish two specifications for equipment for the measurement of interference, in the frequency ranges 0·15—30 Mc/s and 25—300 Mc/s respectively. This brings to fruition the results of many years of investigation and comparative tests on measuring equipment made in different laboratories in many countries.

International agreement on permissible limits of interference is difficult to achieve, on account of the wide differences in geography (affecting signal strength) and population distribution, but a number of Working Groups of the C.I.S.P.R. are pressing ahead with this work and these will report to the next Plenary Session of the C.I.S.P.R. which is scheduled to meet in the U.S.A. in 1961.

7. Standards Overseas

All over the world to-day the techniques of standardization and simplification are being increasingly applied. We see, for example, how the U.S.S.R. has developed a very strong standards regime; it has many thousands of national standards which are very expertly prepared, very speedily drawn up and which are brought speedily into the design and production machinery right across the fabric of industry with a backing of economic and statistical analysis as regards, for example, timing and extent.

On the Continent of Europe we are seeing at this moment the development of the economic integration of over 160 million well-trained, intelligent people and work is proceeding among the "Six" countries for the greater harmonization of standards.

I have travelled to a number of those countries which are less developed industrially. These countries are remarkably "standards-minded." The international standard developed through the I.S.O. and I.E.C. has a great attraction for them. They want widely accepted standards as a means towards easier sales for their export products and as the basis of economic purchasing of capital and other goods they import. A comprehensive library of international standards would release them from the problem of choosing between other nations' standards (whether American, German, British or other). This is, in any case, a natural reaction of national pride; an international standard belongs to all the nations.

8. Conclusions

Standards work presents a very real challenge and opportunity for this country, depending as we do on international trade. It is appropriate that so much of this paper has dealt with the international side of standards work that has special relation to the radio and electronics industry—an industry which is so bound up with international trade and international communications.

# of current interest . . .

Amalgamation of the Institute of Physics and the Physical Society

The incorporation of a new body on 17th May, under the name of "The Institute of Physics and The Physical Society" marks the fulfilment of the desire expressed by the overwhelming majority of the members of the Institute and of the Society that the "necessary action" should be taken to implement the scheme for amalgamation prepared by a Joint Committee. The originating bodies will shortly be formally wound up and their assets handed over to the new one. The first President of the amalgamated body is Sir John Cockcroft, F.R.S.

The Physical Society of London as it was then called was founded in 1874 and, on the initiative of that Society's Council, The Institute of Physics was founded 45 years later. The original scheme envisaged a kind of federation of societies interested in physics, to provide among other objects, rooms for meetings, a library, and a common secretariat. In fact the Institute's offices were in the Society's present rooms in South Kensington from 1927 to 1949 and the Institute provided the secretariat for The Physical Society and The Optical Society which themselves amalgamated in 1931.

Broadly speaking before the war the scientific meetings and publications of the Institute were confined to applied physics while those of the Society were concerned more with pure physics. As, however, the boundary between these two aspects became less definite, there has been increasing overlap in the activities of the new two bodies and in their membership.

The qualification for the award of Fellow of The Institute of Physics, Associate of the Institute of Physics, and Graduate of The Institute of Physics will remain unchanged.

Southern Television Grant for Electronics

Further grants by a television programme Company to aid the arts and sciences have recently been announced. Southern Television Limited is presenting a sum of £1,250 to Southampton University which will be used to found a research studentship in the Department of Electronics. A similar sum will be used for the endowment funds of the new University College in Brighton.

Growth of Dip.-Tech. Courses

The National Council for Technological Awards in its annual report has announced the current figures for students studying for the Diploma in Technology. Twenty-three colleges now conduct a total of 95 recognized courses leading to the award. Almost 4,000 students have been enrolled on these courses, of which 1.558 are enrolled in the first year. The great majority of the students are studying by the sandwich course method. To date 163 Diplomas in Technology have been awarded.

Aeronautical Communications in the Caribbean

An extensive multi-channel v.h.f. scheme for inter-island aeronautical telecommunications has recently been inaugurated in the West Indies. It provides modern automatic telephone and teleprinter services for airline companies operating in the Eastern Caribbean area, giving continuous contact between any airport, airline office and aircraft, irrespective of weather conditions.

Twelve separate and simultaneous voice channels have been provided, along with 12 to 18 teleprinter channels. The main route runs from Trinidad via Grenada, St. Vincent, St. Lucia, Dominica, Antigua and St. Kitts and by a link, through All-American Cable and Radio Company to St. Croix, Puerto Rica, and on by coaxial cable to North America. There are spur circuits from Grenada to St. Vincent, from St. Lucia to Barbados and Martinique, and from Antigua to Guadaloupe. Facilities provided by the system include automatic dialling to any position on the network, air-ground circuits, and automatic routing and selection of all telegraph messages.

All radio units in the system are duplicated and provision made for automatic change-over of any unit should performance fall below a pre-determined level. Indication of such change-over is immediately relayed back to Trinidad where engineers are able to check every unit in the system and change over to stand-by equipment if required.

The system which cost £500,000 was engineered in conjunction with International Aeradio Limited by Pye Telecommunications Limited and Ericsson Telephones Limited.

NEW B.B.C. TELEVISION CENTRE

The B.B.C.'s new Television Centre at Shepherds Bush in West London was officially opened on 29th June. It has been specifically designed for the special requirements of television, and the studios are the first the B.B.C. has had which have been designed and built expressly for this purpose; it is believed to be the largest television centre in Europe.

A circular Main Block houses the technical areas and the equipment directly associated with the production of television programmes, the transmission of films and telerecording. Here too are the facilities for artists, and also the administrative offices. Grouped round this circular building are seven studios, with floor areas ranging from 3,500 sq. ft to 10,800 sq. ft; this arrangement well meets the technical requirements and provides easy access from the centre for staff and artists. Around the outside of the studios (the studio floors are at ground level) runs a covered carriage-way for the transport of scenery to and from the outer ends of the studios; the scenery is built and stored in a separate Scenery Block situated on the outside of the carriage-way.

While the Centre as a whole is a notable engineering achievement, the Technical Control Areas associated with each studio present several features of especial interest to television engineers. A suite of Control Rooms for Vision, Lighting and Sound lies behind continuous plate glass windows extending across the inner end of each studio and behind these are the Apparatus Rooms.

A new departure from established practice is the provision of a vision control console (for the remote control of the camera control units in the Apparatus Room) alongside the lighting control console. The operational staff responsible for the setting and control of the lighting of the studio scene and for the control of the camera exposure and the resultant video signals are thus close together and view the same monitors.

One operator at the vision control console can control electrically all the cameras in a studio, which may be as many as six. This has been achieved, first by arranging the controls and picture monitors in such a way that the minimum of effort is required by the vision control supervisor, and secondly by designing the cameras and their associated control equipment for remote control. This necessitates a very high degree of electrical stability, but it has been proved that an image orthicon camera channel can be used in this way with only two operational controls—one varying the light input, by means of a remotely controlled iris, and the other the picture black level. The remaining controls, numbering about thirty, are pre-set in advance. This important development in camera design was discussed in a paper at last year's Brit.I.R.E. Convention.*

The operational controls in the vision control console have been specially developed to enable three functions to be performed with a single control. Moving the control over a quadrant varies the lens aperture, a knob on the control is rotated to adjust the picture black level and pressure on his knob will switch a single monitor from one camera to another. Each camera has, as usual, its own picture monitor and this last facility enables the pictures from each of the cameras to be displayed in turn on a single pre-view monitor so that the pictures can be accurately matched, eliminating possible differences in individual monitors.

Alongside each picture monitor is a special waveform monitor developed for operational checking of voltage levels. The special feature of this unit is that it is extremely compact, having a width of only 3½ in. This is achieved by using a 5 in. × 2 in. rectangular cathode-ray tube mounted with its major axis vertical. The waveform display is about 5 in. high and can be seen easily from a distance of 5 ft but the time scale is compressed to about 1¾ in. This is of little importance, as the vision controller is mainly interested in setting correct voltage levels. To facilitate this, the monitor includes an "electronic cursor" which superimposes on the display a line corresponding to white level. This line, which is traced during the field suppression period, and black level, which appears during each line suppression period, gives the two limits of the signal excursion. To assist stability further a line-by-line clamp is included in the output stage of the monitor amplifier.

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* D. C. Brothers, "The testing and operation of 4½-in. image orthicon tubes," *J. Brit.I.R.E.*, **19**, pp. 777-805, December 1959.

APPLICANTS FOR ELECTION AND TRANSFER

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

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

Transfer from Associate Member to Member

DORMER. Gp. Capt. Archibald Harry, R.A.F. *B.F.P.O. 40.*
VESELY, Kurt. *Rickmansworth, Herts.*
WORSNOP, Peter Allan. *Newbury, Berks.*

Direct Election to Associate Member

BLOODWORTH, Greville George, M.A.(Oxon). *Southampton.*
BROWN, Lt. Cdr. Geoffrey Simpson, R.N. *Portchester.*
CHAMPION, Ronald Frederick. *Bexley, Kent.*
DANES, John Edwin, B.Sc.(Eng.). *Cheltenham.*
DARLINGTON, Captain Charles Roy, B.Sc., R.N. *Southsea.*
FRIAS, Daniel Eduardo. *San Miguel de Tucuman, Argentine.*
TANNER, Leslie Arthur, B.Sc. *Newport, Monmouthshire.*

Transfer from Associate to Associate Member

BRYAN, George Alan. *West Drayton, Middlesex.*

Transfer from Graduate to Associate Member

BRIGGS, Peter George. *Basingstoke.*
CAWTHRAW, Maurice John, B.Sc. *Greenacre, S. Australia.*
CHAPPELL, Edgar Raymond Reginald. *Cardiff.*
DUTHIE, Rae Lawrence. *Leicester.*
FLENS, Jan. *Cambridge.*
GORTON, Ronald, B.Sc. *Wallington, Surrey.*
LEE, Charles Tet Hien. *Singapore.*
SMITH, David Trevor, B.Sc. *Bristol.*
TAYLOR, Brian. *Crawley, Sussex.*

Direct Election to Associate

BLAKEMORE, Bernard Felix. *Tettenhall, Staffordshire.*
BOTTOMLEY, Eric. *Woking, Surrey.*
CROWTHER, Frank. *Chessington, Surrey.*

Direct Election to Graduate

ATKINSON, Derek John. *Surbiton, Surrey.*
HICKSON, Kenneth, B.Sc.(Hons.). *Wigan, Lancashire.*
HILFI, Hamid Abdulrazak. *Birmingham.*
HOWARD, Peter Thomas. *Coventry, Warwickshire.*
McINTOSH, David John, B.Sc. *St. Albans.*
MADDOCK, Robert John. *Brixham, Devon.*
NWACHUKWU, Boniface Chemazu. *London, N.W.6.*
REID, Cynthia Margaret Bernice, B.A.(Cantab.). *London, S.W.6.*
SARGEANT, Flg. Off. Ralph Major, R.A.F. *Southsea.*
SCHOLFIELD, Derek MacGarvey. *London, S.E.12.*
WHITE, Albert Augustus Derrick. *Cheltenham.*

Transfer from Associate to Graduate

PATERSON, John Lindsay. *Brampton, Hunts.*

Transfer from Student to Graduate

DUCKWORTH, John. *Bournemouth, Hants.*
LEE CHING CHIN. *Hong Kong.*
SHUKLA, Ratan Prakash. *Agra, India.*
VISWANATHAN, G. S., B.Sc. *Calcutta.*

STUDENTSHIP REGISTRATIONS

The following 89 students were registered at the May and June meetings of the Committee.

BALASUBRAMANYAM, Venkatachalam A., B.A. *Bellary, India.*
BALTEJ SINGH. *Dist Bhatinda, India.*
BATRA, Bhim Sen. *Saharanpur, India.*
BEAUMONT, Antony John. *St. Albans.*
BHATIKAR, Savla, B.Sc. *Goa (Port India).*
BLAKE, William. *Dagenham, Essex.*
BLYTH, John Robert. *Colchester.*
BURROWS, Kenneth G. *Wallington, Surrey.*

CHOWDHURY, Jagadishchandra. *India.*
CLAYTON, Fly. Off. A. J. *Diss, Norfolk.*
COWLEY, Peter S. *Pinner, Middlesex.*

DAVIERWALLA, Bomi S. B.Sc. *Bombay.*
DIVEKAR, Vinayak R., B.Sc. *Bombay.*
DOMINIC, Thaiparambil. *Bangalore.*

FENSOME, Charles W. *Hertfordshire.*

GARG, Om Narayan, B.Sc., M.Sc. *Kanpur, India.*
GREEN, M. R. *Hampton Hill, Middlesex.*
GREENWOOD, Peter Lord. *Coventry.*
GROOSHKEVITS, Yoram. *Magdiel, Israel.*

HANCOCK, Donald Michael. *Romsey.*
HARI DAS, E. N. *Bangalore.*
HELTMAN, Tadeusz. *Wrexham, Denbighshire.*
HUMPHRIES, A. J. *Nantwich, Cheshire.*
HUNT, Norman W. *Cambridge.*

IDI, Joseph J. *Ibadan, Nigeria.*
IWUCHUKINU, Chukukadibia J. *Lagos.*

JOSEPH, P. U., B.Sc. *Kerala, India.*

KENNEDY, C. I. *Salisbury, S. Rhodesia.*
KOPPIKAR, S. G., M.Sc., B.Sc. *Bombay.*
KOURAKOS, Michael. *Athens, Greece.*

LEARMONTH, William G. *Orkney.*
LEE YEW KWAN. *Singapore.*
LOCK, Frederick S. *Gloucester.*
LONGHURST, Charles E. *Redhill, Surrey.*

NAIR, Divakaran G. *Kuala Lumpur.*
NAQVI, Seyed N. A. *London, W.5.*
NEVILLE, John. *Arborfield, Berkshire.*

OMOSULE, Adejoro A. *Owo, Nigeria.*

PARRIS, Clifford B. *London, S.E.6.*
PERUMAL, V. K., B.Sc. *Madurai, India.*
PHADNIS, Shankar A. *Indore, India.*

RAJAN, Krishnaswamy P. *Bangalore.*
RATTAN, Avtar S., B.Sc. *Nairobi.*
REGO, Melville C., B.Sc.(Hons.). M.Sc. *Bangalore.*
ROTTIER, Leslie J. *Harlow, Essex.*

SARANG, Digambar A., M.Sc. *Bombay.*
SHAH, R. R., B.Sc., M.Sc. *Kalol (N.G.), India.*
SHARMAN, Harold. *Cambridge.*
SHEPHERD, Walter E. *Ferndown, Dorset.*
SHUTTLEWORTH, John E. *Birkenhead.*
SKINNER, Alan S. *Woodbridge, Suffolk.*
SLADE, Paul M. J. *Weston-Super-Mare.*
SRINIVASA RAO, S. R., B.Sc. *Bangalore.*

VARADARAJAN, Krishnamachariar, B.Sc. *Madras State.*
VINEY, Christopher N. G. *Bournemouth.*

WHITE, Geoffrey P. J. *Ibadan.*
WILLIAMS, Kenneth F. *London, W.5.*
WILLIS, Alan F. *London, S.E.22.*
WILSON, K. *Sasolburg, South Africa.*
WINSBORROW, Alan M. *Battle, Sussex.*
WISEMAN, Edward E. *London, S.W.11.*

YEW, Chew Tham. *Selangor, Malaya.*

ANWAR, Choudary Mohammad. *Lahore.*

BABLIKY, Chaim. *Tel-Aviv.*
BAKER, John R. R. *Redditch, Worcestershire.*
BARRETT, Denis Walter. *Plymouth.*
BENOU, Edwin V. *Sao Paulo, Brazil.*
BRAMSON, Irving John. *London, N.16.*

CANDY, Desmond W. *Sittingbourne.*

FREEMAN, Loyal A. *Dunfermline, Fife.*
FREEMAN, Roy. *Birmingham.*

GEFFROY, Louis Philippe. *Johannesburg.*
GORANIA, Bhimbhai K. *London, N.7.*

HALLS, Ronald S. *Ringwood, Hampshire.*
HARWOOD, Anthony James. *Reading.*

JONES, Alan. *Liverpool.*

KHAN, Mohd Yaqub. *Dist Hazara, West Pakistan.*

MATTHEWS, John A. *Redhill, Surrey.*

OJIAKO, Nathaniel A. U. *London, N.7.*

PIGOTT, Sydney Hesketh. *Antigua.*

RAMACHANDRAN, Mari Muthu. *Trichy, Dist. South India.*
RANGANATHAN, T. Muthuswami, B.Sc. *Madras.*
ROY BARMAN, Subhendu, B.Sc. *Calcutta.*

SCOTT, Derek Victor, *Romford.*
SMITH, Clifford I. *Bangor, N. Wales.*
SRIVASTAVA, Verendra P. *Faizabad, India.*

THAPAR, Rajinder K. *New Delhi.*
TOWILL, Clifford John. *B.F.P.O. 45.*

YASHWANT DEVA, Capt. *Ludhiana, India.*

A Common Carrier Multi-Channel Television Wire Broadcasting System†

by

K. A. RUSSELL, B.SC. ‡ and F. SANCHEZ, ASSOCIATE MEMBER ‡

A paper read on 1st July 1959 during the Institution's Convention in Cambridge.

Summary: The factors governing the choice and design of a television relay system and the history and background of the development of various systems are surveyed. The basic technical features of a system carrying four television and four radio programmes are discussed. Information is given regarding various types of cable and their specifications. Network jointing and matching fittings are described and the method of using the system characteristics to plan a network is explained with examples and an indication of the sort of coverage that can be obtained. Various types of subscriber installations can be provided and their characteristics are defined and typical examples given of subscriber's equipment. The operation of the main receiving station and repeater equipment is explained in some detail and finally test methods and test equipment are described.

1. Factors Governing the Choice and Design of the System

Apart from previous experience gained with television receivers, communal aerial systems and audio wire distribution systems, the following points exercised a considerable influence on the design of the particular system with which this paper is mainly concerned:

(a) It was essential that the installation and operation of the system should require the minimum of semi-skilled labour and the absolute minimum of skilled supervision.

(b) It was essential that the operation of the subscribers' equipment should be simple and reliable and that the standard of picture should not depend on the skill of the viewer.

(c) It was essential that the receiving equipment should provide substantially interference-free reception.

(d) It was essential that the G.P.O. radiation limits of 100 microvolts per metre at 10 yards be maintained where the signal level was a maximum.

(e) It was originally considered desirable that the sound programmes (television and radio) be carried at audio frequency but this has been modified in later systems.

(f) It was desirable that up to four television programmes should be able to be transmitted simultaneously together with up to four radio programmes. Only recently, however, has this full capacity been realized on a reasonable cable system.

(g) It was desirable to provide television signal input facilities to standard television receivers using a simple device working off the network signal.

(h) The cost of the system bearing all these points in mind should be a minimum and should enable a competitive rental to be offered as compared with the rental of normal television receivers.

2. Background and History

In this paper the term television wire broadcasting is meant to cover the various methods of distributing multi-programme television signals to viewers' homes from a central point, thus

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† Manuscript received 26th May 1959. (Paper No. 565.)

‡ British Relay Wireless and Television Ltd., 6 Giltspur Street, London, E.C.1.

U.D.C. No. 621.397.74:621.396.975

eliminating individual aerial reception by these viewers.

Communal aerials which distribute television signals as received by normal aerials have been in existence since shortly after the last war and probably existed before then. The extension of these from installations in single buildings to ones covering whole districts has taken place in the last 10 years, chiefly to provide satisfactory television reception in "black" and "fringe" areas. The principal advantage of such systems is that they provide a signal directly suitable for an unmodified domestic television receiver without the use of an adaptor or converter.

In 1950, various schemes for the distribution of television signals at frequencies lower than those of Band I, which are used in district aerial systems, were devised and on the 15th March 1951 in Gloucester, the first true television wire broadcasting system was inaugurated, followed very shortly afterwards by a similar system developed quite separately in South East England (Thanet). The former system[17] (now superseded by a later system) distributed one television vision programme at a carrier frequency of 10 Mc/s double sideband, the sound being at audio frequency at a power sufficient to drive loudspeakers directly. One screened quad cable and one unscreened quad cable allowed three radio programmes to be distributed also. The signal (there was only one programme at this time), was received on the summit of a hill from either Sutton Coldfield or Wenvoe and transmitted by u.h.f. link (2,000 Mc/s) to the main distribution station in the City some miles away. The Thanet installation[16] was similar but employed a carrier of 9·7 Mc/s. These systems were essentially for a single television channel only, plus three radio programmes, and suffered from a restricted service radius before repeating became necessary, although of course, they were significantly better than a district aerial system in this respect.

At about the same time a coaxial system of distribution was installed in Montreal. The cables in this case were aluminium-sheathed and the system distributed one vision carrier at 16 Mc/s upper sideband and a second vision carrier at 28 Mc/s lower sideband. Eight sound programmes were also transmitted in the Band 180 to 340 kc/s. Since then the addition of two further television programmes has been carried out by adding a second cable[7, 16].

The next stage in the development of these systems occurred in time for Independent Television programmes to be accommodated and two divergent methods arose. The first is an adaptation of the Thanet installation and transmits two television programmes at carrier frequencies of 4·95 Mc/s upper sideband and 8·45 Mc/s lower sideband, one on each pair of a single screened quad. A second quad provides two additional radio programmes. The receiver or viewing unit is fixed tuned with a symmetrical response 6 db down at each of the two carrier frequencies; thus by simple switching from one pair to the other, a choice of television programmes can be obtained without any tuning of the receiver. The chief advantage of this system is that the maximum cross-talk permissible is of the order of − 30 db before mutual interference between the two programmes becomes noticeable. Up to four television programmes can be handled using two screened quad cables and radio programmes may, of course, be substituted for unused television channels[16].

The other system, which came into being during 1953 and with which the authors are associated, was designed from scratch using information available from the operation of the Gloucester system which is now called the Mark I system (the newer one being the Mark II system), and from work done in London and elsewhere. The improved system had as its primary aims the provision of multiple television programmes coupled with a considerably increased operating radius without repeaters, since the original Gloucester (Mark I) system had suffered at times from this particular problem. It should be remembered that although at that time no I.T.A. programme was available, it was becoming obvious that it would be available within a reasonable time.

Considerable information and experience in the use of star quad cables for television distribution had become available from Gloucester and three major points emerged from the use of both unscreened (TR3) cables and also screened (TR7) cables. These are (a) the absolute necessity for effective screening of the cables, (b) the necessity for uniformity in any one length of cable and (c) the desirability for uniformity of Z_0 between different lengths and sizes of cable.

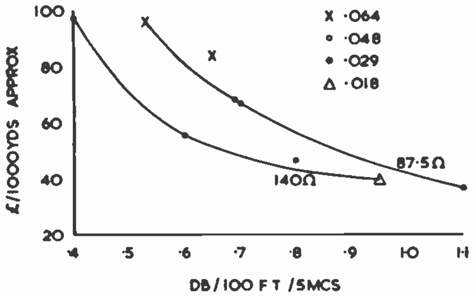
It was proposed, therefore, to specify a new range of cables providing for a constant impedance (87·5 ohms at 5 Mc/s) for all gauges, with tighter tolerances on the homogeneity of any one length of cable and the variation of impedance between lengths. These cables were eventually to become the TR8 range[13].

Previously, measurements had been taken on an unscreened network in Lambeth to assess crosstalk at around 3·5 Mc/s. It was found to be remarkably low and encouraged the belief that a network could be constructed from screened cable that would allow the transmission of two vision programmes on a common carrier frequency each transmitted on its own pair in a single quad. The advantage of this feature was that very simple programme selection facilities could be used and at the same time both programmes would suffer the same attenuation and frequency distortion at any one point on a network, thus further simplifying the equalization and programme selection methods. It was thought at that time that 3·5 Mc/s represented the lowest possible carrier frequency that could be used. Further work caused a change in carrier frequency to 3·75 Mc/s as being the lowest one to allow satisfactory modulation and de-modulation without resorting to very expensive techniques, particularly at the receiving end.

At the same time, an investigation was carried out to find out how much "pre-emphasis" could be applied to the transmitted signal without overloading taking place. Measurements of the power distribution in the spectrum of a television signal (Test Card C) showed that 2½ to 3 Mc/s away from carrier frequency the power was down by 40 to 50 db, and that providing a "pre-emphasis" of +15 db at 3 Mc/s away from carrier made a negligible difference to the carrier power handling capacity of a power amplifier.

All these ideas were put together late in 1953 at a station in Lambeth and it was proved that the system could be made to work carrying two television programmes in the same screened quad. During 1954 and the following years, an extensive rewiring and development scheme was pursued and to date approximately half a million families have been reached by this television relay system and its variants, approximately 30 main distribution stations and approximately 50 repeater stations have been put into service.

In 1957 a further development began. Firstly cables using cellular polythene as an insulant instead of solid polythene became available in experimental quantities but they could not be manufactured with sufficient accuracy for the very thin radial thicknesses of insulant to be extruded on them that were required to give the same impedance as the original type of cable. At the same time, difficulties had arisen with the original system where the subscriber load had exceeded expectations and caused the audio performance to be adversely affected by the capacitance of the network and its junction inserts. It was also felt that the number of channels available on the older system was not likely to be sufficient in the future and that a new system giving four television channels plus four radio channels was the minimum that could be accepted bearing in mind that cable installations must have a life of at least ten years to be economic. The last factor to be taken into account was that a large proportion of the areas already covered such as those in South London were very densely populated, whereas increasing numbers of less dense new housing estates and other similar areas were being encountered. The new system, therefore, had to cater for subscriber densities of from one to ten per acre and provide four television and four radio programmes simultaneously. It was therefore decided to make use of cellular polythene insulated cables of a higher impedance (140 ohms at 5 Mc/s). These provide lower costs for the same attenuation as the original (TR8) cables (Fig. 1) which, of course, had to distribute audio frequency power in appreciable quantities as well as to act as r.f. transmission lines. In order to overcome the original problem of high network capacitance and loading and increase the number of channels, it was decided to transmit television sound channels at carrier frequency while retaining the distribution of



†**Fig. 1.** Relation between cable cost and attenuation for various impedances and conductor gauges.

radio programmes at audio frequency. This demanded the use of a carrier amplifier, detector and audio amplifier in each viewing unit; the audio amplifier was therefore made to assist the reception of radio programmes distributed at audio frequency. A later development was the ability of the cable manufacturers to meet the cable specification using a construction consisting of four twisted pairs within a single screen. (It is not possible to use this type of cable with the Mark II system in which two screens are employed to provide a fifth radio channel.) The Mark VC network therefore consists to a large extent of a single cable carrying four television programmes and four radio programmes instead of the total of five television and radio programmes carried in two separate cables, of the Mark II system[18].

3. Basic Technical Features of the System

As mentioned previously, the available cable performance set the principal design features of the system. Bearing in mind that the cable has to perform two functions, namely the distribution of audio power and the distribution of carrier signals, it is obvious that the optimum cable is the one which just performs both functions satisfactorily. Calculations and analyses of existing networks showed approximate proportionality between subscribers per acre and the inverse of cable impedance cubed (See Fig. 2 and Appendix 1).

It can also be shown that a constant impedance (TR8) range of cables provides a cheaper system than a range of cables such as TR7 with varying impedance (neglecting any costs due to matching between the different sections), and at the same time allows the vision signal to go further. Appendix 2 makes a comparison between hypothetical groups using the two ranges of cables and brings out these points.

The available sending levels using the system are either 9, 11, 14 or 23, or in exceptional cases 45, volts r.m.s. for peak white. These will satisfy the Post Office radiation requirements, although care has to be taken in the case of the 45-volt sending level. The minimum received level is not less than 1 mV. In this case interference picked up is not normally troublesome but a received level of 3 mV is in all cases completely proof against all types of interference so far encountered. This allows a total signal drop from the transmitter to the receiver of between 70db and 93db. This signal drop divides itself into the following sections:

(a) cable loss.

(b) network matching unit loss.

(c) subscriber connection box loss.

For all normal networks the cable loss should not exceed 45 to 50db approximately and the network matching units will make up another 10 to 20db, leaving a subscriber connection box loss of either 15 or 30db. It follows therefore from the information given by Hinchliffe and Beal[13] that with an attenuation at 3·75 Mc/s of 45db, the pre-emphasis at 6·75 Mc/s, to give a "flat" signal at the far end of the network is required to be + 15db. An investigation into the

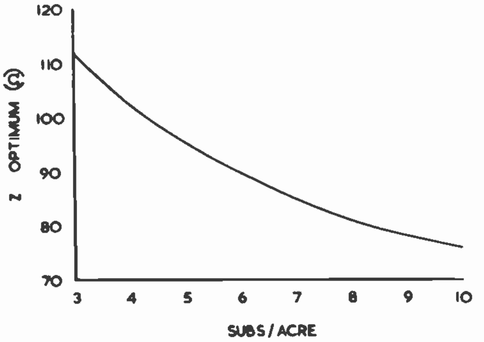


Fig. 2. Approximate relation between subscribers/acre and cable impedance for B.R.W. Mark II Television Relay System.

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†*Editorial note.*—The assistance of the Society of Relay Engineers in loaning a number of illustration blocks is gratefully acknowledged.

power distribution in the spectrum of a television signal (Test Card C) showed that 2·5 to 3 Mc/s away from the carrier frequency the power was down by 40 or 50 db and providing a pre-emphasis of +15db 3 Mc/s away from the carrier made a negligible difference to the overall power content of the signal. However, television signals consist of transients and the effect of pre-emphasis on transients is to produce overshoots which increase the peak-to-peak amplitude of the modulated carrier envelope; this in turn limits the power handling capacity of the amplifiers since in general the maximum power handling capacity of these is limited by the peak-to-peak grid swing of the power output valves. The magnitude of the overshoots depend on the amount of pre-emphasis, the vestigial sideband response and the shape of the video content of the signal.

Measurements obtained with a typical amplifier and a carrier modulated with a rectangular video waveform of 0·18 microseconds rise time gave the results shown in Table 1. Incidentally, 45 db of cable attenuation at 3·75 Mc/s corresponds to 2,900 yards of TR8/·064 in. cable or 2,450 yards of TR8/·048 in. cable, or 4,050 yards of TR9/·048 in.

Table 1

Amplifier Characteristics

Pre-emphasis	5db	10db	15db	20db
Overshoot	0%	3%	15%	25%
Reduction in amplifier power handling capacity	0%	6%	28%	44%

Summarizing the foregoing, the Mark II system basically comprises the use of one or more screened quad cables to a constant impedance specification (TR8) using a carrier fre quency of 3·75 Mc/s upper sideband for vision signal transmission, and audio distribution at full power for television sound and radio programmes. Each television channel (sound and vision together) is carried on one pair of conductors. The vision signal is pre-emphasized to the extent of +15db at 6·75 Mc/s with respect to 3·75 Mc/s, at the transmitting point. This allows a "flat" signal to arrive at the far end of a network of approximately 2,500 yards of cable. Excess pre-emphasis, which will occur near to the station, is removed by a de-emphasis circuit incorporated in the input circuit of the viewing unit, mentioned later. The use of a cable impedance of 87·5 ohms makes it possible to use the system reasonably economically for subscriber densities varying from approximately six to fifteen subscribers per acre although with the higher densities the groups have to be restricted in length below that possible for carrier distribution only. Channel selection at the receiving end is achieved by means of a simple switch which selects the appropriate pair after which a simple LC or RC filter, separates the audio from the carrier. In general, a sufficient gain is available from the two r.f. amplifier stages, a vision detector and one video stage to provide an input sensitivity of not worse than 1 mV for a satisfactory picture contrast.

The Mark VC system is basically similar but uses TR9 and TR11 type cables of 140 ohms impedance giving a maximum average range of the order of 3,500 yards of cable. Since the television sound channel is at a carrier frequency of approximately 2·1 Mc/s, the programme handling capacity of a normal network consisting, say, of one TR11 type cable is four television (with sound) and four radio. The networks are suitable for subscriber densities of from one to ten subscribers per acre. It is possible to adapt the TR8 type of cable system using a television sound at carrier system and this is called Mark IIC. Twisted pair equivalents of the TR8 range of cables (TR10) are becoming available so that in densely populated areas it is possible to use the smaller and cheaper type of cable and provide four television and four radio programmes on a single cable with fairly high subscriber densities. Current practice is to select either the Mark IIC or the Mark VC system dependent on anticipated subscriber density.

4. Matching Units and Other Network Fittings

The following network fittings are used in constructing the network:

(a) T3—equal energy supply (3·25db attenuation) to each branch.

(b) T16—gives negligible loss on the main feeder and 16db loss to the spur.

(c) T10—this lies approximately between the first and second items above giving 10db loss to the spur and 1db loss on the main feeder using a re-matching tap to avoid causing a reflection on the main.

(d) JL—joint and test insert.

(e) E—a cable termination which puts 87·5 ohms (or 140 ohms) across the pairs, blocked by a suitable capacitor.

(f) VS15 and VS30—subscriber matching units are necessary and since it is not desirable to have re-matching facilities on these for obvious reasons, the designs are arranged to provide either minimum loss without any significant reflection on the main feeder, giving an attenuation to the subscriber of 15db with approximately 0·15db shunt loss on the main feeder, or alternatively a negligible feeder loss (much less than 0·1db), resulting a loss of 30db to the subscriber. In both these cases, resistors are used to absorb reflections from the subscriber's unit (for instance when it is unplugged) so preventing it from affecting other adjacent subscribers. A VS20 is used in lieu of the VS15 on 140-ohm networks.

(g) AS—audio subscribers are isolated at carrier frequency by means of pairs of chokes having an impedance in the band 3 Mc/s or 12 Mc/s of not less than 10,000 ohms, and only the a.f. power reaches them.

The various network fittings are made up in pairs on S.R.B.P. plates so that each one will deal with a single screened quad; a moulded plastic box is used with glands and gaskets to accept up to three cable entries without allowing the ingress of moisture (Fig. 3). Using these units, various joints can be built up and extensive use is made of what is called a double decker box which really consists of two single boxes mounted on top of one another with a single lid.

In designing these inserts, it was desirable to avoid shunting the audio frequency power without affecting the r.f. transformer performance in the matching units. Blocking capacitors in the centre taps are used for this purpose and it is essential to keep their capacitance to the absolute minimum.

On a fairly heavily loaded network the total

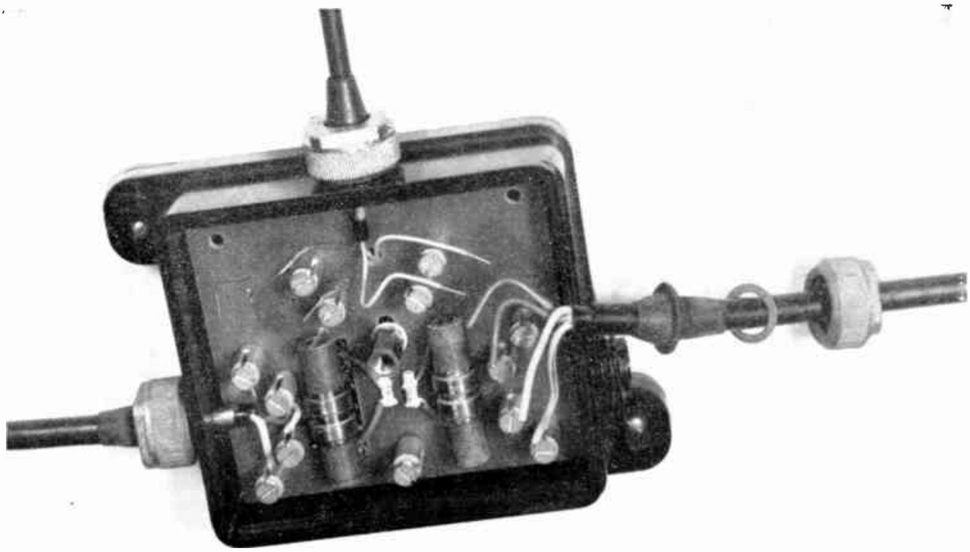

Fig. 3. Joint box complete with 2-channel matching insert and cable glands.

capacitance shown to the audio system per subscriber is of the order of 5,500 pF which is considerable, and if care is not taken in designing the network excessive losses can occur at the higher audio frequencies. The current design of network fittings in the Mark II System has reduced the effect of these fittings to a small proportion of the whole, the bulk of the capacitance being supplied by the subscriber's downlead cable and the main feeder.

5. Network Planning

In order to understand the basic principles governing the planning of Mark II television relay networks it is necessary to summarize the boundary conditions, and the cable and network fittings performance data. Cable and fittings data are given in Tables 2-4.

The boundary conditions are:

Sending levels—9/11/14/23/46V/87·5 ohms—limited by G.P.O. Radiation specification.

V.U. min. input level—1 mV/120 ohms—set by immunity from interference pick-up.

Total level change—80-93db.

(Levels are defined in r.m.s. volts for a peak-white signal).

The nominal pre-emphasis of +15db is equivalent to a cable loss of approximately 40-55db. It can be seen, therefore, that one is dealing with cable lengths of the order of 3,000 yards of TR8/·064 in. and correspondingly shorter lengths of the other gauges. Box losses can amount to 25db or more and include at least 14db for the subscriber's insert.

A typical make-up would be a main feeder of 2,000 yards of TR8/·064 in., 500 yards of TR8/·048 in. fed via a T3, and a girdle of TR8/·029 in., fed via a T10, 300 yards long serving a subscriber with a VS15. The subscriber's downlead attenuation can normally be neglected. This layout is shown in Fig. 4, and gives an attenuation of 48db for the cable plus 27db for boxes, total 75db at 3·75 Mc/s. Some allowance must be made for the losses in the girdle feeders due to VS15s and this requires an estimate of the subscriber density to be made, and a knowledge of the number of families covered by the

Table 2

Details of Cable used on Mark II system.

Cable Type	Nominal Outside Diameter	Nominal Attenuation at 3·75 Mc/s
TR8/·029″	0·232″	2·9db/100 yards
TR8/·048″	·343″	1·8db/100 yards
TR8/·064″	·422″	1·5db/100 yards
TR8/·104″	·6″	0·8db/100 yards

Table 3

Details of Cables used on Mark VC System. (TR9 and TR11 cables of same gauge are approximately equivalent in performance).

Cable Type	Nominal Outside Diameter	Nominal Attenuation at 3·75 Mc/s
TR9/·018″	0·232″	2·5db/100 yards
TR11/·018″	·345″	2·3db/100 yards
TR9/·029″	·300″	1·6db/100 yards
TR11/·029″	·450″	1·4db/100 yards
TR9/·048″	·447″	1·0db/100 yards
TR9/·064″	·594″	0·8db/100 yards

Table 4

Details of Matching Units used on Mark II System.

Insert Type	Attenuation Main Ongoing	Attenuation Spur or Sub.
T3	3·25db	3·23db
T10	1·0 db	10 db
T16	·1 db	16 db
		Attenuation Sub. Feed (120 ohms)
VS15	·2 db	14 db
VS20	·1 db	19 db
VS30	·1 db	30 db

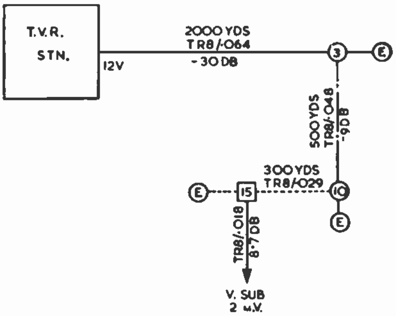

Fig. 4. Network example.

cable. It is advisable to leave 6db in hand for contingencies anyway. Allowance must also be made for the fact that cables do not always go horizontally and therefore 10 per cent. is usually added to the lengths measured horizontally from 25 in./mile or 50 in./mile maps.

It is found that the group loading of a Mark II network must not exceed 300-400 subscribers for a satisfactory audio performance and so it can be seen that with a subscriber density of 20 to 40 per cent. of the families, a group coverage of 1,000 to 2,000 families, depending on expected subscriber density and family density must be planned for. It is essential, therefore, to work out the densities of families per acre, and the expected subscriber densities (per cent.) in an area to be wired in order to load the groups correctly and efficiently.

Generally speaking, it is possible to cover an area of 1,750 yards radius from an amplifying station, but this distance can be increased by using the highest sending levels for particular groups, and also if the main feed is straight (say along a railway), up to distances of 2,500 yards (2,250 yards and 3,500 yards respectively using TR9 or TR11 cables).

For point to point links, distances of up to 8,500 yards are possible (using TR9/·064 in.) without repeaters, and this fits in well with the kiosk medium voltage feeder system which has been described elsewhere[2]. It is possible, therefore, to plan an area to be covered by one station and several kiosk repeaters, which are usually in huts about 6 ft × 9 ft. Repeater groups have similar performances to station groups except that an allowance must be made for the slight loss in the medium voltage feeder at audio frequencies which restricts the audio loading from 300-400 to 250-350 subscribers; this still gives a satisfactory load.

Account must be taken of radio only subscribers in this planning but in general they will not add proportionately to the load since it is the capacitance of a vision subscriber's installation that is most significant in spoiling the a.f. performance of a feeder. While the average vision installation adds some 3,000 pF to the network capacitance, radio-only installation will add only half this amount.

The Mark VC system allows groups to serve up to 3,000 families with a proportionate number of subscribers.

6. Subscribers' Installations

Subscribers to the system may have three principal types of installation:

(a) radio only.

(b) radio and television combined in one unit.

(c) television signals to feed a standard television receiver.

Installations have of necessity to make connections to the main screened network, and the r.f. joint is substantially more expensive than that used in an a.f. wire broadcasting system. It is, therefore, often worthwhile to run a separate unscreened girdle to serve several adjacent radio only subscribers so using only one expensive joint to the main screened network.

Alternatively, two completely separate networks may be employed running side by side, one a single screened quad, and the other a single unscreened quad, feeding two television and two radio programmes respectively. A step further is to employ two screened quads for the main network and a single screened quad and an unscreened double quad for the girdles thus providing two television programmes and three radio programmes.

Usually the radio only subscriber has an unscreened double quad downlead and the installation is similar to the normal sound relay installation. The television subscribers have the relatively expensive joint and a screened quad or twisted pair downlead, terminated in a 12-pin miniature Jones type socket. Both Viewing Units and Loudspeakers with self-contained programme selector switches are available to plug into this type of socket, which is usually at skirting board level near a convenient mains point.

The Viewing Unit has a multicore flexible cable plugged into the socket and also a mains lead that plugs into its rear. Changing the unit is simple and can be carried out speedily by semi-skilled persons who only have to set up a few straight-forward controls in the new Viewing Unit. Apart from Channel Selection, Volume, Brightness and Contrast, the subscriber also has access to the line and frame hold. Broadly speaking the last three need not be touched after initial setting up, and the Brightness control is only needed to counter varying ambient lighting. Channel selection is simple and positive and does not cause any changes in signal level so that even the most inexpert can change programmes without trouble.

Frame and line linearity controls are normally set up in the maintenance workshops, and the only other controls that need adjustment during installation are the mains tap, frame and line hold, sensitivity and de-emphasis. The latter tilts the r.f. response of the Viewing Unit to cancel excess pre-emphasis encountered near the station. It is not critical and on some Viewing Units consists of a three-way plug giving 0, 6 and 12db de-emphasis; others have a variable trimmer. The sensitivity control may consist of a plug type attenuator giving a range of 0-40db or a variable potentiometer. The contrast control has only a limited range of 0-16 or 24db depending on Viewing Unit type.

It is interesting to note that while the Viewing Units are designed to utilize standard television set parts for economical production, the number of Viewing Units that are returned for repair (the organization operates on the basis of exchanging faulty sets and Viewing Units, except for such straight-forward faults as blown fuses and occasional valve changes) is only about one-third of the percentage of television sets returned under similar circumstances. This is attributed to the elimination of frills inside the units and the simple and solid operation, eliminating the need for subscribers to "fiddle" with the controls.

The last type of subscriber installation is the one with a device called a "Relaydapta" which converts the signal of the selected television programme from the form distributed on the network to the form radiated by the B.B.C. on one of the channels in Band I. Such a device effectively provides a communal aerial facility. It took a long time to develop this "Relaydapta" since the possible snags are considerable, but it now works without any difficulty with at least 95 per cent. of the receiver types liable to be encountered, and on very few indeed is it impossible to obtain a completely satisfactory result. It is of interest to note that in Huddersfield it has been found feasible (and preferable) to use "Relaydaptas" that generate Channel 2 (Holme Moss) and in other localities the local B.B.C. channel is used without trouble to either the subscriber or his neighbours. The "Relaydapta" has two valves and is a simple and reliable device.

The Viewing Unit has nine or more valves dependent upon the complexity of the time base circuits employed. Except in one special case, current Viewing Units have two r.f. stages, a detector, video amplifier, the usual sync. separator and time-base circuits. It is, of course, not necessary to provide elaborate time-bases since synchronizing is very solid due to the clean interference-free sync. pulse and relatively strong signal.

Various combinations of the foregoing subscriber installations are possible; for instance a subscriber with a "Relaydapta" can have a radio installation too.

7. Station and Repeater Equipment

Figure 5 is a block diagram of the equipment of a Mark II television wire broadcasting station. The sound amplifying equipment is fairly orthodox, apart from the arrangements made to operate 1 kW amplifiers in parallel to serve the five audio bus bars (six can be served plus a test bus bar). The number of amplifiers installed depends on the station load and varies from 7 to 12. Up to 3 amplifiers normally serve one bus bar. The input facilities provide for

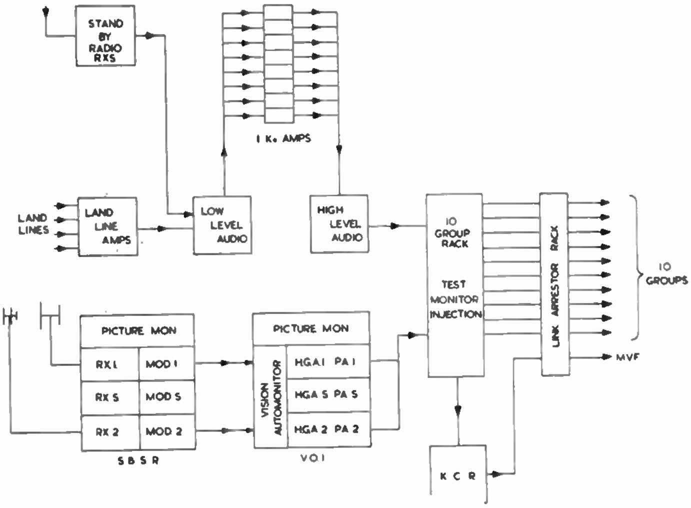

Fig. 5.
Block diagram of television wire broadcasting station equipment.

taking the sound outputs of the main television receivers or land line circuits, and routing them through the sound amplifiers to the appropriate output bus bar.

Each television wire broadcasting station receives its television signals either:

(a) from receivers on the premises, with either local or remote aerials,

(b) from a remote receiving site by line or microwave link, or

(c) via land lines from another television wire broadcasting station—the land lines may be rented from the G.P.O., or be installed by the operating company.

In any case, one or more standby television receivers are installed and a pattern generator is also fitted which can serve all the receivers by tuning them to the channel chosen for it (not the local B.B.C. or I.T.A. of course!). A picture monitor is used to check the setting of the equipment on the rack and a portable oscilloscope is used as a waveform monitor from a video output on the picture monitor.

Associated with each of the main receivers is a vision modulator into which the video output of the related receiver is fed. Each modulator has a crystal oscillator which is connected to a circuit linking all the modulator crystal oscillators together. By switching one on and the others off, a single oscillator is used for all the modulators thus preventing low frequency beats occurring which are particularly objectionable. The modulator block diagram is shown in Fig. 6. A sync. separator and separate sync. amplifier are used to switch the carrier amplifier off during sync. pulses, thus ensuring clean sync. signals.

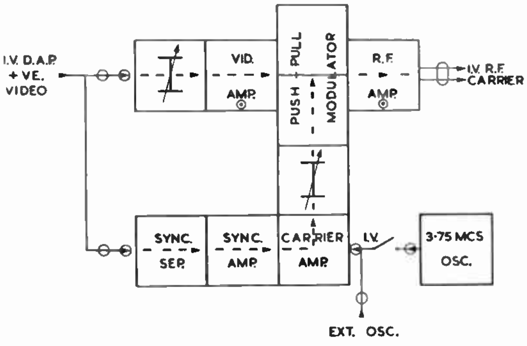

Fig. 6. Vision modulator block diagram.

The outputs from the standby signal rack and the landline (medium voltage feeder) inputs are fed to the Vision Output 1 rack whose input circuits consist of the audio-vision carrier separating filters and vision carrier input switching, routing the signal via main or standby amplifiers. The latter consist of high gain amplifiers raising a land line input of not less than 10 mV r.m.s. for peak white to two 0·5 V r.m.s. outputs and included in each high gain amplifier is an adjustable plug-in attenuation equalizer to correct for the incoming line. An additional standby input on each high gain amplifier takes the outputs of the local modulators and after +15db pre-emphasis passes them via the later stages to the double outputs. This facility is controlled by a manual main/standby switch.

The high gain amplifier output is routed to a power amplifier rated at 40 watts of r.f. output over the band 3-6·75 Mc/s and normally operated at 25 watts for peak white; a second such amplifier on another rack (Vision Output 2) can be fed from the same high gain amplifier. The Vision Output racks each provide for a spare amplifying channel.

Each power amplifier has a monitor circuit that causes the spare channel to check the input if less than black level is coming out of the main channel. If the spare channel monitor circuit finds more than black level at its own output, then it automatically takes over the operational channel and an alarm is sounded.

The outputs of the Vision Output 1 (and V.O.2) racks are fed, together with the outputs of the main audio bus bars, to the group rack(s), where after passing through a normal type of d.c. insulation and loop testing facility, the groups are fed through injection transformers whose primaries in parallel are fed from the vision carrier power amplifiers and whose secondaries inject a suitable proportion of the available carrier power into each main group feed. Figure 7 shows the arrangements of a single vision channel and its injection facilities.

The injection transformer ratios are so chosen that, while together they load the Power Amplifier correctly, individually the feeds receive a carrier voltage to satisfy their planned needs. A link and lighting arrester panel completes the station equipment.

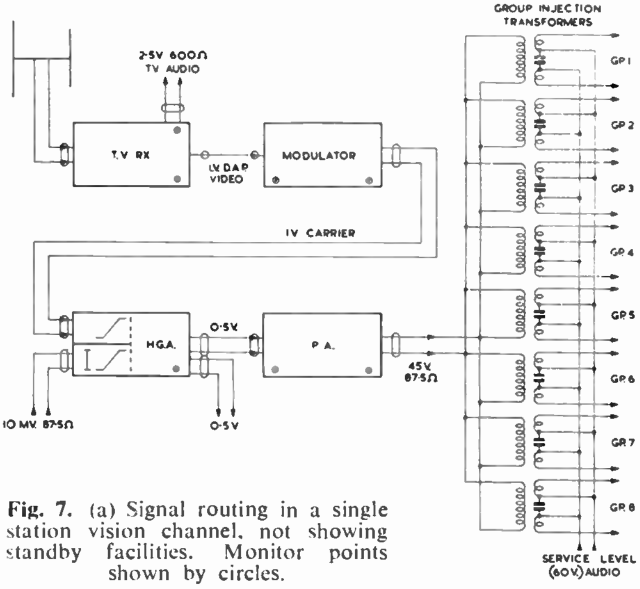

Fig. 7. (a) Signal routing in a single station vision channel, not showing standby facilities. Monitor points shown by circles.

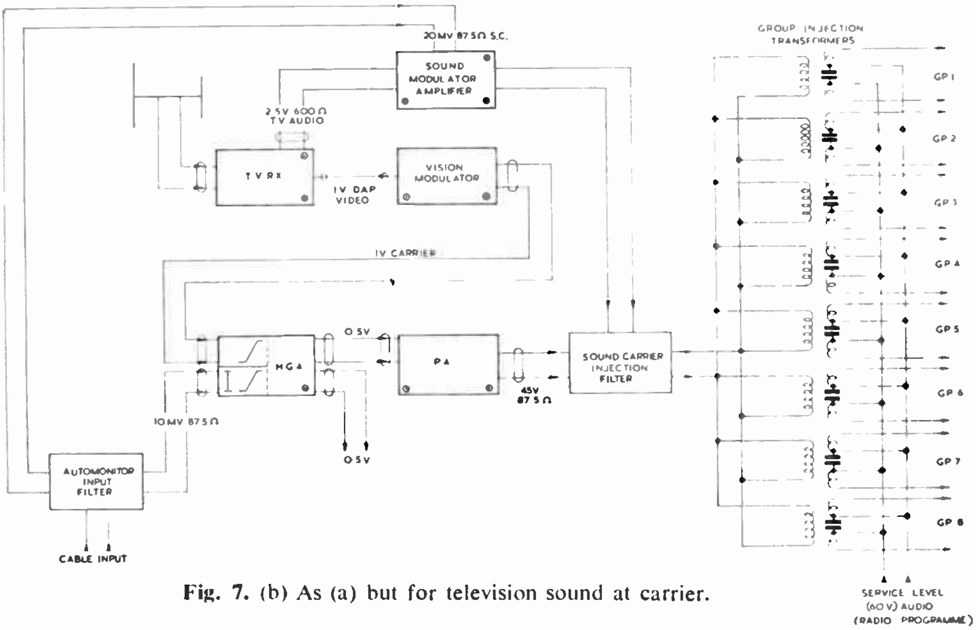

Fig. 7. (b) As (a) but for television sound at carrier.

A vision repeater uses the same type of vision amplifying equipment as the main station, installed on a more suitable, single sided rack. A separate injection, link and arrester panel, fitted to a short international rack, completes the vision equipment.

The audio equipment at a repeater consists of the audio medium voltage feeder transformers and remote monitoring and testing facilities described previously, but modified to take up to six channels[2]. Remote mains switching has also been incorporated, and vision fault warning, by making use of the vision automonitor facilities.

The mains to all vision equipments are stabilized to better than 2½ per cent. and in addition extensive use of negative feed-back in their design has eliminated gain stability troubles with which a series of vision amplifiers in tandem can easily be plagued (1-2db variations can be noticed and 6db is disastrous).

Experience gained with the Mark II system has been used in the design of the sound carrier system and the sound carrier modulator in order to simplify and reduce the number of different units required. In fact the latter consists of an amplifier capable of giving sufficient gain to provide the full power output of some 25 watts at 2·1 Mc/s with an input of approximately 20mV (balanced) at 87·5 ohms in each case. By the simple changing of plugs and the insertion of a crystal, the unit can be converted into a modulator, when it takes the standard 600-ohms balanced audio input of a minimum value of 0·25V. In order to meet the more stringent crosstalk requirements of a sound system (maximum crosstalk of approximately −65 to −70db), the common carrier technique was abandoned and instead each carrier channel is offset by some 15kc/s so that any r.f. crosstalk occurring merely produces a 15kc/s or higher whistle which is not normally audible until the crosstalk figure is worse than approximately −30db. This is a very easy figure to meet in practice. The net effect has been that provided the system is good enough for the distribution of vision signals, then the sound distribution at carrier frequency is also satisfactory.

8. Test Methods and Test Equipment

It is not proposed to deal with d.c. testing since this uses normal fixed and portable test equipment, except to point out that all matching units incorporate d.c. blocking capacitors to facilitate insulation measurements.

Dealing first with the r.f. testing of the cable

Fig. 8. Network transmission measuring equipment. Mains-operated twin transmitter (left) and Portable receiver (right).

network only, the principal parameters required are:

(a) signal level.

(b) signal balance.

(c) cross view.

The signal level and crosstalk at the station and on the main feeders can be readily measured using a germanium crystal diode voltmeter (10mV-50V), with a suitable balancing transformer and attenuator, but elsewhere a more sensitive device is required.

A complete measuring set (Fig. 8) consisting of four transmitters on slightly staggered frequencies around 3·75 Mc/s and a battery operated heterodyne receiver driving a diode voltmeter is used extensively. Each transmitter is crystal controlled on its allocated frequency, and its output level is controlled to within about 1db. It is mains driven and usually plugged into the appropriate link point at the station or repeater. The portable receiver is usually connected across the feeder under investigation by means of its twin screened balanced lead and a special pad, or is plugged into a subscribers outlet socket and then acts as a termination to the download.

By taking a direct signal reading on the frequency appropriate to the pair being measured, the signal level is established relative to the known sending level. By switching the local oscillator (crystal controlled) to any other transmitted frequency and remeasuring the signal level, the crosstalk with any of the other three channels can be measured.

By switching to an unbalanced input, the signal between pair centre tap and screen is measured. This is important since it is a measure of signal unbalance, usually in fittings, but sometimes in cable, and is useful in tracing crosstalk and patterning troubles due to faults on the network.

It might be as well at this point to mention that network balance is most important, but providing that fittings are designed, made and tested correctly, it is largely a question of specifying accurately the methods to be used by wiremen in order to achieve a satisfactory standard. Cable made by reputable manufacturers is normally significantly better than the items attached to it, but in any case it is tested to a stringent specification.

Since the screening factor of the cable used is not high (Z_c is approximately equal to 1 milliohm/metre at 5 Mc/s), the presence of unbalance in the network increases the likelihood of interference pick-up, causes the network to radiate and, when the unbalance affects more than one pair of conductors, it may introduce crosstalk. Hence apart from specifying maximum cable unbalance, it has also been necessary to specify the maximum permissible unbalance of network fittings, using an instrument whose circuit is shown in Fig. 9.

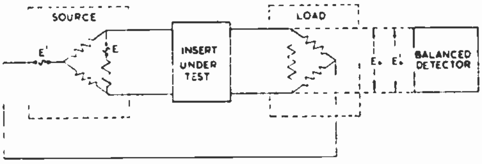

Fig. 9. Method of testing network matching units for balance.

$E/2E_0$ measures the balanced attenuation or insertion loss.

E'/E'_0 measures the degree to which a longitudinal input is converted into a balanced output. The percentage unbalance is defined in terms of this ratio.

Although the cables themselves are either quads or multipair, each pair has individual line inserts connected to it and at the point of the junction the system can be represented, at a single frequency, by a three-terminal passive impedance load connected via the line insert to a three-terminal source[1]. This equivalent circuit is used as the basis of the instrument. The exact values of the impedances depend on the type of cable for which the fitting is intended.

Another possible measurement, namely the ratio of longitudinal input to longitudinal output, is not taken because the interpretation of the result as applied to the network presented considerable difficulties which had not been solved at the time at which the instrument was constructed.

A twin-channel pattern transmitter has also been used, which transmits one vertical bar on Channel 1 and two vertical bars on Channel 2, with sharp edges, thus allowing accurate measurements to be made of reflection times (and hence distances) and estimates of crosstalk. This is a most useful instrument for visually checking in a short time that networks are satisfactory. For testing station equipment, pattern and test cards have their uses, but a proper frequency response is necessary to be really sure that everything is in order, assuming that the equipment has been designed and made in the first place to have a satisfactory phase response.

A method of checking the frequency response of a station and several repeaters in tandem has developed using a "wobbulator" feeding its r.f. output via a suitable attenuator to the station r.f. amplifiers and feeding its time base output to the audio input of the pair under test. An oscilloscope is then connected via a suitable pad to the outgoing feeders, or other points, with a resistor-capacitor filter to separate a.f. and r.f.; a.f. is fed to the X amplifier and r.f. to the Y amplifier. Marker pips are injected at the sending end at 2·5, 5·0 and 7·5 Mc/s (fundamental and harmonics). This equipment makes it easy to go from station to repeater plugging into the link and arrestor panels and checking responses, which should be within 1db from 3 to 7 Mc/s with no sharp irregularities.

9. Improved Systems and Future Trends

The future of domestic television reception in the British Isles seems bound up with the probable advent of 625-line definition and, further in the future, the distribution of television pictures in colour. A number of factors are as yet unresolved regarding these probable future changes. For instance, if 625-line definition is used, will it be a duplicate of an existing programme or programmes or will a separate programme or programmes be made available on the new standard? If the latter is the case, it would not be impracticable to fit a systems converter at various television wire broadcasting stations so that subscribers could receive all the available programmes probably initially on the 405-line definition system and later, when the relay system had been modified, on the 625-line system. This is one of the advantages of a wired distribution system of the type described. The actual adaptation of the existing systems to distribute 625-line definition is chiefly a question of increasing the bandwidth. The networks already have a bandwidth extending from 2 to 12 Mc/s apart from differential cable attenuation and therefore no trouble should arise with them. The problem therefore lies in the design of transmitting equipment to generate a carrier channel within this band and then to design receiving units which can successfully demodulate a 6 Mc/s vision bandwidth from this carrier band, without sacrificing the primary characteristics of the system already described; for instance, if it is possible successfully to demodulate a carrier of 3·75 Mc/s with an upper sideband going to 9·75 Mc/s at an economical cost, then it would appear that the network need not be modified in any way—the only modifications would lie in the main station and repeating equipment and, of course, the Viewing Units. Alternative methods of distributing this large video bandwidth may require additional repeaters in the network which is inconvenient but probably not by any means impracticable especially if transistors can be used. If, when the equipment is being re-designed to accommodate this wider bandwidth, enough is known of the proposed methods of distributing colour television in this country then it should be possible to design the station and repeating equipment to fulfil both requirements. At the present moment such ideas are purely speculative but nevertheless certain precautions can be taken in the design of new equipment which have a very good chance of proving useful later.

One use of the television relay network which is probably not appreciated is that it is now possible after obtaining the appropriate Post Office licence, to distribute background music to commercial and industrial undertakings, and this has been done experimentally using a frequency-modulated carrier just below 12 Mc/s. The characteristics of an f.m. system mean that no additional repeaters are necessary although the cable attenuation is much greater than it is at 2·1 Mc/s. A proposed background music system which may be used in this country is arranged to provide two or three basic types of music continuously and with a simple fixed tuned f.m. receiver it will be possible to select with a switch the type required for any particular installation that can be connected to the existing cable networks.

The changing pattern of television with an increased number of programmes with different standards will of course complicate the position but it seems that television wire broadcasting systems are best fitted to deal with these changes. It seems therefore that the more complex domestic television becomes, the more convenient and competitive television wire broadcasting should be.

Some statistics showing the rate of growth of television wire broadcasting in this country are given in Table 5. It can be seen that the industry is growing at an enormous rate: the principal reason for this appears to be that subscribers obtain a good commercial quality of picture consistently and easily at a competitive price, backed by a good service, that is, a service that ensures that the programmes are available to them without more than an hour or two's break in the case of a fault, and with probably not more than one such break in the course of a year.

While the growth of television wire broadcasting in areas of poor reception is astounding, densities of over 40 per cent. of the families being reached in a year or so, densities of some 20-40 per cent. are reached over slightly longer periods in areas where indoor aerials can be successfully used to feed normal television receivers. Since good reception areas predominate in Great Britain, it is essential that television wire broadcasting is able to compete successfully in these areas in order that it may continue to expand.

10. Acknowledgments

The authors would like to thank the directors of British Relay Wireless and Television Limited for permission to publish this paper.

They would also like to acknowledge the technical and other assistance given to them both in the development of the systems described and in the preparation of this paper by the technical staffs of Murphy Radio Limited, Pye Limited, the Helsby Factory of British Insulated Callender's Cables Limited, and British Relay Wireless Limited.

In addition they are indebted to Mr. R. I. Kinross and Rediffusion Limited for information about certain systems described in Section 2, and to the Postmaster-General for the information in Table 5.

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Table 5

Growth of Television Wire Broadcasting in Great Britain.

End of Year	1951	1952	1953	1954	1955	1956	1957	1958
No. of Television Wire Broadcasting Subscribers.	326	1,283	2,686	7,737	28,418	53,637	108,019	196,165
No. of Television Wire Broadcasting Stations.	—	—	—	—	40	59	81	116

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12. Appendix 1: Calculation of Permissible Subscriber Density

Let Cable attenuation be .... a

Main feeder length be L

Vision carrier service area be .... A

Cable impedance be .... Z_0

Maximum number of subscriber (governed by audio load) be .... N

$a = \frac{k_1}{Z_0}$ (for given conductor gauges and cable materials)

$$L = \frac{k_2}{a} = \frac{k_2}{k_1} Z_0$$

$$A = k_3 L^2 = k_3 \frac{(k_2)^2}{(k_1)} Z_0^2$$

$$N = \frac{k_4}{L} = \frac{k_4 \times k_1}{k_2 \times Z_0}$$

Density of subscribers unit/area $= \frac{N}{A}$

$$= \frac{k_4 \times k_1}{k_2 \times Z_0} \times \frac{k_1^2}{k_2^2 \times k_3 \times Z_0^2}$$

$$= \frac{K}{Z_0^3}$$

13. Appendix 2: Comparison of Performance and Cost for TR7 and TR8 Cables

Attenuation TR7/·064″ = 0·65db/100 feet/5 Mc/s.

Attenuation TR8/·064″ = 0·53db/100 feet/5 Mc/s.

Therefore ratio of areas covered for given sending and receiving levels using 0·064 in. cable for bulk of main feeder is approximately

$$\frac{(0{\cdot}65)^2}{(0{\cdot}53)^2} = 1{\cdot}5$$

Number of families in TR8 Group = 1,200 (average in practice).

Therefore number of families in TR7 Group = 800.

Approximate yards of different gauges used per family in a developed group is:

TR8/·064″ 2·7 yards.

TR8/·048″ 6·4 yards.

TR8/·029″ 6·6 yards.

TR8/·018″ 10 yards (subscriber feed only).

Therefore approximate cost of TR8/family = £·28+·49+·26 = £1·03 and approximate cost of TR7/family = £·24+·46+·33 = £1·03.

Cost of station equipment/family is approximately equal to £0·4 for TR8.

Cost of station equipment/family is approximately equal to £0·6 for TR7.

Therefore total cost/family of cable plus station equipment is approximately £1·4 for TR8 and £1·6 for TR7.

Electronic Digitizing Techniques †

by

G. J. HERRING, M.SC. ‡

The introductory paper at a Symposium on Electronic Digitizing Techniques held in London on 18th November 1959.

In the Chair: Dr. T. B. Tomlinson (*Associate Member*).

Summary: Applications in which analogue-to-digital conversion is required are discussed, and it is shown that converters may be broadly classed as mechanical or electronic. Electronic converters are faster but in general less accurate than mechanical. The principles on which electronic converters have been based are discussed, such as voltage feedback, time encoding and frequency modulation. Factors to be borne in mind in choosing a converter for a particular application are reviewed.

1. The Need for Digitizers

Information handling is becoming important in an increasing number of applications, industrial, commercial and scientific. The volume of data to be recorded in any one project is also on the increase, because either this is the raw material on which studies of improved production techniques are based, or in scientific work the cost of an experiment or the inaccessibility of the equipment involved make it necessary to record vast quantities of information so as to cover even unlikely eventualities. If the full value is to be obtained from this data it is virtually essential to use automatic methods of sorting and processing so that the wanted information can be made available in a reasonable time. It is usually the case that further analysis and correlation must be done on the sorted data and again there is considerable time advantage in using computing machines for this task. Another important use of information is in automatic control, where data on the present state of a process or behaviour of a vehicle is used by a computer to determine the changes that must be made by a control unit to produce some desired effect. One final example of information handling occurs in the field of high-speed computing, where it is becoming increasingly useful to be able to couple different types of machines so as to use, for instance, the simulation properties of the analogue computer for some parts of the problem and the accuracy of the digital machine for other parts.

The digital computer is well suited to sorting and correlating data, and its accuracy is of considerable advantage in certain control applications where its relatively low speed of operation is tolerable. Information must be presented to a digital machine as a numerical representation with a finite number of discrete levels, that is, the information must be digitized (encoded) and also quantized. In many cases, however, the measuring instruments produce outputs in continuous analogue form, for example as a shaft rotation, linear displacement, voltage, frequency change, etc. In the automatic control of machine tools, for instance, the sequence of operations may be detailed in digital fashion on punched cards or magnetic tape, whereas the mechanical process itself is continuous. It is necessary to provide a digital representation of the tool movements so that they may be compared with the instructions in the controller computer, then any correction necessary must be transformed back from digital representation

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to tool movements. Again, information relating to the behaviour of a missile in flight is usually generated as a variable voltage by various forms of potentiometer or transducer. This information is used to frequency or amplitude modulate a carrier for transmission to a ground station where, after demodulation, the original information is recovered as a variable voltage. Once again it is necessary to quantize this and convert to digital form if sorting and subsequent processing is to be automatic. In some cases it would be better if the information were generated in digital form in the first place, but very few suitable measuring devices giving a digital output exist yet, and also the transmission of digital data in real time raises problems of using a limited bandwidth to best advantage.

2. Principles of Digitizers

Whatever the application, it is always the case that the usefulness of hybrid information systems is dependent on the performance of the equipment for converting from one form of information to the other. When a reading of the continuous input is taken it is necessary (if the converter is to be of general use) for two pieces of information to be provided, a quantized, digitized measure of the magnitude and also some indication of the time or other independent variable to which the particular magnitude refers. This latter is usually implicit in the rate at which readings are taken and the number of readings since a starting point. In general there will be errors in amplitude and in timing and these must be below the significance level, which in this case means that the errors must be less than half a quantum of the digital number in magnitude and time. Because it takes time to encode continuous information; there will also be a maximum rate at which readings can be taken.

A number of different physical phenomena have been used as the basis of analogue-to-digital conversion techniques and cover a wide range of speeds and accuracies. As well as the performance required for a given application, the choice of method is influenced by the form in which the analogue information is presented. Converters fall conveniently into two main groups which may be termed mechanical and electronic.

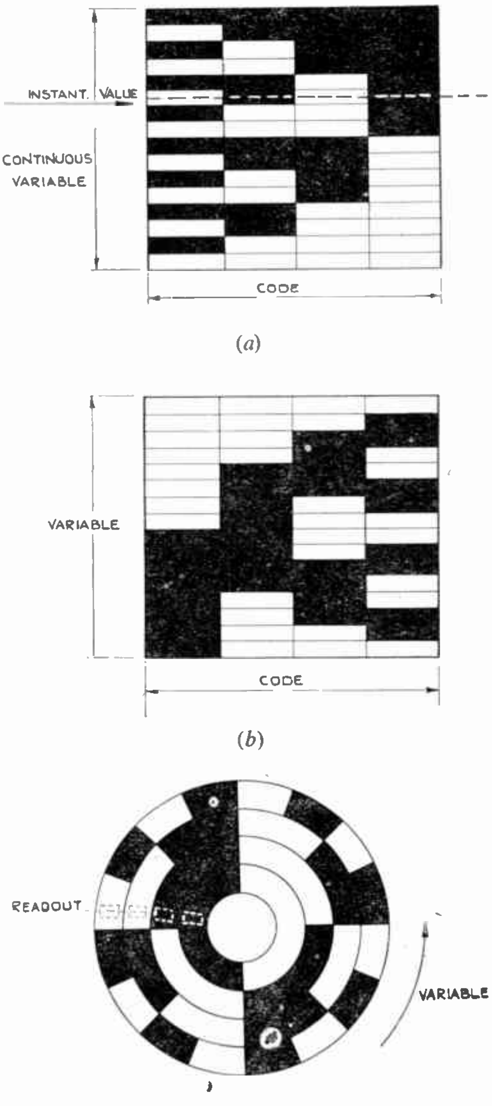

Fig. 1. Forms of binary code (a) Normal binary code; (b) Gray code; (c) Binary disc.

2.1. *Mechanical Analogue-to-Digital Converters*

Mechanical converters are primarily intended to give digital representations of angular or linear position, but may be used to digitize voltages by using that voltage to drive a servo motor, thus producing a shaft rotation which is a known function of the voltage. These type of encoders all have some form of disc which is divided into a large number of segments (for angular motion). Each segment carries a pattern which identifies it uniquely relative to some datum, and at the same time is a numerical representation of the particular position (Fig 1). A pick-off is used to sense relative motion between the rotating disc and a fixed read-out station and to turn the pattern into, usually, a sequence of pulses. Brush contacts are used when the pattern is made of electrically conducting and non-conducting areas, or lights and photo-cells if it is of transparent and opaque areas. With these converters it is necessary to choose the pattern carefully in order to avoid meaningless results at the instant of passing from one segment to the next. For example, a pattern arranged in the form of the Gray code (in which only one digit at a time can change) can cause an error of no more than one quantum whereas a normal binary coded disc can be completely incorrect at these transition points. Other converters using this principle include recording the binary pattern on a magnetic drum, read-out being by a set of magnetic heads, and induction devices in which mechanical motion causes electro-magnetic coupling between rotor and stator elements. Here the windings can be arranged to give positive and negative coupling, resulting in an output voltage pattern like that for the binary disc (Fig. 1), each track representing a stator winding.

Accuracy and resolution to 1 part in 1000 is common for mechanical converters, and this can be increased by using larger plates for the pattern or by using two plates with reduction gearing between. Up to 500 readings per second can be taken with these devices.

3. Electronic Analogue-to-Digital Converters

In general the accuracy of electronic types is not as high as can be achieved with mechanical converters (the limits being set by those parts of the circuit which handle the information in its continuous form) but the rate at which information can be produced is considerably higher. Some of the principles on which converters using only electronic circuits have been based are:—

(a) Voltage feedback systems. Here an internally generated voltage or current is adjusted in steps using a set of switches controlling resistors graded in decimal or binary fashion. When the internal voltage is equal and opposite to the input signal the automatic adjusting process is halted, and the state of the switches gives a numerical representation of the input.

(b) Time encoding. The input voltage is first converted to a time interval by comparing it with a linear voltage sweep or a staircase waveform. A gate is opened when the sweep is started and closed when the input voltage and sweep voltage are equal. During this time interval pulses at a fixed repetition rate are counted and the total is a measure of the input voltage. An alternative is to use a fixed time interval and make the pulse rate a function of the input voltage by using the unknown to control a variable frequency oscillator.

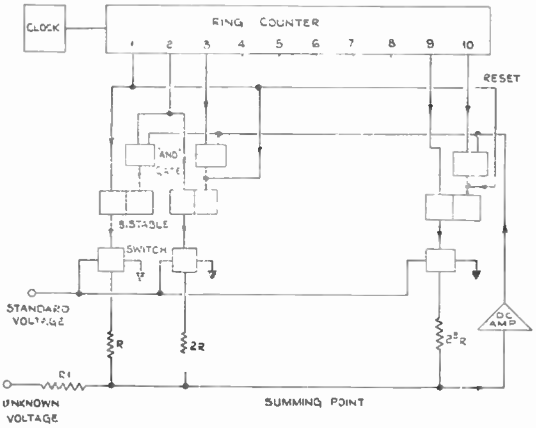

Fig. 2. "Bit-by-bit" converter.

(c) Frequency modulation systems. These are basically time encoding methods, but in some applications the primary information exists as a varying frequency, for example where a crystal is used as a pressure-sensitive element, the frequency of oscillation being a function of pressure on the crystal. By counting cycles over a standard time interval the information is converted directly into digital form.

3.1. *Voltage Feedback Converters*

There are many variations on the theme described in (a) above. Digital voltmeters using banks of stepping switches or relays can give two or three voltage readings per second and accuracies up to 1 part in 10,000 with visual presentation of the result and with facilities for binary coded punched tape output. The circuit arrangements for an electronic device of this type is shown in Fig. 2. A ring counter in which a pulse steps along the stages one after the other controls the sequence of operations. First the resistor R is connected to the standard voltage and all others to earth. If the unknown is the greater this resistor is left on, if it is smaller the d.c. amplifier output, in conjunction with the second pulse from the ring, switches it to earth. In either event the second resistor, 2R, is then switched to the standard voltage and the comparison repeated. When the sequence of operations is complete the bistable circuits hold the binary representation of the unknown voltage and this number can be read out into the input register of a digital computer. A transistorized converter operating on this principle has been constructed for use in missile testing which has a volume of about 200 cubic inches. It can take up 6,000 readings per second, each to an accuracy of 14 binary digits. If a precise measurement of a rapidly changing input at a known time is required, then it is necessary to provide circuits to hold the value of the unknown voltage at that time, until the converter completes the chain of comparisons. This staticizer must be drift-free to the accuracy required by the conversion. Alternatively, if the input is allowed to change, then the final number in the register will correspond to the value of the input voltage at some indeterminate time during the setting-up period.

Another method of programming the switches for the standard voltages is by a reversible counter so that the internally generated voltage rises or falls in a series of equal discrete steps. The number in the counter is made to increase or decrease dependent on the sign of the output from the error detector, so controlling the magnitude of the internal voltage. When equality between this and the input voltage has been reached the counter remains stationary. Then any change in the input voltage is followed by the number in the counter either increasing or decreasing one unit at a time until equality is again reached. Although the method is inherently slow for rapidly changing inputs, in that the state of the counter may increase or decrease by only one unit per clock pulse, an accurate read-out can be made at any time for slowly varying inputs. In this system there is an overall feedback loop so the converter operates as a servo-mechanism. As this feedback loop effectively contains an integration (due to the counter) the output from the error detector is a pulse rate proportional to the rate of change of the input voltage and therefore is in the correct form for feeding to an incremental computer, for example a digital differential analyser.

3.2. *Time Encoding Converters*

The method of time encoding described in (b) and illustrated in Fig. 3 has the advantage of requiring little logical circuitry. The limiting factor in accuracy is the linearity of the voltage sweep, for which a figure of 0·05 per cent. is achievable. The sampling rate is limited by the speed of operation of the pulse counter and the number of digit places desired. For example, the time required for 10-digit accuracy at 5 Mc/s pulse rate is 200 microseconds for reading which, allowing time for re-setting, limits the reading rate to about 2,000 per second.

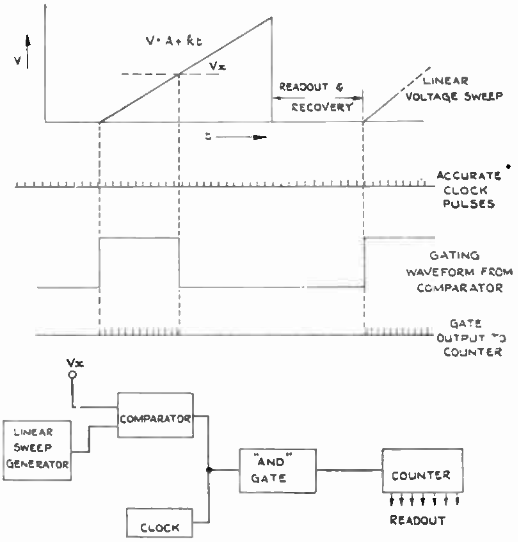

Fig. 3. Time encoder.

3.3. *Frequency Modulation Converters*

The same limitations on sampling rate apply when the primary information is a varying frequency. Once again a large number of cycles must be counted if the value of the variable is to be established with reasonable accuracy, which means that the standard time interval must be long compared to the period of the frequency carrying the information. As a result the answer represents the mean value of the variable during the interval and therefore high frequencies in the information may be filtered out by the sampling process.

The codes produced by the converting elements of the digitizers described above may be normal binary, cyclic progressive binary, or binary coded decimal. The coding arrangement is flexible, however, and in certain cases one code may be transformed into an alternative representation by a suitable conversion matrix. In general the ambiguity difficulties associated with mechanical converters do not arise, so that the normal binary code may be used thus making it easier to feed the information direct to a digital computer.

4. The Choice of Converter

Some care must be exercised in choosing a converter for a particular requirement, and the way in which the data is to be analysed must be considered at an early stage. Analogue-to-digital converters destroy the continuous nature of the input information as they only take spot readings on receipt of an initiating pulse. As more than two readings per cycle are necessary in order to identify a sine wave, the available sampling rate sets a limit to the bandwidth of information that can be handled. For example, in the study of servo systems the spectral content of the output due to a known input function or combination of functions is frequently required. A converter must be chosen which has a high enough sampling rate to take readings at twice the highest frequency of interest. As in all sampling systems, it is necessary to interpose filters between the raw data and the sampling mechanism to ensure that no significant power is present at frequencies greater than half the sampling frequency, otherwise the spectrum is distorted. A realistic assessment of required accuracy must also be made, taking into account the level of random noise on the signal and the possibility of improving the accuracy of the ultimate answer by smoothing operations on the digital data. It is not sufficient to take the fastest and most accurate converter available because this can easily give rise to an embarrassingly large volume of data, requiring many more hours computer time to sort and correlate than should be necessary and thus at best causing an inordinate delay in assimilating results.

A Simple Analogue to Digital Converter with non-linearity Compensation†

by

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A paper read during a Symposium on Electronic Digitizing Techniques, held in London on 18th November 1959.

In the Chair : Dr. T. B. Tomlinson (*Associate Member*).

Summary : The converter combines a high-speed electromechanical switch with a transistor switching amplifier. The electromechanical switch is a motor driven uniselector and a chain of high stability resistances is connected around the two levels of the switch to form a potential divider. A signal from this potential divider is subtracted from the unknown input voltage in the range 0 – 10 volts and the difference appears across the input of the switching amplifier. When balance is reached the amplifier signal reverses in sign and the switching amplifier energizes a high-speed relay to stop the motor uniselector. Balance is achieved in $\frac{1}{2}$ second and the accuracy of digitizing is 1 part in 100. The converter is extremely flexible in output coding and gives complete non-linearity compensation for any function with suitable connections on the spare levels of the motor uniselector. It is very simple and cheap to construct and can be used to digitize from most types of potentiometric recorder.

1. Introduction

The value of punched tape and punched cards as the media for data recording has been increasingly realized in the steel industry, since the original work of Nettell up to 1954.§ The time-consuming analysis of chart records can be eliminated, and the compatibility of the digital form of recording with business machines and digital computers is invaluable in many investigations. On the production side too, slowly but surely managements are realizing the value of a concise statement of plant variables produced by an automatic typewriter or other printout device.

Several electromechanical analogue-to-digital converters have been described, usually using relays or uniselectors for switching resistors in comparison circuits. Such devices give a linear relationship of digital output to analogue input, and any correction for non-linearities, such as are introduced by thermocouples and pyrometers, is carried out in the analogue circuit before conversion. Setting up the converter for given non-linear laws is quite a skilled job, and it is often difficult to maintain the accuracy of which the rest of the equipment is capable.

This paper describes a simple analogue-digital converter in which the non-linearities are corrected on the digital side and by this means any non-linear law which is commonly met in practice can be compensated with accuracy up to the limit set by the resolution on the digital output.

2. The General Design

The analogue-to-digital converter is built around the motor uniselector, a cheap motor-driven switch mass-produced for the General Post Office. When used with single-ended

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‡ The British Iron and Steel Research Association, South Wales Laboratories, Sketty Hall, Swansea.

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§ D. F. Nettell "Automatic recording and analysis of data using teleprinter technique." *Instrument Practice*, 8, pp. 975-80, 1078-82, November and December 1954.

wipers, the switch has 104 outlets which are scanned by wipers in $\frac{1}{2}$ second.

In this application a series of 100 high stability resistors are connected around the bank of the motor uniselector so as to form a potential divider with 100 steps. A d.c. voltage is applied to the potential divider, and the voltage between the wiper and one end of the potential divider is compared with the voltage to be digitized. The switch is run continuously until the difference signal changes polarity; a transistor balance detector then operates a high-speed relay to stop the motor uniselector.

With 104 outlets the motor uniselector has a total of eight levels, seven of which are available for coding the digital output. The non-linear law to be compensated determines the configuration of connections on these levels, and a total of seven digits is available in the output. These can be arranged as one three-digit number and one four-digit number, giving the facility for independent non-linear compensation of two different input signals.

The flexible arrangement for coding the output also allows for variables with any reasonable maximum and minimum values. Thus, in the particular steelworks' application of a strip pyrometer, temperatures might be required in the range 1200°F–2500°F, and it is a simple matter to wire the motor uniselector to cater for a non-linearity between these limits.

3. Details of the Equipment

3.1. *The High-speed Motor Uniselector*

The motor uniselector shown in Fig. 1 is an inexpensive motor-driven rotary switch, mass-produced in Great Britain for the G.P.O. and foreign telephone companies, and encountered hitherto mainly in automatic telephone exchanges.

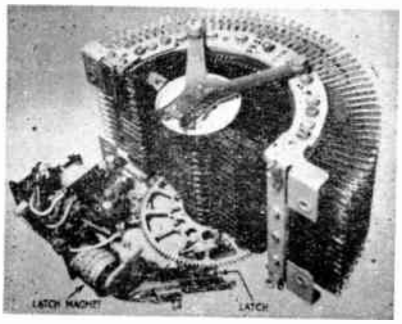


Fig. 1. The motor uniselector.

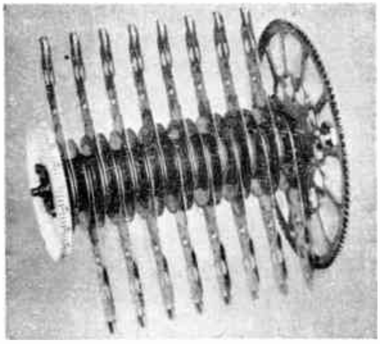


Fig. 2. Arrangement of single-ended wipers.

The basic element is a row of 52 contacts arranged in a semi-circle. In a typical motor uniselector there are sixteen such rows or "levels" arranged side by side. When the uniselector motor runs, each level is swept by a wiper that engages with each of its 52 contacts or "outlets" in turn. Wipers may be bridging or non-bridging. The sixteen wipers, insulated from one another, are aligned with each other, usually in two sets of eight, 180 deg. apart, so that the wipers of each set always engage at the same time with corresponding contacts in each of eight levels. Such an arrangement of "single-ended" wipers, shown in Fig. 2, makes a 16-level, 52-way switch effectively an 8-level switch with 104 positions or outlets, and it is in this form with bridging wipers that the motor uniselector is used in the present analogue-digital converter. Merits of the motor uniselector include its high speed of operation (it rotates through 200 positions in one second), its large number of contacts, and the fact that it can be stopped from full speed at any "marked" position. In the usual way the "marking" of a motor uniselector merely involves connecting one contact of the appropriate position to positive. In its simplest form the circuit for stopping a motor uniselector at a given outlet is shown in Fig. 3. While the switch is running the high-speed relay is de-energized and the latch magnet energized through normally closed contacts on the high-speed relay. The latch itself can be seen in Fig. 1. It has three teeth which, while the latch magnet is energized, are held from engagement with the gear wheel of 104 teeth attached to the wiper assembly. Contacts on the latch, also visible in Fig. 1, are connected in the motor circuit.

As soon as the wipers reach the marked outlet the high-speed relay is energized and the latch magnet is de-energized. The timing is such that the latch drops cleanly into engagement and the uniselector stops at the marked outlet. The movement of the motor uniselector to a marked outlet is called "searching", and the circuit associated with the high-speed relay is called the "searching circuit".

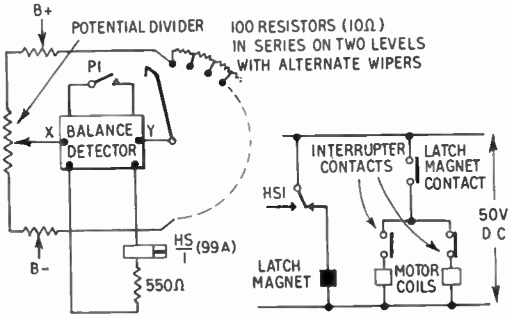


Fig. 3. Simple circuit for stopping and holding a motor uniselector at a given outlet.

3.2. *The Motor Uniselector in the Converter Circuit*

The motor uniselector stopping circuit as used in the present application differs from the conventional method only in that the marking connection is omitted and replaced by a balance detector and a chain of high-stability resistors, shown schematically in Fig. 4. The resistors are connected between adjacent outlets on two levels of the uniselector, which have opposite single-ended wipers, so as to form a continuous 100-way potential divider across the supply. In Fig. 4 the input signal is a voltage arising from a potential divider connected to form a bridge with the motor uniselector potential divider, but in other applications the potential divider is eliminated and voltage fed direct to the detector circuit. In either case the circuit operates as follows. As a starting point it will be assumed that the balance detector is maintaining the high-speed relay in the de-energized condition and the motor uniselector is therefore turning. As soon as the voltage between the wiper Y and the point B – becomes less than the input voltage (in this case between X and B –), the high-speed relay becomes energized by the balance detector. The motor uniselector therefore stops when the potential XY reverses polarity in the sense to make Y negative in relation to X. The detector is sensitive enough to discriminate between single steps on the uniselector and the position of the motor uniselector after the detector operates thus represents the position on the input potential divider to ± $\frac{1}{2}$% approximately (i.e. 100 positions). After the uniselector stops, it remains stationary until the trigger is reset manually or by a relay. Immediately after the detector has been reset, the uniselector rotates until Y becomes more negative than X again. The detector does not respond when X becomes more negative than Y.

3.3. *The Balance Detector Circuit*

Figure 5 is the circuit diagram for the d.c. transistor trigger amplifier which operates the high-speed relay HS/1.

VT1 and VT2 form a voltage comparison circuit operating normally in one of two stable states :

(a) When the potential Y is more negative than X; in this condition VT1 is switched on and VT2 switched off.

(b) When X is more negative than Y; then VT1 is off and VT2 on. The diodes protect VT1 and VT2 against over voltage.

The high-speed relay is required to become

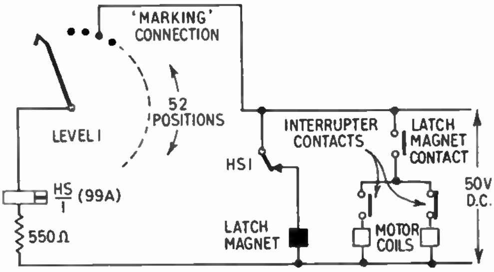


Fig. 4. Potentiometer circuit.

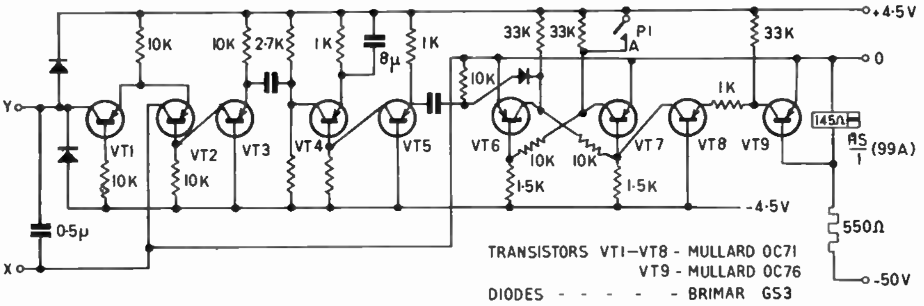
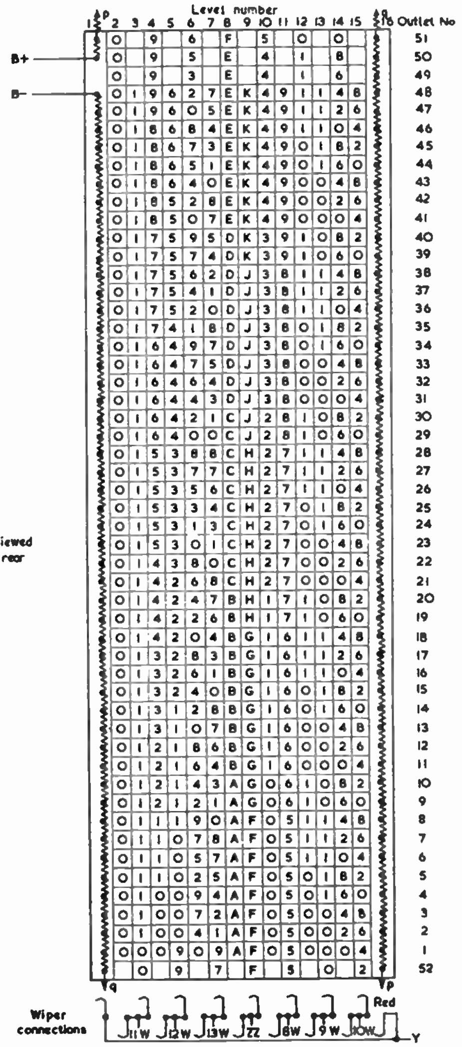


Fig. 5. Circuit diagram of the balance detector.

energized when Y becomes more negative than X (i.e. when VT2 switches off) and the sequence is as follows: When VT2 switches off, the emitter follower VT3 passes on the voltage change at lower impedance to the a.c. voltage amplifier VT4. The positive pulse appearing at the collector of VT4 is passed through the emitter follower VT5 to the stay-put (bistable) pair VT6 and VT7. It must be assumed that at this stage VT8 is switched off and VT6 switched on. The arrival of the pulse from VT5 switches VT7 on and VT6 off. The voltage change on VT7 is passed through the impedance lowering emitter follower VT8 to VT9 which is thereby switched off. Hitherto VT9 has been holding HS/1 de-energized by maintaining a short circuit across the coil but with VT9 now switched off, the relay becomes energized and the motor uniselector stops. The reset button is used to switch VT7 off again and in turn to de-energize HS/1 and allow a further search to be made.

3.4. *The Digital Output*

The outlets of the motor uniselector are shown in Fig. 6, as they appear when viewing the switch from the rear. Each square in the drawing represents one outlet. Because of the use of single-ended wipers the switch has effectively 104 outlets and eight levels. Levels 1 and 16 are thus effectively one level and used for the potential divider. Levels 2–15 inclusive are used for the digital output of these, levels 2 and 3 forming effectively one level, 4 and 5 another, and so on. The numbers in the squares relate to a set of ten coding wires, numbered 0–9. These are connected to the magnets of an



Level number														
2	3	4	5	6	7	8	9	10	11	12	13	14	15	Outlet No
0		9		6		F		5		0		0		51
0		9		5		E		4		1		8		50
0		9		3		E		4		1		6		49
0	1	9	6	2	7	E	K	4	9	1	1	4	8	48
0	1	9	6	0	5	E	K	4	9	1	1	2	6	47
0	1	8	6	8	4	E	K	4	9	1	1	0	4	46
0	1	8	6	7	3	E	K	4	9	0	1	8	2	45
0	1	8	6	5	1	E	K	4	9	0	1	6	0	44
0	1	8	6	4	0	E	K	4	9	0	0	4	8	43
0	1	8	5	2	8	E	K	4	9	0	0	2	6	42
0	1	8	5	0	7	E	K	4	9	0	0	0	4	41
0	1	7	5	9	5	D	K	3	9	1	0	8	2	40
0	1	7	5	7	4	D	K	3	9	1	0	6	0	39
0	1	7	5	6	2	D	J	3	8	1	1	4	8	38
0	1	7	5	4	1	D	J	3	8	1	1	2	6	37
0	1	7	5	2	0	D	J	3	8	1	1	0	4	36
0	1	7	4	1	8	D	J	3	8	0	1	8	2	35
0	1	6	4	9	7	D	J	3	8	0	1	6	0	34
0	1	6	4	7	5	D	J	3	8	0	0	4	8	33
0	1	6	4	6	4	D	J	3	8	0	0	2	6	32
0	1	6	4	4	3	D	J	3	8	0	0	0	4	31
0	1	6	4	2	1	C	J	2	8	1	0	8	2	30
0	1	6	4	0	0	C	J	2	8	1	0	6	0	29
0	1	5	3	8	8	C	H	2	7	1	1	4	8	28
0	1	5	3	7	7	C	H	2	7	1	1	2	6	27
0	1	5	3	5	6	C	H	2	7	1	1	0	4	26
0	1	5	3	3	4	C	H	2	7	0	1	8	2	25
0	1	5	3	1	3	C	H	2	7	0	1	6	0	24
0	1	5	3	0	1	C	H	2	7	0	0	4	8	23
0	1	4	3	8	0	C	H	2	7	0	0	2	6	22
0	1	4	2	6	8	C	H	2	7	0	0	0	4	21
0	1	4	2	4	7	B	H	1	7	1	0	8	2	20
0	1	4	2	2	6	B	H	1	7	1	0	6	0	19
0	1	4	2	0	4	B	G	1	6	1	1	4	8	18
0	1	3	2	8	3	B	G	1	6	1	1	2	6	17
0	1	3	2	6	1	B	G	1	6	1	1	0	4	16
0	1	3	2	4	0	B	G	1	6	0	1	8	2	15
0	1	3	1	2	8	B	G	1	6	0	1	6	0	14
0	1	3	1	0	7	B	G	1	6	0	0	4	8	13
0	1	2	1	8	6	B	G	1	6	0	0	2	6	12
0	1	2	1	6	4	B	G	1	6	0	0	0	4	11
0	1	2	1	4	3	A	G	0	6	1	0	8	2	10
0	1	2	1	2	1	A	G	0	6	1	0	6	0	9
0	1	1	1	9	0	A	F	0	5	1	1	4	8	8
0	1	1	0	7	8	A	F	0	5	1	1	2	6	7
0	1	1	0	5	7	A	F	0	5	1	1	0	4	6
0	1	1	0	2	5	A	F	0	5	0	1	8	2	5
0	1	0	0	9	4	A	F	0	5	0	1	6	0	4
0	1	0	0	7	2	A	F	0	5	0	0	4	8	3
0	1	0	0	4	1	A	F	0	5	0	0	2	6	2
0	0	0	9	0	9	A	F	0	5	0	0	0	4	1
	0		9		7		F		5		0		2	52

Fig. 6. Motor uniselector coding.

electric typewriter or via a matrix to the coding magnets of a tape perforator. Read-out is effected by connecting positive in sequence to the appropriate wipers. Levels 2–7 are used for an output representing temperature in the range 0–1,670. (The last digit is always taken to be zero and does not appear on the motor uniselector.) Levels 8 and 9 are used for automatic histogram recording. The range is divided up into ten sub-groups (labelled A–K), and after each operation of the converter a pulse is routed through the wipers of these levels to record in one of ten counters associated with the sub-groups. Levels 10–15 are used for the digital recording of weight from a weighbridge. In this application a low torque potential divider was attached to the pointer of a scales and this was connected bridge-fashion to the motor uniselector potential divider. The law was linear in this case.

4. Accuracy

The accuracy of the instrument for single readings is limited by the resolution of the digital output (100 distinct values), and tests have shown that the accuracy of the conversion is such as to warrant this degree of discrimination on the digital side. Tests on the prototype using a precision 1,000-ohms potential divider for the input signals, and a 50-volts bridge supply, showed that the changeover points between consecutive output readings in no case departed from the correct values by more than ±0·15%. This figure could probably be improved by grading the resistors for the motor uniselector potential divider. The accuracy of the changeover points is extremely important in applications where an average of a number of readings is required.

Temperature drift is of course present due to the transistors in the comparator of the balance detector, and this can be minimized by arranging for the input to be of low impedance. In a test, again using a 1,000-ohms input potential divider and a 50-volts bridge supply, the temperature drift between 22°C and 44°C was found to be less than 1 part in 1,000. This was to be expected since 1 part in 1,000 represents a variation of 50 millivolts at the input to the balance detector, which is much greater than the expected drift for a balanced d.c. comparator.

The prototype converter was used continuously for a period of six months in a steelworks, during which time it received no maintenance. The application involved calculating aggregates of weighbridge recordings. Over a period, the overall accuracy of aggregates was found to be better than ±·1%.

5. Reliability

The component most suspect from the point of view of reliability might be thought to be the motor uniselector, but experience has shown this to be very dependable and to require very little maintenance. Motor uniselectors used in more conventional circuits are vital components in automatic controls at present operating on rolling mills in this country. The fact that these switches operate over long periods in the adverse conditions in a steelworks, and in circuits where dependability is vital, is an adequate testimonial for the switch. The makers state that no maintenance is required during the first million operations, and at the end of this time some adjustment is required to the latch mechanism. This represents a maintenance problem no worse than for relays, and certainly less severe than for the electro-mechanical read-out devices usually associated with a converter.

6. Conclusions

The motor uniselector analogue-to-digital converter provides an inexpensive means of obtaining punched tape or printed records of industrial variables.

The facility for compensation for non-linearities is valuable in thermocouple and pyrometer applications, and could be useful for flow measurements in which a square law is involved.

In future applications the converter could be used in conjunction with a chain of resistors graded in values to give a scale with "open" and "cramped" positions. Logarithms of variables can also be recorded when this facilitates subsequent computation.

The Step-by-Step Potentiometer as a Digitizer †

by

G. P. TONKIN, B.SC. ‡

A paper read during a Symposium on Electronic Digitizing Techniques, held in London on 18th November 1959.

In the Chair : Dr. T. B. Tomlinson (*Associate Member*)

Summary : A digital potentiometer-type millivolt recorder is described in which resistances are successively paralleled by relays to modify the current in a standard resistor and hence the p.d. across it. This process progresses automatically until balance is detected, when the relay state is transferred into a store. Three separate digitizing channels are employed in series-parallel to give a speed of 25 characters per second at a tape punch, or 10 characters per second with a simultaneous typed record. Alternatively, single chosen channels can be brought out on a visual figure display. The equipment can be provided with inputs as multiples of 72 channels with a maximum sensitivity corresponding to 15 mV full scale at 200 ohms source impedance. The resolution is 1 part in 1000 of full scale. The instrument is of bench-top size and is suitable for measurements in multiple installations of resistance strain gauges, thermocouples and other transducers of similar output.

1. Introduction

The aircraft industry has for many years measured temperatures electrically, and about twenty years ago, began to be interested in the wire resistance strain gauge. Fundamental instruments were naturally the first to be considered for measuring the d.c. millivolts of the former and one-per-cent. resistive strains of the latter. Much valuable work was, and is, done with instruments of the classical form, such as Poggendorf's potentiometer or Wheatstone's bridge, often extended to include the a.c. versions with amplifier and detector in place of galvanometer.

Meanwhile, the process-instrumentation industry has made notable advances in automation of the basic instruments. Slide-wire wipers are motor-driven to balance from detector-amplifiers of high gain : stability in the d.c. case is achieved by synchronous input chopping, while automatic standardising at intervals with a standard cell produces a very sophisticated instrument capable of half-millivolt full scale spans.

Many of these instruments have found application in laboratories and test rigs. The addition of digital shaft transducers has given further possibilities for data logging, and most of us are familiar with a multiple system of such instruments, energized from a variety of sources, but periodically sampled and recorded centrally for further processing.

Whilst admirable for these purposes, the "chart recorder" type of instrument did not quickly displace the manual type in multiple strain-gauge or temperature installations. Here the desire for improvement was in the direction of speed, and the average 2 sec balancing time did not commend itself as a great advance.

What was needed was an instrument which would work right up to the maximum speed of conventional logging devices — say the twenty-five characters/second of the paper tape punch. It should, of course, have digital output, an accuracy considerably better than one per

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cent. of the normal millivolt or low-strain ranges, and be capable of sampling large numbers of transducers.

2. The Principle

Work began at Bristol in 1953, and a model step-by-step bridge using Post Office type 3000 relays was produced. The essential features of the system are a bank of ascending order resistors which can shunt a bridge arm via contacts of individual relays, an out-of-balance detector in the form of sensitive relay, and a programming device (uniselector) to call successively the shunting relays in ascending resistance order until balance is achieved. The much increased speed was found to be limited only by the relay characteristics, while use of binary resistance ratios afforded direct output in binary coding from auxiliary contacts.

During the years following, workable units of equipment were produced with the additions of amplifier-detectors and multiple input selectors. Termed the Multichannel Digital Millivolt Recorders, the first of these had a 300-channel capacity for a.c. 800 c/s energized strain bridges, while the second was for 240 channels of d.c. sources, primarily thermocouples. About this time others were working in the field† and Sturgeon of the R.A.E. has recently published an account of work done for a very similar application.‡

To achieve the desired sampling speed, it was realized early that a single automatic step-by-step potentiometer was inadequate. Accordingly three such "digitizers" were used together, and on the basis of decimal reading at three characters plus space per channel, each had to cope with two complete channels per second to achieve twenty-four characters/second for the punch.

Much has been said for and against decimal coding. It was eventually preferred over the binary since digital decimal plotters were available and permitted a running monitor of results by typewriter and simplified the use of five-hole paper tape. The disadvantages are well-known: no direct applicability to computers, and waste of bits.

Some experience gained with these first two models led to the Mk. III design which will now be described. No equivalent apparatus had appeared on the market, and it was resolved to engineer the equipment to good commercial standard. Transistorized amplifiers had already been a feature of the Mk. II: the size was to be reduced for transportability, and certain known functional difficulties alleviated.

3. The Equipment

The specification of the Mk. III Recorder is given in Appendix. It will sample automatically 288 channels of thermocouple, d.c. strain gauge, or other similar source of small voltages complying with a maximum source impedance, and will convert the signal voltages to a three-digit decimal form suitable for operating a tape punch or electric typewriter.

A unit/sub-unit system of construction is used, comprising selector units, digitizers in a chassis, control unit, output unit, display unit, and power supply. These are housed in a 3 ft. 6 in. high by 19 in. wide rack.

Figure 1 shows a block diagram of the system. It will be seen that four selector units, each of 72 channels, make up the input system: any number of these up to four may be used as required. Three channels are sampled at a time by 8-bank uniselectors, and passed simultaneously to the trio of digitizers. The sampling sequence can begin at any desired selector unit, or particular channels may be chosen for repetition.

The digitizing operations, with sampling advance and read-out, are timed by the control unit, in which a relay ring generates suitable actuating pulses. The three digitizers are called to function in parallel during the first cycle of the ring, with transference of data into adjacent stores and digitizer clearance. During the subsequent cycle the three stores are read-out serially while the digitizers operate upon the next three samples.

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† H. Fessler, "Summarized proceedings of a conference on stress analysis—Cranfield, September, 1956," *Brit. J. Appl. Phys.*, **8**, pp. 307-14, August 1957.

‡ J. R. Sturgeon, "A multipoint digital strain-gauge recorder," *Trans. Soc. Instrum. Tech.*, **11**, No. 4, pp. 213-9, December 1959.

In addition to tape punch and typewriter, a visual "Nodistron" tube display is provided to permit single channel checks with more rapid readability than the typewriter can provide. Both it and the typewriter are pure decimally operated, and, since also tape coding requirements vary, the binary-coded-decimal inherent from the digitizer is converted to pure decimal before leaving the store. An output unit then intervenes to set up the tape code required.

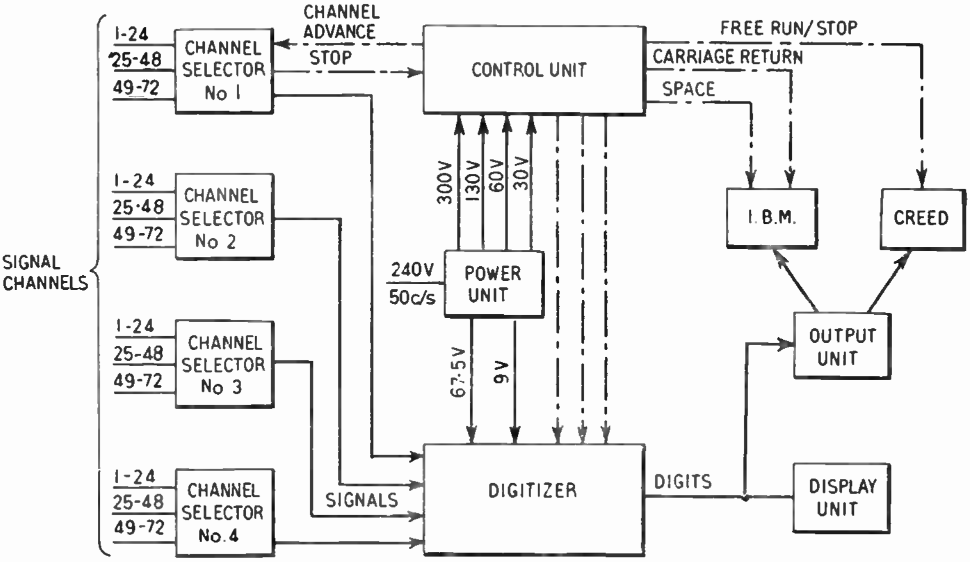

Fig. 1. Block diagram of the multi-channel millivolt digital recorder.

4. Unit Details

Apart from the timing of the system, the kernel is the digitizer, and this, in turn, relies upon its sensing amplifier sub-unit or detector. This comprises two push-pull stages of d.c. amplification followed by a single-sided long-tailed pair and a Schmidt trigger actuating a Carpenter polarized relay. OC 71 transistors are used throughout, and with a common heat-sink stability corresponding to a little over 1 microvolt per minute is achieved. A galvanometer is provided to give external indication of amplifier balance, a control for which is also brought out to front panel for adjustment purposes between runs. There are three relay-resistor sub-units per digitizer, differing only in the decimal orders of the resistance shunts for the three digit system.

The simplified mode of connection for these units to function as potentiometers is given in Fig. 2. The 10 ohms standard resistance R1 makes the potentiometer with selected digitizer resistances, which are all at least several orders of magnitude greater. Each of these is called in turn, and holds only if the detector polarized relay does not drop out. Ultimately all twelve are interrogated, and remaining connected are those which cause the current i_D to be below threshold at the last digit. It is important to note that the back contacts of each relay are used to maintain the total current flow i_E as a constant, and hence the potential across R5 is maintained.

The 5211 code used had some advantages inherent in a quinary system for earlier equipments, but is retained here for other reasons. Primarily it happens by chance that the resistance ratios can be satisfied with selected preferred values. The fact that its arithmetical sum does not exceed nine also avoids a build-up of inevident logical errors arising from a very occasional relay hold failure.

The store sub-units are of similar construction and incorporate a simple "tree" decoding circuit. In turn these feed the display and output units, in the latter of which, besides providing the output connector for typewriter, a recoding matrix for punch code and punch connector are incorporated. The complete digitizer unit is shown in Fig. 3.

Digital equipments of comparable speed have often been controlled by uniselectors, but experience had shown that 50 pulses/sec was to be regarded as a maximum rate for consistent operation of these components. With the necessity for 25 full operations, i.e. digit generation, per second and requiring smaller subdivisions, a relay-operated ring timer is here used. Further, the limit above mentioned for uniselectors assumes half-sinewave frequency locked operation, whereas a requirement here is change of speed to suit output device.

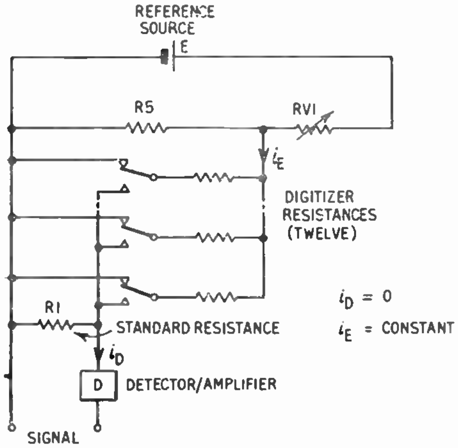

Fig. 2. Action of digital potentiometer.

The ring has fourteen sections, each consisting of two miniature relays, supported by sixteen others for auxiliary and supervisory purposes. A complete sub-sequence employs one cycle for digitizing and another for read-out, but the next digitizing operation is in progress during the second cycle. Thus the sub-sequences proceed, three channels being recorded at a time, until the final occupied group of channels is digitized. The control system then adds one further cycle to extract the last stored data, and stops. Included in each three sub-cycles is a "space" digit instruction, which is applied both to typewriter and tape punch to separate the channels, but the third can be arranged to return the typewriter carriage in order to provide three column tabulation of numbers of channels for which one typed line is insufficient.

Power supplies are partly from a.c. mains, dry batteries being used where stability and purity are critical.

The preferred output devices are an I.B.M. electric typewriter (as modified by Automatic Telephone and Electric Ltd.), and a Creed type 25 tape punch.

The complete system is for bench-top use, as seen in Fig. 4. The main equipment is a two-man load, and may be carried easily in a light van or brake with its recording devices.

5. Operation

A feature of the equipment is the variety of modes of operation permitted by the external controls. Beginning with the selector unit, a switch provides a choice between manual and automatic channel selection, with a homing position for zero reset purposes. In the manual position any desired one of the 24 three-channel groups can be demanded with the 25-position switch: the setting of this switch in the "auto" condition determines the point at which the scan shall cease. A toggle switch is fitted for operation should the selector unit be the last of a

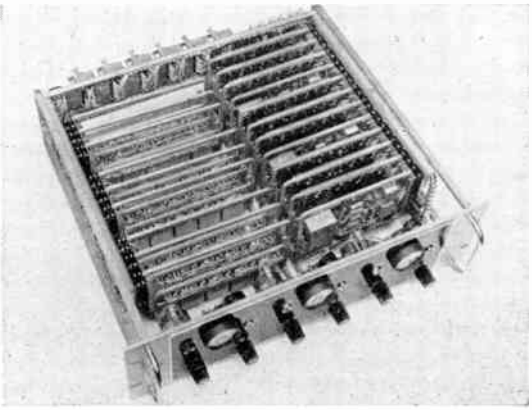

Fig. 3. Assembly of digitizer unit.

chain, so that the stop circuits in it are prepared.

To enable a single channel within a group to be selected, a switch on the control unit calls either for auto operation or a chosen digitizer. In the latter case, coupled with a manually chosen selector group and the output switch to "display," the Nodistron tubes are illuminated for a particular channel value. The output switch also sets the other types of output listed in the specification. Besides start and stop switches, and a "free run" switch to eject a length of unpunched tape, a rotary switch decides which of the four selectors is to operate first, thus giving latitude in the ordering of the investigation on hand.

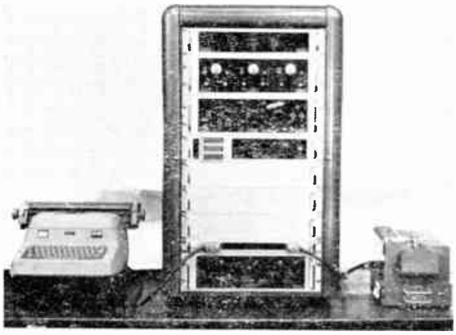

Fig. 4. The complete instrument system.

Mention has been made above of the amplifier balance controls and meters for the digitizers. Step and fine sensitivity adjustments are also provided, with jacking points for standardizing by standard voltage source.

Normal practice is to sort and process punched tape as an elementary operation in a digital computer, applying factors as required by calibration. Other necessary numbers are inserted by analogue means as channels.

6. Discussion

Something has been said above on the design philosophy for the instrument, together with the previous experience which led to it. The art does not stand still, however, and by the time any instrument reaches the stage where it is no longer a laboratory but a production item as has this, many critical thoughts and new ideas have arisen.

There is no doubt that one would wish to look forward to a better low-level sampling switch than the uniselector. It is possible that some improvement in contact potential errors can be achieved by gold plating, but a more fruitful field may be multiple precision instrument switches actuated by rotary solenoids. This problem must be tackled if higher sensitivities are to be attempted.

Some problem arises with the digital units themselves for increasing sensitivity: the relay contacts merely become an even smaller proportion of shunt resistance, but these resistances can become prohibitive in size. The present detector-amplifier, albeit remarkably stable for its size, is the other limiting factor for sensitivity improvement. Considerable sophistication of this would probably give another order of magnitude, at the expense of size, simplicity and digital stability. This would be an important step, since the equipment would then be open to use for a multitude of low strain tests and lower temperature applications.

Indications are that a controlled temperature system on the input stage to the amplifier produces the necessary improvement, and it is hoped that the effect is sufficiently consistent for production.

Speed in operation is the other most desired improvement, and it should be said at the outset that no large increases are possible with this type of equipment. Though there could be an increase in number of parallel digitizers, relay timing imposes a limitation for serial readout, quite apart from the output devices. Consideration has been given to use of the "gang punch," but design becomes top-heavy and expense high. There is and will be, it is felt, a requirement for such medium-speed recorders as this in process monitoring for some time to come. Where its speed is quite inadequate, there is no alternative but recourse to semi-conductor timed and operated digitizers, with all that they mean in terms of high voltage level operation, precision input amplifiers and the low level switching problem mentioned above, or multiplicity of equipment. Many are working in this field, and we look with interest to see what may be offered to us in the future.

7. Acknowledgments

In presenting a paper on equipment the work for which has been done largely by others, it is especially necessary that they should have their contributions recognized. Early design was done by A. K. Hathway, with J. Yard doing subsequent development in the Instrumentation Laboratories of Bristol Aircraft Limited, to which Company thanks are due for permission to publish this paper. Acknowledgments are due also to Messrs. Southern Instruments Ltd. who are associated in the project.

8. Appendix: Specification of the Recorder

Number of channels: 288 max. in units of 72.

Signal input: Thermocouple operation, 15mV to 50mV full scale. Strain gauge operation, 2% dR/R or 5% dR/R full scale.

Signal source impedance: 200 ohms max. (120 ohms strain gauges recommended).

Strain gauge energizing d.c. voltage: External.

Number of decades: 3.

Accuracy: 1 part in 999 of maximum signal level.

Channel selection: Automatic or manual.

Read-out systems:

(1) Paper tape punch. (Code as required).

(2) Electric typewriter.

(3) Tape punch and typewriter.

(4) Visual numeral display.

(5) Systems 1, 2 and 3 may be operated direct from keyboard.

Read-out speed:

Typewriter, 120 channels/min.

Tape punch, 300 channels/min.

Power supply: 110/200-250V. 50-60 c/s. 6 internal 4½V dry batteries.

Power consumption: 250 watts.

Dimensions: 3 ft 6 in. × 2 ft 0 in. × 1 ft 9 in.

Weight: 280 lb for 288 channels less read-out machines.

An Analogue-Digital Converter with Long Life †

by

R. L. G. GILBERT, PH.D. ‡

A paper read during a Symposium on Electronic Digitizing Techniques held in London on 18th November 1959.

In the Chair: Dr. T. B. Tomlinson (*Associate Member*)

Summary: An instrument has been developed for converting small voltages representing a measured parameter into a digital representation of the parameter. Features of the instrument include a high input impedance, extremely long service-free life (due to lack of any moving parts), accuracy of 0·1 per cent. of full scale deflection, and conversion time of 25 milliseconds or less. The instrument is unusual in that conversion is performed at the input level, thus eliminating the necessity for a d.c. amplifier with stable gain, and circuits have been designed to "linearize" the outputs from copper-constantan or chromel-alumel thermocouples so that the output is in degrees centigrade rather than in thermocouple e.m.f. Some observations are made on the problems of switching low-level signals. Suggestions are made as to suitable uses for such converters.

1. Introduction

The increasing complexity of modern industrial plant, leading to very large numbers of monitoring instruments, has created a demand for digital measuring instruments, which often feed into data-processing units; in this manner satisfactory routine measurements may be passed over and only measurements which lie outside pre-set limits are brought to the notice of the operator of the equipment. The digital measuring system is often shared in time sequence amongst a number of sensing elements, and a single display unit suffices for all the sensing elements. Digital information may be readily memorized in a short-period storage system, so that readings from each sensing element made during a preceding interval are available if required, although no permanent records have been made; in this way, the "history" can be traced if a fault occurs.

The equipment described here was designed for temperature measurements in nuclear power stations, the sensing elements being chromel-alumel or copper-constantan thermocouples. The digitizer may also be used with any input signal where the minimum detectable signal is greater than 20 microvolts, and so may be used to digitize outputs from strain gauges, accelerometers, etc. A predominant aim in the design has been to achieve a life expectation of twenty years with a minimum of servicing and faults, and this has led to the rejection of many conventional circuit techniques.

2. General Description of the Digitizer

The digitizer is required to convert the e.m.f. generated by a thermocouple to the corresponding temperature in degrees centigrade. Conversion must be completed in less than one fifth of a second, and the discrimination must be better than one thousandth of full scale deflection. The range of measurement is from 0 to 700°C, and the absolute accuracy must be better than $\frac{1}{3}$ per cent., whilst the drift must be less than 1 part in 2,000 of full scale deflection in a period of two minutes. There will be a voltage at 50 c/s between the "earth" lead of the thermocouple and the "earth" of the digitizer, and the digitizer must operate correctly if this

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† Manuscript received 21st October 1959. (Paper No. 569.)

‡ Marconi Instruments Ltd., St. Albans, Hertfordshire.

U.D.C. No. 621.317.725

voltage is less than 10 volts; the digitizer must not be damaged if the voltage rises to a few hundred volts. The resistance of the thermocouple leads is of the order of 200 ohms and the digitizer must not "load" the thermocouple so as to change the reading of another instrument permanently connected to the thermocouple.

The digitizer consists of four units—the timing unit, the voltage feedback unit, the subtractor, and the sign detector (Fig. 1). The timing unit consecutively energizes each of a number of lines, so controlling the sequence and duration of the various operations of the system. The voltage feedback unit generates a voltage in a digital sequence controlled by the timing unit and the sign detector. The subtractor unit generates a voltage equal to the difference between the thermocouple e.m.f. and the voltage from the voltage feedback unit, and feeds the result to the sign detector which then controls the voltage feedback unit.

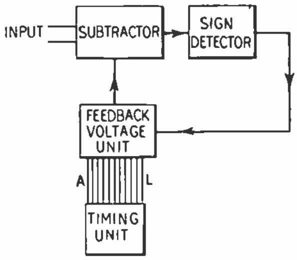

Fig. 1. Block diagram of digitizer.

3. Method of Operation of the Digitizer

During the first period of digitization, the feedback unit generates a voltage corresponding to the highest measured digit (512°C); this voltage is subtracted from the input voltage in the subtractor unit, and the difference is fed into the sign detector. The sign detector is an amplifier which gives full output for an input signal equivalent to less than the smallest measured digit, the output remaining saturated for higher inputs. If the input voltage is higher than the feedback voltage, the input to the sign detector will be of the same polarity as before, and the output from the sign detector will not change during the first period; in this case, the feedback voltage corresponding to the highest digit will remain set during the rest of the digitization. If the input is less than the feedback voltage, the polarity of the input to the sign detector will change, which will cause the output to change; this causes the feedback voltage corresponding to the highest digit to be cut off.

During the second period of digitization, the feedback unit generates a voltage corresponding to the second highest digit (256°C); if the previous digit was left "on," the second digit is added to it to give a total input corresponding to 768°C, and if the first digit is "off" only the second digit is generated. Again the digit remains on whilst the digitization proceeds only if the input is greater than the feedback voltage. The process continues, with steadily smaller digits, until the lowest digit is reached. At the end of that period, the input voltage has been converted into a digital form, and is available to be fed into indicators or data-handling equipment.

The system outlined above offers some advantages over the more usual systems where the input signal is amplified before digitization. The accuracy of the system depends on the zero stability of the sign detector amplifier, on the stability of the feedback voltage supply and on the accuracy of the subtraction unit; the latter is, in fact, a resistance across which the feedback voltage is generated in opposition to the thermocouple input which is connected in series with it, and its accuracy depends on the stability of the resistance. Systems where the signal is amplified before digitization must have a stable voltage supply, a subtraction unit, and an amplifier whose zero is stable and whose gain is both linear and stable; it may be seen that the system described here is likely to have better stability as it is not so dependent on amplifier characteristics.

4. The Timing Unit

The construction of the timing unit is conventional and will not be described in detail. The outputs are on twelve lines, as shown, each of which is energized to − 6V for a fixed period. The time for which each line is energized may be as low as 1 millisec for satisfactory digitization, but for the nuclear power station application is 10 millisec so that digitization is complete in 110 millisec.

5. The Feedback Voltage Unit and Subtractor

The block diagram of the two units is shown in Fig. 2. The feedback resistance, r, is inserted in the thermocouple line so that voltages generated across it act in opposition to the thermocouple e.m.f. The values of the resistances R1 to R11 are in a power series, R_n having twice the resistance of R(n − 1); it would of course be possible to proportion these resistances so that a binary-decimal scale resulted. The stabilized voltage supply maintains a reference voltage of 6·0 volts between lines A and B, although current flows between B and C. If S1 is closed, and S2 to S11 are open, a current of $6{\cdot}0/R_1$ amps flows, which generates a voltage of $6{\cdot}0\,r/R_1$ across the feedback resistance. This voltage corresponds to the highest digit of temperature. Each switch and resistance acts as a current generator, the currents being summed to generate the feedback voltage; in practice the switches are transistors rather than mechanical switches, in order to achieve rapid operation and long life. The input is not earthed to the local earth of the digitizer, so the switches must also be isolated from the digitizer earth. The circuit of a switch is shown in Fig. 3. The toggle which controls the switch is shown as a block; if the output from the toggle is at − 6V, VT1 will oscillate, but if the toggle output is at 0V, the base of VT1 is held positive with respect to ground, and oscillations cease. The secondary of the transformer, and all the rest of the circuit, is isolated from local earth; a separate, isolated power supply is used to provide power. When VT1 is oscillating, an a.c. voltage appears across the secondary of the transformer and is rectified by the diode to cause point "P" to become 2 volts negative with respect to zero. Current is then fed into the base of VT2 via the smoothing chain, and the transistor conducts, its collector and emitter being at substantially the same voltage, i.e. + 1V. VT3 is connected in an inverted configuration; no current gain is expected from this stage, and the inverted configuration gives much better switching characteristics than the normal configuration.† VT3 is used, in fact, as an emitter follower, and when the base is at + 1V it will be cut off; when VT2 is not conducting, the base of VT3 attempts to go more negative than its emitter (which is connected to the stabilized voltage line) and it is found that the current in line B may be in either direction depending on the value of R. The voltage drop across VT3 when conducting is less than 6 millivolts, even on the highest digit, and the leakage current when not conducting is less than 1 microamp at 30°C. The total errors in the digitizer, due to these imperfections in the switch, are less than 1 part in 1,000, and may be easily stabilized to some extent if required.

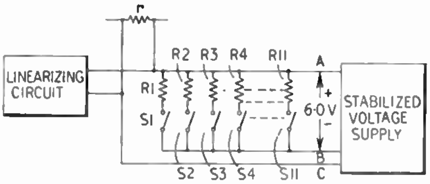

Fig. 2. Block diagram of voltage feedback unit and subtractor.

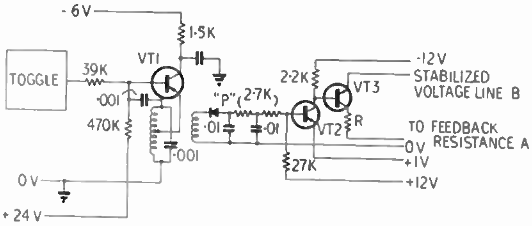

Fig. 3. Digital switch.

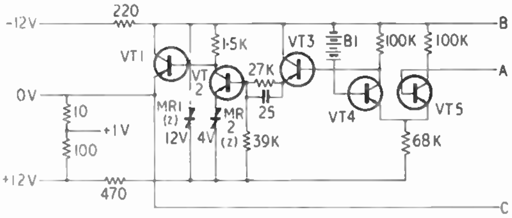

Fig. 4. Voltage reference supply.

The circuit diagram of the stabilized voltage supply is shown in Fig. 4. VT4 and VT5 form a "long tailed pair," the base of VT4 being held

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† G. B. B. Chaplin and A. R. Owens. "Some transistor input stages for high-gain d.c. amplifiers," *Proc. Instn Elect. Engrs*, Paper No. 2382M. (**105B**, pp. 249-257, 1958.)

6·0V positive with respect to the line B by the mercury battery B1 and the base of VT5 being connected to line A. VT4 and VT5 are operated at low currents so that the current taken from line A is small, and little error is produced in the feedback system. VT3 is an emitter follower, and drives VT2 via a resistance chain, the 27 kilohms resistance being by-passed so as to give a high a.c. gain. If A moves negative (i.e. the voltage B-A decreases) VT5 conducts more heavily, VT4 less heavily and the collector of VT4 becomes more negative. VT3 and so the base of VT2 also become more negative, so that the collector of VT2 rises so cutting off VT1. As VT1 conducts less heavily, the voltage drop across the 220-ohms load decreases, and the voltage on line B becomes more negative. The line L is kept at +12V with respect to the stabilized line by means of the zener diode MR1, and the emitter of VT2 is kept 4 volts negative from L by MR2. Thus, as A is approximately at 0V, and B at −6V, the emitter of VT2 is at about +2V; its collector is at about $-\frac{1}{2}$V, as VT1 must be conducting to control the voltage of B. The output impedance of the supply is of the order of 10 milliohms, and depends largely on wiring resistances; the voltage between A and B remains constant within 5 millivolts as A is moved from 0V to 1V, or the mains is varied ±15 per cent.

The linearizing circuit is necessary as the e.m.f./temperature relation of thermocouples is generally not linear. Chromel-alumel thermocouples may be regarded as having a characteristic composed of two straight lines, over the range 0 to 700°C, and the linearizing circuit operates on this assumption. The circuit is shown in Fig. 5, and the resistances r1-r9 and switches S1-S9 can be seen to be similar to those in the feedback network described above; as before a current is produced, which is proportional to the digitized temperature. The current is fed from the emitter of VT1, and so the collector current flowing in VT1 is slightly less than this. The emitter-base diode of VT2 and the zener diode MR1 ensure that the current in R1 is constant, and the current in the collector of VT2 can be seen to be approximately equal to the current in R1 less the current from the resistance network r1 to r9.

In the following description, it is assumed that the current gain of both transistors is unity; a real current gain modifies component values slightly. R1 is adjusted so that the current flowing in it is equal to the current from r1-r9 at the maximum temperature, so that no current flows in VT2. R2 is adjusted so that VT2 bottoms at the temperature of the junction between the two straight lines mentioned above; below this temperature the collector of VT2 remains at ground potential, whilst above it, the collector voltage rises linearly with the digital reading. R3, in combination with the collector voltage, generates a current which is added to the main current which flows in the feedback resistance, and the value of R3 governs the incremental slope above the junction. The system gives an error which is 1°C or less over the range 0-700°C, the maximum error occurring at 130°C, whilst over most of the range the error is less than $\frac{1}{2}$°C.

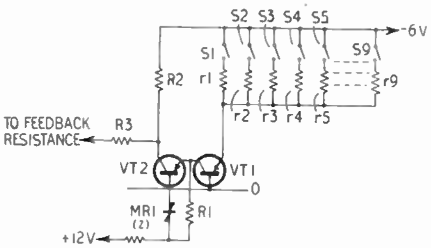

Fig. 5. Linearizing circuit.

6. The Sign Detector

The sign detector is basically a d.c. amplifier, but with some unusual characteristics. The long-term zero-drift must be of the order of 50 microvolts or less, but the gain need not be more stable than ±50 per cent. with time, etc. The output should move from 0V to −6V for a change in input of 20 microvolts or $\frac{1}{2}$°C. The amplifier must be capable of recovering very rapidly from considerable overloads, as can be seen if a temperature of about 256°C is being measured. Initially, the input will be equivalent to +256°C; during the first digitization period it becomes 256 − 512°C or −256°C, reverting to +256°C when the highest digit is switched off. During the second period, the input will be

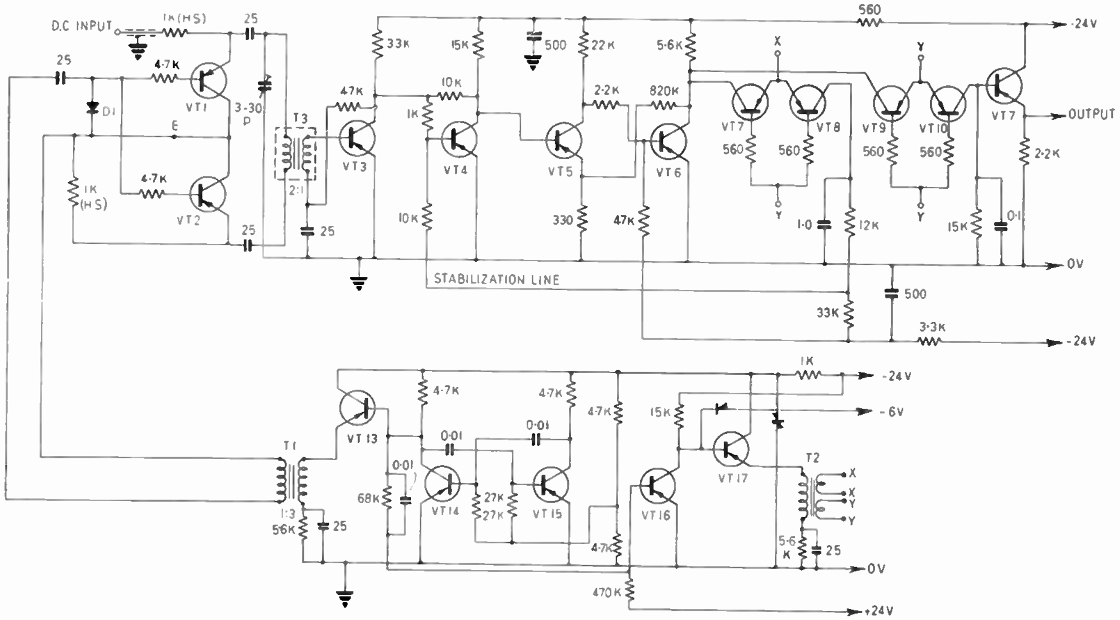

Fig. 6. Sign detector.

approximately zero, and the amplifier must clearly distinguish correctly between 255½°C and 256°C,—i.e. it must recover from a five-hundred fold overload in less than one period of digitization.

A transistor chopper type of amplifier was selected as being likely to satisfy the zero-stability requirements. A mechanical chopper would be preferable in this respect, but the life of such an amplifier would be quite inadequate for nuclear power station applications. The circuit diagram is shown in Fig. 6. VT14 and VT15 form a multivibrator which gives a square wave at about 2 kc/s; VT13 drives the transformer T1 to provide the chopping waveform, and VT16 and VT17 drive T2 to provide a reference waveform for synchronous detection of the chopped d.c. signal. VT1 and VT2 are the chopping transistors, VT1 chopping the d.c. input voltage and VT2 providing a "balancing voltage" to reduce the spurious d.c. signal generated because a transistor is not a perfect chopper. The chopping transistors act in a manner described by Chaplin and Owens‡, with a "pedestal" of about 1 millivolt for 0V input, and the pedestal is reduced to about 50 microvolts by the balancing transistor VT2. The chopped signal is fed through T3 to the a.c. amplifier, VT3 to VT6.

It can be seen that VT1 and VT2 are isolated from local earth by the transformers T1 and T3. It is found that if the d.c. input is grounded, and a 50-c/s voltage is applied between the line E and ground of the a.c. amplifier, a small (chopped) 50 c/s output is observed in the a.c. amplifier. The pick-up is produced by stray capacitances, mainly in T3, and is reduced by the 3-30 pf trimmer capacitor connected between one side of T3 and ground. A voltage of 100 V a.c. between E and ground gives an output equivalent to 50 microvolts on the input lead, so that the thermocouple earth may carry several volts a.c. relative to the amplifier ground without affecting the digitizer.

The a.c. amplifier is direct coupled so that after it has been overloaded the output will recover rapidly. The d.c. operating points of the transistors have of course to be stabilized, as an input square wave of 20 microvolts causes full-scale output, and the input d.c. level will drift in the order of millivolts. When VT1 and VT2 are conducting (i.e. the input is "shorted") the transistors VT7 and VT8 also conduct whilst VT9 and VT10 are cut off. The collector

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‡ *loc. cit.*

of VT6 is then connected to the stabilization line via the 12 kilohms resistance, and if the d.c. operating point moves, at zero input, the voltage on the stabilization line will move to restore normal conditions. During the portion of the cycle when VT1 and VT2 are cut off, so that the input voltage appears across the amplifier via transformer T3, VT7 and VT8 are cut off and the collector of VT6 is connected to the output emitter follower VT11. For zero input the output is at − 6V, and positive or negative inputs to the amplifier cause positive or negative deviations from this point.

7. Behaviour of the Digitizer

Two models of the digitizer have been built and tested. The first takes 120 millisec to digitize a thermocouple input, covering a range of ½°C-128°C, and is as described above. The second takes 12 millisec to digitize a voltage in a range 0·001-1·00V, and is substantially as described above except that the input earth is not isolated from the digitizer earth. Both models work satisfactorily, and the first fulfils all the design requirements described above. The high-speed digitizer can easily be converted to operate in the more sensitive range, and to operate with a floating input, so that measurements could be made at up to 70 readings per second, and it appears likely that 250 readings per second are possible with this system.

The input impedance of the digitizer is variable with time, at some times current being drawn from the source whilst at other times current is forced into the source. The input impedance of the sign detector is of the order of 5,000 ohms, so that at balance, when there is a maximum voltage of 20 microvolts across the input to the sign detector, the current will be less than 4 millimicroamps; this current is independent of the measured voltage, but at the full-scale value of 40 millivolts the impedance is greater than 10 megohms. The input impedance of the sign detector could be increased if required by perhaps a factor of ten.

A mechanical chopper could be used in the sign detector to provide a more stable zero; in this manner a digitizer could be built to cover the range 5 microvolts-5 millivolts, with a resolution and accuracy better than 0·1 per cent. of full scale deflection, and with a speed of the order of 50 measurements per second. In addition the input impedance of such a sign detector could be increased considerably above that of the transistor chopper, so that the balanced input impedance of the digitizer could be raised by perhaps a factor of 100.

It can be seen that by relatively simple modifications digitizers can be built to suit a wide range of specifications.

8. Switching Thermocouple Inputs

The difficulties encountered in switching thermocouple signals are not always obvious. To be of use as a scanning switch, a suitable device must be reasonably fast—a total turn-on and turn-off time of up to half the time available for digitization could be tolerated if necessary, but a shorter time is desirable. The device must operate over long periods without attention, and must not introduce spurious voltages. Normal types of relays may generally be rejected on account of life considerations (mainly due to accumulation of dirt on the contacts) and speed of operation. Continuously rotating scanning switches are not suitable on account of the noise introduced; as the wiper moves across a contact, connection is occasionally interrupted by dirt or roughness, and noise is generated. Uniselector-type switches are suitable, particularly if the contacts are gold-plated and the switching mechanism is sealed or immersed in oil. The life expectancy of a uniselector is not always satisfactory, the switching time may be too long in a scanner operating at more than 10 points per second, and the high power required to drive the unit increases the likelihood of electrical pick-up. Transistors might be used to switch the thermocouples, but in order to achieve a switching error of less than 20 microvolts over a reasonable ambient temperature range, selection of transistors would be necessary and the system would become expensive. The leakage resistance of a transistor switch is usually only of the order of megohms, so that the number of switches which could be connected in parallel (operated one at a time) is limited if high accuracy is required and the source impedance is high.

A type of relay which has proved very satisfactory in use at up to a few hundred cycles per second is known as the dry-reed relay. Two strips of ferromagnetic material are sealed in a glass tube, as shown in Fig. 7. The tips of the strips are plated with gold or other precious metal to ensure a low resistance contact, and the whole is mounted in an exciting coil. When current is passed through the coil, an axial field is produced which magnetizes the strips longitudinally and causes the two tips to be attracted so as to make contact. The contacts are sealed (if desired in an inert gas or a vacuum) so that no trouble is likely to be experienced from corrosion or dirt; the life of the relay is very high—well over 10^8 operations for low voltage and current across the contacts—and the operating speed is of the order of 1 millisec to open or close. A number of reeds may be placed in a coil to give a multiple contact relay. A switching system made up from these relays is likely to prove good so far as reliability is concerned, and is also much more flexible than a uniselector-type switch, in that alteration of one thermocouple may be made by changing the relay coil connections, rather than the low-level thermocouple leads. The thermocouples may be simultaneously scanned at high speed if required, using the same relays together with a simple matrix arrangement.

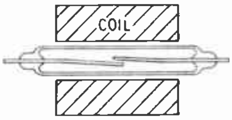

Fig. 7. Dry reed relay.

9. Some Uses of Analogue-Digital Converters

The converter described above has greater accuracy than a normal pointer instrument, has a much greater speed of response, and gives a digitized output; the input impedance is high, and it will safely withstand considerable overloads. It is considerably more complex than a pointer instrument, and so more costly.

These assets and liabilities point to the main uses of converters. The accuracy gives some obvious applications, especially where accurate measurements have to be made by only partially skilled operators, as the reading may be clearly and unambiguously presented. The speed of response provides many opportunities for using the converter to scan a number of inputs, or to make successive measurements with high accuracy on a rapidly varying quantity. The principal limit to the speed of measurement lies in output devices; if continuous readings are required, the maximum speed of the output printer is the maximum speed of scanning; however, if a transient is to be recorded, the readings may be stored in some way to be printed out later, and the speed of scanning may then be increased to the maximum permitted by the converter (with its switching system if one is used). The digital form of output is clearly necessary if the reading has to be arithmetically processed in any way—e.g., the maximum or minimum value found over a period, or computations performed.

10. Conclusions

The analogue-digital converter described here has been designed with a view to high accuracy and long life. The accuracy is dependent only on a number of resistances, the stabilized voltage supply and the zero-drift of an amplifier, and a high input impedance enables sources of medium impedance to be used without loss of accuracy. The life of the equipment has been considered to be of paramount importance, and the equipment might well be modified to provide better facilities in various directions if a shorter life can be tolerated. The speed of operation of the digitizer is not particularly high, but is sufficiently high to load most print-out devices to their maximum speed. The switching unit, which is used when a number of detectors are scanned by one measuring equipment, is adequate in all respects to handle the demands made of it.

The digitizer may usefully be used for accurate measurements by semi-skilled operators, for monitoring a number of detectors (using a scanning system) or for accurate measurements on transient phenomena; in all cases, computing equipment may be used to convert the data into a more convenient form for final presentation.

11. Acknowledgments

The author would like to thank the management of Marconi Instruments Ltd. for their permission to publish this paper, and also all those working at Marconi Instruments who have assisted in the design and construction of the prototype system.

A Wide-range Fully-automatic Digital Voltmeter †

by

J. A. IRVINE, B.SC. ‡ and D. A. PUCKNELL, A.H.-W.C. ‡

A paper read during a Symposium on Electronic Digitizing Techniques, held in London on 18th November 1959.

In the Chair : Dr. T. B. Tomlinson (*Associate Member*)

Summary : The requirements which led to the development of a digital voltmeter are discussed and various possible systems are considered. The reasons for choosing the present system are given. The potentiometer network and reference supply, the transistorized comparator and difference amplifier, and the selector switch control circuitry are described. The voltmeter has an input impedance of 10MΩ and automatic polarity and range selection. It reads to 3 digits with an accuracy of ±1 digit over the range 10mV to 1000V.

1. Introduction

With technical progress in the Electronics Industry has come the need for the engineer to be able to measure basic electrical parameters with greater degrees of accuracy. The demands of military equipment in particular have pushed the state of the electronics art to a point where routine production testing must be carried out with accuracy of an order usually associated with Standards Laboratories. Also, the range of measurements to be made has greatly increased, particularly in the case of voltage measurements.

It is obviously undesirable and uneconomic to use delicate instruments and highly skilled personnel to make such routine measurements, but the use of the unskilled operator must not introduce any chance of error. Therefore, the ideal measuring equipment should be robust and should display the desired information simply and clearly.

From this point of view, the digital form of presentation is ideal since no interpolation is required and a digital instrument may be fully automatic. In a voltmeter for instance the range and polarity selection may be made by the instrument, thus considerably reducing the chance of damage to the instrument as well as eliminating possible reading error. Also it is possible to reduce considerably the time taken in making accurate measurements by choosing a suitable digital system.

A high degree of accuracy may readily be obtained by using a digital voltmeter working on the potentiometer principle. Such systems are inherently linear and are easily checked for absolute accuracy by simple periodic spot checks.

2. Design Considerations

The requirements and considerations which have been discussed led to the development of a digital voltmeter intended for routine production testing. The design aims were as set out in Table 1.

The display was required to be in decimal form and the first decision made was that the system should be balanced decimally. This avoided the complication of binary to decimal conversion.

3. Early Models

During the course of development various systems were considered. The first approach was a four-digit model designed round a servo-operated cam-corrected potentiometer which

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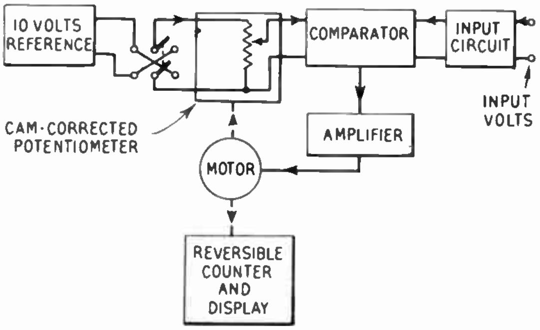

Fig. 1. Servo potentiometer system.

was fed from an accurately calibrated 10 volt d.c. source. This system is shown schematically in Fig. 1.

The potentiometer was driven from the servo motor through a gear box such that the full travel of the potentiometer track corresponded to 10,000 revolutions of the motor. The incoming unknown voltage was compared with the output from the potentiometer slider, the difference causing the servo system to drive the potentiometer to balance. The revolutions of the motor shaft in balancing were counted by a dekatron counter, the state of the count directly indicating the measured voltage. A model of this type was constructed, the display being the dekatron tubes.

This system suffered from a number of disadvantages mainly due to difficulty in increasing the reading speed and the inherent overshoot of the servo system. To overcome this latter fault a reversible dekatron counter was developed but the system was eventually discarded.

Table 1

Design Aims for the Digital Voltmeter

Accuracy	0·1% at full scale or better.
Range	Up to 1000V d.c. from a least significant digit of 10 millivolts or less on the bottom range.
Resolution	Better than 1 least significant digit.
Ranging	Automatic.
Polarity Selection	Automatic.
Input Impedance	10 megohms.
Reading Time	Less than 1 second.

The next model replaced the servo potentiometer with a step-by-step relay system operating a unidirectional counter. This system was unreliable due to contact resistance and the relatively short life of the relay contacts available at that time.

4. Description of the Automatic Three-digit Voltmeter

It was finally decided to adopt a self-balancing Kelvin-Varley potentiometer switched by unidirectional high-speed stepping switches. This system is very attractive, the potentiometer being arranged in decades and the load imposed on the reference source being constant. An unknown voltage may be measured by balancing against the Kelvin-Varley, switching each decade of the Kelvin-Varley in turn.

The original model of this type displayed four digits but the accuracy of easily obtained and moderately priced components rendered the fourth digit meaningless at the top of the scales and therefore the final three-digit model was developed. The complete system may be considered by reference to Fig. 2.

The input voltage, attenuated by the input circuit if necessary, is fed to the comparator circuit and the difference between it and the output from a three decade potentiometer is fed to the difference amplifier. The amplifier senses the difference and the output is used to actuate stepping switches which comprise the control circuitry. The outputs from the amplifier are so routed that the correct range and polarity are selected first and then each decade steps to a balance, the least significant decade being the last to drive. The resulting position of the decades at balance is read out directly on a projection type of digital display.

4.1. *The Kelvin-Varley Potentiometer*

The instrument will now be considered in more detail. The heart of the instrument is the stepping switch unit comprising four eight-level 12-position stepping switches and the precision resistors forming the potentiometer. The switch unit is shown in Fig. 3.

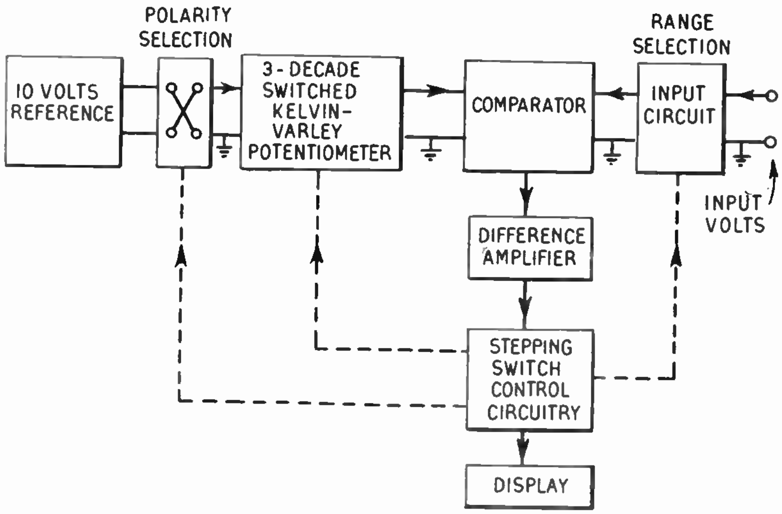

Fig. 2. Three-digit stepping switch system used in the automatic digital voltmeter.

Three of the switches are associated with the three decades of the Kelvin-Varley potentiometer. The fourth switch performs the functions of ranging and polarity selection. A level of each switch operates a projection lamp read out system indicating the digit selected on each column, the polarity sign and the position of the decimal point.

The method of switching the potentiometer is shown in Fig. 4, two levels each of switches 1 and 2 and one level of switch 3 being utilized. The critical factor here is the contact resistance and special measures were taken to ensure long contact life at low resistance.

It will be noted that the 10V reference voltage is derived from mercury cells which give adequate stability when on the constant load of the potentiometer. Calibration is achieved by the use of a series potentiometer and is carried out at 9·17V by comparing the decade output with a bank of Weston standard cells. The resistor tolerance and matching of the decades is so chosen as to be more than adequate for the accuracy of the instrument as a whole.

4.2. *Input and Comparator Circuits*

The input circuitry comprises a switched attenuator network of 10 megohms impedance giving input attenuations of 1:1 10:1 or 100:1. This gives the three ranges 10V, 100V and 1000V. The ratio accuracy of the input attenuators is a critical factor.

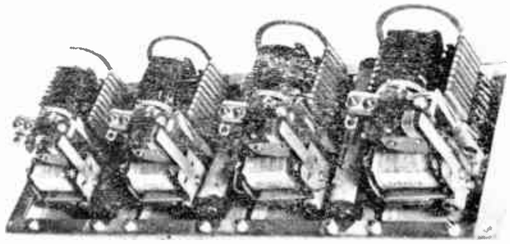

Fig. 3. The switch unit.

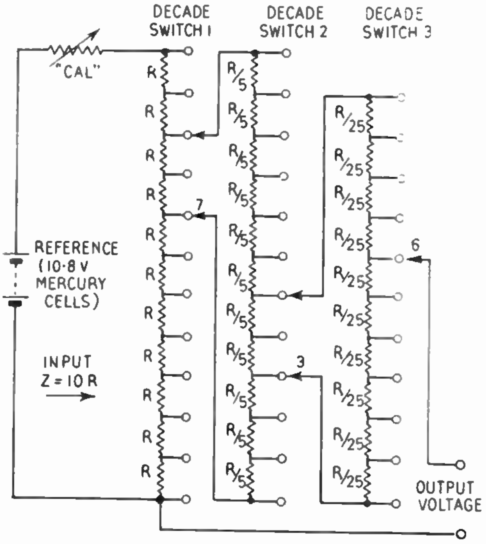

Fig. 4. Three-decade Kelvin-Varley potentiometer.

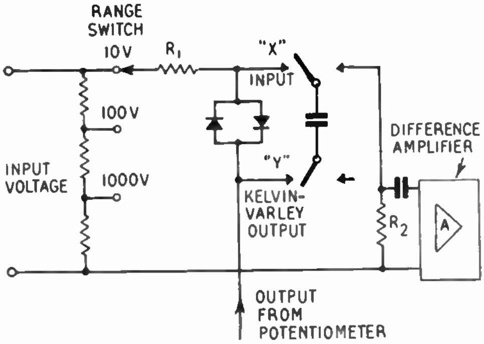

Fig. 5. Input and comparator circuit.

The comparator circuit consists of a double synchronous converter circuit shown in Fig. 5. Capacitor C charges to the difference between points X and Y and the double chopper arrangement transfers the charged capacitor to the difference amplifier input where it discharges through R2. This gives a short voltage spike at the input of the amplifier. It will be noticed that two silicon diodes are connected in opposite directions across points X and Y. This is to limit the voltage to be handled by the choppers and thus ensure long contact life. At low voltage differences between X and Y both diodes are non-conducting and may be ignored when the final balancing steps are being taken.

4.3. *The Difference Amplifier and Stepping Switch Drive*

The voltage spike across R2 is a.c. coupled to the difference amplifier. The amplifier, shown in Fig. 6 has two output channels each one responding to one polarity of input only. One or other of these outputs produces a positive-going 10 volt pulse when the difference voltage exceeds 6 millivolts. The spike produced by the comparator is amplified by the cascode circuit and then directly coupled to a phase splitter. This part of the circuit employs overall d.c. feedback for thermal stability. The phase splitter outputs are a.c. coupled to the two output transistors which are normally cut off. Thus the collector of each output transistor is normally at – 10V.

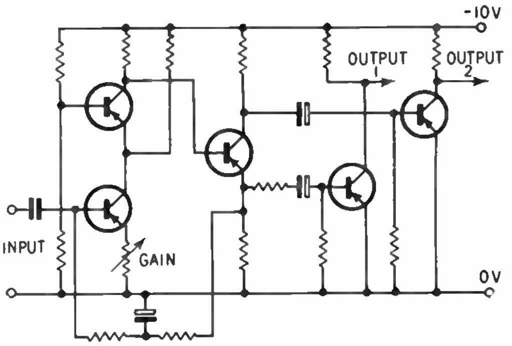

Fig. 6. The difference amplifier.

Each output stage is directly connected via the control circuitry to one or other of the control grids of two thyratrons (Fig. 7) and the – 10V normally at the collector acts as bias to hold off the thyratrons. The thyratron anode circuits are connected to the operating coils of the stepping switches and thence through control switching to 150V a.c. An output pulse from the amplifier lifts the bias on a thyratron which conducts during the positive half cycle of a.c. to the anode. A switch operating coil is thus energized and is de-energized again when the a.c. to the anode goes into the negative half cycle. The stepping switches step when the coil de-energizes. The 150V supply is derived from the mains and therefore the stepping speed of the system is 50 steps per second.

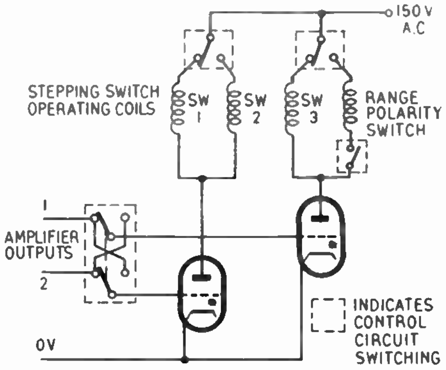

Fig. 7. Drive to stepping switches.

A fast reading time is therefore possible and the switching logic of the control circuitry has been carefully evolved to reduce the reading time. It is rather difficult and meaningless to try to quote an average reading time but the maximum reading time for this instrument including ranging time does not exceed 1·3 sec.

5. Mode of Operation

To understand the switching logic of the voltmeter it is easiest to consider the most direct way of balancing an unknown voltage against the output from a three-decade Kelvin-Varley potentiometer fed from a 10V d.c. source.

Assume that the unknown voltage is, say, 5·64 and that a polarity sensitive difference detector is connected between the Kelvin-Varley output and the unknown voltage.

Assume that all decades are initially on zero; therefore the unknown voltage is above the decade setting. This gives us, say, a positive difference voltage. We then step the most significant decade (decade 1) to 9 and the difference reverses since the potentiometer setting is now too high. We then reduce the setting of decade 1 until we come to position 5 where the potentiometer output is again below the unknown. This is indicated by a polarity reversal on the difference detector. Decade 1 is left on 5 and Decade 2 is similarly set to 6. Decade 3 is balanced last and on setting this to 4 the difference voltage disappears or is reduced below the threshold level of the detector. The reading sequence is given in Table 2.

Table 2

Switching Sequence to 5·64V

Decade 1	Decade 2	Decade 3	Difference Detector
0	0	0	+ve (Say) Polarity
9	0	0	– ve Change
8	0	0	– ve
7	0	0	– ve
6	0	0	– ve
5	0	0	+ve Polarity Change
5	9	0	– ve Polarity Change
5	8	0	– ve
5	7	0	– ve
5	6	0	+ve Polarity Change
5	6	9	– ve Polarity Change
5	6	8	– ve
5	6	7	– ve
5	6	6	– ve
5	6	5	– ve
5	6	4	0 Balance

The voltmeter employs the same switching logic, the switch drives being unidirectional and stepping in a direction 0-9-8-7-6, etc. It will be noticed that each decade balances directly to the correct setting.

Twelve-position switches are used for the decades although it would appear that ten positions only are required. This is not the case, however, as an extra zero position is required, identified as "N" to arrange for the initial step from 0 to 9 on each decade.

The voltmeter normally rests at 0·00 on the bottom range. This must be so otherwise the voltmeter might fail to respond to very small inputs if these were attenuated by the input circuit. If the voltage to be measured is greater than 10 volts each decade will step to 9 but there will be no balance and the difference is such that the input voltage is still above the potentiometer output. A 9-9-9 coincidence circuit is arranged in this case to drive the range switch and attenuate the input until the input to the comparator is less than the output of the Kelvin-Varley potentiometer standing at 999. Then each decade is balanced once the range has been selected.

Similarly if the polarity of the input voltage is opposite to that selected by the instrument the difference voltage will be reversed and a control circuit coincidence of NNN and the reversed difference signal will drive the range switch to the correct polarity and then normal ranging and balancing will occur.

A further coincidence circuit prevents any but the most significant reading from being displayed. For example it is impossible for 9·64 volts say to be read as 09·6V or 009· V. This ensures that the full accuracy of the instrument is always utilized.

The voltmeter, therefore, is fully automatic, the ranging, polarity selection and balancing being initiated by connecting the unknown voltage to the input. The display used is such that all figures, polarity sign and correctly placed decimal point are at all times directly displayed.

6. Acknowledgment

The authors wish to thank Messrs. Ferranti Ltd., for their permission to present this paper.

An All-electronic Four-digit Digital Voltmeter †

by

H. FUCHS, B.SC., PH.D. ‡ and D. WHEABLE ‡

A paper read during a Symposium on Electronic Digitizing Techniques held in London on 18th November 1959.

In the Chair: Dr. T. B. Tomlinson (*Associate Member*).

Summary: The paper describes a four-digit electronic digital voltmeter and deals with the mode of operation of this instrument and a number of problems that have been solved in engineering it. A feature of the instrument is the automatic range change circuit which operates the input attenuator and minimizes the errors arising from the reverse grid current flowing in this attenuator. The fundamental accuracy of the instrument depends on the method of voltage comparison and particular emphasis is placed upon drift correcting these comparators using the principle of time-sharing. The generation of linear ramps is described and results of laboratory measurements verifying theoretical predictions are given. The high speed decimal counter using the trochotron tube is described and shown to be ideally suitable for operating with neon-type number tubes. The paper closes with the discussion of all the errors.

1. Introduction

The paper describes an electronic digital voltmeter and deals with its mode of operation. It also outlines, briefly, a number of problems which have had to be solved in designing this unit and in particular discusses the achievement of a high input impedance, automatic range change and sign selection and high speed counting to achieve a short conversion time.

2. System Description

The digital voltmeter is shown in block diagramatic form in Fig. 1. An input voltage is fed to a high input impedance, linear cathode follower via the range selector circuit, which automatically selects the optimum range on which the instrument will operate. This range is always $9{\cdot}6 \times 10^x$ where x may be 0, 1 or 2.

The voltage is then compared in amplitude comparator No. 1 with a ramp voltage, generated by a linear integrating circuit, which is fed from a reference supply. The ramp voltage is also compared in amplitude comparator No. 2 with earth voltage. If the incoming voltage is negative, amplitude comparator No. 1 operates first and amplitude comparator No. 2 operates last. If the incoming voltage is positive, this order is reversed.

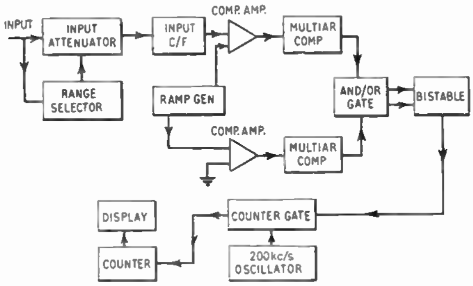

Fig. 1. Block diagram—digital voltmeter.

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‡ Blackburn Electronics Ltd., Brough, Yorkshire.

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The operation of either amplitude comparator triggers one of two sign selector valves and in so doing inhibits the other sign selector valve. The amplitude comparator which operates first hence indicates the polarity of the incoming d.c. voltage.

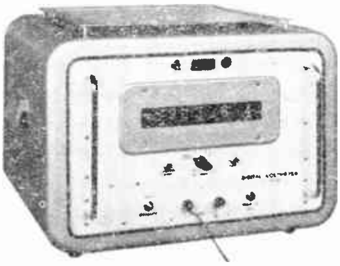

Fig. 2. The four-digit voltmeter.

The operation of an amplitude comparator also energizes the bistable gate valve which is de-energized by the operation of the second amplitude comparator, this operation being irrespective of which amplitude comparator operates first. The gate valve controls the supply of a 200 kc/s crystal-controlled oscillator to the four-trochotron counter.

At the completion of the count, when the gate valve has de-energized, the count held in the counter is an indication of the magnitude of the d.c. voltage and this is given on four in-line neon number tubes. The complete voltmeter is shown in Fig. 2.

3. Circuit Description

3.1. *Range Selector*

The range selector comprises three biased triodes each having a relay in its anode. A voltage which exceeds the grid base of these valves operates the appropriate relay, which in turn operates the range change circuits.

Although these circuits are not accurate amplitude comparators, the drift only affects the voltage at which the range changing occurs. Typically this way may vary from 9·5 to 9·7 × 10^x.

The range change circuit comprises a number of precision resistors arranged as an attenuator. In the most sensitive mode, i.e. 9·6 volts full scale, the input impedance is that of the insulation resistance of the input relay, plus the input current into the open grid of the range selector. This impedance is greater than 50 megohms. On the other two ranges of 96 and 999 volts, the input impedance is approximately 5 megohms.

3.2. *Input Cathode Follower*

The input cathode follower must have a linearity comparable with the precision required from the voltmeter, that is, at least 1 part in 10,000. This linearity is achieved by using a pentode as the cathode load, resulting in a high variational impedance.

Drift also affects the accuracy of this circuit but this is dealt with later, when discussing the amplitude comparators.

3.3. *Amplitude Comparators*

The output voltage from the cathode follower is compared in an amplitude comparator with the ramp voltage and a pulse is generated when the sum of the two voltages is zero.

Each amplitude comparator comprises a d.c. amplifier having a gain of approximately 800, operating a multiar. The d.c. amplifier in one case sums at its input the ramp and the incoming voltage. The other d.c. amplifier sums at its input the ramp and earth voltage.

The output of each d.c. amplifier is fed to the multiar which is, basically, a blocking oscillator with a diode in its feedback loop. The valve does not oscillate until the input voltage exceeds earth voltage negatively.

The multiar oscillates and produces an output pulse, when and only when, the input is negative with respect to earth. Since drift in both the d.c. amplifier and the cathode follower affects the accuracy of the instrument, some solution to this must be found. The technique employed in this case is that of time sharing. Since the amplifier is only required to operate for a period equal to the longest possible count time, that is 100 millisec, the remaining period before the next sample (typically $\frac{1}{3}$ sec) is available for drift correction.

Figure 3 shows the circuit diagram of the input cathode follower and time shared amplifiers. At the completion of a count, the input of the cathode follower is short circuited to earth using a high speed relay. The outputs of the two d.c. amplifiers are now connected to their inputs via series resistors which charge up capacitors to the total drift voltage. Upon release of these relay contacts, the amplifiers remain balanced for a period depending upon their maximum drift and leakage rate. The total input drift during the period of 100 millisec required to perform a conversion is considerably less than 1 millivolt. Most of the errors introduced by this system accrue from the noise of the relay contacts and this has been reduced to a minimum by the use of mercury wetted relays.

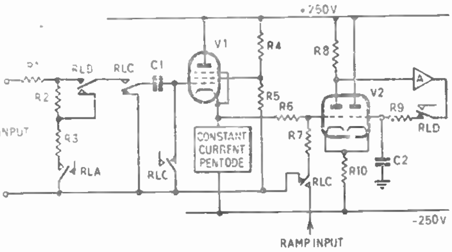

Fig. 3. Input cathode follower and comparator amplifier.

3.4. *Ramp Generator*

A screen-coupled phantastron is used as the linear ramp generator, the time-constant components being a high stability wire wound resistor and a polystyrene capacitor. These are necessary in order to maintain a high order of stability over a reasonable period of time and a low leakage across the capacitor. The repetition rate is varied by varying the time-constant of the coupling network between the screen and suppressor grids. At the beginning of the ramp, the screen voltage goes positive, in this case to earth potential and at the end of the ramp it returns to some negative potential. The screen voltage is a square wave, and is used as a timing signal in the ramp circuit. In the following discussion it will be referred to as the screen waveform.

The linearity of the integrator is given by the following formula:

$$E = \frac{50T}{(1-A)RC} \times \frac{(1-A)R+1}{R_L}$$

where E = maximum percentage error
T = maximum computing time
A = amplifier gain
C = computing capacitance
R = computing resistance
R_L = leakage resistance of capacitance

It $A \gg 1$

$$E \simeq \left(\frac{50T}{ARC}\right)\left(\frac{AR}{R_L}+1\right)$$

Therefore

$$A = \frac{\dfrac{50T}{RC}}{E - \dfrac{50T}{R_L C}}$$

A limit condition occurs when

$$E = \frac{50T}{R_L C}$$

This means, that, when R_L is less than the value required to satisfy the equation, no further increase in gain can compensate for leakage. It is for this reason necessary to use polystyrene capacitors, despite the more favourable temperature coefficient of other types of high stability capacitors, such as silver mica.

Assuming the leakage resistance to be high enough to be neglected then

$$A = \frac{50T}{RCV}$$

Since T = 100 milliseconds, and
$RC \simeq 1$
V = 250 volts then $A = 500$.

The measured gain of the ramp amplifier is about 500, giving a computed linearity of approximately 0·01 per cent.

3.5. *Gate Circuit*

The outputs from the multiar comparators are fed into the AND/OR gates MR1, MR2, MR3 and MR4 in Fig. 4. When one multiar fires, an output is obtained from the OR gate which triggers the bi-stable circuit. This in turn operates a short suppressor base oscillator gate valve. The output from the AND gate triggers the bi-stable circuit again, thereby de-energizing the gate valve.

Figure 4 shows that the bistable circuit is a.c. coupled on the side which energizes the gate valve and d.c. coupled on the side which de-energizes the gate valve.

This arrangement prevents the bi-stable circuit from being triggered again when the multiars return to their stable state on the completion of the ramp.

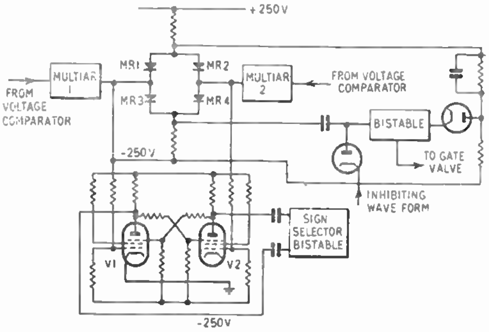

Fig. 4. Counter gate circuit and sign selector.

The screen wave form is applied to one side of the bi-stable circuits to ensure that it is not triggered by spurious pulses. The positive-going leading edge of this waveform is also delayed to hold the bi-stable circuits inoperative until the time sharing relays have operated.

3.6. *Counter*

When deciding on the type of counter to use, a decision had to be made whether to count in binary, binary-coded decimal, or decimal. As the output of the digital voltmeter has to be in decimal form it was decided to count in this form. The counter has also to drive some form of in-line number display and the counting speed must be fairly high in order to reduce the conversion time. The trochotron covers all the above points, using neon number tubes driven directly from their targets. The authors feel that as the trochotron is not yet a familiar type of counting tube, a brief account of the working of the tube is justified here.

Four trochotrons are used, the least significant counting at a frequency of 200 kc/s. The indication of the final count is displayed on neon number tubes coupled directly to the trochotron targets. Figure 5 shows a trochotron counting tube with an inter-stage bi-stable circuit.

Briefly, this counting tube works as follows. Ten targets are spaced symmetrically around a cathode which is placed axially in a strong magnetic field, producing a circulatory electron current. Between each target are further electrodes, called spades and bi-spades. The electrons are formed into a beam locked to a particular target by the spade of that target. All the even bi-spades are coupled together and are brought out to a common terminal, as are all the odd bi-spades. In order to switch the beam from one target to the next, the potentials on the odd or even bi-spades are brought down to some negative potential below the cathode voltage. If the beam is locked on an even target, the even bi-spade potentials are lowered and the odd bi-spade potentials are raised. The beam will then form on the next target. This switching is performed by a bi-stable valve circuit. The input stage is driven from the oscillator via the gate valve. The inter-stage bi-stable circuits are driven from the 0 targets of the previous trochotron. At the beginning of each ramp the counter is returned to the zero count position.

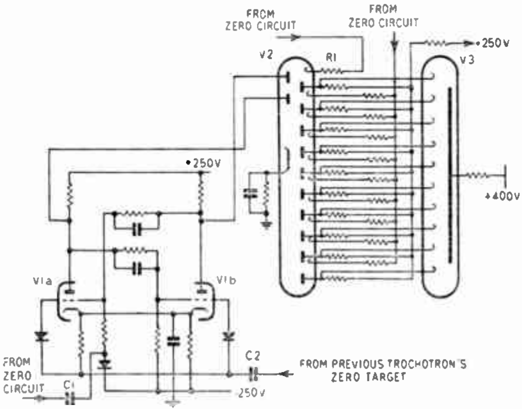

Fig. 5. Inter-stage driving circuit for trochotron.

All the spades of each trochotron except the 0 spades are coupled via the spade resistors to a cathode follower which holds these to a constant potential during the normal count period. All the 0 spades are coupled in a similar way to another cathode follower.

The ramp screen waveform is used to energize a mono-stable circuit which delivers a pulse to the two cathode followers. The pulse to the first cathode follower is differentiated resulting in a sharp pulse being applied to all except the 0 spades. The full pulse is applied to the 0 spades. The pulse is also applied to one side of the bi-stable circuits which are thus triggered to the even state. The sharp spike on the spades frees the beams from the targets, and the beams are reformed on the 0 targets.

4. Calibration and Stability

There are four factors governing the accuracy and stability of the instrument namely: calibration standard; input attenuator; ramp generator; crystal oscillator stability. Each factor will be discussed separately.

4.1. *Input Attenuator*

The components in the attenuator are precision wire-wound resistors, wound to a ratio accuracy of ±0·01 per cent. Other errors due to the attenuator are caused by currents flowing in it, such as leakage currents and reverse grid currents.

The error due to grid current will be

$$V_e = i_g \frac{R_1 R_2}{R_1 + R_2}$$

where R_1 and R_2 are the two resistors of the attenuator.

This is a fixed error and could be balanced out, but on the instrument changing range the factor $R_1 R_2/(R_1+R_2)$ will be changed by 10:1. Hence V_e must be less than $V/10^4$ where V is the maximum voltage of the basic range of the instrument and $V_e = 10^{-3}$ volts = 1 mV.

On the first attenuated range

$$R_1 = 4{\cdot}5\text{M}\Omega.$$

$$R_2 = 500\text{k}\Omega.$$

therefore

$$\frac{R_1 R_2}{R_1 + R_2} \cong 500\text{k}\Omega.$$

therefore

$$i_g < \frac{10^{-3}}{500 \times 10^3} = 2 \times 10^{-9}$$

This is a fairly small grid current and is not easily maintained except in electrometer valves and it would be difficult to obtain the linearity required with these valves. For this season a blocking capacitor, C1, was introduced as shown in Fig. 3.

The capacitor will block the grid current but the capacitance must be of such a value as to ensure that the voltage change across it, due to the charging effect of the grid current during the conversion time, does not exceed a value which would impair the accuracy.

For a grid current not exceeding 10^{-7} amps, a 1-μF capacitor is required to keep the charge build-up to less than 1 digit during the conversion time.

4.2. *Calibration Standard*

The instrument is calibrated against two industrial reference cells connected in series, the absolute voltage being 1·0193 ±0·0002 volts.

The temperature coefficient will not exceed ±5μV per °C between 10°C and 40°C, and the maximum voltage change, in this temperature range, is therefore 150μV. The total error in one volt will be 150+200μV which results in a total error of 0·035 per cent. The setting accuracy of this instrument at 2 volts is however only ± 1 part in 2,000, namely 0·05 per cent.

It is possible to allow for 0·02 per cent. of this error as an absolute measurement of the cells can be obtained. The error is not variable for a particular cell and for the normal temperature change expected in the laboratory, say ±5°C, the error due to this will therefore be less 0·01 per cent.

In order to keep the temperature change to a minimum, the time-constant components are placed in the bottom of the instrument case where the temperature is very nearly equal to the ambient temperature.

4.3. *Ramp Generator*

The linearity of the ramp generator was dealt with in Section 3.4. Stability will depend upon the stability of the time-constant components and the stability of the reference voltage. The reference voltage in this case is the − 250 volt h.t. supply.

The drift in the negative h.t. supply and the cathode grid drift in the ramp generator valve, due to heater voltage change, will change in opposite directions and tend to compensate. Combined effect of a 10 per cent. mains change is about 50 millivolts, i.e. a 0·02 per cent. change in ramp voltage rates.

Changes in the time-constant components can be divided into two main parts, long-term drift, and short-term drift, the latter being mainly due to temperature change. The former is a slow drift which is taken account of by routine calibration checks. The drift due to temperature has been compensated for as far as possible. The temperature coefficient of a polystyrene capacitor between 20°C and 60°C is -110 ± 20 parts in 10^6 per degree centigrade. This can be compensated for by a wire-wound resistor with a positive temperature coefficient equal to 110 parts in 10^6 ± 10 per cent. and the total error of the two combined, in the worst case, could be $\pm 0{\cdot}003$ per °C.

In fact, the computing resistance is made up of two resistors with different temperature coefficients. The first is a wire-wound resistor and has a positive temperature coefficient of 0·007 per cent./°C and the second is a metal-film fibre resistor which has a temperature coefficient of 0·035 per cent./°C. The ratio of the resistance of the two types of resistance to give the required temperature coefficient is given by:

$$\frac{R_1}{R_2} = \frac{(\alpha_2 - \alpha_T)}{(\alpha_T \quad \alpha_1)} \frac{(1 + \alpha_1\, t)}{(1 + \alpha_2\, t)}$$

where R_1 = metal-film resistor

R_2 = wire-wound resistor

α_1 = temperature coefficient of metal-film resistor

α_2 = temperature coefficient wire-wound resistor

α_T = temperature coefficient required

Another source of error is drift in the reference neon. This error can be attributed to three main causes:

(1) Drift with temperature

(2) General long term drift

(3) Voltage jumps

(1) The temperature coefficient of a good quality reference neon tube is about -4mV/°C, hence the percentage change is

$$-\frac{4 \times 10^{-3} \times 100}{85} \cong -0{\cdot}005\% \text{ per °C.}$$

This causes a negative change on the reference voltage supply.

(2) Drift per thousand hours will be about 0·1 per cent. This will be corrected by the periodic calibration checks. Drift per eight hours is stated by the manufacturers to be $< 0{\cdot}01$ per cent.

(3) Voltage jumps can be minimized by keeping the current through the neon constant. They are of about the order of five millivolts which is an error of approximately 0·005 per cent.

4.4. *Oscillator*

The oscillator is crystal-controlled by a DT-cut crystal. The frequency is dependent upon the stability of the crystal and the main drift is again due to temperature effects. This is about 100 parts in 10^6 over the temperature range the crystal is likely to experience in the instrument. The oscillator frequency will not deviate enough to detract from the accuracy of the instrument.

4.5. *Summation of Errors*

All the above errors, if added up in the worst case, are as follows:

Changes with Temperature

Ramp $\pm 0{\cdot}003$ per cent. per °C.

Reference voltage $-0{\cdot}005$ per cent. per °C.

Calibration voltage $\pm 0{\cdot}0005$ per cent. per °C.

Total: $-0{\cdot}008$ per cent. per °C
$+0{\cdot}002$ per cent. per °C.

Input Mains Changes

Ramp $\pm 0{\cdot}002\%$ per 1% mains change.

Other parameters are substantially free from normal mains change effects.

Input Attenuator

Calibration error 0·01 per cent.

Temperature coefficient over normal temperature changes, namely 10°C. to 40°C, are negligible.

4.6. *Conclusion*

It should be pointed out that the above figures are limit conditions with all the errors adding up in the worst possible direction. This does not normally happen to be the case in practice and Tables 1 and 2 show the drift of a typical voltmeter with temperature and mains variation. An increase in the accuracy of the instrument can be obtained if an external reference source of approximately 9 volts is used.

The voltmeter was tested in the Laboratory to obtain its variation with temperature. This was achieved by blocking the normal ventilating aperture in the case and allowing the temperature inside the instrument to rise above normal working temperature. The temperature was measured at the position of the ramp generator computing components which are situated near the bottom of the case. The instrument was calibrated and an input voltage was applied from nine Weston standard cells connected in series. Table 1 shows the variation in reading with temperature from 30°C to 40°C. The lower value is the normal running temperature at the bottom of the case with an ambient temperature of 20°C; the results shown are typical sets of readings over several complete temperature cycles.

Table 2 shows variation of reading with mains voltage.

Table 1

Temperature	Voltage Reading
30·0	9·165
33·0	9·166
34·0	9·167
35·0	9·167
36·0	9·166
38·0	9·165
39·0	9·164
40·0	9·165

Table 2

Mains Variation	Voltage Reading
−10%	9·170
−5%	9·168
Nominal	9·167
+5%	9·167
+10%	9·166

5. Acknowledgments

The authors wish to acknowledge the assistance of Mr. J. C. H. Marshall for a substantial amount of the laboratory design, and to thank the Directors of Blackburn Electronics Limited for permission to publish this paper.

Discussion on "Electronic Digitizing Techniques"

R. E. Wright: I would like to describe briefly the experiences we have had during design studies of airborne digital systems. We have often found that only a small number of inputs are in the form of d.c. signals, but that a number are in the form of 400 c/s synchro transmissions. An instrument has therefore been developed to digitize a.c. analogue signals. The principle used is basically that disclosed by Dr. R. H. Barker in his patent specification No. 691,810, although his system is intended to decode d.c. signals.

The input signal is successively backed off against a series of reference a.c. signals of amplitude decreasing in the binary scale, until the difference signal is reduced nominally to zero. The position of the various relays controlling the selection of reference voltages then gives a coded representation of the input signal. The particular unit developed accepted a 400-c/s amplitude modulated signal which could vary from 0 to 5 V r.m.s. and be either in-phase or anti-phase with the reference voltage, and gave a nine digit cyclic-binary coded output, that is, an accuracy of about 0·2% or 20 mV r.m.s.

A feature of the equipment is the ease with which reasonably precise reference voltages can be produced with transformers, the relative amplitudes being determined by the number of turns on each winding. With a system of this type the absolute value of the reference voltages is unimportant, provided that the inputs are derived from the same power supply as the reference voltages. The sampling rate of this equipment was about five inputs a second, this being determined by the speed of the relays. A later fully transistorized version would have had a higher speed of response, which would, however, have been restricted by the carrier frequency of the signal. Some limitation is also imposed on the rate at which amplitude of the input signal can be allowed to vary.

This system based on a.c.-to-digital conversion has not been adopted, partly because a number of inputs were in the form of fine-coarse synchro transmissions. The system now being considered uses repeaters for all the synchro inputs. These repeaters drive shaft position encoders. The encoders used are "induction digitizers", a new form of absolute position encoder, invented and developed by Mr. C. J. Wayman, which is considerably more reliable and flexible in operation than any other type of absolute position encoder. Another advantage of using repeaters is that they enable counter displays of input information to be provided, including displays in mixed units.

With reference to Dr. Gilbert's paper, I would like to know if he has investigated the measurement of small d.c. signals in the presence of large 50 c/s signals, as would occur, for example, if a thermocouple developed a fault to earth. I would also like to know if the characteristics of thermocouples are affected by exposure to high levels of radiation.

Mr. Tonkin's equipment is of great interest, as there is a need in this country for an airborne version of the equipment. Has he in fact used this equipment in an aircraft in flight, and if so has he experienced any effects from stray pick-up voltages, including those arising from atmospheric discharges?

A noticeable difference between the voltmeters described is in the type of numerical output display adopted. We have experienced unreliable operation with equipments using both incandescent lamps and neon discharge tubes. Would the authors please comment on the reliability of the displays that they have adopted.

G. J. Herring (*in reply*): The converter described by Mr. Wright is very interesting in that it uses the same techniques to set up the number as the more familiar device except that the error detector need only handle a 400-c/s signal. It is also necessary to match the phases of the references and the input, as well as amplitudes. It would presumably be possible to peak-detect the input 400-c/s waveform, pass it through a pulse-stretching circuit and then compare it with a set of d.c. reference potentials, although the accuracy requirement may be difficult to meet.

Dr. Gilbert (*in reply*): I can assure Mr. Wright that the figures quoted in section 6 for the performance of the amplifier in the presence of 50-c/s interference are maintained during digitization: an error of $\frac{1}{2}$°C may be caused by about 25 V a.c. between thermocouple "ground" and the digitizer "ground"; this assumes, of course, that no 50-c/s voltage is injected in series with the d.c. voltage by such a cause as unbalanced lines, but that both leads of the thermocouple are varying in phase at 50 c/s with respect to the digitizer "ground". I am informed that thermocouples are affected but little by high level of radiation (such as are found in a power reactor) over a number of years, but have no references on the subject.

G. P. Tonkin (*in reply*): There are no special airborne versions of this equipment yet for voltage measurement since projects on which we have been working have had very rigorous space difficulties. The solution must lie in semi-conductor devices, and it might be hoped, in due course, to ally such equipment as Mr. Herring has described with existing airborne equipment for frequency digitizing ("Fresco").

D. A. Pucknell (*in reply*): The supply lines available in the instrument determined the type of display to be used as it would have been inconvenient to have provided potentials suitable for operating discharge tube displays. We can only comment, therefore, on the low-voltage incandescent lamp displays which we have employed. We have found them extremely reliable and, although lamp replacements are easily made, lamp failures have been few and far between. Average lamp life is well in excess of that quoted by the manufacturers.

R. P. Budgen (Associate Member): I would like to enquire about two aspects of the high accuracy encoder mentioned by Mr. Herring. Over what ambient temperature range is stated accuracy of 0·01% maintained, and what is the minimum voltage quanta corresponding to the least significant digit?

I would also like to mention another type of encoder which is suitable for very high speed applications requiring relatively low accuracy. We recently had a requirement to encode the amplitude of 1·5 microsec pulses to an accuracy of five bits; these pulses could occur at a rate of 250 kc/s. This was solved by applying the pulses to 31 comparator circuits, the outputs of which triggered flip-flops. The flip-flop outputs were then decoded into five parallel binary digits. In other words, if we wish to encode a voltage to an accuracy of N bits we can make $2^N - 1$ decisions in parallel rather than the more normal N decisions in series. Obviously this method becomes impracticable for large values of N.

G. J. Herring (*in reply*): In reply to Mr. Budgen's question, the converter, which was designed for missile-borne applications and to be used in conjunction with the transmission of high-accuracy telemetry information, will give the full 0·01% accuracy over a range of only $\pm$ 4°C centred on whatever temperature is used for calibrating ($\ngtr$ 35°C). This is primarily due to the difference in temperature coefficients of the binary resistors in the comparison circuits. In fact the unit formed part of a larger missile installation, the whole of which was temperature controlled for other reasons. In a converter of this type the value of one quantum is determined by the threshold and drift in the error detector, which in this unit fixes the quantum at not less than 1 mV at the input terminal, i.e. 10 V full-scale is the lowest range that can be used.

J. A. Goss: Why is a mechanical chopper amplifier used in the instrument described by Messrs. Irvine and Pucknell when the required resolution is only 6 mV; or alternatively, if it is considered that the chopper should be retained for some reason or other, why not utilize it to the full and provide ranges below 10 V?

D. A. Pucknell (*in reply*): The following considerations governed the choice of the mechanical chopper system in 3-digit voltmeters.

(1) The system must be drift free.

(2) The comparator must not load the input circuit or the Kelvin-Varley potentiometer.

(3) The output from the comparator must be in a form suitable for a.c. coupling.

(4) No current must flow from the comparator into the input circuit.

The comparator circuit described may be used at levels lower than the 6 mV resolution required by this instrument. Other considerations limited the number of ranges on the instrument to a maximum of six (three positive and three negative ranges) and it was impracticable to provide a range below 10 V without sacrificing the 1,000 V ranges.

D. R. Ollington (Graduate): I would be interested to know from the authors of the papers on the digital voltmeters whether they have developed true r.m.s.-d.c. converters for use with these voltmeters?

D. A. Pucknell (*in reply*): A.c. to d.c. converters have been developed for use with the digital voltmeter but to date no true r.m.s. to d.c. converter has been successfully evolved. Suitable systems must be linear to considerably better than 0·1% over a wide range of input voltages and frequencies. The response time must be less than 1 sec under all circumstances to be compatible with the digital voltmeter response time.

D. Wheable (*in reply*): The a.c.-d.c. converter is at present under development but this will only deal with sinusoidal waveforms and will essentially be a peak-reading instrument calibrated to read r.m.s. voltages.

J. F. Winterbottom (Associate Member): The paper by Mr. G. P. Tonkin would appear to claim that the digital potentiometer has been produced for measurement of resistance strain gauges, thermocouples or other transducers of similar output. This statement appears misleading since 288 channels have later been specified and by simple application of the sampling theorem† the highest frequency component that could be observed is approximately 0·01 c/s. In practice the instrument is only applicable to static tests using the punched tape or typewriter output and becomes the "rich man's" laboratory assistant. However, this provides an opportunity for discussing the basic philosophy of the use of information.

It is usually accepted that virtually all physical quantities such as temperature, displacement, velocity, acceleration, stress, angular motions, etc., can be measured by means of the appropriate transducer having an output generally of only a few millivolts. In the motor industry, information is often collected from a series of transducers and recorded in a vehicle undergoing specific tests over various road surfaces. The recording techniques generally in use may be grouped into the three basic categories:—

(i) Paper—associated with ink, wax, ultra-violet-sensitive, teledeltos.
(ii) Film—associated with mirror-galvonometers or cathode-ray tubes.
(iii) Magnetic tape—usually associated with a modulation system.

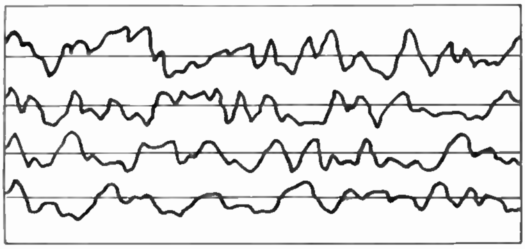

Fig. A.

The recording would normally be multi-channel and a typical result is shown in Fig. A. Generally it would be true to say that several feet of recorded data represents perhaps the vehicle travelling say fifty feet on the test surface.

Whilst providing an apparently detailed picture of the behaviour of the particular parameters measured, conventional techniques allow little more than deducing maximum/minimum readings by means of a calibration test. Clearly the amount of information present in such a recording is considerably greater but, apart from wave analysis of a tape record, we lack techniques for extracting it.

By careful application of modern statistical theory involving probability theory, correlation techniques, sampling theorem, etc., it should prove possible to break down the information‡ contained in a trace, provided that this information can be read—and this almost invariably implies either

(1) straight analogue—digital conversion;
(2) some intermediary step such as curve-following to provide an electrical (analogue) reproduction.

As a first step, a simple technique would consist of quantizing the signal either by digital converter, or modulating the signal with a square wave and rectifying, (i.e. equivalent to pulse amplitude modulation) then using biased diodes as amplitude level detectors. The next stage would consist of a counting system at each level such that the final count of a sample recording would enable a conventional histogram to be plotted showing the number of times an event occurred plotted to a base of the actual event. Suppose we consider the problem, "Can we show the displacement history of a shock-absorber"?

If a simple linear switch having, say, ten or twenty parallel stations had a bridging piece fitted to the damper arm, each switch output would represent digital displacement information and could be recorded on a multiple fixed-pen array using teledeltos paper as the recording medium. (Fig. B). If each channel level was inspected over the length of the record and a count made of the number of times each event occurred, the two extreme types of distributions that might occur are as shown in Fig. C. "A" represents a vehicle travelling down the Motorway with negligible pitch and roll, and "B" represents a violent ride over say, Australian bush country.

The plot indicates firstly how much work the damper has been doing and secondly should provide a means of relating the ride over special test tracks such as the pavé surface on the Motor Industry Research Association's Proving Ground, (this surface was designed in order to conduct

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† C. E. Shannon, "Communication in the presence of noise," *Proc. Inst. Radio Engrs*, **37**, pp. 10-21, January 1949.

‡ J. G. Henderson and C. J. Pengilley, "The experimental determination of system transfer functions from normal operating data." *J. Brit.I.R.E.*, **18**, pp. 179-186, March 1958.

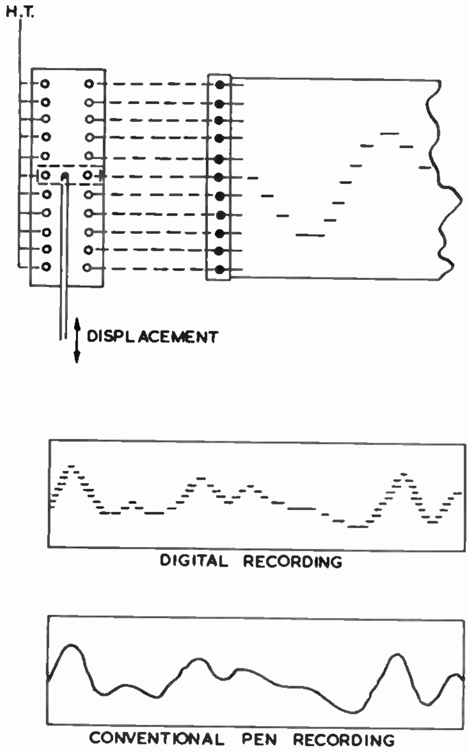

Fig. B.

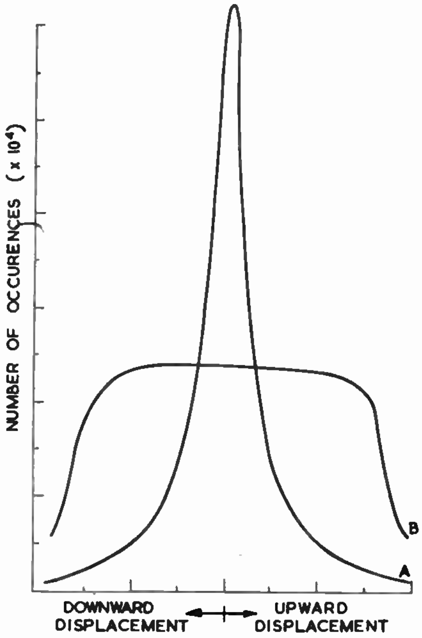

Fig. C.

accelerated life tests and detect structural weaknesses in vehicles), and various types of road surfaces likely to be met by the vehicle in service. If the counting operation is carried out in the vehicle under test, all other information is lost.

In fatigue studies, the pattern of events is of considerable significance, and thus the information may require further processing in order to determine say, additional information on say, rate of change or possibly include a frequency analysis. This is especially true of the type of information being currently measured in vehicle ride investigations. Here, due to the essentially subjective reactions, the many physical quantities have to be studied parallel with subjective results in order to assess if relationships exist. The really significant point is that this information is already recorded daily without undue complexity, weight, bulk, or power supply problems and with a relatively high accuracy and reliability.

Once the record has been made, reading equipment could be considerably more complex since it would normally be installed in a laboratory where weight, space, power consumption place no restrictions on the specification. The record could be played back at extremely slow speed, if necessary, since one would be prepared to wait several hours for the processing to be completed. The data handing could consist of several stages each representing a mathematical process.

In view of the fact that almost identical problems exist in all aircraft flight testing and guided weapon and satellite programmes, it would be interesting to receive any contributions from the authors and in particular to see whether the data processing groups within the industry have carried out a critical examination of this problem.

G. P. Tonkin (*in reply*) : In reply to Mr. Winterbottom, no claims are made for other than quasi-static measurements. As regards expense, it is felt that the number of channels offered and the speed will render the machine competitive.

G. J. Herring (*in reply*) : Mr. Winterbottom's comments suggest that a standard telemetry system might be useful in his work. This may also cover the data reduction problem because equipment to perform just this sort of analysis automatically has been produced. The great drawback is probably expense but a simpler system may suffice, in which case some development will be needed. In any event the problem is one of economics rather than technical feasibility. It is evident from past experience that this and similar industrial application of techniques developed for military reasons would well repay detailed study.

A. Isaacs: A high input impedance is required for the digitizer described by Dr. Gilbert and this was obtained by backing off the input voltage. It can be seen, however, that the input impedance can be low off balance.

Dr. R. L. G. Gilbert (*in reply*): When using a reversible digitizer the chances of running in from either direction are equal, thereby cancelling the effective input impedance.

A. Isaacs (*communicated*): Dr. Gilbert's explanation does not take account of the following effect. In practice, the digitizer will sample transducers in a given sequence. Therefore, sampling of a given transducer will always start at the voltage of the previous transducer. Thus, the digitizer voltage will always move in the same direction by a similar voltage and not cancel the effective input impedance. Furthermore, if the voltage difference is greater than the input voltage then this impedance is lower than that of the detector.

Dr. Gilbert (*in reply*): My reply at the meeting to Mr. Isaacs' question was evidently not sufficiently clear. A high input impedance for the system is useful in two ways; firstly the reading of another instrument connected in parallel with the digitizer is not affected by the latter, and secondly the "open-circuit" e.m.f. is not appreciably reduced by the loading caused by the digitizer input impedance.

The interaction of the digitizer upon another detector connected to the thermocouple depends on the impedance of the thermocouple, the natural period of the second detector, and the speed of digitization. Let us assume a thermocouple impedance of 500 ohms, generating an e.m.f. of 15 mV. The digital switches are reset at the same time as the thermocouple is switched to the digitizer, and so the e.m.f. is reduced by the ratio 500/5,500 or by 1·4 mV; this situation persists for a period of about 10 millisec. The highest digit (512°C or 20·4 mV) is then switched into circuit, and the total e.m.f. round the loop is −5·4 mV, so that the apparent e.m.f. at the thermocouple terminals is 15 + (5·4/11), i.e. an increase of 0·5 mV; this persists for 10 msec. The next digit, of 10·2 mV, gives a deficit of 0·4 mV for 10 msec, the third an excess of 0·03 mV for 10 msec, and the average decrease in apparent e.m.f. over the 120 msec digitization period is 0.13 mV, or 1%, of the total; it should be noted that the effect is proportional to the thermocouple resistance, and that the value of 500 ohms assumed here is high. If the second detector has a period of the order of 1 sec, then the deflection caused by the digitization will be of the order of 0·1% of the total; the perturbation depends on the successive error voltages during digitization, but the example quoted above gives an effect which is above the average.

The normal criterion for the input impedance of a detector to be sufficiently high to give a result of given accuracy is that $R_n \gg R_s \times 100/n$ where n is the percentage accuracy required, R_n is the input impedance of the detector and R_s is the source impedance. If we take R_n as 10 megohms (as quoted in section 7), and n as 0·05% then $R_s \leqslant$ 5,000 ohms. Considering first the conditions when $R_S=0$, if the error voltage (the difference between the input e.m.f. and the feedback voltage) is +20 μV, the current into the sign detector is +4 mμA; if the error voltage is −20 μV, the current is −4 mμA. These two input currents saturate the amplifier, resetting the controlling switch in one case and leaving it set in the other. If now R_s is raised to 5,000 ohms, then an error voltage of +40 μV and −40 μV are required to give the currents of +4 μA and −4 μA quoted above. The last digit (or 20 μV) may give insufficient input to operate its switch correctly, but all previous operations will be correct, and so the maximum error will be 20 μV, or 0·05%.

At the conclusion of the Symposium Mr. D. R. Ollington requested a demonstration of both digital voltmeters measuring the same potential, and the effect which an increase and decrease of potential had on the instruments. After this demonstration both he and the audience were satisfied that the two voltmeters agreed within the limits of their respective specifications.

A Mobile Television Camera and Recording Vehicle†

by

AUBREY HARRIS, ASSOCIATE MEMBER‡

A paper presented on 3rd July 1959 during the Institution's Convention in Cambridge.

Summary : The paper describes the design and construction of a mobile television camera and recording unit which mounts all the necessary apparatus to televise and record live scenes, even while the vehicle is in motion. The mobile unit contains a television tape recorder, two image orthicon cameras, vision and sound mixing equipment, a synchronizing-pulse generator and a petrol-electric alternator set, as well as miscellaneous accessory equipment. Details are given of vision and sound facilities and power supply system; the mechanical arrangement of the vehicle and equipment mounting is also described.

1. Introduction

This equipment, known as the "Videotape§ Cruiser," was designed in order to enable television pictures to be picked-up and simultaneously recorded by a single self-contained vehicle in motion. The advantages of such a vehicle are not confined to the feature of recording whilst in motion. The unit provides unique opportunities for other applications such as recording television commercials on location, recording of military and scientific activities in the field and recording of industrial operations for closed-circuit reproduction. The superiority of tape recording equipment in these spheres is the facility of immediate reproduction. Further applications include the recording of on-the-spot news items, special events, or location sequences with "live" quality for inclusion in television plays. In these instances great benefits accrue due to the fact that almost no setting-up time is required; the vehicle may arrive on location and be available for immediate recording, the cameras having been previously warmed up en route.

On the occasions when it is desired to televise and record in motion, either one or two cameras may be mounted on the roof, which is covered with "diamond-deck" sheeting and is provided with tie-down points for the tripods. For certain applications, a 4-feet square platform can be cantilevered from the front of the vehicle, in front of and below the driver, from which point one of the cameras may be operated.

Apart from the Videotape recorder and its accessories, the unit carries two image orthicon cameras and all their associated equipment, a vision mixer, a synchronizing generator, sound equipment, test apparatus and spare parts.

In the design of a vehicle of this nature careful consideration must be given to many factors including:

(a) Mechanical mounting of the equipment.
(b) Storage of the camera equipment and accessories while travelling.
(c) The provision of power for the equipment both while moving and when stationary.

These points are covered in the following sections of the paper.

2. Mechanical Aspects and Mountings

The Cruiser was built on a standard passenger coach chassis with a forward control driving position (Fig. 1). It is fitted with torsion-bar suspension and was designed for maximum passenger comfort, thus providing a very smooth means of transportation for the equipment with a minimum of vibration. The overall dimensions of the vehicle are: length 34 ft 2 in., width 7 ft $11\frac{1}{2}$ in.; the useful interior length of the front compartment is 22 ft 8 in.

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† Manuscript first received 11th May 1959 and in final form on 25th May 1959. (Paper No. 572.)

‡ Ampex International, 934 Charter Street, Redwood City, California.

U.D.C. No. 621.397.61

§ Trademark, Ampex Corporation.

A partition divides the interior into two areas. The rear compartment houses the vehicle driving motor, the alternator set, air conditioning equipment, the power supply connection panel, hydraulic hoist equipment, and a vision, sound and camera cable connector panel. The dividing wall is of double-skin construction, with glass wool filling the cavity, and effectively insulates the rear compartment from the remainder of the vehicle both thermally and acoustically.

The driving compartment is continuous with the main equipment area of the vehicle; additional seating is provided behind the driver for other crew members. In the front part of the vehicle is mounted all the vision and sound equipment; Figs. 2, 3, 4 and 5 indicate the layout of the equipment in this area.

Fig. 1. General view of the Videotape Cruiser.

The Videotape recorder console and racks are mounted centrally between the front and rear wheel housings with the rear of the console against the side of the vehicle. In a normal studio installation provision is made for access to the rear of the console in order to adjust and service certain units in the recorder. For this installation, however, these units were removed from their usual positions and mounted in the left-hand side of the console. On the right-hand side of the console were installed the two 19-inch equipment racks associated with the recorder. Both the console and the rack assembly are secured to the floor by heavy-duty rubber shock-mounts. Additionally, sway-mounts are fitted between the racks and the wall to prevent excessive movement of the racks whilst the vehicle is in motion.

Fig. 2. The inside of the vehicle. The Videotape recorder is at the left foreground and the camera control and monitoring equipment in the background.

Closer to the bulkhead, at the rear, is the centralized control area, where the camera controls, vision mixer, sound control panel and remote Videotape recorder controls are located. A Formica topped desk occupies the width of the vehicle; between this desk and the bulkhead are mounted the two image orthicon camera controls, their power supplies, the vision mixer and power supply, and the synchronizing generator. All these units are of the mobile suitcase type of housing. Instead of the conventional means of individually shock-mounting this type of unit, the following method is adopted.

Fig. 3. The operating area. In the centre are the camera control units, synchronizing generator, vision mixer and power supplies. Recessed in the centre of the desk is the sound control panel.

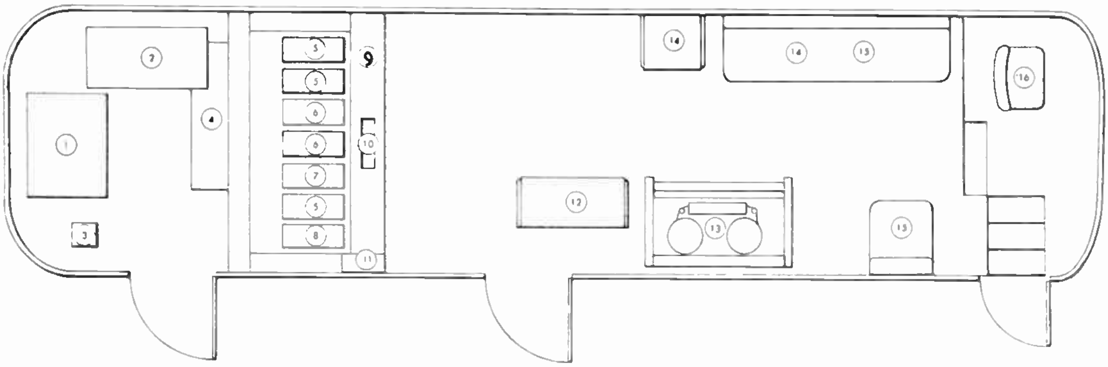

Fig. 4. Floor plan.

1 Driving motor
2 Alternator set
3 Hoist mechanism
4 Air conditioning
5 Power supply
6 Camera control unit
7 Vision mixer
8. Synchronizing generator
9 Control desk
10 Sound control panel
11 Power distribution and control panel
12 Recorder racks
13 Recorder console
14 Storage
15 Seating
16 Driver's seat

Two lengths of channel iron, the width of the vehicle, are mounted 18 inches apart at approximately the same height as the desk. Each length of channel iron is secured to the wall and the wheel guards by a 250-lb shock-mount at each of its ends; it is to these channel sections that are rigidly fixed the seven metal trays into which slide the suitcase units. (These metal trays are in fact the original shock-mount trays with the four rubber mounts removed.) With the type of shock-mounting described the high period vibration effects of individual mounting are eliminated.

Centrally recessed into the desk is the sound control panel, together with the Videotape recorder remote control panel.

Above the control desk are fitted two 17-inch picture monitors, a 5-inch waveform monitor, loudspeaker and a sound tape recorder. At each side, below the desk, actually forming part of its support, are two short 19-inch racks in which are mounted various auxiliary items. In the left-hand rack are housed a fifteen-circuit vision jack field, the vision and sound receiver and the image orthicon camera orbiters. The right-hand rack contains the sound jack field, sound monitor switching panel and amplifiers. Directly above the desk on this same side is fitted a radio telephone; at the left-hand side above the desk the power supply distribution and control panel is mounted.

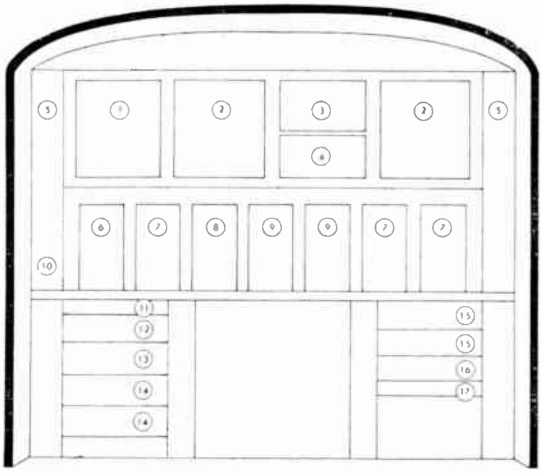

Fig. 5. The control equipment.

1 Sound tape recorder/reproducer
2 Picture monitor
3 Loud speaker
4 Waveform monitor
5 Air conditioning ducting
6 Sychronizing generator
7 Power supply
8 Vision mixer
9 Camera control unit
10 Power distribution and control panel
11 Vision jack field
12 Vision distribution amplifier
13 Vision and sound receiver
14 Orbiting unit
15 Sound amplifier
16 Sound monitor switching panel
17 Sound jack field

Accessible from the outside of the vehicle are five underfloor storage compartments, three on one side, two on the other. Two are fitted with slide out drawers, lined with foam rubber, which are used for storage of the cameras and viewfinders while travelling to and from assignments. In the other compartments are carried the camera tripods and dollies, pan and tilt heads, lenses and also power and camera cables. Additional storage is provided by cabinets inside the vehicle for reels of recording tape, a tape splicer, degausser, and other recorder accessories.

At the rear of the vehicle, on the curb side, a telescopic hydraulic hoisting arrangement is located. This hoist, capable of lifting a 250-lb load, is used for raising the cameras and tripods on to the roof of the vehicle and may additionally be used for the mounting of a receiving aerial.

An air conditioning plant of 5-ton capacity with its own petrol-engine is installed, and conditioned air is circulated inside the vehicle throughout its length along both sides. The large amount of heat generated by the control and monitoring equipment is ducted away, and a stream of cooling air from a ½ h.p. blower motor is directed onto this equipment, in order to restrict the amount of hot air entering the body of the vehicle.

3. Power Supply

A two-cylinder, horizontally-opposed petrol-engined alternator is carried in the rear of the vehicle and has sufficient capacity to supply all the mains driven equipment. It develops an output of 10 kVA at 120/208 volts, 60 c/s, three-phase (4-wire); the measured load with all the vision and sound equipment working is 60·5 amperes (7·26 kVA).

A power supply connexion panel mounted in the rear compartment permits the substitution of an external source of power to feed the equipment for occasions when the vehicle is stationary. The power feed may then be either 3-phase, 4-wire (120/208 volts) or single phase, 3-wire (120/240 volts). A distribution and control panel mounted to the left-hand side of, and above, the control desk houses a voltmeter and an ammeter for each phase of the supply, a frequency meter, individual circuit breakers for the power sub-circuits, and remote starting and stopping switches for the alternator.

4. Vision Equipment

The basic item of vision equipment in the vehicle is the Videotape recorder† and this is, apart from certain minor mechanical modifications, identical to that used in broadcast television studio operations. The recorder uses two-inch wide, 0·001 in. thick Mylar-base tape; a length of 4800 ft of this tape provides a playing time of 64 minutes at a tape speed of 15 in./sec. The peak-to-peak signal/r.m.s. noise ratio of the reproduced picture is 36 db and the horizontal resolution is 350 lines.

The two camera channels fitted in the cruiser are of the standard outside broadcast design‡, and use 3-inch image orthicon pick-up-tubes. Operation of these cameras at distances of up to 1000 feet from the control equipment in the vehicle is possible. An incident scene illumination of only 1 ft-candle at a lens aperture of $f/3{\cdot}5$ is necessary for acceptable pictures, although for best results an incident level of between 25-75 ft-candles is required. The focal lengths of the lenses used are 50 mm, 90 mm and 135 mm for each camera. Additionally two zoom lenses are carried on the vehicle; one of these has a focal length range of 55 mm to 180 mm. The other lens is fitted with adaptors and has two ranges of focal length, 63 mm to 400 mm and 165 mm to 1002 mm.

Folding, telescopic, metal tripods are utilized for mounting the cameras and they provide a working height range of between 25 and 42 inches. In order to permit mobility on level, smooth surfaces each tripod can be fitted to a three-wheeled metal dolly; this may also be folded when not in use for ease of stowage.

The vision mixer has provision for six inputs, two of which, normally the outputs of the camera channels, are non-composite and have

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† C. P. Ginsburg, C. E. Anderson, and R. M. Dolby, "Video tape recorder design," *J. Soc. Mot. Pict. Telev. Engrs*, **66**, pp. 177-188, April 1957.
C. P. Ginsburg, "Recent developments in video tape recording," 1959 Brit.I.R.E. Convention paper.

‡ A. Reisz, "A new television camera for studio and field uses," *Broadcast News*, No. 68, p. 30, March/April 1952.

synchronizing signals added to them in the mixer. It is possible to cut or fade between any of the inputs to the mixer and additionally mixing may be carried out between inputs connected to the same synchronizing source. Other inputs to the mixer include two external vision lines, the output of the Videotape recorder in the reproduce mode and the output of a vision receiver. This latter serves as a useful source of signal for the testing and adjustment of the recorder when other vision signals are not available. The recorder output is connected to the mixer, primarily in order to feed the monitors and distribution amplifiers, rather than for mixing with other input signals.

Vision signals are fed at 1 volt peak-to-peak level, black negative, throughout the vehicle and with the exception of the camera channel outputs are all of composite waveform. A diagram of the vision facilities is given in Fig. 6.

The vision mixer output is connected to the recorder via the bridging sockets of input "A" of a two-input waveform monitor, a 17-inch picture monitor and a three-output vision distribution amplifier. This picture monitor is permanently associated with the input to the recorder; the distribution amplifier is used to feed the mixer output to commentator's, artist's or audience monitors near to the vehicle or by vision lines to adjacent areas.

A monitoring switch at the vision mixer is used in a preview arrangement, connected to input "B" of the waveform monitor and a second 17-inch picture monitor. By means of the monitoring switch it is possible to preview the camera inputs, incoming lines, the vision receiver output, the input to the recorder and also the output of the recorder.

A single synchronizing generator is fitted and has provided good service without a standby. The synchronizing generator feeds drive and blanking pulses to the camera control units and mixed synchronizing pulses to the vision mixer and also to the recorder for occasions when power used by this unit is derived from the alternator. The need for this synchronizing feed will be appreciated on consideration of the following.

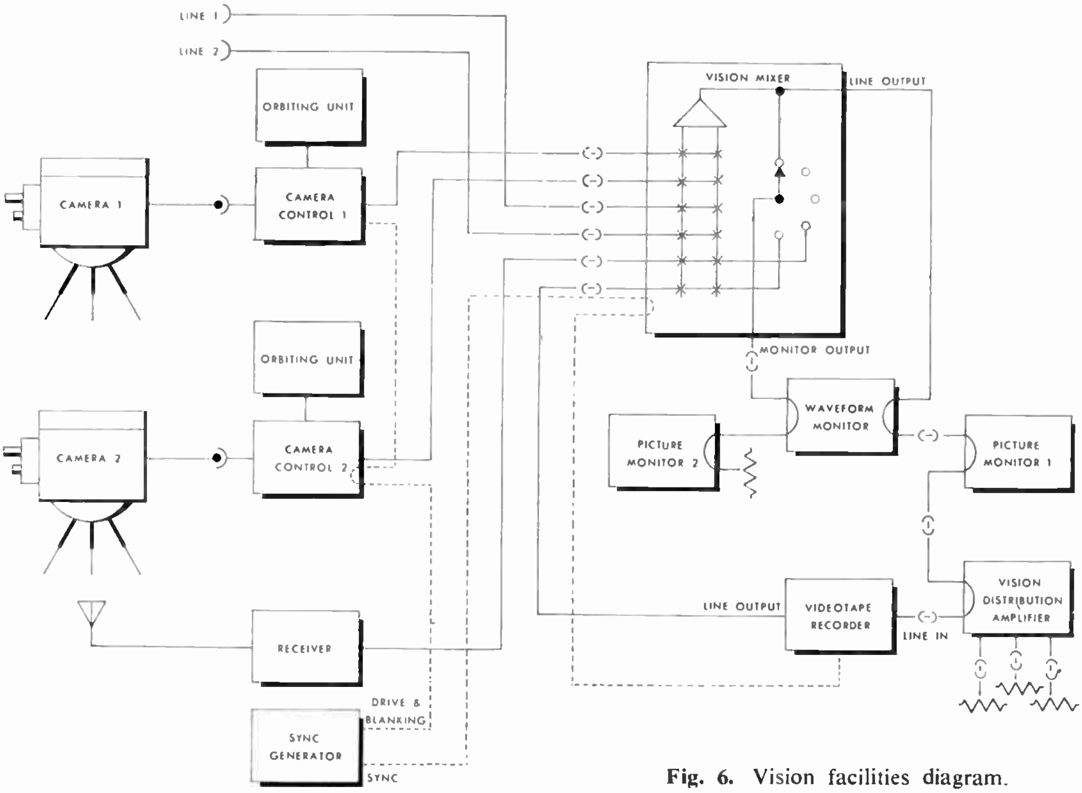

Fig. 6. Vision facilities diagram.

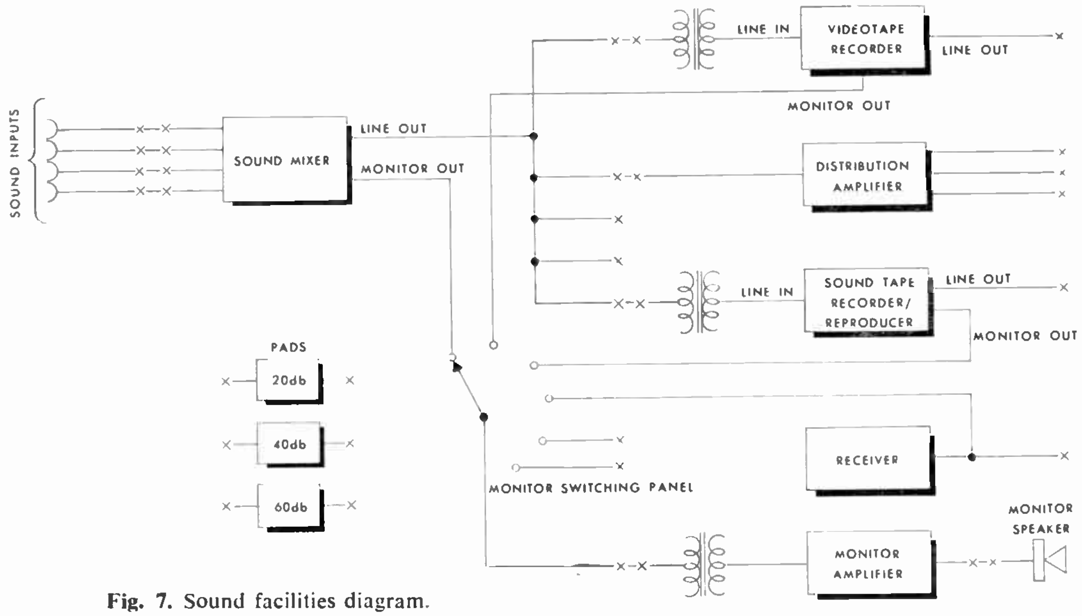

Fig. 7. Sound facilities diagram.

At a studio installation the timing reference for the recorder head drum motor is normally derived in the reproduce mode from the mains power frequency, and in the record mode from the field information of the vision input signal; this field information is itself synchronous with the mains frequency when the synchronizing generator is set to mains lock. In this vehicle the supply frequency, when the power is obtained from the alternator set, is not of sufficient stability (±3·0 c/s) to provide consistently timed recorded tapes. If during recording the supply frequency was 1 c/s fast, the tape, when reproduced in a studio with the correct mains frequency, would run for a time 1·67 per cent. longer than its time on recording. It was thus considered advantageous to refer the timing reference to a more stable frequency source; this is conveniently arranged by switching the synchronizing generator to crystal control and utilizing a mixed synchronizing pulse signal as the recorder timing reference, both in the record and reproduce modes, while using the alternator as the power source.

5. Sound Equipment

The sound facilities required in this type of installation are limited mainly to the requirement of recording a spoken commentary simultaneously with the picture. For this reason the amount of sound equipment needed is small. A four-input (low-level), transistor sound mixer is provided which has a maximum output level of +18 dbm into an impedance of 600 ohms; each channel has a gain of 87 db. For use when higher level signals are required to be fed to the mixer, a series of attenuating pads terminated on the sound jack field is provided.

Other items of sound equipment carried are: a monitor switching panel, a monitor amplifier and loudspeaker, a television sound receiver, a sound tape recorder and reproducer, and distribution amplifiers. A block diagram of the way in which these units are interconnected is given in Fig. 7.

6. Conclusion

With the introduction of this vehicle a new facility is available for the recording of television pictures with applications in many industrial and commercial fields, apart from its more obvious use in broadcasting. Many unique applications are apparent; for example it is possible to record television pictures in motion or while at rest, as the unit is completely self-sufficient. It is this latter feature which enables the vehicle to operate at locations where there is no suitable external source of power. The entire equipment may be operated by only one person, as all controls needed during operation are centralized at the control desk.

Up to the time of writing the vehicle has travelled some 10,000 miles and has made recordings totalling over 400 hours. Of this nearly 300 hours were made using the auxiliary power unit and about 160 hours while the vehicle was moving.

A unit containing two Videotape recorders as well as camera and control equipment is now under construction, and much further development is indicated.

7. Acknowledgments

Acknowledgment is gratefully made to the coordinator of this project, Mr. H. G. Hummell, and also to Mr. C. F. Swisher, both of Ampex Corporation. Thanks are also due to the Directors of Ampex Corporation for their permission to publish this paper.

DISCUSSION

F. H. Steele: Having been concerned with the design of television outside broadcast units, I know that one is frequently aware after completing the equipment, of the points where the design could be improved. Has Mr. Harris any improvements which he would like to see incorporated in another video tape cruiser?

Aubrey Harris (*in reply*)*:* I think that possibly the accessibility of some of the cabling behind the control desk could be improved as this is now rather close to the back of the suitcase-type units. No particular difficulties have been encountered in mounting the equipment in smaller racks in order to accommodate it in the vehicle.

L. F. Mathews (Member): There are one or two questions I would like to raise with Mr. Harris on the design of these television recording vehicles. First of all, I was interested to see how he uses a 10-kW generator. Would he wish to use a larger generator after having had operating experience of the vehicle? Secondly, I appreciate the advantages of putting the recording equipment within the wheel base of the vehicle, but I wonder why the generator is right at the rear end and just behind the racks. Would he not think that there is a better spot to put this item when one takes account of both its noise and weight?

Aubrey Harris (*in reply*)*:* The requirements of the vehicle are about 7½-kW which gives a 33 per cent margin and its regulation is quite good. It provides also adequate lighting and heating supplies. The positioning of the generator is nicely balanced because looking forward into the vehicle the generator is behind and to the left, whereas the video tape recorder is in front and to the right slightly forward of the centre line of the two axles, while the bulkhead in between effectively keeps most of the noise away.

Radio Engineering Overseas . . .

The following abstracts are taken from Commonwealth, European and Asian journals received by the Institution's Library. Members who wish to consult any of these papers should apply to the Librarian, giving full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the journal unless otherwise stated. The Institution regrets that translations cannot be supplied; information on translating services will be found in the publication "Library Services and Technical Information."

TRANSISTORS IN TELEVISION CIRCUITS

The horizontal deflection circuit of a television receiver is a particularly high current density switching circuit and has a low input impedance with an inductive load. Since a high voltage fly-back pulse arises during a re-trace period, the transistors employed in this circuit require high reverse break-down voltages with low input impedance. A Japanese paper describes the properties necessary in transistors intended to be used in such a switching circuit and shows that the bilateral and symmetrical *n-p-n* alloy type transistor is most suitable for this purpose. Details taken into account in arriving at this conclusion are the relation between collector-to-emitter break-down voltage, collector-to-base break-down voltage, maximum short-circuit current, short-or-open-circuit impedance, switching times, etc. The paper gives a scatter diagram for the ratio of these breakdown voltages to the factor $1-\alpha$ and a simple figure of merit for the transistor used in this circuit is proposed.

"The characteristics of transistors used in horizontal deflection circuits," I. Tagoshima. *Journal of the Institute of Electrical Communication Engineers of Japan*, **43**, pp. 25-32, January 1960.

ELECTRONICS AND RAIL TRANSPORT

The French National Railways (S.N.C.F.) have always been well-known for their advanced techniques and a series of papers which was published recently in the journal of the Société des Radio-électriciens describing some of the applications of electronics will therefore be of special interest. The first of the six papers surveys the present applications with special reference to installations on rolling stock. The second paper discusses electronic methods employing valves, thyratrons and transistors which monitor the track circuit, replacing the earlier methods employing d.c. or 50-c/s a.c. relays. A further paper deals with switching circuits associated with long-distance transmission systems, and particularly the methods employed to minimize risks due to possible breakdown of the electronic components. Two further papers deal with the applications of electronic techniques in directional interlocking for single track working and with the general problem of traffic control. The final paper deals with the mobile maritime radio telephone service installed in the cross-channel and passenger cargo vessels operated by S.N.C.F.

"Electronics in the service of the railways" number. *L'Onde Electrique*, **40**, pp. 287-336, April 1960.

MEASURING SURFACE ROUGHNESS WITH MICROWAVES

Work has been carried out at the Institute of Telecommunication of the Polytechnical University of Budapest on measuring surface roughness using microwaves It is shown that microwave surface roughness can be characterized by the ratio of specific resistances measured on microwaves and at very high frequencies respectively. When measured at v.h.f., the test piece is placed within a radio-frequency coil and the resulting Q-factor determines the specific conductance of the test piece. This same test piece can then be placed between dielectric stubs in a cavity resonator and determination of the Q-factor of the cavity will provide a value for the specific conductance of the test piece at these frequencies. The author has designed a method for measuring the Q-factors of resonance cavities which is claimed to be quick, very accurate and suitable for quantity measurements.

"A microwave method of measuring surface roughness," G. Almassy. *Periodica Polytechnica, Budapest*, **4**, pp. 17-29, 1960.

HEAT AND POWER TRANSISTORS

A recent Polish paper discusses the influence of the thermal resistances occurring between the collector junction and air surrounding the heat radiator upon the magnitude of the admissible power dissipation in germanium power transistors of the *p-n-p* type. The paper shows the dependence of these resistances on the construction of the transistor, the dimensions of the radiator and its surface treatment. The author discusses the methods employed to measure the temperature of the collector junction and the transistor container and the thermal resistance between the radiator and the surrounding air.

"The thermal problem in power transistors," T. Janicki. *Rozprawy Elektrotechniczne, Warsaw*, **6**, No. 1-2, pp. 107-121. 1960.