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ENCOURAGING MORE TECHNOLOGISTS

Britain's plans to meet the technological challenge of the age have been revealed in a Government publication on a scheme for extending technical education.*

Whilst between 1938 and 1955 the number of university students in science and technology has doubled, the Government now confirms that more must be done to stimulate the recruitment of technologists, technicians, and craftsmen, and plans to spend over £90,000,000 in England, Scotland, and Wales, in order to achieve this aim.

The term technologist is more embracing than that of engineer for it covers industries other than engineering. The Command Paper gives the following definitions of technical personnel:—

The Technologist has the qualifications and experience required for membership of a professional institution. A technologist has studied the fundamental principles of his chosen technology and should be able to use his knowledge and experience to initiate practical developments. He is expected to accept a high degree of responsibility and in many cases to push forward the boundaries of knowledge in his own particular field.

The Technician is qualified by specialized technical education and practical training to work under the direction of a technologist. (*In relation to the radio and electronics industry the editorial in the June 1949 issue of the Journal outlined the place and importance of recognizing the technician in industry.*)

The Craftsman: Craftsmen represent the skilled labour of manufacturing industry and account for more than one-third of its manpower. With the growing complexity of machines and the introduction of new materials it becomes all the more necessary for them to appreciate not only how but also the why of the work they do.

Having given official approval to definitions already well understood in most branches of engineering, the Command Paper summarizes other background information, including many of the measures suggested by numerous reports, some made by our own and other Institutions, the Parliamentary and Scientific Committee, and the recommendations put forward some eleven years ago by the Percy Committee.

The Command Paper must, however, be generally welcomed as recognition, albeit belated, of the extreme urgency of the problem of shortage of technical manpower. The decision to sanction heavy capital expenditure has been described by the Minister of Education, Sir David Eccles, as "—a long range weapon against inflation."

Much has been done in Great Britain toward expanding university facilities. The number of full time university students of science and technology is now 29,013, which is 124 per cent. above the 1938-39 figure and is a new peak. This represents 34½ per cent. of the university population, and an output of 6,000 degrees in science and technology a year, of which pure science accounts for 4,200 and technology 1,800. In addition, some 450 students annually obtain diplomas in technology.

Britain's many industrial and commercial undertakings make great demands on a total population of 50¼ million people.† The Government has nevertheless recognized the need to

* "Technical Education"—H.M.S.O. Cmd. 9703.

† The total working population is estimated to be 24¼ millions.

increase by half, the number of young people taking advanced courses at technical colleges or attending universities. Bearing in mind that the proportion of children at school over the age of 15 years is increasing and will reach a very high level around 1960, there is already an urgent need for a larger building programme for technical colleges.

Additional accommodation is, however, only the first approach to the problem. Much more important is the means of attracting more students and the ability to place them in careers offering incentive for further technical progress. The White Paper rightly, therefore, stresses the need to win the support of parents to the need for further education, and the support of individual employers and trade unions by giving all the practical help they can to making the plan a success.

It might not be out of place to mention the point made by a Vice-President of the Institution at a recent meeting of the Parliamentary and Scientific Committee that " . . . encouragement to take up training and secure qualifications as an engineer is to a large extent dependent upon recognition of the status of the engineer." This point of view has been put to the Minister of Labour, whose successors in office will be very dependent upon the success of the current Government report.

In the field of technological training, as distinct from pure science at the universities, it is hoped to raise the capacity for full-time advanced courses in technical colleges from 9,500 candidates per year to about 15,000. It is visualized that advanced full time and sandwich courses—the latter being particularly stressed in Government reports—will extend beyond the higher national certificate in order to recruit candidates for awards by the National Council for Technological Awards which has recently been set up under the Chairmanship of Lord Hives of the Rolls-Royce Company.

Emphasis on sandwich courses reiterates the role which the Government expects industry to take in future plans for technical education.* This contribution to the pool of supply of technologists must also include the part played by the Scientific Civil Service in absorbing apprentices and the like, bearing in mind that the scientific and technical branches of Government establishments are now the largest single employers of technologists and technicians.

The Ministry of Education recently held a meeting on "The Development of Sandwich Courses." These courses must be encouraged but it is obvious that expenditure on such training partly comes from an indirect subsidy of industry. Permitting payment of fees to count as a business expense is a step in the right direction, but Government departments employing technologists and technicians should also be encouraged to play their part in sandwich training schemes.

The Command paper is not very explicit on ways and means of recruiting science teachers. A previous editorial in *J.Brit.I.R.E.*† stated that teachers of science and mathematics are required at the rate of 600 a year over the next five years; this need is in competition with vacancies in industry and Government for qualified technologists or engineers.

In extending the capacity and the standard of technical colleges, therefore, it is first necessary to ensure the quality, as well as quantity, of teaching staff. This is a long-term problem and the immediate solution may well lie in recruiting engineers already employed by Government and industry for part-time teaching in specialist subjects.

Educational and professional bodies concerned with the training and work of the professional engineer can make an important contribution towards solving manpower problems—a point stressed three years ago in this Journal.‡ Machinery for this purpose already exists through the various Advisory Committees set up by the Ministry of Labour toward the end of the last war ostensibly to operate the Technical and Scientific Registers. These various committees could do much to implement the proposals for increasing technical education.

It is believed that the Minister of Labour is at present reviewing the work of these Advisory Committees. It is hoped that any revision of their constitution or activity will be such as to enable engineers to make their contribution to this new national effort by adequate representation of their appropriate professional bodies.

* Reference is made particularly to "Recruitment of Scientists and Engineers by the Engineering Industry"—H.M.S.O. publication No. 94650.

† "Liberal Education in a Technical Age" *J.Brit.I.R.E.*, **15**, page 333, July, 1955.

‡ "Man-Power Problems" *J.Brit.I.R.E.*, **13**, page 181, April, 1953.

FACSIMILE TRANSMISSION OF WEATHER CHARTS AND OTHER MATERIAL BY LANDLINE AND RADIO*

by

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Read in the Symposium on "Electronic Methods of Pictorial Reproduction", held in London on 25th January, 1956. In the Chair: Mr. W. E. Miller, M.A. (Cantab.), Past-President.

SUMMARY

A rapid expansion in the facsimile broadcasting of meteorological information has taken place throughout the world during the past few years. An outline of the present situation is given in the paper, which also discusses the technical requirements of the service and examines special problems relating to radio transmission. Descriptions of facsimile terminal apparatus developed for this service are given. Recorders feature the use of direct recording electrolytic paper and automatic operation. Reference is also made to facsimile equipments designed to handle other material including half-tone pictorial representations.

1. Introduction

The rapid growth of civil and military aviation has given rise to a greatly increased demand for meteorological information and forecasts. This information is required in readily usable form at a large number of widely scattered receiving points, and is distributed in the United Kingdom by the Meteorological Telecommunication Centre at Dunstable.[1] Similar centres exist in the U.S.A., Canada, France, Germany, U.S.S.R. and many other countries. The principal method of communication in Europe has been by teleprinter coded messages. The transmission of weather maps by this means involves the presence of decoding, plotting and forecasting staff at each receiving station. One of the principal advantages of using facsimile for such a service is that the bulk of the trained staff can be concentrated at the centres. As a means of transmission it is incapable of making errors in the sense that it cannot change the meaning of a character, symbol or figure. The recorded information is either capable of correct interpretation or is illegible. Further it is inherently capable of preserving legibility under conditions of very low signal-to-noise ratio. In this feature it resembles the reception of morse signals by a highly skilled operator, who can read through noise which would baffle an automatic machine. The important difference however is that no special skill is required in reading a facsimile chart recorded in the presence of noise.

For these and other reasons great interest is being shown in the facsimile transmission of weather charts. The U.S. Weather Bureau have for years broadcast maps from Washington over a landline network to several hundred receiving stations. In addition, regular U.S. radio broadcasts are made from Washington, New York, Frankfurt, Port Lyautey, Balboa, Honolulu and Guam. The Canadian Meteorological service instituted in 1953 a broadcast facsimile service covering the whole of Canada by landline.[2, 3] Radio links connect this broadcast with Goose Bay and Frobisher and other stations. The Canadian network is the only one in the world which uses throughout automatic recorders capable of unattended operation. There are a number of equipments operating in the U.K. and there has been a regular radio facsimile transmission from Dunstable since 1953. Both the U.S.S.R. and Norway have recently started radio facsimile broadcasts.

Work was begun by the author's Company on the development of weather chart transmitters and recorders during 1951. At that time the U.S. Weather Bureau were using a considerable number of Times recorders working with Teledeltos paper. These machines handle a chart 12 in. × 18 in. but the recorders are not of the continuous type and are therefore unsuitable for unattended operation.

* Manuscript received 3rd December, 1955. (Paper No. 346.)

† Muirhead & Co. Ltd., Beckenham, Kent.

U. D. C. No. 621.397.2:551.509.

The objective set was the production of transmitters and recorders capable of handling copy size 18 in. × 22 in. The first equipments to be completed were for alternative radio or landline working and these were followed by an automatic recorder for landline operation together with its companion transmitter. It is convenient for the purpose of this paper to discuss the landline machines first.

2. General Principles

The broad principles of facsimile transmission are fairly well known and have been described in a previous paper.[4] It is not proposed to examine them in any great detail here. The transmitter in this case has a drum 6 in. in diameter and 22 in. long associated with an optical carriage which traverses parallel to the drum axis. The document on the transmitter drum is scanned in a spiral by virtue of the drum rotation and the traverse of the optical carriage. The light signals from the drum are picked up by a photomultiplier cell and are used to amplitude modulate a carrier frequency in the range 1,000–2,500 c/s. This carrier is sent to line with maximum amplitude corresponding to a black signal. In the recorder the electrolytic paper is drawn at a constant rate between a fixed writing blade extending across the width of the paper and a helical electrode carried on a cylindrical former which rotates synchronously with the transmitter drum. The point of contact between fixed and moving electrodes makes successive strokes across the width of the paper and so performs the function of scanning. The amplified and demodulated signals from the line are applied directly to the marking electrodes. Current then flows through the paper and marks it to a density corresponding with the original. The recording paper is impregnated with a colourless solution and is made up in rolls 100 ft. long. In the recording process the writing blade, which is made of steel, acts as the anode and the helix as the cathode. The passage of current transfers iron from the writing blade to the paper where it forms an indelible colour lake with the chemicals in the solution. The paper produces a pleasing black and white record and is clean to handle; being translucent it is suitable for the production of copies by ordinary photo-printing, e.g., dyeline methods.

3. Compatibility of Equipments

Compatibility of meteorological facsimile equipments is of fundamental importance. Both the C.C.I.T.* and the W.M.O.† are interested in laying down standards to ensure as far as possible that all equipments wherever they are produced are capable of co-operation with one another. Both of these bodies have recently done considerable work along these lines. In 1951 the obvious course was to follow existing U.S. practice and the machines produced are capable of co-operating with U.S. equipments.

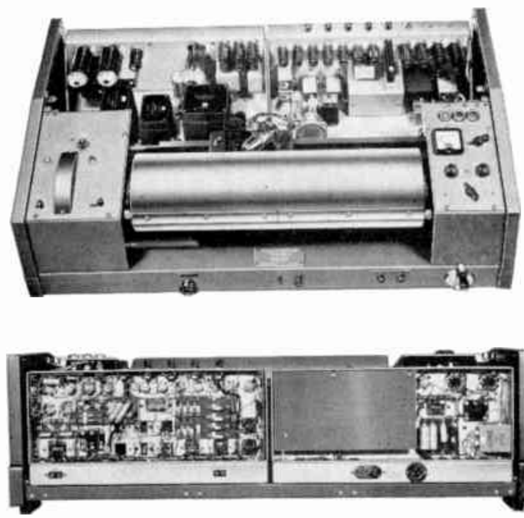


Fig. 1.—Meteorological facsimile equipment—views of the transmitter with covers removed.

For a pair of machines to co-operate the following relationships must hold between them:

(1) They must have the same number of scanning lines per minute.

(2) The direction of the scanning spirals (i.e. right or left hand) must be the same for each.

(3) For 1 : 1 reproduction the scanning lines on the two machines must have the same length and the same pitch. The reproduction will have the same aspect ratio as the original if the ratio $\frac{\text{Length}}{\text{Pitch}}$ for the scanning lines is the same at transmitter and recorder. It is the practice in phototelegraphy to express

* International Telegraph Consultative Committee.

† World Meteorological Organisation.

this ratio as Index of Co-operation, defined as $\frac{D}{P}$ where D is the drum diameter and P is the pitch of the scanning lines.

(4) Recorders must be capable of being phased to transmitters, therefore phasing signals must be standardized.

(5) The scanning speeds must be equalized to within ± 10 parts in 10^6 of each other.

4. Machines Developed for Canadian Service

Transmitters and recorders were designed to the requirements of the Canadian Meteorological Service. A brief specification is given below:

Index of co-operation	576.
Scanning rate	96 lines per inch.
Helix Speed	60 or 120 r.p.m.
Helix direction ...	Left hand.
Maximum chart size ...	18″ × 22″.
Method of recording...	Continuous and direct on electrosensitive paper.
Line signal	1,800 c/s carrier amplitude modulated. Maximum amplitude black.
Contrast ratio ...	25 db or 12—14 db black/White.
Phasing signal ...	Black signal interrupted once per revolution. On/off ratio 20:1.
Sending level	+5 dbm to −15 dbm.
Receiving level ...	+5 dbm to −40 dbm.
Recorder setting up ...	Automatic or manual.
Synchronizing	Independent 1,000 c/s tuning forks at transmitter and recorder.
Time for complete chart	32 minutes at 60 r.p.m. 16 minutes at 120 r.p.m.

Before describing the machines in detail, it is advisable to discuss the requirements for automatic reception. At the recorder the necessary conditions at the commencement of a transmission are:

Preparatory	(1) Recorder power supplies switched on. (2) Paper available in recorder. (3) Recorder set to correct speed. (4) Recorder motor running at synchronous speed.
At Commencement of each Transmission	(1) Recorder is automatically set up to correct marking power level. (2) Paper feed starts. (3) Helix starts in phase with transmitter.
At end of Message	(1) Helix stops. (2) Paper feed stops. (3) Recorder level setter returns to standby.

At the transmitter an operator is required to accept the charts from the plotting room and place them on the drum. Because of this and because in general one transmitter serves many recorders there is no great economic advantage in making the transmitter completely automatic in operation. Consequently the transmitter has been arranged so that the operator loads the drum, selects the speed, sets up black and white levels and starts the drum. He then operates a Transmit switch which causes phasing signals to be sent to line. After an interval of 30 seconds he starts the drum traverse and the phasing signals are replaced by picture signals. He may now leave the transmitter to transmit the chart and close down automatically when the chart has been sent. Transmissions are made on a timed schedule which includes information regarding speeds of transmission.

5. Transmitter—Mechanical Features

The general construction of the transmitter is shown in Fig. 1. It is mounted in a casting at the front of which is the 6 in. diameter drum with its associated hysteresis motor, gear box and clutch. An optical carriage comprising lamp and condensing system, objective lens, aperture and photo-multiplier cell, is arranged to traverse at the rear of the drum. Fig. 2 shows the optical system diagrammatically. The

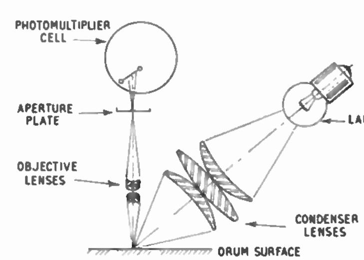


Fig. 2.—Optical system of the chart transmitter.

rotation of a lead screw which drives the carriage is effected by a ratchet and pawl mechanism driven by the motor. The optical carriage carries a partial nut which engages with the lead screw. The front end of the carriage slides along a vee-rail block parallel to the drum. The rear end slides on a flat rail so there is no constraint in the sliding motion. The carriage can be positioned by a hand wheel in either direction and can be returned to its starting point by means of a motorized drive.

The drive to the drum from the hysteresis motor is taken through a single tooth clutch and a compliant coupling which ensures that the inertia load of the drum is gradually applied to the motor when the drum is started. The drum is concentric within $\pm 0{\cdot}003$ in. and is dynamically balanced. It is highly important that the rotational vibrations of the drum while it is revolving should be kept to the absolute minimum. To this end the gears are precision cut and in addition at the right hand end of the drum there is a hysteresis brake which applies a small amount of frictional damping. This brake and the compliant driving member together form a mechanical filter which greatly reduces any rotational vibration which may be present in the gearing. The device for securing charts to the drum is illustrated in Fig. 3. It

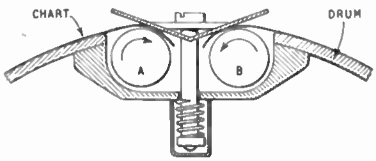


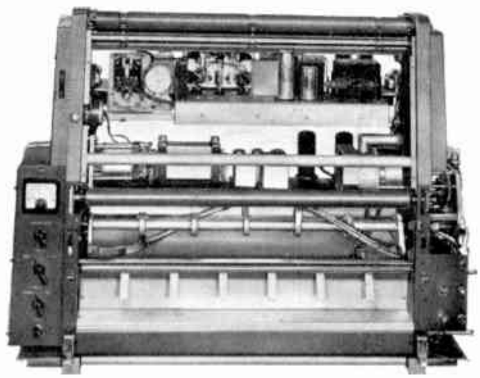
Fig. 3.—Method of loading drum.

consists of a V-shaped metal strip running the full length of the drum and two knurled rollers A and B. One end of the chart is inserted under the strip and gripped by rotation of roller A. The drum is then rotated so that the chart wraps around it and the other end of the chart is inserted under the strip where it can be gripped by turning the roller B. Once the chart has been gripped it can be tensioned up and made to lie flat by simultaneous rotation of both rollers.

6. Recorder—Mechanical Features

The general construction of the recorder is shown in Fig 4 and the method of recording is presented diagrammatically in Fig. 5. The main frame carries the paper magazine, helix, main and upper driving rollers together with the hysteresis motor, gear system and clutch for engaging the helix and paper drives. On this frame is a door hinged at the bottom which carries the front

(a) Front view.



(b) Front part of paper magazine removed.

(c) Rear view.

Fig. 4.—Meteorological facsimile equipment—views of the recorder.

part of the paper magazine, writing blade and the main pressure roller. The door is opened for inserting a fresh roll of paper, the end of which is drawn up over the helix and the main and upper driving rollers. No threading of paper is necessary and the action of closing the door seals the paper box, brings the writing blade to the paper and engages the main and driving pressure rollers. A small amount of friction is applied to the paper roll through a number of sprung fingers at the back of the paper box. When the clutch is engaged the helix starts to turn and the paper is drawn upwards by the main rollers. A fast paper run

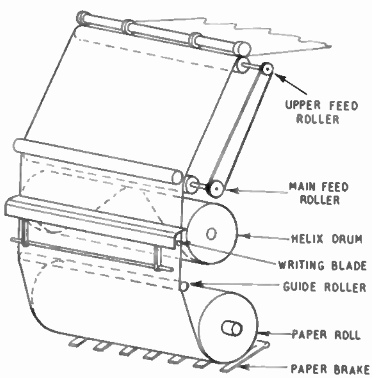


Fig. 5.—Method of recording.

up is available under the control of a push button. Arrangements for cutting off the charts are provided immediately above the main rollers and behind the upper rollers. Three electronic chassis are mounted one above the other at the back of the machine. These are connected through multiple way plugs and sockets. They can be rapidly removed for service and replaced meantime with a spare chassis.

7. Transmitter Circuit

The essential parts of the transmitter circuit and their operation are described with reference to Fig. 6. The circuit consists basically of a carrier oscillator feeding a balanced modulator, the output of which is connected to line. The chart signals from the photomultiplier cell are arranged to bias the modulator and to produce minimum bias for a black signal. The control signals are arranged to cut the carrier on and off as necessary.

The operators controls shown on Fig. 6 are the Transmit and Traverse start switches. Prior to transmission, white and black levels into the modulator are set up, and the line is disconnected by SW3C. On TRANSMIT, the PH relay is energized and contact PH2 puts zero bias on the modulator (producing full carrier output) while PH1 and SW3A connect phasing contacts SW11 across the primary of the transformer. The upper contact of SW11 is closed once per revolution of the drum, cutting off the carrier so that the required phasing signals, black level interrupted by brief pulses of zero carrier level, are sent to line. The mark space ratio is about 20:1. The lower contacts of SW11 having 40:1 mark space ratio are at this stage masked by the 20:1 contacts.

The operator sends phasing signals for a period of 30 seconds and then operates the Traverse Start switch. PH relay is de-energized and an M relay (not shown) connects 50 cycles to the modulator grid for a period of 2 seconds. This signal is for the purpose of starting any U.S. "Timesfax" recorders which may be on the network. After 2 seconds the picture signal is re-connected to the modulator via M2 and chart signals go out to line. The 40:1 contacts of SW11 now operate to cut off the carrier once per revolution when the clip is being scanned. This ensures that a white pulse is sent every revolution even when a totally black part of the chart is being scanned. These contacts are only necessary because certain radio facsimile recorders connected to the network require a modulated signal to keep them running.

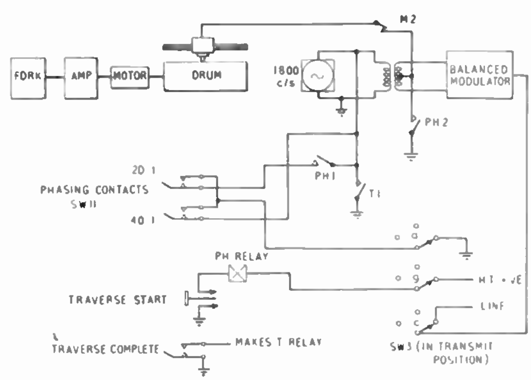


Fig. 6.—Block circuit diagram of the chart transmitter.

At the end of transmission the traverse complete switch is operated by the carriage and a T relay is energized which shuts off the carrier by contact T1. The optical unit also trips the traverse mechanism and in so doing restores the traverse start switch to its original position. The operator then stops the drum rotation and returns the carriage to its start position.

8. Recorder—Circuit and Operation

The block schematic of the recorder is shown in Fig. 7. The standby condition of the recorder is with supplies switched on, speed change lever in the appropriate position, hysteresis motor running in synchronism and no signal on the line.

A signal detector connected across the input to the recorder is responsible for detecting phase and facsimile signals of the correct carrier frequency but will not respond to voice or noise frequencies. The function of the signal detector circuit is to prepare the recorder for facsimile signals and keep it running as long as these signals are present. It responds to modulated signals only. When phasing signals appear on the line a relay RLA in the signal detector is operated and starts a servo motor which winds up the input level control of the recorder. The output from the recorder demodulator which at this time is connected to a dummy load is compared in a comparator circuit with a pre-determined reference voltage, and when the correct black marking voltage is obtained a relay RLB in the comparator operates and stops the servomotor. It also applies the phasing signals to certain relays in the block marked PHASE. These in turn operate the multi-tooth clutch and thus start the helix and normal paper feed. When the clutch operates the marking power is transferred from the dummy load to the helix and writing blade. A paper run up circuit is available which automatically runs up a few inches of paper half a second after the helix has started. This ensures that under all conditions there is moist paper under the writing blade at the commencement of each chart. Under normal conditions where transmissions follow each other continuously this feature is unnecessary and can be switched out by the operator. At the end of the chart the signal is removed and the signal detector allows the RLA relay to drop out. After a time delay of a few seconds the clutch is de-energized, the helix stops and the servo motor drives the input level control back to its starting position. This time delay is put in to ensure that the recorder will not close down during accidental momentary interruption of the circuit.

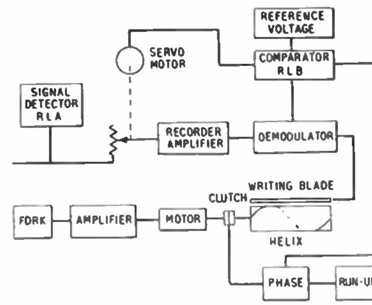


Fig. 7.—Block circuit diagram of the chart recorder.

9. Line Circuits

Facsimile transmissions over line circuits are more sensitive to delay distortion than to variations in attenuation/frequency characteristics. It has been stated[5] that for satisfactory transmission of pictures involving modulation frequencies of 1,000 c/s the maximum time delay between significant sideband components should be not greater than ±250 microseconds. In practice time delays of ±1 or 2 milliseconds are common, but satisfactory transmissions of reasonably fine detail at 60 r.p.m. involving modulation frequencies of 900 c/s can usually be obtained. The higher speed of 120 r.p.m. is useful but is limited to material of coarse detail such as upper air charts unless the line circuit is short. The merits of 90 r.p.m. are becoming generally accepted and later machines are arranged to be capable of running at this speed. Noise on line circuits is not usually of high enough level to affect the charts.

More than 150 machines of the types described above have been supplied to Canada and have been in continuous use during the past two years, during which time they have proved very reliable in service. It has been noted that both Canada and the United States make extensive use of permanent landline networks for their meteorological facsimile services. However, there is also considerable demand for such services to operate over radio links and it is proposed in the remainder of the paper to examine this subject.

10. Facsimile Transmission by Radio

Facsimile transmission of pictures by radio is quite old. Experimental work was carried out by Dr. Korn in the early part of this century resulting in transmission of pictures by radio from Berlin to Paris in 1913. A good account of the historical background is given in the paper by Cole and Smale.[6] It is interesting to note that the first commercial Transatlantic radio transmissions in 1924 were made with a combination of pulse width and pulse tone modulation. This was later developed into a pulse width system but the biggest advance in quality and reliability of reception came with the advent of sub-carrier frequency modulation which was introduced on the London-New York circuit in 1938. S.c.f.m., as it is called, appears to have been originated in Japan in 1932 by Niwa.[7] It was also described in a paper by Mathes and Whitaker[8] and is still the most important system in use today although it seems likely that in the future it will give way to direct frequency shift of the radio carrier (f.s.). In the s.c.f.m. system the densities of the picture tones are represented by different audio frequencies. By international (C.C.I.T. and C.C.I.R.*) agreement, for phototelegraphy the white frequency is 1,500 c/s and the black frequency 2,300 c/s. Intermediate tones are of course represented by frequencies between these two values. This subcarrier is used to amplitude modulate the radio transmitter. The advantage of this system over the normal a.m. method is that amplitude limiting can be used after demodulation at the receiver to combat the effects of fading. The question of the bandwidth of the subcarrier for phototelegraphy is discussed in a paper by Carter and Wheeler.[9] Since the modulation index for the highest picture frequencies is always less than unity, the amplitude of 2nd and higher order sidebands is very small. Generally speaking it is a safe assumption that the important picture information is contained within the band given by the mean frequency (in this case 1,900 c/s) plus twice the maximum picture frequency plus the total frequency swing. For the case of weather charts the maximum picture frequency at 1 r.p.s. is 900 c/s. The frequency limits are reversed, i.e. black is 1,500 c/s and white is 2,300 c/s. The sub-carrier bandwidth is therefore $1{,}900 \pm 900 \pm 400$ c/s, i.e. 600–3,200 c/s. This figure should be taken as a guide only. In practice the results obtainable with a given bandwidth are affected by such factors as the type of material to be transmitted, the phase characteristics of economically realizable filters, and the amount of noise present in the band.

* International Radio Consultative Committee.

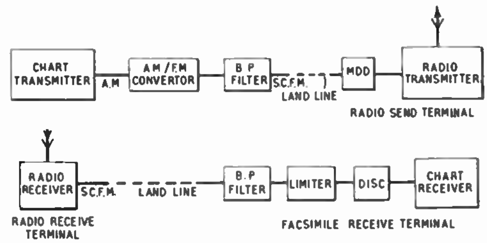


Fig. 8.—Typical sub-carrier frequency modulation installation.

Figure 8 shows in block diagram form units for s.c.f.m. transmission of weather charts. The a.m. signals from the chart transmitter are converted to s.c.f.m. signals in an a.m./f.m. converter which is conveniently under the control of the transmitter operator. Black and white steady signals are available from the transmitter for the purpose of setting frequency limits in the converter. The resulting s.c.f.m. signals are then filtered and sent by landline to the radio transmitting terminal. Normal communication receivers are used at the radio receiving terminal and at the facsimile receiving terminal the signals are amplified, limited and discriminated before being applied to the chart recorder.

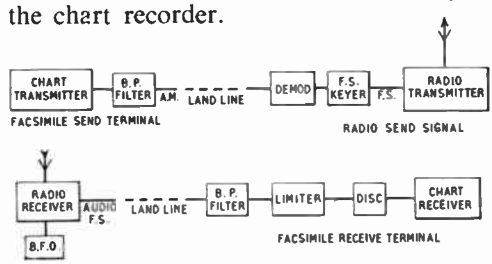


Fig. 9.—Typical frequency-shift installation.

A corresponding diagram for frequency shift transmission is shown in Fig. 9. The a.m. signals from the chart transmitter are filtered and sent by landline to the radio transmitting terminal. Here they are demodulated and the demodulated output is used to swing the frequency of the frequency keyer 800 c/s from white to black. The responsibility for setting frequency limits is now the concern of the radio staff. The radio receiver is required to heterodyne the incoming signals to produce an output of 1,500 c/s for black and 2,300 c/s for black. The signals passed to the facsimile receiving terminal are exactly the same as in the s.c.f.m. case. The black and white frequencies must remain within 50 c/s of their nominal values during transmission and this requirement places considerable demands on the frequency stability of the radio transmitter and receiver. The tuning of the radio receiver is much more critical than is the case with s.c.f.m.

The superiority of f.s. over double sideband s.c.f.m. in signal/noise ratio and reduction of bandwidth however, outweighs the operational simplicity of the latter method. With f.s. the whole of the transmitted power is used to convey intelligence whereas with double side-band s.c.f.m. a large proportion of the power is used to transmit the carrier. The normal bandwidth for f.s. is the shift plus twice the highest modulating frequency. For the case of weather charts this gives 2,600 c/s for f.s. as against 6,400 c/s for double sideband s.c.f.m. Single band s.c.f.m. with reduced carrier as used on transatlantic telephony circuits is practically equivalent to f.s., but without the same requirements for frequency stability.

11. Distortion in Radio Circuits

Apart from noise and interfering signals, the most prevalent form of distortion affecting facsimile transmissions is that caused by multi-path selective fading.[6] The difference in arrival time between signals following different paths may amount to 2 milliseconds or more. Such signals are subject to different fading conditions and the limiter is controlled by whichever signal happens to be of maximum amplitude at any particular instant. The result is an irregular phase stagger on the recorded chart which may, in severe cases, interfere seriously with legibility. Multi-path selective fading may also affect the amplitude and phase characteristics of the transmission path.[10] When this occurs the resultant distortion increases with the trans-mission band width and sets a limit to the maximum modulation frequency which may be used over the circuit. Multi-path distortion may be reduced by the use of space diversity reception. Atwood[11] has described a series of tests on such a system in connection with the reception of radio-photo signals.

12. Equipments for Radio and Landline Transmission

It was mentioned earlier that the first weather chart equipments to be completed were for alternative line and radio working. The first models were supplied to Dunstable in 1952 and a regular radio broadcast of weather charts using these machines was instituted by the Meteorological Communication Centre in 1953. The transmitter is arranged for a.m. or s.c.f.m. working and can be used for f.s. with a suitable converter. The recorder is equipped to receive charts on a.m., s.c.f.m. or f.s. Both machines are very similar in appearance to those illustrated in Figs. 1 and 4 but are for manual operation only. They have three speeds, 30, 60 and 120 r.p.m. Experience has shown that 30 r.p.m. is hardly ever used and most machines are now supplied with speeds of 60, 90 and 120 r.p.m. if required. The circuitry of the transmitter on a.m. is similar to the transmitter already described; on s.c.f.m. the output from the photomultiplier cell swings the frequency of a 100 kc/s oscillator by means of a reactance tube. The audio frequency is produced by heterodyning this oscillator with another oscillator of fixed frequency. Built in oscillators of 1,500 c/s and 2,300 c/s are provided for checking black and white frequency limits. On the a.m. side, the recorder again is very similar to the machine already described but without the automatic features. For s.c.f.m. or f.s. reception the input signal is first passed through a band pass filter with a pass range of 400-3,400 c/s, and is then applied to a flip-flop type limiter which gives a constant output for input levels from +10 dbm to −55 dbm. The square wave from the limiter passes through a low pass filter which restores it to a sinusoidal wave form. The signal then goes to a composite discriminator consisting of three sections. The first section is an attenuation equalizer which progressively attenuates frequencies between 1,500 c/s and zero, the second section is a Wien bridge tuned to a null slightly above 2,300 c/s and the third section is a low pass filter with cut off at 2,300 c/s. The composite frequency characteristic of this discriminator is somewhat similar to that of a low pass filter with cut off at 1,500 c/s and 30 db attenuation at 2,300 c/s. Such a characteristic is difficult to achieve with ordinary filter sections without introducing transient distortion; this is the reason for the somewhat complicated construction described above. The output from the discriminator is treated by the recorder amplifier in exactly the same way as an a.m. signal. For reception on f.s. it is necessary to adjust the beat frequency oscillator of the radio receiver until the audio beat note is correct. The 2,300 c/s oscillator provided in the recorder can be used as an aid to set the b.f.o. provided the radio receiver is sited adjacent to the recorder.

13. Future Trends

Automatic operation of facsimile weather chart recorders on landline circuits is established. Stimulated by British example, U.S. manufacturers are now beginning to market such equipment. It will undoubtedly be necessary to provide auto working on radio channels. There is no special difficulty with s.c.f.m. but the situation is complicated by the fact that operators are tending more and more to favour f.s. radio techniques. With f.s. the problem is mainly one of frequency stabilization. The Canadians have operated radio outstations on fixed frequencies on f.s. with routine adjustments carried out once per week only. This is a noteworthy achievement and an example of what can be done, but the problem cannot be regarded as solved until autoworking can be carried out with standard tunable communication receivers. On landlines the signal for stopping the recorder can be the cessation of signals but on radio it appears likely that definite stop signals will be required because of noise levels.

Automatic speed change would appear to be desirable and there is no special technical difficulty in providing this feature. On radio facsimile circuits there is a requirement for automatic broadcasting of station call signs during transmission intervals. Owing to the international character of meteorological information there is a need for control signals for automatic working of facsimile stations to be standardized generally.

There is also a demand for the simultaneous transmission of facsimile and telegraphy over the same circuit. Weather chart facsimile equipments have already been produced for the Air Ministry which use the upper half of the available bandwidth for facsimile and allow sufficient space in the lower half for 8 to 10 voice frequency telegraph channels.

14. Other Facsimile Machines

Two other facsimile equipments which have been produced serve to illustrate the versatility of facsimile as a communication method.

Machines have been produced to G.P.O. specification for the transmission of telegrams. These machines are designed to operate over physical circuits and employ d.c. signalling. The transmitter accepts $7\frac{1}{2}$ in. × 5 in. forms and transmits them in just over 2 minutes. Loading of the form is done by pulling out a transparent wrapper attached to the drum, placing the form on it and releasing the wrapper which then springs back and wraps the form round the drum. Operation of one key starts the transmission which is completely automatic from then on. The receiver signals back, when it has phased and is ready to accept the message and also at the end of message. This second signal closes down both machines. Should a fault in the line or equipment occur during transmission, the machines are closed down and a FAIL pilot is brought up at the transmitter.

Other facsimile recorders have been produced by the Author's Company for the Associated Press phototelegraphy network in the United States. The Associated Press transmit a regular service of news-pictures over their network and rent photographic receivers to the various newspaper offices who subscribe to the service. The facsimile recorders are designed for the automatic reception of these pictures on electrosensitive paper. A large number have been installed in television stations where they provide topical pictures for illustrating news broadcasts. The picture can be televised directly as it comes off the recorder without any processing. Other recorders of this type are used in small publishing offices which subscribe to the picture service but which have very limited photographic processing facilities of their own. In the U.S.A. the labour costs involved in photographic processing and block-making are extremely high. In this application the picture coming off the facsimile recorder is used as the original for an automatic engraving copier which produces a half tone block ready for the printing process.[12]

Over 100 of these recorders are in daily use in the U.S. and by their introduction have considerably enhanced the facilities which Associated Press offer to their subscribers.

15. Acknowledgments

The author wishes to emphasize that the development of the apparatus described in the paper is a result of combined effort by many of his colleagues in the Design and Production Departments. He also wishes to acknowledge the helpful collaboration of the Technical Staff of the Air Ministry Meteorological Communication Centre, Dunstable, and the Canadian Meteorological Service. Finally, thanks are due to the Directors of Messrs. Muirhead and Company Limited for their encouragement in the work and for their permission to publish this paper.

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(*For the Discussion on this Paper see pages* 158-161.)

NOTICES

The 1957 Convention—Preliminary Notice

The Council has agreed that the next Institution Convention will be held at King's College, Cambridge, from Thursday, 28th June, to Monday, 2nd July, 1957. Detailed information will be published in subsequent *Journals*. It is probable that the main subject of the Convention will be Electronics in Automation. In the meantime, members who are likely to be in a position to contribute papers are invited to get in touch with the Chairman of the Papers Committee.

November Graduateship Examination

The closing date for entries from overseas candidates for the November 1956 Graduateship Examination will be 1st May. This will be the first examination to be held under the revised scheme, of which details were given in the November 1955 *Journal*. Specimen examination papers on the revised syllabus are being prepared, and their publication will be announced in the *Journal*.

Tickets for Exhibitions

The 13th Annual Radio Components Show arranged by the Radio and Electronic Component Manufacturers' Federation will be held at Grosvenor House, Park Lane, London, W.1, from 10th to 12th April. Members are asked to note that applications for admission to this exhibition should be made directly to the Secretary, R.E.C.M.F., 22 Surrey Street, Strand, London, W.C.2, and *not* to the Institution.

The Physical Society's 1956 exhibition of Scientific Instruments and Apparatus will be held at the Royal Horticultural Society's Old and New Halls, Westminster, London, S.W.1, from Monday, 14th May, to Thursday, 17th May. Tickets for this exhibition will be available from the Institution shortly and in addition to the general tickets available for Monday afternoon or any other complete day, the Physical Society has kindly invited members of the Institution to attend on the "Members" morning (10.30 a.m. to 2.0 p.m., Monday, 14th May). When applying to the Institution for tickets, it should therefore be stated for which day they will be required.

As in previous years, discourses or demonstration lectures will be given in the evenings. The discourse on the Wednesday, at 6.15 p.m., will be on "Colour Television: Considerations which have led to Recent Trends," by Mr. G. G. Gouriet. Special admission tickets are not required.

Annual Subscription Reminders

Owing to printing difficulties, it has not proved possible to send out the annual subscription reminders for the coming year with this issue of the *Journal*. The reminders will therefore be sent out separately, as in previous years.

Scottish Section Symposium

A successful three-day symposium on Industrial Electronics arranged by the Scottish Section Committee has just concluded. Six papers were presented on various applications of electronics and visits to factories and laboratories also took place. At the Section Dinner held on March 21st at the Central Hotel, Glasgow, to mark the opening of the Symposium, Mr. G. A. Marriott, a Vice-President of the Institution, replied to the Toast of "The Institution." A full report will be given in subsequent issues of the *Journal*.

New Engineering Buildings at University College, London

An appeal has been launched to all sections of British Industry for financial support in erecting new buildings for the Faculty of Engineering at University College, London. The ultimate cost is expected to be £2 million, of which £250,000 has already been subscribed. The work is to be carried out in three stages, and when completed will enable the College to accommodate six hundred engineering students, which corresponds to an annual output of two hundred graduates. The present capacity of the College is seventy engineering graduates per year.

In his introduction, Lord Strang, G.C.B., G.C.M.G., Chairman of the College Appeal Committee, referred to the advantages of institutions such as University College, where "engineering students mingle at large with students of other subjects. They are not confined to a technological world." The Right Honourable the Viscount Chandos, P.C., D.S.O., M.C., who also spoke, referred to the fact that the United Kingdom economy was very vulnerable to a shortage of "brains," and that this country depended to a greater extent than many others on technical achievement. As an industrialist, he daily experienced the far-reaching effects of the shortage of qualified engineers and scientists. Lord Chandos stated that other countries were doing a great deal to stimulate recruitment of engineers.

# of current interest . . .

Electronics and the Musician

That the introduction of electronic technique into musical instrument manufacture carries with it one unrecognized implication—the unfettering of keyboard instruments from the restriction of a fixed temperament—was the interesting point of view put forward in a recent lecture entitled "The Arithmetic of the Musical Scale," which was given before the Royal Society of Arts by Mr. L. H. Bedford, O.B.E., M.A., B.Sc., a Past President of the Institution.

Mr. Bedford illustrated his thesis with musical demonstrations on two pianos, one tuned to the normal even-tempered scale, the other tuned (by an electronic method) to the natural scale.*

He pointed out the intrinsically beautiful arithmetical patterns which relate to the natural temperaments, and his paper throughout attempted to establish some common ground between the languages and ideas of physics and music. He suggested that the electronic organ was a particularly suitable instrument for exploiting the subtle distinctions between different temperaments.

* Even-tempered scale: all semitones have frequencies of the same ratio, so that twelve semitones amount to one octave.
Natural, or Just, scale: the frequencies of the notes within the octave are proportional to 24, 27, 30, 32, 36, 40, 45 and 48.

Advances in Production Techniques

The great increase of interest in recent years in the problems of materials handling, work study and automation is reflected in the number of bodies now established to give advice on such problems.

The advisory service provided by the College of Production Technology now operates residential courses of from one to six weeks' duration, and evening courses at many of the principal industrial towns in the United Kingdom. The aim of the College's Work Study course is to show how it can be applied so that production, or work of any description, is executed with maximum efficiency by making the most effective use of existing or proposed plant and equipment. The Materials Handling course, designed for all levels of management, instructs in the application of up-to-date handling techniques as a means of reducing costs and increasing output. Both courses try to show how to use the available machinery, labour and time to achieve the best results, rather than teaching the necessity for acquiring new or more machinery and equipment.

The College has recently published a complete set of notes on these two courses, and these are available for reference in the Institution's Library, together with a list of the courses which will be taking place during 1956.*

Another publication now available in the Library is "Method Study" (Part II of an Outline of Work Study), published by the British Institute of Management.† As explained in the introduction, method study is the systematic recording, analysis and critical examination of the methods and movements involved in the performance of existing or proposed ways of doing work, as a means of developing easier and more productive methods.

In order that the activities selected for investigation may be visualized in their entirety, with a view to improving them by subsequent critical analysis, it is essential to have some means of placing on record all the necessary facts of the existing method. Several chapters are given on ways of recording work, and the book goes on to show how improved production methods may be developed from an examination of these results. This book is a valuable continuation to H. G. Wood's paper, "A Survey of Work Study," which was published in the December issue of the *Journal*.

* Further information may be obtained from the Registrar, College of Production Technology, Charing, Ashford, Kent.

† "Outline of Work Study—Part II: Method Study." British Institute of Management, London. 1955. 9"×6". 72 pp. 7s. 6d.

Television Interference Caused by Converters

One of the problems in television interference which will undoubtedly be discussed at the London Section meeting on 25th April is that caused in some cases where converters are added to Band I sets to receive Band III transmissions.

The Post Office cannot itself undertake the work of curing the interference, and in consultation with the British Radio Equipment Manufacturers' Association, has advised users of Band III converters which cause interference to ask their radio dealers about the most suitable steps which should be taken to stop the interference. It is a condition of the receiving licence, the Post Office points out, that the set shall not cause interference to other wireless (including television) users.

APPLICANTS FOR MEMBERSHIP

New proposals were considered by the Membership Committee at a meeting held on 23rd February, 1956, as follows:—27 proposals for direct election to Graduateship or higher grade of membership, and 26 proposals for transfer to Graduateship or higher grade of membership. In addition, 38 applications for Studentship were considered. This list also contains the names of five applicants who have subsequently agreed to accept lower grades than those for which they originally applied.

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

Direct Election to Member

CROSSMAN, Capt. John Danvers, R.N. *Hindhead.*

Transfer from Associate Member to Member

GOODALL, John Stephen Hartwell. *Hastings.*

Direct Election to Associate Member

CRAWFORD, Alan Edgar. *London, S.E.23.*
McINTYRE, Major Neil, R.Sigs. *Richmond, Yorkshire.*
WRIGHT, John Eric. *Aberporth.*
YOUNG, John Frederick. *Birmingham.*

Transfer from Associate to Associate Member

LOLAYEKAR, Nagesh Gangaram. *Bombay.*
MEHTA, Lt.-Col. Krishna Kumar, B.Sc., Indian E.M.E. *London, S.E.9.*
WILLIS, Douglas Ray. *Hemel Hempstead.*

Transfer from Graduate to Associate Member

ASBERY, John Harrison, B.Sc. *Greenford.*
BLACK, Jan, B.Sc.(Eng.). *Wallington.*
HICKS, Flt. Lt. David Bertram John, D.F.C., R.A.F. *Pewsey.*
HORLOCK, Bertrand Albert. *Cambridge.*
MASON, Denis Connell. *Wolverhampton.*
SUBBARAO, Bommakanti Siva, M.Sc. *Rajkot.*

Direct Election to Associate

BAXTER, Dennis. *Morecambe.**
NOYCE, Sidney John. *Stevenage.*

Direct Election to Graduate

BARCLAY, Leslie William, B.Sc. *Leigh-on-Sea.*
BLACKWOOD, Douglas, B.Sc. *Bristol.*
CAMPBELL, Iain Robert. *Maidenhead.*
DEAR, Leslie Donald. *Hillingdon.*
EVANS, Peter Rowland. *Wembley.*
GOOD, Joseph Rodney. *Banstead.*
HIRST, Capt. Raymond, R.E.M.E. *Finchampstead.*
KOH AH SENG. *Brighton.*
LYE, Frank Charles. *Bexleyheath.*
McCAW, John. *Darvel, Ayrshire.*
MACLEOD, Donald Brodie. *Glasgow.*
NORTHMORE, Flg. Off. William John James, R.A.F. *Henlow.*
POWLING, Derek Clifford. *Carshalton.*
WARFORD, David John. *London, N.11.*

Transfer from Student to Graduate

BHAT, Manjeshwar Yashwanth. *Poona.*
BRUSH, Alberto Valera. *London, N.W.2.*
CHARANJIT SINGH. *Agra.*
CHARLTON, George Peter. *London, S.W.19.*
GILL, Santokh Singh. *Delhi.*
HAMMOND, Harold. *Hove.*
JAMES, James Roderick. *Swindon.*
JOSHIRAO, Bhalanchandra G. *Poona.*
KARTAR SINGH. *Mhow.*
KENDALL, Ernest Walter. *Denham.*
LEGGETT, Geoffrey Charles. *London, W.3.*
MEHAR SINGH, B.Sc. *Simla.*
MORRIS, Brian Percival, B.Sc. *Nottingham.*
RIESEL, Chaim Manfred. *Tel-Aviv.*
ROSEN, Solomon. *Tel-Aviv.*
SMITH, Edward James. *Ilford.*
TYLER, Graham Reginald. *Sarnia, Ontario.*
UDYAVER, Manohar Shripad, B.Sc. *Bombay.*
VENKATRAMAN, Anthiyur Raju. *Bangalore.*
WADHAWAN, Krishnan Lal, B.Sc.(Hons.). *Delhi.*

STUDENTSHIP REGISTRATIONS

ABBOTT, Michael Ronald. *West Byfleet.*
AHMAD, Nasim. *London, N.W.6.*
ALI, Abdul Majid Mohd. *Southampton.*
ASTON, George Alfred Anderton. *Preston.*
BRIGHT, James Bernard. *Whitstable.*
BURKE, Alan. *London, N.19.*
BURNS, John Fotheringham. *Edinburgh.**
DWARAKANATH, P. K., B.Sc. *Bangalore.*
GALLIVER, Geoffrey Edward Lewis. *Port Talbot.*
HALTON, Dennis Lewin. *Barrow-in-Furness.*
HIGGINS, Geoffrey Alfred. *Southampton.*
HOPE, Adam William. *Edinburgh.*
HORGAN, Francis. *London, E.C.2.*
KENNY, Gerald. *London, W.14.*
KHIN MAUNG TUN, Capt., Burma Army. *Catterick.*
KHOR TEIK LOON. *Singapore.*
KING, Anthony Sydney. *Alton.*
KISHIN DIALMAL ADVANI. *London, S.W.1.*
KRIEGSMAN, Anthonius Hendericus. *Bergen-op-Zoom.*
LI, Jack Chia-Hsiang. *London, N.W.5.*
MACRAE, Alexander. *Portree, Isle of Skye*
MUDDELL, Bryan Douglas. *London, S.E.27.*
OEI DJONG HAY. *Singapore.*
ONN, Peter. *Leicester.*
PEVERETT, Anthony Michael. *Eastbourne.*
PRASAD, Voorakara Krishna. *Bellary, Madras State.*
RATHORE, Jagdish Singh. *Bangalore.*
SENG KIM GOH. *Singapore.*
SHARP, Gerard Louis. *London, N.W.3.*
STEELE, Lt. Peter Michael, R.Sigs. *Guildford.*
STORNEBRINK, Petrus Jacobus. *Irnsum, Netherlands.*
SULTAN MOHD DOGAR, Lt. Choudry, Pakistan E.M.E. *Abbottabad.*
TSANG, Kwan Cheuk. *London, N.W.3.*
TYE, Alfred Henry. *Coventry.*
VINNER, Reuben. *Tel-Aviv.**
WALKER, Cyril James. *London, E.C.1.*
WALKER, James Martin. *London, W.2.*
WINTERBOTTOM, Keith. *Wallasey.*
WRONA, Stanislav, B.Sc. *Liverpool.*
YOUNG, Gordon Henry. *London, N.W.10.*

* Reinstatement.

PREMIUM WINNERS—1954

Montagu Terrell Elvy was born at Whitstable in 1920 and educated at Kent College, Canterbury. He gained his technical education and training while apprenticed with Electric and Musical Industries Ltd.

During the War, Mr. Elvy served with the Royal Artillery and R.E.M.E. in Northern Europe and the Mediterranean, being concerned with field army wireless and the installation and operation of radar stations.

On demobilization in 1946, Mr. Elvy joined the Industrial Electronics Department of the English Electric Co., Ltd., Stafford, where he was in charge of the radio-frequency heating section. In 1951 he joined Redifon Ltd., and in 1953 was appointed Chief Engineer of the Industrial Electronics Division, where he is at present concerned with the development and application of industrial electronic heating and ultrasonic equipment.

Mr. Elvy was elected an Associate of the Institution in 1950 and qualified for transfer to Associate Member of the Institution in 1954. He was awarded a 1954 Convention Premium for his paper "Electronic Heating in the Woodworking Industry."

Born in 1918 in Newport, Monmouthshire, **Peter Huggins** was educated at Winton House, Winchester, and in France and Trinidad. From 1940 to 1947 he was with International Marine Radio Co., Ltd., and subsequently joined Electric and Musical Industries Ltd., as a development engineer in the communications field.

In 1949 he was appointed Chief Electronics Engineer with Sciaky Electric Welding Machines Ltd., and from 1952 until December last he held a similar post with Sargrove Electronics Ltd. Mr. Huggins is now Senior Research Engineer in the Automation Section of the Technological Department of T.I. (Group Services) Ltd., Birmingham.

First elected a Student of the Institution in 1942, Mr. Huggins was transferred to Associate in 1945 and to Associate Member in 1951. He is the author of a number of articles in the technical press on various aspects of industrial electronics, the paper for which he received a 1954 Convention Premium—"Statistical Computers as Applied to Industrial Control"—being based on work carried out while with Sargrove Electronics.

Roderick William Walker was born in 1920 in Newcastle-on-Tyne, where he received his technical education at the Rutherford College of Technology. Early in 1939 he joined the Royal Corps of Signals, and served during the War in this country and in India.

In 1949 Mr. Walker was appointed electronics technician in the Physics Department of King's College, Newcastle, where he was concerned with the construction and maintenance of electronic equipment for teaching and research. In April 1955 Mr. Walker joined Microwave Instruments Ltd., as a development engineer.

Mr. Walker has served as Student Representative on the North-Eastern Section Committee for the past four years. He was awarded the 1954 Student's Premium for his paper on "An Electronic Random Selector," which described equipment constructed during his service with King's College.

Convention Premiums were also awarded to Mr. C. W. Miller, M.Sc. (Associate Member), of Metropolitan-Vickers Electrical Co. Ltd., for his paper on "Industrial Radiography and the Linear Accelerator"; to Messrs. K. Kandiah, M.A., and D. W. Chambers of A.E.R.E., Harwell, for their paper on "Multi-Electrode Counting Tubes"; and to Mr. J. L. Thompson (Member), of J. Langham Thompson Ltd., for his paper on "Wire Strain-Gauge Transducers for the Measurement of Pressure, Force, Displacement and Acceleration". Biographies of Mr. Miller and Mr. Thompson were published in the December, 1954 and April, 1950 *Journals* respectively.

FACSIMILE COMMUNICATION*

by

H. F. Woodman† and P. H. J. Taylor†, B.Sc.(Eng.)

Read in the Symposium on "Electronic Methods of Pictorial Reproduction", held in London on 25th January, 1956. In the Chair: Mr. W. E. Miller, M.A.(Cantab.), Past-President.

SUMMARY

The requirements for facsimile communication in public telegraph networks, commerce and industry are discussed and some of the factors concerned in the choice of suitable equipment for various applications are considered. The principles of operation of some types of equipment already in use are described and details are given of various methods of control. An outline is given of new equipment under development to simplify message-handling and to provide extended facilities.

1. Introduction

The possibility of transmitting facsimile copies of documents was conceived over a century ago when Morse telegraphy was still in the experimental stage. Although for many years the economic and operational limitations of the facsimile equipment available favoured the development of coded telegraph systems, the evolution of a cheap and simple facsimile system has always been a challenge to communications engineers.

The development of the photocell and of photographic processes led to the evolution of photo-telegraphy as the next major step in the use of facsimile methods, and subsequent improvements in components and techniques have enabled this branch of facsimile communication to provide an international service of extremely high fidelity for the transmission of pictures.[1] Since, for this particular application of facsimile, it is necessary to reproduce faithfully the whole range of tonal values, there is no simple alternative solution, and on that account development has been mainly directed to achieving the highest possible quality of reproduction. Reduction of the initial cost and of the annual charges for operation and maintenance have been regarded as of secondary importance.

The use of facsimile for the transmission of hand-written, typed or printed documents, however, does not demand the faithful reproduction of the full tone scale, since it is necessary to provide on the receiver only a black and white representation of the transmitted copy. For this reason it is possible to use recording techniques which avoid the need for photographic processing of the received copy and facilitate the design of far simpler and less costly apparatus.

The first successful application of this type of equipment was for the transmission of meteorological information. This is now playing a very valuable part internationally in increasing the safety of air travel, by providing means for the rapid transmission of weather maps giving up-to-date information to Air Traffic Control stations over a very wide area. The equipment used for this service is somewhat specialized, in that the size of the maps which have to be transmitted is generally larger than that which would be necessary for other applications, and the economic aspects take a secondary place because of the essential nature of the service provided and the disadvantages of possible alternative methods.

A much broader application of facsimile, to which much attention has been given in recent years, is the collection and delivery of telegrams in Public Telegraph Services. This is of vital importance to Telegraph Administrations since, with the existing wage rates for messengers and the difficulties of getting suitable staff, a large proportion of the income from each telegram is expended in delivery costs and, in many cases, even though an extremely high efficiency has been achieved in the main telegraph network by mechanisation, the overall cost of handling a telegram is greater than the amount which can reasonably be charged.

* Manuscript received 22nd September, 1955. (Paper No. 345).
† Creed & Co., Ltd., Croydon, Surrey.
U.D.C. No. 621.397.2.

In the United States of America, where this problem is very acute due to the high rates of pay, the Western Union Telegraph Company have explored the possibilities of facsimile collection and delivery services, and have succeeded in evolving a system which has not only materially reduced their handling costs and enabled them to provide a fast and economical service, but has appealed to the public and stimulated traffic.[2] The equipment used in this system is cheap, simple to operate and easy to maintain. Subscribers sending or receiving more than about three messages a day are provided with a small desk type machine which can be used either to send or receive telegrams. These are connected to a concentrator at a local centre at which the traffic between a maximum of 100 subscribers and the main network can be handled by a single operator. A typical concentrator of this type is shown in Fig. 1. The system has proved so successful that it has been installed in over sixty cities and provides service for nearly 20,000 subscribers. The speed of operation of this equipment has been fixed at a level at which satisfactory resolution of the subject matter results in a modulating frequency which is suitable for transmission by the lines available. Its traffic carrying capacity for a given bandwidth is very much lower than that of code transmission systems, in which far less information has to be transmitted, and its main use is the extension of mechanization to telegraph offices or subscriber offices having traffic levels which do not justify Teleprinter operation. For this purpose it is indeed ideal, since the equipment at the out-station can be operated by completely unskilled personnel.

The possibility of using facsimile for the high speed transmission of large quantities of information has been explored by several organizations in Europe and America, but although it has been demonstrated that such systems are practicable, and in fact one was used in a prolonged emergency to carry a very heavy traffic load, they must still be considered as experimental both in their design and application.[3]

A mobile radio-facsimile system, in which telegrams are selectively diverted to patrol cars for final delivery has also been tried out with some success in one of the larger American cities.[4] Replies are sent back from the patrol cars by radio-telephone.

Apart from the work which has been done in connection with equipment for Public Telegraph Facsimile Services, systems have been designed for many applications. Among these perhaps the most important is a Tape Facsimile Transmitter-Receiver (Transceiver) for use by Banks, Department Stores and similar organi-

Fig. 1.—Western Union 100-Line Desk-Fax Concentrator.

zations for verification of the status of customers' accounts and for other purposes where only a small amount of information is transmitted at a time. Another important system provides for the issue of space reservations on trains.[5]

There remains for consideration the general application of facsimile for use in commerce and industry, which in America is now being keenly exploited, and which in this country is the subject of an extensive practical market investigation based on the use of British counterparts of American equipment. This investigation has assisted in demonstrating to the users the value of facsimile communication and also in helping to determine more clearly what facilities are required to meet commercial and industrial needs: some of these facilities have already been provided and these are described in a subsequent section of this paper together with the basic equipment already available for exploitation.

2. Principles of Operation

Facsimile communication is based on the successive examination of minute areas of the document being transmitted to determine whether each of them is "black" or "white", and the transmission of these elements of information to a recorder, in which they are used to cause the corresponding areas of a sensitized recording medium to correspond in shade to those of the original document. It is therefore essential for the scanning means used for examination of the original document, and the corresponding means for distributing the signals over the recording medium, to be brought into phase at the beginning of each message and to remain in phase during its transmission.

Discrimination between the "black" and "white" areas of the original document is achieved electrically or photo-electrically and the scanning process results in the modulation of a voice-frequency carrier. At the receiver, the modulated carrier is amplified and applied to a recording member which marks the recording medium whenever tone of sufficient amplitude is present. It is therefore necessary for tone to correspond to "black" at the output of the recording amplifier and, if the transmitter output does not provide this condition, a signal inverter must be included at some point in the transmission path.

Controls are provided to start the equipment and to stop it either automatically at the end of a message or manually if desired. Supervisory controls, which vary considerably according to the application, are also needed together with means to guard against faulty operation.

2. 1. *Transmitting Scanners*

Essentially, a transmitting scanner comprises a means to detect whether elemental areas of the subject matter are "black" or "white" and mechanism to cause the "detector" to examine or scan successively all the elemental areas of the document being transmitted.

All the early scanners relied on the detection of a change in resistance between the "black" and "white" portions of the subject matter, but since this necessitates processing the message on a special medium this method has been abandoned and photo-electric scanning is now almost universally employed. A tape facsimile system which uses resistance discrimination is, however, described later.

The scanning motion is normally provided by wrapping the subject matter round a drum which is rotated and moved axially at constant speeds past the "detector". These two motions combine to cause the detector to scan the subject matter in a spiral path, the pitch being dependent on the resolution required. Alternatively, the axial drum movement may be replaced by a similar movement of the detector along a path parallel to the drum axis.

The drum rotation is always effected by a synchronous motor powered from an a.c. source which is either common to that used in the recorder or based on an accurate frequency. The traverse of the detector is frequently derived from the same motor but in some cases a separate motor is used to simplify the mechanism and control arrangements.

In some of the simpler systems the document is wrapped around the drum by the operator, where it is secured by a metal toroidal spring as can be seen in Fig. 8. In others, the operator secures the document behind a transparent wrapper, whilst in the more elaborate systems the loading is completely automatic.

In photo-electric scanners a beam of light is focused into a spot on the rotating message, from which it is reflected and re-focused on to a small aperture through which the significant portion passes to fall on the cathode of a

Hectograph ink can also be used in pen recorders to achieve the same result, whilst stencils may be cut by electromagnetic percussion methods.

2. 4. *Synchronization, Phasing and Control Means*

Where facsimile equipments are grouped in small areas served by the same power supplies, and metallic connection can be provided between the various offices, very simple means for synchronization, phasing and control can be employed. Since the frequency and phase of the supply is the same at each office synchronization is automatically ensured, whilst d.c. signalling can be used for phasing and other controls. Where these conditions do not apply, as frequently occurs in radio facsimile communication, means have to be provided to ensure sufficient accuracy of synchronization between the equipments and to permit the control signals to pass over discontinuous circuits.

2. 4. 1. Synchronization

Assuming that the sending and receiving scanners are driven by synchronous motors, the maintenance of synchronism between equipments not powered from the same mains can be achieved by one of two basic methods.

In the first case each machine is driven from a stable frequency source which is set from time to time to a standard reference frequency. The source must have a short-term stability of the order of $\pm$ 1 part in 10^5 to avoid excessive skew distortion of the record. In the second, the transmitting machine may be driven from a reasonably stable source which is also transmitted to any associated receiving stations and amplified to drive the scanners.

The first of these methods, which is more flexible in its applications, is in more general use, although the second may well be found cheaper in some cases since frequency stability is not as important and a source of stable frequency is not needed at the receiving stations. In both cases power amplifiers are needed to produce, from the frequency source, or from the pilot frequency transmitted over the line, the output needed for driving the drum or stylus driving motors.

2. 4. 2. Phasing

At the beginning of each message the transmitting and receiving processes must be started when the scanners are in correct phase with one another. In one method of phasing the two scanners are driven by clutches which are released as soon as both machines are in a fully operative condition.

In an alternative method generally associated with drum type recorders or transceivers the clutches are dispensed with. At the commencement of a message the transmitting and receiving drums are set to rotate at slightly different speeds with the traverse mechanism disabled and the transmitting and receiving circuits disconnected. As the transmitting drum revolves it generates one pulse per revolution which is transmitted to the receiver, where it is compared with similar pulses generated locally. As soon as the drums have drifted into phase, these pulses combine to energize circuits which cause the traverse to begin and the signal connections to be completed on both the transmitter and the receiver.

Combinations of these two methods are also used where operation is between outstation transceivers and clutch driven continuous recorders and transmitters at central office concentrators.

2. 4. 3. Control means

The controls used for facsimile apparatu vary widely in detail according to the type o apparatus used, the nature of the connection and the class of personnel employed. Mos systems, however, are based on the sending o a calling signal when the transmitting machin is ready to send a message and the return of go-ahead signal from the receiver when it i ready to receive it.

Where separate transmitters and continuou recorders are used, the controls are generall completely automatic after transmission ha been initiated. In the case of single-sheet trans mitters, transmission is usually initiated by th operator depressing a start button at the begin ning of each message, but in magazine trans mitters the control cycle is restarted automat cally at the end of each message until n messages remain in the machine. The go-ahea signal is automatically returned when th receiver motors have reached operating spee and the output of the recording amplifier ha reached the correct output level.

Where transceivers are used, manual contr is needed at the receiving end since the operat has to insert a receiving blank into the machin

Transceivers are usually equipped with a "Send" button, which conditions the machine as a transmitter and sends out the calling signal, a "Receive" button which conditions the machine as a receiver, stops the buzzer and initiates the go-ahead signal, and a "Stop" button which restores the machine to the idle condition.

Most equipments are provided with automatic means to stop them on the completion of each message.

Since facsimile apparatus is intended for operation by completely unskilled personnel, safeguards are provided to ensure that the operator is given suitable indications should the controls be operated wrongly or should the "Send" button be pressed simultaneously with the one on the distant machine.

Many other special features have been devised to simplify the work of the operators. These include various methods whereby the receiving operator can indicate to the sending operator whether the message has been legibly received or requires re-transmission. The general trend is now, however, to make the controls and control circuitry as simple as possible and to avoid any undue complication of the equipment.

In the simplest and cheapest form of control circuitry, the calling and phasing signals are in the form of d.c. signals applied to one line of the pair connecting the equipments, whilst a d.c. go-ahead signal is returned over the other line of the pair. A good example of simple d.c. control circuitry is that used in the Desk-Fax transceiver, which is shown in Fig. 2 and described more fully in a later section of this paper. Since this method requires a metallic circuit between the equipments, it cannot generally be used for facsimile communication over circuits including telephone repeaters or exchanges, for which voice-frequency signalling is necessary.

In apparatus using voice frequency signalling the calling, phasing and go-ahead signals result in tones being applied to the line pair instead of d.c. signals to each of the lines. Detectors are provided at each equipment to convert the received tones into d.c. signals for operating the electro-magnetic controls of the facsimile apparatus.

To avoid false operation due to signal imitation it is considered desirable to use a combination of two frequencies for each of the signals. Coded pulse-trains could also be used, but these involve complication of the detectors.

Precautions have to be taken in the design of facsimile voice-frequency signalling systems to avoid faulty operation of the detectors by shock excitation from locally transmitted signals or from line reflections. A very effective method is the use of different frequencies for the calling and go-ahead signals and the disablement of the detector of each machine whilst it is transmitting any signals.

If the manual stop facility is required, it is necessary to provide a third signalling condition which can be recognised by a detector which monitors the picture signal during the whole of its transmission. A combination of two frequencies used in the calling and go-ahead signals may be conveniently used for this purpose, since they will not be present in combination in the picture signal.

The foregoing remarks apply largely to signalling over two-wire circuits; where four-wire circuits are used the control circuitry can be considerably simplified.

The frequencies used in facsimile signalling have to be carefully chosen to avoid interference with telephone signalling systems.

2. 5. *Transmission Considerations*

Since it is obviously impossible, in a general paper of this nature, to give more than cursory consideration to the broad subject of facsimile transmission, it is proposed to deal very briefly with some of the factors only which concern documentary facsimile transmission.

The amount of information which has to be transmitted to ensure a legible reconstitution of the original document by the receiver depends upon the size and complexity of the characters used in the document. Practical experience has indicated that for the transmission of printing in 8-point or larger sizes, typing or handwriting, a resolution corresponding to 130 lines per inch (about five lines per mm.) is adequate for the majority of requirements, while for some applications 100 lines per inch will suffice.

At the speeds currently used for transmission of commercial documents and for collection and delivery services, this corresponds to the transmission of from 2,000 to 2,500 elemental areas per second, or a maximum modulating frequency of from 1,000 to 1,250 c/s. It is obviously desirable for the ratio between the carrier frequency and the modulating frequency to be as high as possible, but for transmission over normal telephone channels a low ratio of about two cannot be avoided. Even with this ratio the carrier frequency lies toward the upper end of the frequency band available, with the result that the lower sideband only is fully transmitted together with the carrier and a part of the upper sideband. This is found satisfactory on circuits having a smooth exponential attenuation/frequency characteristic, but leads to difficulties on circuits having sharp cut-offs.

American Desk-Fax equipments operating at a drum speed of 180 r.p.m. produce a carrier frequency of approximately 2,500 c/s, whilst the European counterparts having a drum speed of 150 r.p.m. use a carrier frequency of about 2,100 c/s. The latter transmission speed corresponds with a time of about $2\frac{1}{2}$ minutes for sending a message 3 ins. in depth when the resolution is 130 lines per inch or 2 minutes when 100 lines per inch resolution is used.

A transmission level of between −10 and +5 dbm is usually employed and in most cases the receiver is designed to record satisfactorily when the line attenuation is as high as 25 db.

The ratio of black signal to white background should be at least 20 db for good contrast, and the noise level on the line should not exceed −45 dbm for freedom from background marks on the received copy.

When transmitting over long-distance or switched telephone circuits the line attenuation may vary by as much as 20 db from call to call, due to different routings or maintenance operations on the line. It is therefore essential to incorporate a gain control, either manual or automatic, in equipment designed for operation over such lines.

For transmission over radio channels, the Consultative Committee of the International Telecommunication Union have recommended the use of sub-carrier frequency modulation. Over land-line extensions to the radio channels, amplitude modulation has, in the past, been recommended, but further consideration is now being given to advantages which may be gained by the use of frequency modulation which, apart from other considerations, avoids the use of converters at the radio channel terminations.

2. 6. *Interoperation between Facsimile Equipments*

For undistorted reproduction of the transmitted copy by the recorder it is essential for the time taken to scan a line to be exactly the same on the recorder and the transmitter, and for the ratio of the drum diameter and the pitch of the scanning lines to be the same on both machines. This ratio, or Index of Co-operation, determines the relationship between the length of the scanning line and the depth of the area scanned in unit time.

For the transmission of pictures, maps, scale drawings and information of this nature, no distortion of the received copy is permissible and agreement between the indices of co-operation is essential. For the transmission of printed or written matter a considerable difference can be tolerated, and it may be found desirable to allow considerable deviation from nominal standards to permit simplification in equipment design.

For full interoperation it is also necessary for the control systems to be in accord, and it is hoped that in the not too distant future agreed standards will be laid down for the signals to be used in these systems.

International standards governing the interoperation of phototelegraph equipments are fully covered in C.C.I.T. Recommendation No. D.1 and the aspects of documentary facsimile apparatus which should be standardised are under active consideration by C.C.I.T. Study Group No. IV.

3. Some Current British Models of Documentary Facsimile Apparatus

Since another paper* in this symposium deals with facsimile apparatus using electro-chemical recording for the transmission of meteorological information, it is intended here to describe, briefly, equipment using dry recording paper for collection and delivery service and for commercial applications.

The range of models in this class has been based on Western Union designs modified, where necessary, to meet the operational requirements of the commercial market and the technical requirements of European Administrations, and to enable British components to

* J. A. B. Davidson, "Facsimile transmission of weather charts," *J. Brit.I.R.E.*, **16**, No. 3, pp. 115-126, March, 1956.

be used. It includes the Desk-Fax transceiver, the Desk-Fax transmitter, the automatic continuous recorder, the Teletape transceiver and a variety of concentrators and broadcast units to meet various requirements.

3. 1. *The Desk-Fax Transceiver*

As its name implies, the Desk-Fax transceiver was designed with the object of providing a simple equipment which would be sufficiently compact to enable it to be used on an office desk for the transmission and reception of messages. It was first intended for collection and delivery services where low prime cost and annual charges are of vital importance. This is reflected in the simplicity of its conception and the absence of any unessential frills, and also in the extensive use of cheap proprietary components.

Fig. 2.—Desk-Fax transceiver with cover removed.

Since compactness was also a major requirement, the equipment was designed to use small 6½ x 4½ in. forms. The transmitting form, which can be of white or slightly tinted paper, will take about 150 typed words, which is ample for telegrams sent from subscribers' offices and adequate for many commercial applications as well. The recording forms are of Teledeltos recording paper. The use of this small size of form has enabled a machine measuring only 12 x 12 x 7 in. high to be produced, as shown in Fig. 2.

Optical scanning and inversion are used in the transmitter and a single 2 in. diameter drum, driven by a synchronous motor, is used both for transmission and reception. In America, where the mains frequency is 60 c/s, a drum speed of 180 r.p.m. is used, but for 50 c/s applications the speed is dropped to 150 r.p.m. since, to avoid distortion, it is desirable to use an integral gear ratio. When operating at 150 r.p.m., the scanning speed is 15.7 inches per second. The drum is moved axially by a separate motor through alternative gearing giving resolutions of either 130 or 100 lines per inch. The transmission time is about 2½ minutes or 2 minutes, according to the respective resolutions. The signal and control circuitry is shown in Fig. 3.

The transmitting amplifier, which has a maximum output of about +10 dbm and an output impedance of 500 to 600Ω, has several special features. A twin-T filter inserted in the grid circuit of the output triode attenuates unwanted harmonics introduced by the chopper disc method of carrier generation.

Owing to the very small amplitude of the signals generated by the photocell, the output of the transmitting amplifier is greatly affected by any change in the anode voltage of the photocell and the amplification factor of the first valve. The output of the photocell is also affected by any change in exciter lamp voltage. Hence in order to prevent the output level being affected by variations in mains voltage, it is necessary to compensate for the corresponding variations in the h.t. and exciter lamp voltage. The anode supply for the photocell is stabilized by two miniature neon tubes, which also provide a stabilized bias for the control grid of the 6AU6 valve. In addition to this grid bias, a positive bias is applied to the cathode of the 6AU6 from the main h.t. potential-divider chain. The variable resistor R16 enables the stabilized bias for the grid of the 6AU6 to be set to such a value that the effective bias is at the optimum point on the valve characteristic, so that variations in h.t. and exciter lamp voltage are automatically compensated by a corresponding change in the effective bias on the 6AU6. In practice, R16 is set so that the output from the transceiver does not change by more than 2db for a mains voltage variation of ±10 per cent.

The receiving amplifier is of a conventional type, which provides a suitable output to the 0·008 in. diameter tungsten wire recording stylus. The stylus has a life of about 1,000 messages.

The connecting line should be a twisted or transposed pair having an attenuation of not more than 25 db at 2,100 c/s, a bandwidth of 300-2,800 c/s and a d.c. loop resistance of not more than 3,000Ω. Each wire of the pair is used separately for d.c. signalling, the separation being effected by means of capacitors in the transceivers. The line connections at the circuit terminations are reversed with respect to each other so that the transmitting control path is connected to the receiving control path at the other end of the circuit. A nominal voltage of 50 is now used for the d.c. controls to meet the requirements of European Telegraph Administrations. The original models used 100 V, which is acceptable in the U.S.A.

Operation: Control is effected by three push-buttons at the front of the transceiver. Two of these, labelled SEND and RECEIVE respectively, lock in position when pressed. The third button, labelled STOP, is non-locking, and, when pressed, releases each of the other two buttons. Either of the locking buttons will, when depressed, release the other button, if this has previously been depressed. The locking buttons are also released automatically when the drum reaches the end of its travel.

To send a message, the operator places the completed message form around a drum and presses the SEND button. This automatically conditions the machine as a transmitter and applies d.c. to one wire of the line pair. This d.c. operates a line relay in the distant transceiver, which sounds a buzzer to summon an attendant, who then wraps a Teledeltos blank around the drum and presses the RECEIVE button. This stops the buzzer and automatically sets up the called transceiver as a recorder. The d.c. is interrupted once every revolution of the transmitter drum, and these interruptions are compared at the receiver with pulses generated once every revolution of the receiver drum, rotating at sub-synchronous speed, as described in Section 2. 4. 2. When the two drums are in step, the transmitter and receiver pulses coincide and a relay is operated in the receiver which applies d.c. to the other wire of the line pair. This operates the line relay in the transmitter, which stops the interruptions and initiates scanning. Simultaneously, at the receiver, the drum is brought up to synchronous speed, the stylus is brought into the recording position and scanning started. The time taken for phasing varies from practically zero to a maximum of about 20 seconds. The facsimile signals are superposed on the steady d.c. on each wire, which is maintained during the transmission.

Each machine shuts down automatically when the drum reaches the end of its travel, but the transmission may be stopped at any time after the first half-inch of travel by pressing the STOP button at the transmitter. This returns the machine to the stand-by condition and removes the steady d.c. from the line. The line relay at the receiver de-operates and removes d.c. from the other wire of the pair, and sounds a buzzer to indicate that the transmission is finished. The operator can then press her STOP button, returning the receiver to the stand-by condition. If the receiver is not stopped manually, it will shut down automatically in the normal manner when the drum reaches the end of its travel.

Should the wrong button be pressed inadvertently at any time, safeguard circuits ensure that the transceiver will not phase and the buzzer will sound to warn of an error.

Should the SEND buttons at each end of a circuit be pressed simultaneously, the buzzer will sound at each machine until one operator presses her RECEIVE button, when transmission will take place in the normal manner.

3. 2. *The Desk-Fax Transmitter*

This machine has been derived from the Desk-Fax transceiver to meet immediate requirements for a transmitter which will accommodate page teleprinter copy. It differs from the transceiver in having a 2½ in. diameter drum and no receiving mechanism or circuitry. Its control circuitry is also simpler, the transmitter phasing contacts interrupting the line directly and only one relay, the line relay, being used.

The transmitter will operate normally in conjunction with a continuous recorder, but when operated with a Desk-Fax transceiver the copy is compressed in width in a ratio of five to four.

3. 3. *Automatic Page Recorder* (Fig. 4)

This model records automatically on an 8¼ in. wide continuous Teledeltos roll 450 feet long, sufficient for 1,200 average messages. There are no operating controls. Transmission can be from either a Desk-Fax transceiver or a

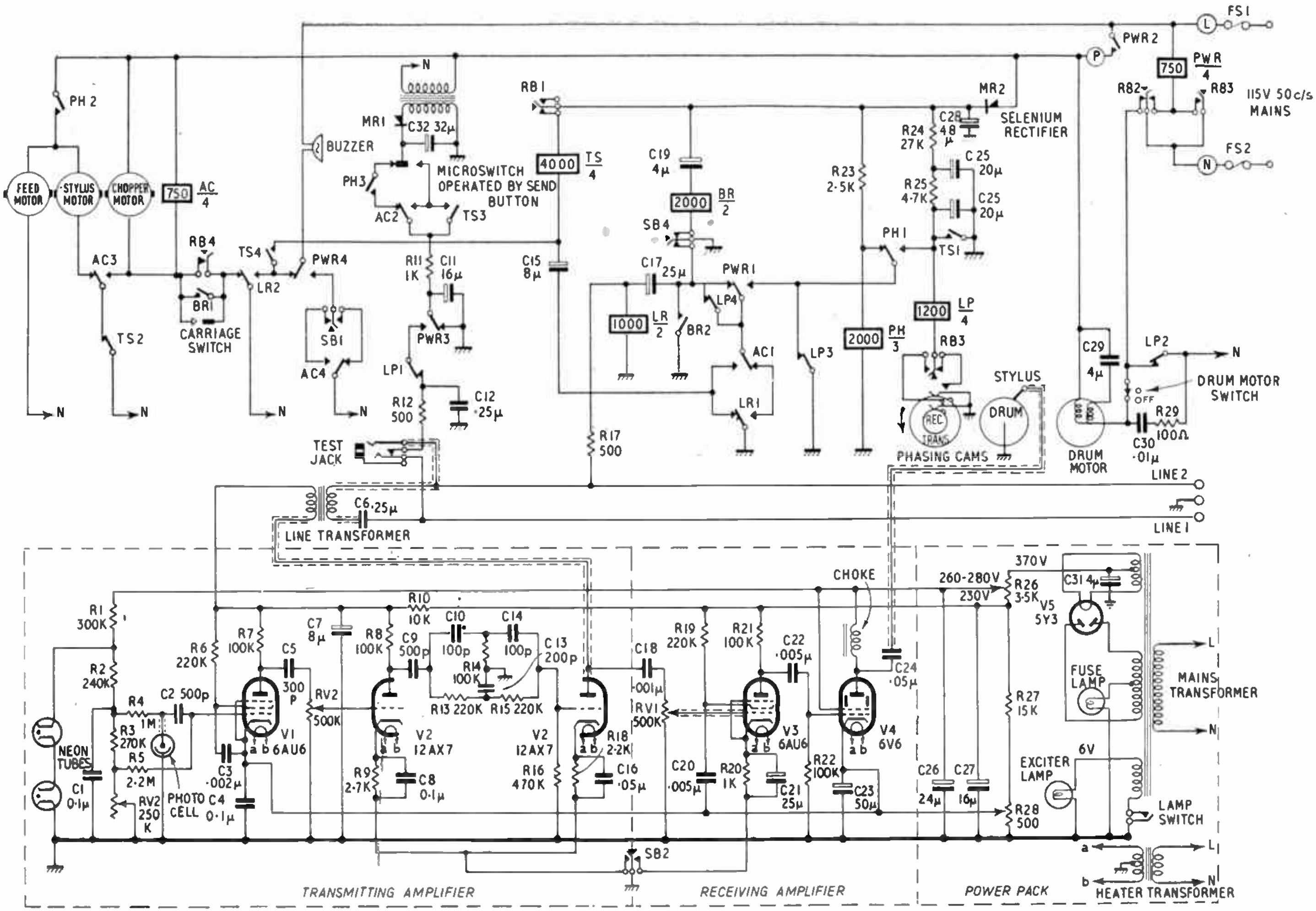

Fig. 3.—Desk-Fax transceiver circuit schematic.

separate transmitter. Phasing is clutch-controlled so that the phasing time is reduced to about 4 seconds.

The resolution is 100 lines per inch, with the result that recordings made from a Desk-Fax transceiver are enlarged in the ratio of four to five in each direction.

The recorder itself is a completely separate assembly which can be jack-mounted onto a plinth or a console accommodating the electronic and control circuitry and provided with an exhaust unit to extract the gaseous products of the recording process. The recorder and plinth are 16 in. wide, 13 in. deep and 16½ in. high.

3. 3. 1. Recorder (Fig. 4)

The Recorder comprises a paper feed and platen assembly and an easily removable scanning head. These two units are completely enclosed in a cover except for slots providing access to two manual paper-feed wheels and the paper tear-off knife.

The paper is mounted on a spindle at the rear of the machine, from which it passes downwards through guides which direct it toward the front of the machine, where it is driven by a feed roller upwards between the platen and the scanning head and behind the paper tear-off knife, to emerge from the top of the machine. It is fed forward continuously at 1½ in. per minute by the feed roller, which is driven through gearing by a small synchronous motor.

In the scanning head, a flexible steel belt mounting three equidistantly spaced styli is driven by a sprocketed pulley in association with a similar idler pulley in a clockwise direction, so that the styli move in contact with the paper from left to right. The styli are mounted so that they trail slightly and are spaced so that, as one of them leaves the paper on the right-hand side, the following one engages the paper on the left-hand side. The belt and pulleys are in the stylus circuit and are therefore insulated from the frame.

This arrangement is equivalent to a single stylus scanning paper wrapped round a rotating cylinder, but has the operational advantage of requiring only a continuous roll of paper for recording messages instead of separate blanks, thereby permitting unattended reception.

The stylus belt is driven through gearing and a compound friction and ratchet clutch by a synchronous motor, so that 150 stylus traverses occur per minute, and, since the paper is travelling past the stylus belt at a speed of 1½ in. per minute, this results in the stylus tracks being 1/100th inch apart. The scanning resolution is therefore 100 lines per inch.

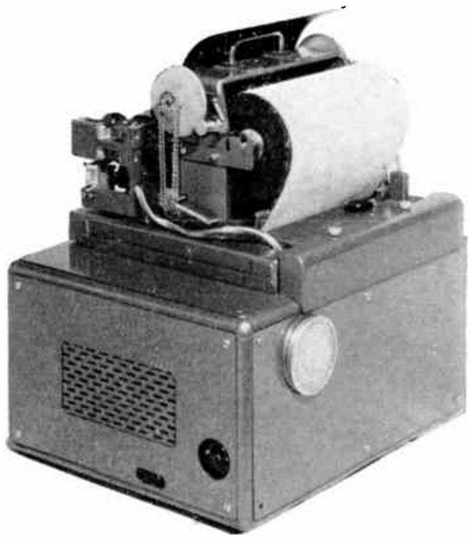

Fig. 4.—Page recorder with cover removed.

A "paper-exhausted" detector and a "low-paper" switch are provided for the operation of corresponding controls and indications in the plinth. The feed roller is coupled to a shaft on which are mounted the two paper feed hand-wheels, in such a way that when the hand-wheels are turned round once a standard message length is fed out. To prevent this manual feeding out of the paper from damaging the paper feed motor, the latter is fitted with a one-way friction clutch.

3. 3. 2. Recorder plinth (Fig. 5)

The recorder plinth, or, alternatively, a recorder console, contains the complementary electronic and control circuitry to form a complete receiving equipment. It contains a receiving amplifier, a control unit which may be for either d.c. or v.f. signalling, a power pack and a smoke extractor and filter unit.

These are self-contained units, all connections between them being made by means of plugs and sockets in order to simplify their removal for servicing. Rapid access to the top surfaces of the recording amplifier and control units for adjusting the recording level, replacing valves, etc., may be gained by removing the left-hand and rear panels respectively of the plinth and swinging the units outwards, or by removing the back panel of the console.

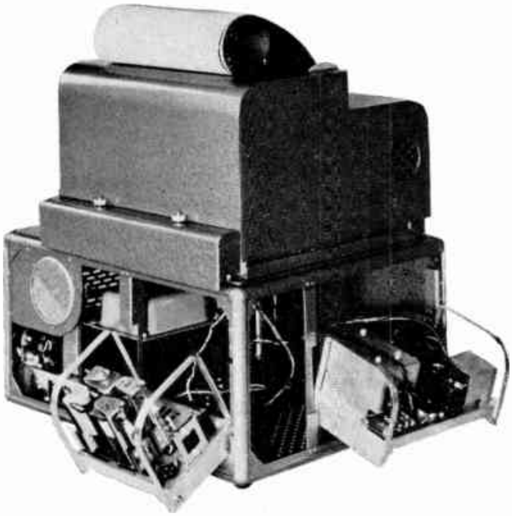

Fig. 5.—Page recorder plinth (units swung out).

The power pack unit is designed to operate from a 50-c/s supply of 115 or 200-250 volts, a power cord from the unit being provided which only requires to be connected to a suitable power supply. The power on/off switch is on the front panel, next to a green lamp which lights when the power is on.

The blower and smoke filter unit is provided to draw off and filter the smoke produced during recording. The filter is located at the rear of the plinth and is of the screw-in cartridge type for ease of replacement.

Two "paper-fail" circuits are included in the plinth, operated by the "low-paper" switch and "paper-out" detector on the recorder. When the Teledeltos paper roll is nearly exhausted, the "low-paper" switch operates and lights a red lamp on the front panel of the plinth as a warning. When the end of the Teledeltos paper is finally reached, the "paper-out" detector switch operates. This stops the recorder automatically and prevents it from being started again until a new roll of paper has been installed.

The circuit schematic is shown in Fig. 7. This can be used with the Desk-Fax Transceiver and Transmitter diagrams to follow the interoperation between them.

3. 4. *Facsimile Concentrators*

Whilst there has been no demand in Europe for the large concentrators used in America and illustrated in Fig. 1, except for those used by the Western Union Telegraph Company for their London collection and delivery service, there has been a general demand for small concentrators having a capacity up to twenty lines.

Figure 6 shows an early model having a capacity for twelve outstations and using Desk-Fax transceivers at the central office. Later models have been designed on cheaper and more flexible lines, the model now being exploited having an ultimate capacity of twenty lines in steps of five lines. This manually-operated cord type concentrator is shown in Fig. 6 equipped for five lines.

The outstation lines are terminated in self-contained sections of five lines each on numbered or labelled jacks and calling lamps mounted on the front panel of the concentrator. Provision is made for each group of five out-station lines to be served by two central office machines terminated on plug-ended cords. These machines may be Desk-Fax Transceivers, Transmitters or Automatic Page Recorders, as required. Local test jacks are also provided for checking the operation of the central office machines and running off local copies.

The concentrator measures 21½ in. wide x 6½ in. deep x 9 in. high. A smaller version

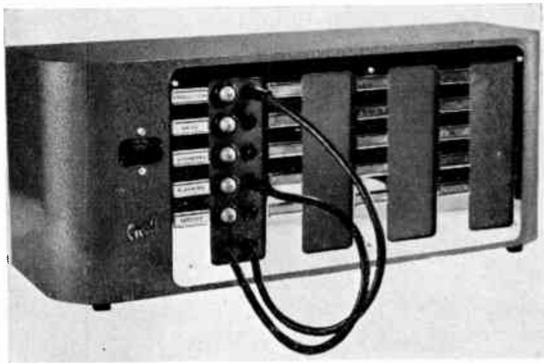

Fig. 6.—20-line cord type concentrator.

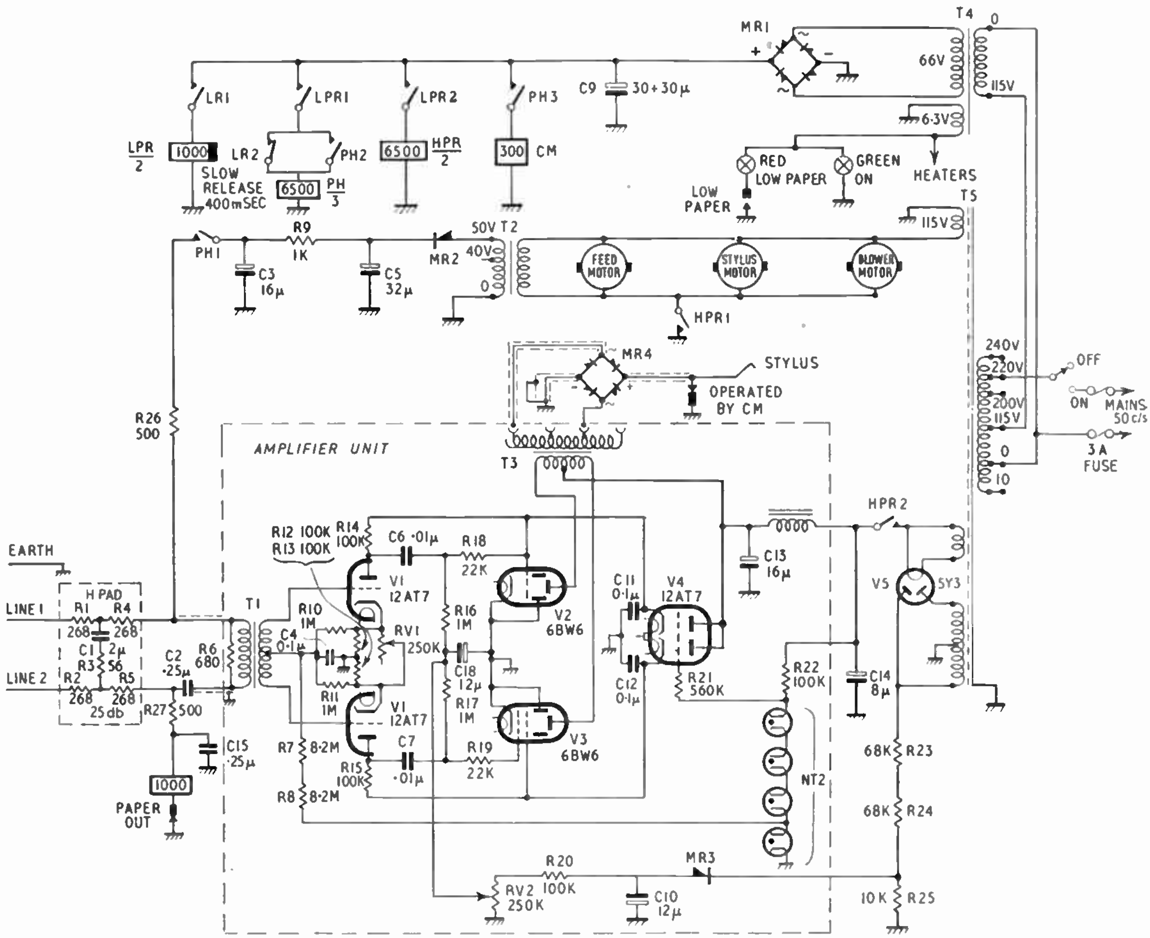

Fig. 7.—Automatic page recorder circuit schematic.

equipped for a maximum of ten lines is also available.

Operation.—An incoming call from an outstation is signalled at the concentrator by a buzzer and the lighting of the lamp associated with the calling line jack. To establish connection, the concentrator operator simply plugs a free central office receiver cord into the appropriate line jack. Thereafter, the machines are operated in the normal manner for ordinary point-to-point working. To initiate a call to an outstation, the concentrator operator similarly plugs a central office transmitter cord into the wanted line jack.

Upon completion of communication, the operator at the central office clears the connection by removing the plug from the jack.

An optional feature enables outstation operators to give a signal at the concentrator to acknowledge the receipt of messages transmitted to them from a central office machine.

3. 5. *Broadcast Unit*

This unit enables a Desk-Fax Transmitter to send out to a number of selected Page Recorder outstations simultaneously.

One type is shown in Fig. 8; this model is designed as a plinth to mount the Desk-Fax

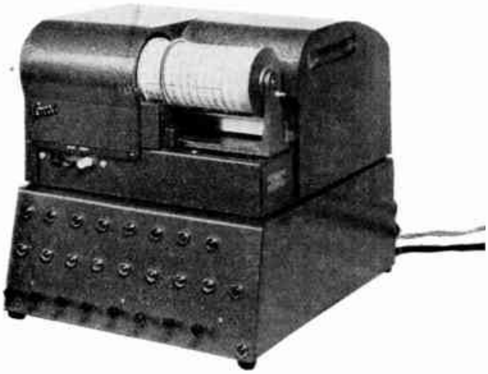

Fig. 8.—Desk-Fax broadcast unit.

Transmitter, and can serve up to eight stations. Other models have capacities of ten or twenty lines, and can be cross-connected to serve up to 100 lines.

To send out a message from the master transmitter to any one, or any desired group of outstations, it is only necessary to operate the appropriate push-buttons. The SEND button on the transmitter itself is then pressed in the normal way and transmission proceeds as soon as all selected outstation recorders have phased. (This takes about four seconds).

3. 6. *Teletape Transceiver* (Fig. 9)

This machine is designed for use in situations requiring the rapid facsimile communication of brief handwritten messages over relatively short distances.

Messages to be sent are written in HB pencil on a ¾ in. wide tape of Teledeltos exposed on a writing platform at the front of the machine, and protected by a hinged cover. The opening of the tape cover at one terminal locks the corresponding cover on the distant machine, thereby preventing messages being written at both ends of the line simultaneously. Transmission starts immediately the tape cover is closed, during which time the covers on both machines are locked. On completion of transmission the covers of both machines automatically unlock ready for the next transmission in either direction.

Reception is fully automatic, and a buzzer can be arranged to give audible warning at the end of an incoming message if required. The buzzer will sound until an operator attends the machine and presses a button.

A small green indicator lamp, set into the top of the dust cover, glows when the circuit is in the standby condition and is cancelled by a red lamp which lights when the circuit is busy.

Thirteen inches of tape are available for each message and the transmission time for each length is 18 seconds.

The tape is scanned by a small four-point stylus of hardened steel. At the transmitter, the pencil breaks down the thin insulating top layer of the Teledeltos and the carbon trace forms a conducting path. This unbalances a bridge in one arm of which the stylus is connected, and results in an output to line. The bridge is connected across an oscillator which provides a 5,000-c/s carrier frequency, which is amplitude-modulated by the stylus signals.

At the receiver, the stylus records on the Teledeltos tape in the normal manner.

Synchronism is obtained by using a synchronous power supply, and each stylus point corresponds to a pole on the stylus drive motor, which runs at synchronous frequency, so that the styli at each end are always in phase.

The bandwidth required is 2,500-7,500 c/s, and the maximum permissible attenuation is 30 db. The input and output impedance is 450-750 Ω. The overall dimensions are 19 in. x 11 in. x 6 in.

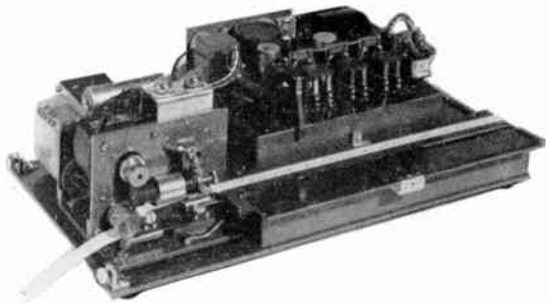

Fig. 9.—Teletape transceiver with cover removed.

4. Future Development Trends.

While loading the message form to a drum is a relatively simple and quick operation, there are nevertheless many applications where it is desirable to eliminate even this manual operation. This necessitates either an automatic drum-loading device or the adoption of a scanning means not involving a drum. The latter system involves the development of a "flat bed" scanner, in which copy remains flat and is scanned by a linear or rotating scanning device. Many problems remain to be overcome, however, and for the immediate future it is anticipated that drum type scanners will be retained, provision being made for automatic loading.

The new Creed Page Transmitter is of the automatic drum loading type. This machine (see Fig. 10) handles paper sizes from 4½ in. x 3½ in. up to 8½ in. x 14 in. (approximately 160-1,200 typed words). A magazine loading facility permits up to a dozen messages of mixed sizes and colours to be loaded at one time for sequential automatic transmission to a Page Recorder, giving up to 2½ hours' continuous unattended transmission. Transmitted messages are automatically ejected in correct order on to a delivery tray located at the front of the machine. D.c. or tone control is provided as required. The Transmitter is 21 in. wide, 15 in. deep and 18 in. high.

Fig. 10.—Page transmitter.

Another direction in which rapid expansion is anticipated in the near future is in the extension of voice-frequency control systems. Voice frequency control greatly broadens the operating field for facsimile communication over normal point-to-point circuits, as well as for alternative "speech-facsimile" working over ordinary leased Post Office private wires or private automatic or manual telephone systems. Calls are set up by telephoning the distant subscriber in the usual way and normal conversation can take place. Thereafter, the parties may at any stage switch over to facsimile communication for the transmission of written matter. On completion of facsimile communication the subscriber may revert to speech or terminate the call, as desired.

A tone control unit for the Desk-Fax Transceiver or Transmitter has been developed, in the form of a plinth on which the machine is mounted. This unit operates by converting the d.c. phasing pulses produced by the Desk-Fax into tone, re-conversion being effected at the distant terminal.

Tone control units have also been developed for the Automatic Page Recorder and the Page Transmitter, the Recorder Unit being housed in the Recorder plinth or console while the Page Transmitter Unit is contained in the machine itself.

5. Acknowledgment

The authors are indebted to Creed & Co. Ltd. for permission to publish this paper.

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ELECTRONIC ENGRAVING*

by

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Read in the Symposium on "Electronic Methods of Pictorial Reproduction", held in London on 25th January, 1956. In the Chair: Mr. W. E. Miller, M.A. (Cantab.), Past-President.

(Presented by G. S. Allen‡)

SUMMARY

The half-tone printing process is outlined, and the means of achieving it electronically on plastic plates is described. The paper refers mainly to an equipment which effects the engraving by means of a hot cutting tool, using helical scanning, but brief mention is also made of a similar equipment using a cold tool, and an oscillating flat bed. Electronic devices for tone correction, reproduction of coloured copy, and enlargement and reduction are also described.

1. Introduction

In the past few years electronic techniques have been applied to the graphic arts field at an ever increasing rate. One such application is to the electronic engraver for producing half-tone printing plates. The conventional method of producing half-tone plates is to expose metal blocks covered with a photo-sensitive, acid-resisting coating to a screened negative and proceed with an acid etch to give a printing plate.

This method of producing half-tone printing plates requires a special skill and is relatively expensive; in addition, there is a shortage of photo-engravers at the present time.

A machine that produces the half-tone printing plates without the use of the acid etching process has been perfected by Fairchild Camera and Instrument Corporation, U.S.A. This machine was first put on the market on a trial basis in 1947. The last published figures in early 1954 indicated 1,200 of the machines in use. This machine electronically engraves plastic plates to give the half-tone printing blocks.

Since the advent of the Fairchild machine, two other electronic engravers have appeared on the market. These are the German-made Clichograph and the Swiss-made Elgrama. A French electronic engraver known as the Luxograph has also been designed but it has been combined in France with the Fairchild machine. This engraver is basically the same as the Fairchild.

The Clichograph and Elgrama engrave on both metal and plastic with the Elgrama engraving a non-conventional line screen of the "hill and dale" type. A second version of the Clichograph can engrave line plates in which copy is entirely black or white, such as type, without any intermediate tones of grey.

Electronically-engraved half-tone printing plates have found wide acceptance in the United States and in Europe. Many other countries throughout the world are accepting these machines and in many cases the engravers are making possible photographic reproductions for newspapers where they were not otherwise used. The machines which produce these plates are called electronic engravers because scanning of the original copy is accomplished by electro-optical methods and the information is placed on the printing plate by means of an electro-magnetically driven torsion motor.

2. The Half-tone Printing Process

An explanation of the electronic requirements for the engraving machine requires an understanding of the half-tone printing process. In order to print on paper a continuous tone image such as the photograph of a person, it is necessary to break the image into a multitude of small dots. If this were not done the printing process would have only two ink densities, either black or white, apparent to the eye; the final result would thus be something equivalent to a silhouette figure.

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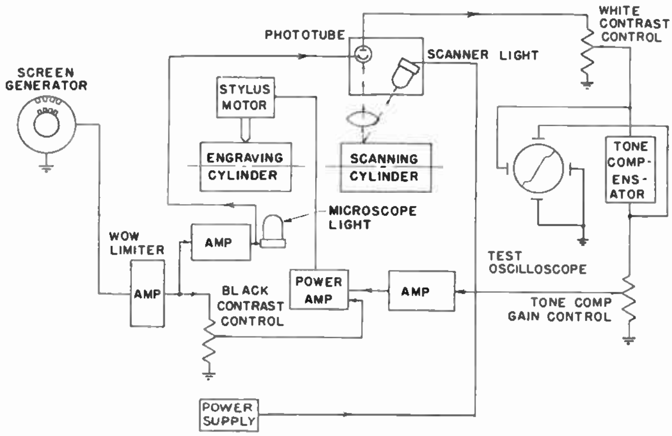


Fig. 4.—Block diagram of Scan-A-Graver.

reproduced in this dimension on the plastic printing plate. The exact relationship of the other dimension is fixed by the equal diameters of the two cylinders.

There are many electrical requirements in this engraver. A frequency must be generated which is equal to the dot frequency of the half-tone screen. There are several ways of accomplishing this and the one being used in the Fairchild Scan-A-Graver is an electrostatic screen generating wheel. This device is shown in Fig. 4.

The male and female gear wheels have flat-topped teeth. There are exactly the number of teeth per unit angle on the tone wheel as dots must appear in unit angle on the engraving cylinder. The two wheels are in exact concentric alignment and a polarizing voltage is placed across the two wheels. When the teeth are in alignment the capacitance effect increases to a maximum and when they are 180 deg. out of phase the capacitance is a minimum. In operation the inner tone wheel is relatively stationary and the outer tone wheel revolves on the same shaft that holds the copy and plastic cylinders. As the wheel rotates, an a.c. signal is produced which is a function of the rotational speed of the cylinders. The number of dots per unit length of scan is precisely fixed by the number of teeth on the wheel.

The primary advantage of the electrostatic type of dot-frequency generator is the extremely uniform signal produced. Although there may be many irregularities among individual teeth on the wheel, this effect is integrated over all the teeth and a signal of very constant waveform and amplitude is obtained. In order to insure an absolutely uniform signal from the dot-frequency generator, electronic limiting is used. This part of the circuit is referred to as the "wow limiter."

The inner wheel is connected by means of a cable and a series of pulleys to the stylus motor carriage in such a way that the inner wheel rotates one half of a tooth spacing for each revolution of the engraving drum. Each row of dots will be delayed by 180 deg. with respect to the preceding row, resulting in the familiar 45-deg. pattern of dots of the Levy half-tone screen.

Figure 5 illustrates schematically the method of modulation incorporated. The steady signal supplied by the dot-frequency generator is applied to the eighth dynode of a 931A multiplier phototube. This produces a focusing and defocusing action at the dynode which effectively chops the photo current to the anode.

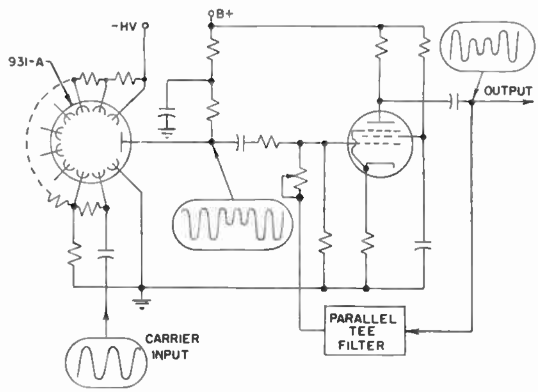


Fig. 5.—Modulation and filtering.

The output signal at this point is a d.c. modulated carrier. Before this signal can be passed through the following amplifier stages, the extra modulating component must be removed, i.e. the modulation must be rendered symmetrical. If this extra component were not removed a form of time constant distortion would result in the following RC-coupled stages. The composite phototube signal is passed into the first amplifier through a CR coupling having a time constant which is short compared with the period of the carrier frequency. This amounts to a high pass filter having an infinite attenuation at 0 c/s, and removes most of the unwanted component from the modulation. The remainder of the corrrection is performed by a parallel-tee feedback filter. The wanted signal is attenuated by the CR coupling, but this is acceptable.

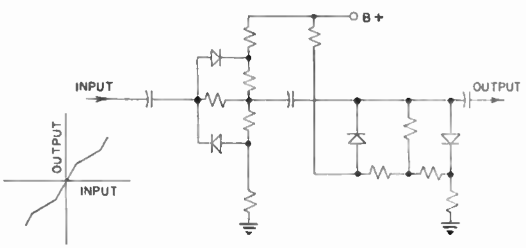


Fig. 6.—Square law—inverse square law compensation circuit.

The transient response of the entire system must be extremely good in many respects. It must be possible to lay down a series of highlight or maximum penetrations and then, quite abruptly, proceed to lay down shadows or minimum penetrations. It is possible for the Scan-A-Graver to accomplish a black/white transition in the period of one cycle. It has been shown in television design that this may be accomplished with a system having a response such that there is no attenuation of the upper sidebands, fifty per cent. attenuation of the carrier frequency, and maximum attenuation of the lower sidebands. This requirement is met to a first approximation by the combination of short time constant coupling and parallel-tee feedback network described. The feedback through the parallel tee network is made adjustable to permit alteration of the pass band characteristics over a limited range in order to accommodate practical component tolerances.

The necessary compensation for the square law-inverse square law characteristic is accomplished by a simple biased diode matrix as illustrated in Fig. 6. This matrix consists of two sets of diodes, each set biased to cut in at an appropriate signal amplitude.

For small signals the attenuation is low and none of the diodes are conducting. When the first bias point is reached the shunt diodes conduct and the attenuation is increased. Further increase in signal amplitude brings the series diodes into conduction and the attenuation is reduced. This results in a non-linear characteristic with two points of inflection that corresponds roughly to the square law-inverse square law characteristic. Pairs of diodes are required for each break in the attenuation characteristic in order to operate on both the positive and negative half cycles of the signal. Although only the positive half cycles will determine the depth of penetration in the engraving, it is necessary to perform equal compensation on the negative half cycles or the modulated signal would in effect be partially detected. This would re-introduce some of the original modulating signal and the finite time constants of the following amplifiers would produce a distortion of this component that would ruin the engraving. Some harmonics are generated in this compensating network but are effectively removed by a second parallel-tee filter.

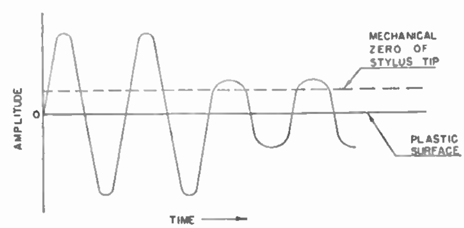


Fig. 7.—Black signal biasing.

After the tone compensator and second amplifier, a relatively low amplitude signal from the dot-frequency generator is mixed with the information derived from the scanning phototube. This signal is of fixed amplitude and is in phase with the information carrying signal. The requirement for such a signal is indicated in Fig. 7. This varying sine curve approximation represents the current through the stylus motor and is also representative of the motion of the reciprocating stylus tip. If the stylus tip is mechanically zeroed to the surface of the plastic, then for very small scanning signals an elongated, smeared dot would result when a small, square dot is required. By mechanically indexing the stylus tip back from the surface of the plastic and feeding in a non-information-carrying, steady signal from the dot frequency generator, the stylus tip is in contact with the plastic for a short time and engraves a square dot instead of a long smear. This mechanical biasing is indicated by the dotted line above zero level in Fig. 7.

The power amplifier is required to deliver a maximum output in the order of 100 VA to the stylus motor. The stylus motor is similar in construction to a conventional vertical recording stylus motor except for its size. The large size and very stiff construction of this stylus motor is desirable in order to minimize the loading effect of engraving operation. If a small, low power stylus motor were used, a large depth of penetration would reflect a mechanical load on the stylus tip and this would result in a falling off of the deflection linearity characteristic at high amplitudes. Displacements in the order of $\pm 0{\cdot}015$ in. are required with a frequency response extending to $1\frac{1}{2}$ times the carrier frequency. This accounts for the bulk of the motor. No mechanical damping material is incorporated in the motor and it is designed to have a mechanical resonance a few hundred cycles above the carrier frequency. Damping of the mechanical resonance is obtained electronically and is adjusted by means of voltage and current feedback around the power amplifier. It should be noted that the minimum pass band requirements for satisfactory transient response must include the characteristics of the stylus motor as well as the characteristics of all of the circuits between it and the phototube.

Several auxiliary circuits are provided for the convenience of the operator. The carrier tone signal is sampled and fed through pulse forming networks to drive a strobe light. The strobe light is focused on the engraving drum to stop the motion of the engraved dots visually so that they may be viewed through a microscope while the machine is in operation. This is a convenience to the operator in making initial adjustments for an engraving. Another auxiliary circuit connects a group of limit switches and a stall relay, which is energized by the carrier dot-frequency to a hold-down magnet on the stylus motor carriage. If the machine is allowed to run to the end of an engraving, or if for any reason the machine should be stalled, the stylus motor is automatically released and the machine stopped.

4. The Hell Clichograph

A block diagram of the Hell Clichograph is shown in Fig. 8. This machine is an oscillating, flatbed engraver as compared to the Fairchild rotary engraver. The plastic plate is mounted on an oscillating flat bed with the original copy placed back-to-back with the plastic printing plate. A light source is projected through a spinning disc light chopper and this chopped light is projected to the copy. Reflected light is picked up by two parallel photocells and the electrical signal is fed into the circuits. As the flat bed oscillates back and forth, the stylus motor chips out the small dots. The stylus motor carriage traverses in the direction perpendicular to the direction of table oscillation during the engraving operation. In this manner the original copy is completely line scanned. In order to minimize the time lost in scanning blank area because of the 45-deg. rotation requirement, limit switches are placed at the edge of the copy so that only copy area is scanned. When scanning at 45 deg. and cutting with a sharp pointed tool, it is not necessary to obtain the 180-deg. dot advance from line to line as is required in the vertical scanning. Engraving is accomplished in one direction only and

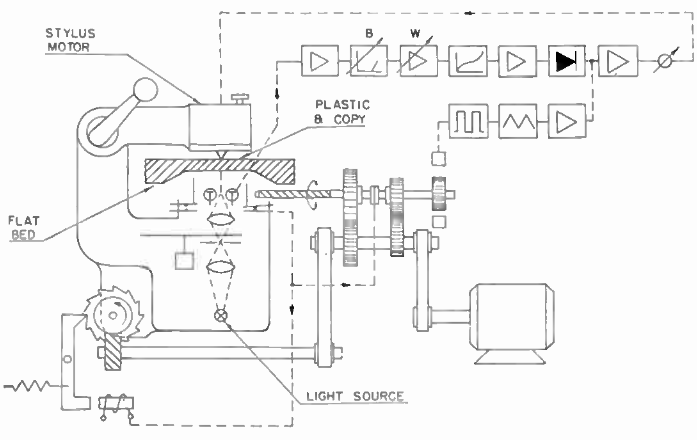


Fig. 8.—Block circuit diagram of Clichograph.

the table returns to its fixed direction of scan in a relatively short time after the engraving of each line.

The electronic requirements for the cold cutting engraver differ in many respects from the hot engraving machine. In order to cold cut, a steady sawtooth waveform signal must be mixed with a varying d.c. information carrying signal to give the proper stylus tip motion. In the Hell Clichograph, a triangular constant amplitude waveform is derived from a dot-frequency generator and is mixed in the power amplifier. The signal from the photocells, which is at a high frequency compared to the dot frequency, passes into a tone compensating circuit and is then detected and mixed with the sawtooth dot frequency signal in the power amplifier. An analysis of the requirement for cold cutting will show that a symmetrical dot frequency signal cannot be used and the fixed a.c. signal with the varying d.c. bias is required.

5. Other Developments

5.1. *Tone Correction*

Several additions have been made to the basic electronic engraver in order to make it more versatile. In the Fairchild machine a Variable Response Unit has been designed to give almost infinite control over the tone response characteristics of the machine. This enables an operator to modify the tonal characteristics of the original copy as it is being translated to the half-tone plate. If photographic copy with poor density characteristics must be used for plate making, an appropriate adjustment is made to the Variable Response Unit in order to correct for the deficiency in the original copy.

This Variable Response Unit is an electro-optical unit which is substituted for the tone compensator and is inserted between the photocell and the power amplifier. The output of the photocell is fed into the horizontal plates of an electrostatic deflection type cathode ray tube. Into the vertical plates is fed a constant amplitude tone frequency signal which has the same frequency and phase as the copy signal. A Lissajous figure results and the mixing of the signals in the cathode ray tube gives a straight line. As the copy signal changes, the line rotates about the zero axis of the electron beam. An opaque mask is placed in front of the tube and the desired reproduction characteristic is cut into this mask. The light output from the face of the tube becomes a function of the copy signal input and the configuration of the mask. A phototube picks up this light and feeds it into the power amplifier to actuate the stylus motor. By changing the shape of the aperture in the mask, the desired tonal characteristic is achieved. It is possible to obtain expansion of the tone scale in the darks or highlights or in the middle-tones or any combination of two of these. It is possible to obtain reverse effects as well as step effects where given continuous density variations are digitalized into a single density. This results in the reproduction having a poster-like appearance.

5.2. *Reproduction of Coloured Copy*

An electronic computer has been added to the electronic circuitry to make possible the production of three and four colour printing plates for reproducing coloured copy. In this type of machine three photo-multiplier tubes scan the copy at the same time and appropriate colour filters are placed before these photo-multipliers. The computer corrects for the spectrophotometric properties of the printing inks, the type of paper being used, printing conditions, original copy characteristics, and other factors. An equivalent result is being achieved in the Time-Life scanner, the RCA colour scanner, and other electronic colour correctors, except the output of these machines is a continuous tone, colour corrected negative of film and metal plates must be engraved from this film. In the Fairchild machine a colour corrected, relief type printing plate is the final product and the metal etch process is eliminated. The Hell Clichograph also has a colour correction computer and colour blocks can be made directly from original copy with this equipment. The Elgrama machine requires a colour corrected separation positive to engrave a colour plate. The Elgrama machine does have the advantage of lower susceptibility to *moiré* interference patterns resulting from the structure of the screen.

5.3. *Enlargement and Reduction of Copy*

One of the important practical problems associated with electronic engraving is the need for change of size. It is unusual that a printing plate is required which has the same size as the original copy. An electronic engraver which accomplishes a change of size in the engraving process, known as the Scan-A-Sizer, has been produced (Fig. 9). In this machine the enlarging

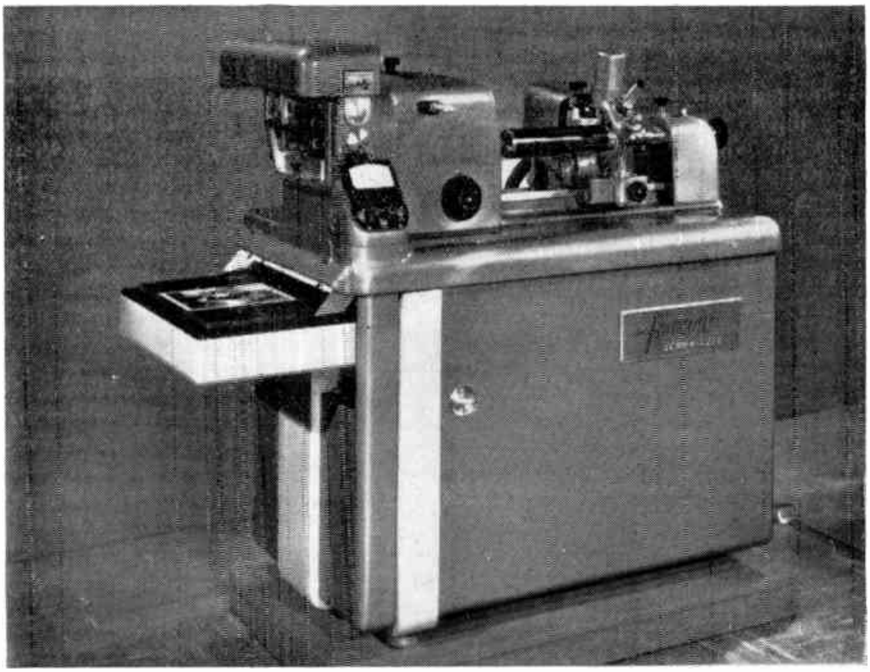


Fig. 9.—The Fairchild Scan-A-Sizer.
Note.—This illustration was printed from a 100-screen Scan-A-Graver plate.

and reducing is accomplished in the scanning process by mechanical methods. An oscillating mirror scans the copy which is mounted on a flat bed. Enlarging and reducing in the scanning direction is accomplished by changing the angle of scan and maintaining a constant scanning cycle. The flat bed copy table travels in a direction perpendicular to the scanning direction and change of size is accomplished in this direction by varying the rate of movement. Line illumination of the copy is accomplished with a fluorescent tube. It is reported that the Clichograph will have an enlarging and reducing version available in the not-too-distant future.

6. Conclusions

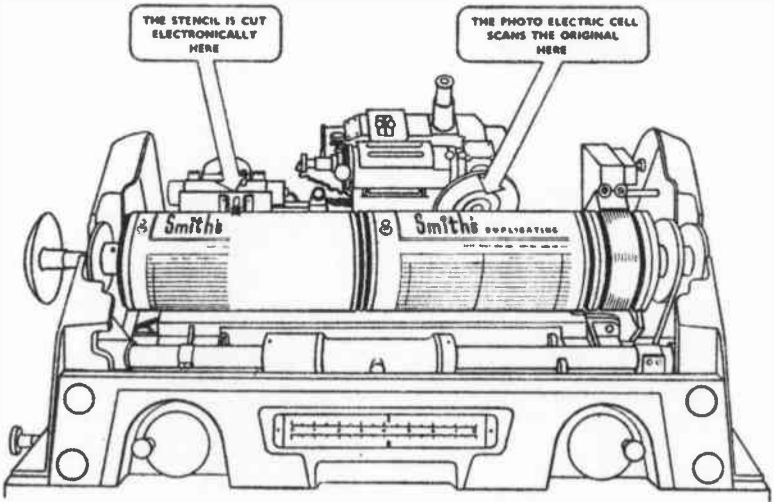
In America the electronic engraver has been a great boon to the small town newspaper publisher. Here the distances between publishing houses are relatively great and the ability to engrave in the printing plant is a great asset in convenience and time: there is also a definite economic advantage. At the present time approximately seventy per cent. of all the newspaper publishers in the United States are using plates from the Fairchild Scan-A-Graver.

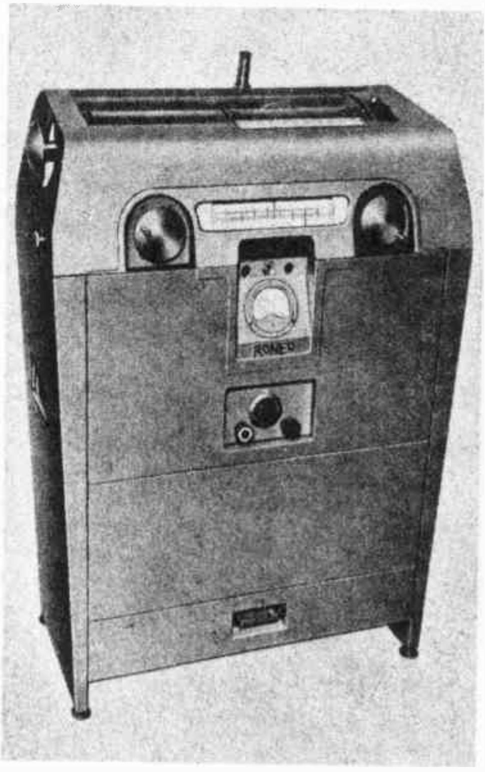
In Europe, where the distances between engraving plants are not so great, the advantages of time and convenience are not as important and the electronic engraver is not being accepted as rapidly as in America. With improvement in the colour correction phase of the electronic engraver there will be an accelerated use of this method of making plates. With colour television taking away some of the advertising market from the newspaper and magazine, the publishers' requirements for low cost colour printing plates may be met with the electronic engraver equipped with the colour computer.

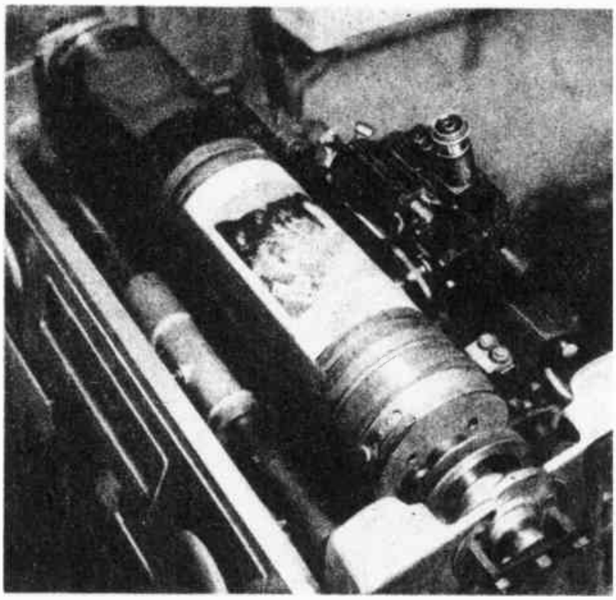
Electronic engraving has thus become a very important tool in the field of graphic arts. Undoubtedly, its use will grow very rapidly in the near future.

Fig. 1

THE RONEO ELECTRONIC STENCIL MAKER







Top — a diagrammatic view showing the scanning of the original and the cutting of the stencil. Left — a full length view of the machine. Right — a close-up of the cylinders.

TONE REPRODUCTION WITH ELECTRONICALLY-CUT STENCILS*

by

R. Lant, Dr. Techn. Sc. †

Presented in the Symposium on "Electronic Methods of Pictorial Reproduction" held in London on January 25th, 1956.

SUMMARY

The principle of cutting stencils by means of an electronically-controlled spark discharge was established about twenty years ago for black and white reproduction. A more recent development is the Roneo electronic stencil machine which also reproduces intermediate tone values shown by photographs. Various mechanical and electrical refinements are required to achieve satisfactory results. Tone reproduction is based on the fact that a linear increase of current across the electrodes produces a linear increase of density on the copies. It is shown how the reflected light signal received from the original has to be corrected in order to match the various densities of the copies with those of the original. Besides tone reproduction the machine can also cut stencils from line work originals which are not sufficiently "black" such as letter-heads in colour. Copies in full colour are obtained by use of the "contrast knob" which causes a deliberate distortion of the "tone setting".

1. Principle of Stencil Cutting by a Spark

An electronically controlled spark discharge can be used on a scanning machine to destroy the coating of a stencil sheet which is impermeable to the ink of a duplicator and thus permit the passage of ink wherever a spark discharge has taken place. If the discharge is controlled by the scanning of an original, facsimile copies can be produced. This principle was established about twenty years ago for black and white reproduction and several scanning machines are offered to the public which make use of this principle. The original to be reproduced and a stencil sheet are wrapped round a cylinder side by side. A powerful beam of light is concentrated on a small area of the original and any light reflected from the original is collected by an optical system and thrown on the cathode of a phototube. When the cylinder is rotating the photohead, consisting of the light source, the optical system and the phototube, is made to move slowly parallel with the axis of the cylinder causing the beam of light to scan the original in a helix. Rigidly connected with the photohead is a tungsten wire electrode which is held down on to the stencil by a light spring pressure. The other electrode is formed by the earthed metal cylinder. By this arrangement the tungsten wire electrode scans the stencil in an identical manner as the beam of light scans the original. Whenever the beam of light scans a white spot on the original no current passes through the electrodes and if a black printed area is scanned a current of sufficient magnitude passes through the electrodes to destroy the coating of the stencil.

2. Various Mechanical and Electrical Refinements

The Roneo Electronic Stencil Machine, the construction of which is shown in Fig. 1, is unique in as much as it also reproduces the intermediate tone values shown by photographs. As the author has described in earlier publications‡, various refinements have to be incorporated into the machine in order to produce results which are commercially satisfactory. A ten-times enlarged image of the original is reproduced in a square aperture of 0·05 cm side length. Thus the light which is

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U.D.C. No. 621.37/8: 652.3.

‡ "The Roneo electronic stencil machine," *Penrose Annual*, 47, pp. 135-136, 1953. "Pictorial reproduction by electronic scanning in stencil duplicating," *Proc. Int. Conf. Roy. Photogr. Soc. Gt. Btn*, pp. 540-542, September 1953.

allowed to pass through this aperture originates from a square area of the original of a side length of 0·005 cm and this is thrown on the cathode of a photo-multiplier tube having a sensitivity of 10 amperes per lumen. An ordinary vacuum photocell with a performance of 20–30 μA/lumen or a gas-filled cell with 200 μA/lumen are inadequate for the requirements. The supply to the projector lamp is stabilized against fluctuations of mains voltage and frequency. It is also rectified and smoothed in order to suppress mains hum. The resolving power of the scanning has been increased to approximately 125 lines to the inch, but to avoid interference patterns it is necessary to use a scanning pitch four times finer, that is, 500 lines to the inch. The tungsten wire electrode is continually consumed by the spark discharge, but for the reproduction of line work the consumption of the tungsten is low because as a rule only a small percentage area of the original is black. When reproducing tone, there is always a spark discharge of greater or lesser intensity and the total consumption of the electrode may amount to 0·010 in. and even 0·020 in. during one reproduction. This loss of length of electrode would cause a loss of registration, a horizontal line on the original for instance would drop from start to finish on the reproduction. The length of the electrode has therefore to be maintained constant within 0·002–0·003 in. This is done by a rather intricate recording instrument which automatically pushes the wire forward as it burns away.

3. Fundamental Fact on which Tone Reproduction is Based

Tone reproduction is based on the more recent recognition that a spark discharge produced by a smaller current than is required to give a black copy will yield a grey copy, the smaller the current the lighter being the shade of grey.

The various grey tones of the copies are distinguished by the number of fine black dots and not by their size, similar to the distribution of the silver grain in a photographic image. The current across the spark electrodes is amplitude modulated and maintained at a constant carrier frequency. The variation in the number of holes provided by the spark discharge in the stencil sheet at varying current ratings can perhaps be explained by the structure of the stencil sheet which, consisting of a dispersion of a conductor in a plastic film, is not truly homogeneous. Thus the current as it declines in its magnitude may find fewer and fewer spots where it is capable of burning a hole.

Under a given set of operating conditions in respect of the stencil cutting machine, the running of the duplicator, and stencil characteristics, and starting with very low current ratings, say one or two mA, one will find that no ink at all passes through the stencil after such a recording. Increasing the current gradually, a very faint grey copy will be obtained, say from a current of 4 mA. Increasing the current step by step will yield copies of an increasingly intense grey until a current rating is found where the copies are black and a further increase of current will make them no darker.

If such a copy is mounted on the cylinder as the original, the machine can be used for measuring the light reflected from these strips of varying intensity. The current emitted by the phototube stands in a linear relation to the light. The strips were all cut with a constant increase of current and it will be found that the photocurrents emitted from any two adjoining strips show a constant ratio. Therefore, for an infinitely large number of infinitely narrow strips, taking into account the fact that the photocurrent i declines with growing current I, this relation can be expressed by

$$\frac{di}{dI} = -ki,\ I = -k\int\frac{1}{i}di + c \qquad \text{..............(1)}$$

the value of I being defined in relation to the "white level", where the current I_0 is just insufficient to yield a copy and for which the photocurrent i_0 is a maximum, by

$$I = -k\int_{i_0}^{i}\frac{1}{i}di = k\log\frac{i_0}{i} \qquad \text{.................(2)}$$

The varying intensities of grey tones observed on a photograph are measured photometrically by comparing the intensity of light reflected from the white background paper with that of any particular shade. If the first is L_I and the latter L_{II} any shade can be expressed by its reflectance (L_{II}/L_I) or by its density

$$D = \log_{10}\frac{L_I}{L_{II}} \qquad \text{.................(3)}$$

If a photograph is now mounted on the ıachine the density of any given shade can ɛ determined according to (3) by comparing ıe photocurrent i_0 generated by the white ackground with i from any particular shade.

$$D = \log_{10}\frac{i_0}{i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

A comparison of equation (4) with (2) reveals ıe fact that, within useful limits, a linear ıcrease of output current produces copies of a near increase in density.

In order to obtain faithful reproduction of ɔne values the output current for any given ensity is determined by

$$I = kD + I_0 = k\log_{10}\frac{i_0}{i} + I_0 \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

. Determining the Characteristics of the Stencil

The photocurrent i_0 for the white level has ɔ be determined as a constant for the working f the machine, fixing the white level. At this ɜvel of Density 0 a current of I_0 is required, a onstant determined by experiment and defining ne characteristic of the stencil. The current /hich gives a copy of the darkest grey still istinguishable from black is another important haracteristic of the stencil, and finally there is he density of this darkest shade of grey. These ıree characteristics of the stencil are connected ·y the expression

$$I = \frac{I_c}{D_c}D + I_0 \qquad \ldots\ldots\ldots\ldots\ldots(6)$$

/here I_c and D_c define current for and density ·f the darkest distinguishable grey shade, and the current required to provide a density D. $)_c/I_c$ can be considered as the electronic amma of the stencil.

꞉. Calculation of the Necessary Corrections

An ammeter is inserted in the d.c. output tage of the amplifier. The highest point of he available modulation range, 100, is fixed as black level" with zero signal, the range from '0 to 100 is left for black shades, the darkest ;rey with density D_c is fixed at 90 and the white ɜvel with constant maximum signal is fixed at 0. Hence the range over which the signal is equired to increase linearly with the density ·xtends from 10 to 90. In order to make the orrections less complicated and to make the lemands for sensitivity less exacting it is desirable to leave as great a part as permissible of the darkest shades uncorrected. If correction is confined to 80 per cent. of the total range a distortion from the linear relation of −1·5 per cent. occurs at 85 per cent. and of −3·3 per cent. at 90 per cent. corresponding to the highest significant grey density. Experience has shown that this is quite acceptable.

The amplifier requires E volts across an input resistance R to modulate 100 per cent. of the available d.c. output, therefore a photocurrent of $0{\cdot}7\,E/R$ (in amperes) is necessary to modulate from density 0 (10 per cent.) to density D_s at 80 per cent. and

$$\frac{di}{dD} = 0{\cdot}7\frac{E}{RD_s} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

defines the slope of the required photocurrent signal. Referring to equation (4) the slope of the photocurrent curve plotted over the density can be calculated for any point by

$$\frac{di}{dD} = -\frac{1}{\log_{10}e}\,i \qquad \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Thus the photocurrent required at 80 per cent. range:

$$i_s = -\log_{10}e\;0{\cdot}7\frac{E}{RD_s} = -0{\cdot}304\frac{E}{RD_s} \qquad \ldots\ldots\ldots(9)$$

and the maximum photocurrent i_0 for the fixed white level is determined according to (4) by

$$i_0 = 0{\cdot}304\frac{E}{RD_s}10^{D_s} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Constant k in equation (5) is defined by

$$k = \frac{I_C - I_0}{D_C} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

and is taken care of by adjustment of the signal into the a.c. stage of the amplifier.

Thus all constants in the fundamental equation (5) are now defined by the characteristics of the stencil and by the gain of the d.c. stage of the amplifier. The following parameters for the Roneo machine and stencils conform approximately to equations (9) and (10): $E=7{\cdot}5$ V, $R=0{\cdot}5$ MΩ, $I_0=4$ mA, $I_c=36$ mA, $D_C=1{\cdot}62$, $i_S=3\,\mu$A, $D_S=1{\cdot}42$, $i_0=80\,\mu$A, $k=19{\cdot}75$.

6. Application of the Corrections

For the density range from 0 to D_S the signal from the phototube has to be corrected. The photocurrent flows through an input resistance R and the signal for the amplifier is defined by iR. The condition imposed by equation (5) is that iR should vary in a relation linear to D and this can be brought about by making R a variable r for the corrected range. The signal is to conform to the following equation:

$$ir = i_0r_0 - (i_0r_0 - i_SR)\frac{D}{D_S}$$

$$r = R\,\frac{i_0r_0D_S - (i_0r_0 - i_SR)D}{i_SR\,10^{(D_S-D)}D_S} \quad \text{.........(12)}$$

By inserting the values for the constants resulting from fixing the white level $D=0$ at 10 per cent. of the available d.c. range and the beginning of the corrected signal for D_S at 80 per cent. the necessary variation in the resistance value is expressed by

$$r = R\,\frac{4{\cdot}5\,D_S - 3{\cdot}5\,D}{10^{(D_S-D)}D_S} \quad \text{......(13)}$$

The reduction of the resistance is made empirically and by approximation only through bypassing the excessive photocurrent via two

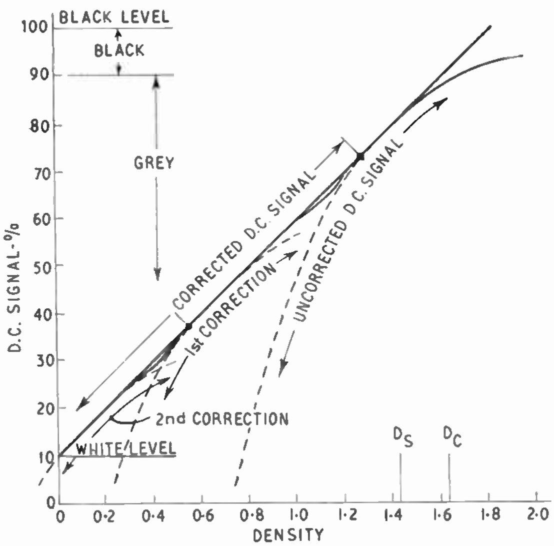

Fig. 2.—Correction of d.c. signal.

diodes which come into operation at two carefully selected successive points, each of the diodes having a carefully selected anode resistance. Fig. 2 shows the effect of these diodes on the d.c. signal.

7. Inversion of the Corrected D.C. Signal

The corrected d.c. signals are fed into one grid of a double triode, the other grid being biased for a maximum differential current through the two triodes to obtain when no signal

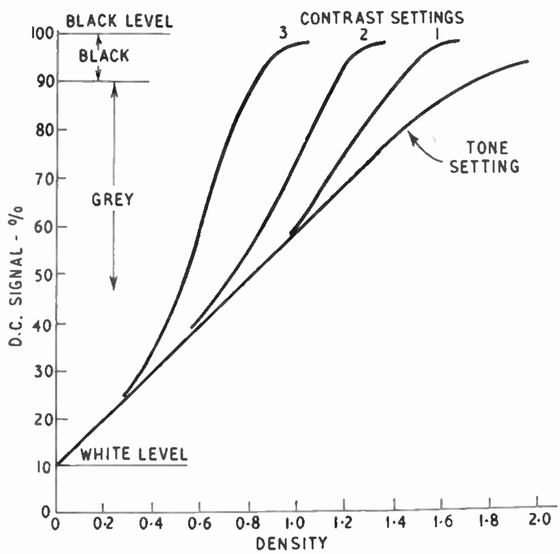

Fig. 3.—Tone setting by contrast control.

is received. Any signal received reduces the differential current linearly. This current is passed through a ring modulator circuit where it is mixed with a carrier frequency of 20 kc/s which is chosen to equal approximately 1½ times the maximum signal frequency. The output from the ring modulator circuit consists of 20 kc/s signals, amplitude modulated by the d.c. signals. The a.c. signals are amplified in a linear two-stage push-pull amplifier. The output of this amplifier is fed into the spark gap with the stencil representing the load impedance.

8. Increasing Contrast by Distortion of "Tone Setting"

With the signals corrected for faithful tone reproduction the problem arises how to cope with originals of a comparatively low density which are to be reproduced in full colour, for instance, an original letterhead printed in blue ink is supposed to yield copies on the duplicator in full blue colour. The stencil will have to be cut with the full energy required for giving an

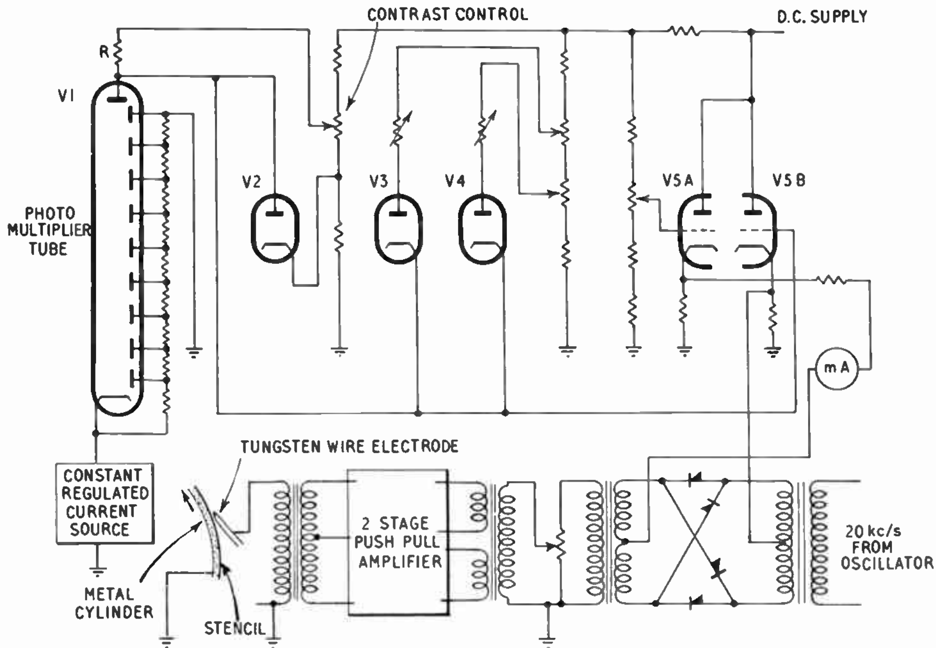

Fig. 4.—Basic circuit showing tone control arrangements.

unimpeded passage to the ink whereas the density of the blue original registers say as 0·8 only. The density of black and white originals is not high enough as a rule to ensure a stencil for intensely black work on the duplicator. Finally many photographs lack in density and it is desirable to increase their contrast for reproduction. These problems have been overcome in this machine by the use of a third hand-controlled knob, the "contrast." It controls the working of a third diode which, as distinct from those mentioned previously, is connected to the input grid of the amplifier with its anode. The cathode is connected with the minus terminal of a potentiometer arranged in a bleeder circuit and the supply for the uncorrected photocurrent is drawn from the slide of this potentiometer. If the slide is moved into a position *v* volts positive to the cathode then all signals less than *v* volts will be drained off through this diode and will not affect the working grid which will maintain its black level setting. By turning the contrast knob to various positions one can decide how much to increase the density on the reproduction. Fig. 3 shows the distortion of the tone setting by use of the contrast.

The circuit diagram of Fig. 4 shows the basic arrangements for the method of tone reproduction which has been discussed.

9. Acknowledgment

The author is indebted to Roneo Limited for the facilities to publish this communication.

DISCUSSION

Dr. G. L. Hamburger (*Member*): We certainly have witnessed a most interesting and stimulating symposium on the art of electronic facsimile transmission, and I am very happy to be given the opportunity of opening the discussion. I should first like to ask Dr. Lant whether he can throw some light on the mechanism of the spark which enables him to produce half tone pictures in his process. Do I take it that there is a substantially constant size of hole, but that the number of holes varies with the strength of the current? What would be the size of these holes, and is it necessary to use a special ink for printing the electronic stencil?

My second question concerns the reproduction of half tones with the chemical recording medium as used in Mr. Davidson's apparatus on the one hand and the teledeltos recording paper of Messrs. Woodman and Taylor on the other. I should like to know what the significant difference is between these two types of recording media.

W. E. Miller (*Past President*): Until the Scan-A-Sizer is available in this country, it seems to me that the use of the Scan-A-Graver will probably be quite small because it is only possible to reproduce at the same size. This therefore means that you must take your original and make a photographic copy to the required size before cutting it on the Scan-A-Graver, thus involving a double process.

The second question I want to ask is whether a metal stereo can be made from a plastic block? In many printing works where there are long printing runs, several machines are used and stereos of the blocks are taken for use on each machine.

Next, could Mr. Allen give us some idea of the relative number of reproductions obtainable from the plastic block as compared with the normal metal one?

Another point is the question of the skilled operators required. Would Mr. Allen say that the operators required for the Scan-A-Graver can be less skilled than those required for the ordinary photo-engraving process, or whether fewer skilled operators would be required? Many of the operations in ordinary engraving require really skilled men.

I have had blocks made on the Scan-A-Graver and compared them with the ordinary photo-engraved block, and I must say they gave extremely good reproduction. However, in one or two cases the contrast was rather poor compared with the photo-engraved block. That may have been due to a fault in operation, but I would like to know whether there is any fundamental reason why the contrast should not be as good from a given original as by the older method.

S. Khanna (*Graduate*): Dr. Lant has mentioned that a photocell performance of 200 microamperes per lumen is not sufficient. Could not an amplifier be used to follow the photocell instead of using a special photo-multiplier?

F. Mackenzie: I am wondering whether Dr. Lant can give a little more information on this question of the formation of dots on the stencil; because I did notice when this machine was first introduced that there appeared to be a metallic coating on the stencil sheet.

A. E. Jaquemet (*Associate Member*): I would like to ask Messrs. Woodman and Taylor if they can give me information on the teleprinter copy that comes over Desk-Fax, the particular size being used, and whether any idea can be given of the time period taken to transmit it. Are there any comparative tests in the speed of handling or transmission and reception of that message, as compared to the normal teleprinter working at sixty-six words per minute?

C. E. Harris: I would like to ask Mr. Davidson a question concerning the frequency shift equipment used on chart facsimile. I notice that on this type of reproduction there are considerable areas of grey. Can he give me any idea as to what degree of linearity of shift is required in order to reproduce the grey, as opposed to the black?

Dr. Ing. P. Eisler (*Member*): I understand that one of the main tasks of the engraver when making a block, particularly a block for colour printing, is to correct the tone values derived from the colour separations, or from the negatives, and that it is on his judgement that this correction is made. As his main tool he has the art of fine etching these blocks. I wonder whether equivalent controls, aiming at giving a similar facility to the electronic engraver, are built into the machine, or whether such controls may be contemplated?

Secondly, can Mr. Allen tell us something about the cutter used with the other machines?

The Fairchild electronic engraver uses an impression tool, while the others use a cutter. It does appear that the cutting action is of interest and has its own problems.

R. Jones: Mr. Allen has left me with the impression that the Scan-A-Graver has its limitations. These limitations I feel are where a first class reproduction is required from copy either lacking contrast, or the other extreme where the tone range is severe. My opinion is that there is *at present* work for both the Scan-A-Graver and conventional methods, the type of of copy determining which method to use. I would like to have Mr. Allen's confirmation of this. It may well be that a few years hence electronic engraving will be so perfected that conventional methods of today will be forgotten.

C. F. R. Griffin: As the engraving is carried out at a very high temperature, do we understand that the material is burnt out from a thermoplastic, or is it melted out? Is there any need for dressing down the surface of the plate? Also, is there any "recovery effect" of the plastic?

J. R. Harvey: Regarding this question of dots, I would like to hear more from Dr. Lant about the high frequency discharge. I wonder if a suitable high frequency would cause a line of very minute dots, and whether the holes would be randomly spaced.

In conventional process engraving care has to be taken to ensure that the colours concerned are put correctly upon the surface of the paper. The screen in fact is moved to form a dot pattern in a slightly different position so that the colours are not overlapping one another. What is the electronic equivalent of this process, because if it is not observed you will get muddy colours?

AUTHORS' REPLIES

Dr. R. Lant: According to the blackness to be reproduced there are fewer or more holes, they are more or less the same size but they do not grow appreciably in size with an increase in current. I do not believe anybody—certainly not I—can give an incontestable explanation why the holes vary in number, although it is a fact on which the whole process is really based. I should say there is a variation in the size of the holes with the magnitude of the current, a fine hole would be one thousandth of an inch in diameter or of that order. That is all I can say. The performance of the spark has not been studied, as in general, sparks are very elusive things and I can only confess my ignorance. It is very difficult to investigate because the moment you attach any instrument to the circuit you alter its characteristics.

One does not have to use special ink, but one uses a special pad because an ordinary pad is not thick enough to carry sufficient ink to feed into the large black areas the ink which the copies take away; so a special pad which is thicker than the ordinary pad is used to carry more ink. It is still the same ink.

The conductor embedded in the stencil at an earlier date was metal powder, and eventually it was found advantageous to replace this by carbon black which had certain advantages, but in principle it is just the same. You have to have a conductor dispersed in a dielectric. The tonal rendering was improved because we were able to improve on the dispersion of the carbon black. We found this to be more readily dispersible than the metal powder; but it still does not explain the spark action.

We use a frequency of 20 kc/s which is not a high frequency, but I know the circuit is resonant and there are various frequencies there up to 60 Mc/s which we have measured, but what causes the formation of these holes, I still do not know. We have done quite a bit on the side in the way of investigation, but it has not yet led to a satisfactory explanation. I am offering one explanation in my paper which I believe has a good foundation. It is that with the inhomogeneity of the stencil sheet, if the current is too low then there will be no sparks in certain spots; but if a higher current is used in these spots then holes will result. A voltage is always built up before the spark breaks through. A higher voltage is probably capable of breaking through in more places than a lower voltage.

The holes are spaced in such a manner that there is no justification for assuming the need for a higher frequency than that which is put in.

A photocell with a performance of 200 microamperes per lumen is not feasible because the signal/noise ratio becomes too unfavourable. You cannot proceed with your amplification beyond a certain point, you must have enough light signal, or light response of the photocell so that you can use an amplification by electronic means which does not produce too much noise. The machine actually works with a maximum photocurrent of 80 microamperes. It is not possible, since the light in the machine is less than one-thousandth of a lumen, to use an ordinary photocell without producing too much noise. This is beyond the scope of electronic amplification.

H. F. Woodman and P. H. J. Taylor: With regard to Mr. Jaquemet's query, for the direct onward routing of teleprinter messages the large drum Desk-Fax transmitter (Model T.200) is used, and the maximum depth of copy which can be transmitted in one message is three inches. If a definition of 100 lines/inch is used, this area is transmitted in approximately 2 minutes; if 130 lines/inch definition is used to give better resolution, then the transmission time is about $2\frac{1}{2}$ minutes. For actual teleprinter copy, the transmission time will normally be less for teleprinter than for facsimile, and for heavily-loaded main transmission links teleprinters will usually provide the most economic service. Facsimile finds its main application in the onward routing of teleprinter messages from the main office to sub-offices where the traffic density is insufficient to warrant the provision of teleprinters and the necessary skilled operators, or where the nature of the transmitted copy is unsuitable for teleprinter (such as foreign language messages, diagrams, formulae, etc.).

It should be noted that if teleprinter messages are re-typed for any reason, then the maximum speed of transmission obtainable with facsimile is roughly the same as that obtainable by teleprinter, that is the number of words which can be typed in the useful message area on the sending form is about the same as could be transmitted over a teleprinter circuit in the same time.

In reply to Dr. Hamburger, recording on electro-chemical papers is achieved by a chemical reaction between the recording member and the specially treated, damp paper, which darkens at the area of contact. The degree of darkening is proportional to the current flowing through the paper, so permitting half-tone reproduction.

Teledeltos paper consists of a black conducting base paper, thinly coated with a light grey insulating material and backed with an aluminium lacquer. When the recording potential is applied, the thin insulating top surface of the paper partially changes colour and is partially burnt away by the current flow to reveal the black base paper underneath. The higher the recording potential, the greater is the current through the paper and the denser the mark, so that shades of darkness from dense black to very faint copy are obtainable.

J. A. B. Davidson: In reply to Dr. G. L. Hamburger, the characteristics of the electro-chemical paper are very suitable for the reproduction of transmitted photographs and the paper has been used for this purpose in many applications. The unmarked background of the paper is truly white and with a black marking power of the order of 5 watts and a writing speed of 18 inches a second, the recorded black has a density of about 1·2. This density figure may be considerably increased by using lower writing speeds and also by the application of heat to the paper after marking. The general shape of the curves relating voltage across the paper to density of recording are similar in character to the exposure/density curves for photographic papers.

In reply to Mr. C. E. Harris, the keyers used for frequency shift transmission of facsimile are designed to have a linear relationship between d.c. input and frequency shift output. The extent to which intermediate tones are reproduced is a function of the facsimile recorder design. In the case of half-tone photographs it is obviously desirable to reproduce as far as possible all the tones in the original and the input/output characteristic of the recorder amplifier is previously adjusted to produce this result with a given recording paper. For black and white originals best results are achieved if the overall recording characteristic is relatively flat in the near black and near white tones but has a fairly steep slope in between these two limits.

G. S. Allen: Regarding the questions put by our Chairman, Mr. W. E. Miller, firstly, it is true to say that a double process is often involved with a "same size" machine. The Scan-a-Sizer has been designed to overcome this disadvantage. Secondly, metal stereos are made from scan plates, but a cold flong process is recommended. In cases where a hot flong is used, the temperature is limited to 185° F. Then, in this country, the number of reproductions officially achieved by

Scan-a-Graver blocks is about 200,000, but in the United States they have exceeded half a million copies without any appreciable wear being shown. Finally on the question of operative skill and tonal fidelity, the machines are not difficult to operate and very little time is required for training. However, if the operator is to produce good blocks, he must know what a good block looks like, which means that he must be well versed in the dot aspect of photoengraving. In the cases where contrast was found to be poor, this was probably due to faulty operation. A microscope is supplied with each machine, the field of which is illuminated stroboscopically so that the dots are effectively stopped. This enables the highlight and shadow dots to be adjusted accurately before the picture engraving is started. The fine screen machines have a built-in tone-law control so that the most suitable tonal rendering may be achieved for each subject.

Replying to Dr. Eisler, as the Fairchild machine scans with three photomultipliers, the RGB tristimulus values are fed into computing circuits which carry out colour correction operations in a manner similar to the Time-Life, and R.C.A. Colour Scanners. In the Clichograph colour machine, however, only two photomultipliers are used, which limit the extent to which colour correction can be made.

I regard the cutting operation used in the Clichograph and Elgrama machines as a chipping rather than a carving action. For example, a piece of material could be removed from a plastic block by carving it out with a sharp tool. Another way would be to create a high stress at a point and cause the material to crack. However, at high speed these two actions may occur together and as I have no practical experience of the cold cutting machines I cannot formulate a more definite idea.

The question by Mr. Jones raises the controversial subject of scanned block versus conventional, on a quality basis. It has been stated that better quality blocks could be obtained from a conventional process than by electronic engraving, in particular, that the dot distortion produced in the etching process, gives rise to better resolution than can be achieved in electronic engraving, where this phenomena does not occur. However, this statement, based largely on theory, is not borne out in practice. For example, the first Scan-a-Graver to be installed in this country was operated initially by a director of a process house, who is an experienced blockmaker. His opinion since then has been that the resolution of a Scan-a-Graver block is as good as a conventional block made with the next finest screen. That is to say, an 85 lines/inch scanned block has an apparent resolution equivalent to a 100 lines/inch block made by the conventional method.

Since the scanned block is made directly from the photograph and the highlight and shadow dots and tone law can be set *in situ*, the electronic engraving machine is capable of much more accurate reproduction than the conventional process where the image must pass through so many hands.

In answer to Mr. Griffin's question about high temperature engraving, I believe I am right in saying that a high temperature wave front which precedes the heated stylus burns the plastic without physical contact between the stylus and the plastic. Most of the plastic is evaporated and the residual ash left on the surface is easily scrubbed off with water.

Mr. Harvey asks about screen rotation in engraving machines. This is accomplished in a number of ways. On the Clichograph, since it is a flat-bed machine, the bed is simply rotated in the same way as the screen is rotated in the conventional method. On the Fairchild machines two methods are possible. In one, the copy is rotated by the appropriate angle; this method has the disadvantage of reducing the effective area available on the plastic. A second more elegant system employs variation of frequency and phase of the dot generator along with a change in the traversing rate. In this way, the screen angle is effectively rotated and the whole area of the plastic can be utilised.

* * *

A vote of thanks to the authors was proposed by Mr. G. P. Thwaites, a member of the Programme and Papers Committee.

THE TRAINING OF RADIO ENGINEERS

A Discussion Meeting held in Cardiff on 7th December, 1955

In the Chair: Professor Emrys Williams, Ph.D., B.Eng., Chairman of the South Wales Section.

The meeting was opened by **Mr. H. Roberts,** manager of a radio factory in South Wales, who gave an account of the growth of the radio and electronics industry and its importance in the national economy today. He pointed out how the industry had grown phenomenally in the period from 1939 to the present day, and how the very wide employment of electronics engineers in many other industries had created a tremendous demand for qualified engineers and technologists. There were five thousand vacancies on the Technical and Scientific Register for engineers, many of them for electronics engineers, and Mr. Roberts quoted the "Financial Times": "This presents a challenge to the Technical Colleges. There is little doubt that the pace of scientific advance is, in the field of electronics probably more than elsewhere in industry, exceeding the output of technologists who are competent to make use of the latest developments."

Dr. W. J. Thomas (*Member*), one of Her Majesty's Inspectors in South Wales, dealt with the background and training necessary for the radio and electronics engineer and with the training facilities available.

The Radio Engineer must be a man of many parts, having received a sound training in physical principles and specialized mathematics, which falls not far short of that required for a student of pure science; he has then to gain experience, and through this the ability to apply the results of scientific knowledge and discovery to industry. Education, training and experience, therefore, are all required to produce the complete engineer.

The majority of radio engineers have passed through the Grammar or Public Schools—the number may possibly be put as high as eighty to eighty-five per cent.—where they will have received a basic general education and prepared for the G.C.E. (Ordinary) examination in five to eight subjects including Mathematics and Science. About one in five of the successful candidates for the G.C.E. (Ordinary) Level remains at school to prepare for the Advanced Level examination.

Of the 250 or so technical colleges in the country, about 150 offer training in radio or telecommunications, to various levels. (See Table 1.) The output from these various teaching institutions, in terms of successful candidates, is shown in Table 2.

Table 1

Numbers of Institutions which provide training in Radio and/or Electronics

University Colleges	20
Technical Colleges preparing for:	
(i) B.Sc. including radio or electronics	28
(ii) H.N.C. including radio or electronics	55
(iii) City and Guilds examinations in Telecommunications Engineering	116

Table 2

Annual Output of Potential Radio Engineers

(i) Degrees. Students taking a Radio subject in Final Degree Examination ...	*1948* ~300	*1954* <300
(ii) Grad.Brit.I.R.E.(completions)	68	79
(iii) H.N.C. Electrical Engineering	*1938*	*1954*
Entrants	640	2,794
Successful candidates ...	379	1,950
(10% of the 1954 figures can be assumed to have taken a radio subject in the A.2 year)		
(iv) City and Guilds Full Technological Certificate in Telecommunications Engineering	*1950* 32	*1954* 67

* Discussion Meeting No. 10.
U.D.C. No. 378:621.37/9.

In 1950 the Radio Industry Council estimated the number of professional radio engineers required in the period 1950-60 to be 720 per annum. The Hankey Report, issued in 1949, estimated that the annual demand for professionally qualified electrical engineers (including radio engineers) over the same period would be 1,670. From these facts it will therefore be seen that the demand exceeds the supply.

One point is brought home very forcibly by an analysis of the Brit.I.R.E. Graduateship Examination results. Although entries to the Graduateship Examination have increased five-fold in the years from 1947 to 1955, the number of candidates who have succeeded in gaining the qualification has remained fairly constant. It is reasonable to expect the percentage figure to be fairly low, since in any one year a substantial proportion of the candidates will not be attempting to complete the qualification, but the fall from twenty-four per cent. to six per cent. is rather disturbing.

There are two possible explanations for this fall. Firstly, the number of overseas candidates has obviously increased considerably during the period under review, and this may have brought in its train a large number of failures due perhaps to inadequate training facilities. Even if this be true, the whole blame cannot fall on overseas candidates. Home candidates must surely bear some of the blame. The second possibility is that, up to the present, the Institution has not insisted on candidates providing evidence of course work, in the form of written-up reports of laboratory experiments carried out during courses of study. It is understood that this omission is to be rectified in the near future.

This non-insistence on evidence of practical work being shown by candidates for the Institution's examination and also for the examinations of the City and Guilds has encouraged some of our teaching to become what is commonly called the "chalk and talk" type. The aim seems to be "Cover the syllabus at all costs." It would be better to cover half the syllabus and by use of demonstrations in teaching and ample practical work. The efforts would be rewarded by more examination successes and, in consequence, better trained students.

The present problem is how to bridge the gap between demand and supply. The existing training facilities are far from over-taxed, and the deficiency is not due to a bottle-neck in these facilities. The root of the trouble lies in the inability of the industry to recruit, in sufficient numbers, suitable school-leavers who will enter the industry as student apprentices or will embark on a full-time course of study leading to graduate standard.

Industry and other interested organizations are at present making a valuable contribution to the training of radio engineers by releasing students for one or more days per week to attend classes at Institutions of Further Education, but if the desired improvement in recruitment is to be achieved, then representatives of industry must have closer co-operation with headmasters and careers masters of our Public and Grammar Schools. Boys at these schools, and their parents, rely to a considerable extent on the advice given by the headmasters and careers masters in connection with the choice of a career, and personnel officers should ensure that schools are kept aware of the excellent opportunities and prospects offered by the industry.

It is estimated that at present about 17,000 boys and girls complete a sixth-form course leading to two subjects at the Advanced Level of the G.C.E., and that an additional 10,000 could well do so. Of these 10,000 premature leavers, about 4,200 are regarded as competent to follow courses of Advanced Level in mathematics and science. A number of them will, of course, become student apprentices or enter technical colleges as full-time students, and will eventually reach engineer status. To induce a substantial proportion of the remainder to stay at school until the age of eighteen would undoubtedly be a most important factor in improving the present industrial situation.

The closer co-operation of industry and schools might also, through the advice given by headmasters and careers masters on the choice of careers, lead to a different state of affairs at the Universities. The following table, which gives an analysis of the university population in 1953, is deplorable from the point of view of technology. (Table 3.)

Comment has been omitted on the content or curriculum of the various types of courses now in existence, but it is desirable that every course—particularly full-time courses—should include engineering practice, i.e. technical

Table 3

Grammar Schools—Sixth-Form Boys:	*1953*
Mathematics and Science	55%
Arts subjects	45%
University Population:	
Arts subjects	43%
Medicine and allied subjects ...	24%
Science	21%
Technology	12%

drawing and workshop practice, and that all courses should devote some time to the technique of technical report writing.

Mr. A. J. Kenward, B.Sc., Education Officer of the Institution, reviewed the Institution's role in the education and training of radio engineers.

The considerable gap between the requirements of industry and what the technical colleges and the Ministry of Education are able to provide is not only in quantity, but also in quality. Training facilities often lag behind demand, since technical colleges may have to wait until the demand reaches the stage of clamour before particular courses are started. The Institution and industry have, therefore, a big part to play in voicing demand.

Lord Kelvin, speaking on the progress of science some eighty years ago, said that the age when the amateur could make any significant contribution to science had long since passed. This is particularly true of the radio industry today and the future progress of radio engineering is dependent on the calibre of the professional radio engineer.

The Institution's principal function is to further "the advancement of the science and practice of radio and electronic engineering." There are two corollary objects which immediately follow from this, which are "to hold or promote examinations in radio and electronic science and engineering," and "to procure the recognition of the status of the Institution by Government, public, local and other authorities." It is largely through the standard of its examination that any institution is judged. The professional status of any engineer whilst dependent on a number of factors, is basically assessed on his academic qualifications. Thus the Institution, through its own examination, provides an established and recognized standard to which other external examinations can be related and subsequently accepted as alternative qualifications for the purposes of election to membership. The Institution's aim is not to set itself up as an examining authority, but rather to encourage the establishment of proper training schemes and examinations which meet the minimum requirements laid down by the Institution. The Institution examines well over one thousand candidates each year, and this emphasizes the need for more suitable exempting examinations. This can be shown to be the case by tracing the development of training since the Institution was established.

The first Institution examinations were held in 1929 when there were virtually no other external examinations in the subject. During the succeeding years, other examinations have been established but it is only comparatively recently that suitable courses of study have been available which pay sufficient attention to the special needs of the radio and electronics engineer, and these are limited in number and not generally available.

The majority of research and design engineers are recruited from University graduates. It must be remembered that a degree is not necessarily a technological qualification; rather it is designed to train the student how to learn. Nevertheless, since the war, engineering faculties have realized the need for more training in radio and electronics, and, as an example of the progress which has been made, an external degree of London University can now contain up to four radio or electronics subjects out of six studied in the final year. There are, however, still only two universities in Great Britain with Chairs in Radio and Electronics—Southampton, where a Chair was founded in 1948, and Liverpool, where one was founded last year. This point was stressed recently by Mr. C. I. Orr-Ewing, Parliamentary Secretary to the Minister of Labour, when he appealed to industry to see what could be done to establish more Chairs in the universities in these subjects.

In the Technical Colleges, the two main courses of training are designed to cover the Higher National Certificate and Diploma and the City and Guilds of London Institute Full Technological Certificate. There are in addition a number of courses designed specially to cover the Institution's examination and other professional qualifications.

The Higher National Certificate scheme first included radio or telecommunications subjects in 1941. More and more colleges are now including radio and electronics subjects for the first time, and in many colleges the radio content is being increased. Although called a National Certificate, the syllabus varies considerably from college to college and is only national as regards a minimum syllabus; above that minimum there is considerable variation. Members will be aware that the Institution has recently approved for full exemption the Higher National Certificate (with credits) of certain colleges where three radio or electronics subjects are included in the final years.

The Full Technological Certificate of the City and Guilds is a group certificate scheme which did not commence until 1947, and is a specialized qualification. It reaches a very high standard in radio and telecommunications engineering but unfortunately, without that basis of fundamentals which is so essential for the professional engineer. An indication of the standard is given by the fact that over 30,000 candidates enter for these subjects each year and only 60 to 70 qualify for the Full Technological Certificate.

Training for the engineering profession does not end with the completion of an academic course of study and the passing of a particular examination. It must be supplemented by practical training in the industry. One of the main reasons for the great shortage of engineers in our profession has been that practical training schemes, properly established on an apprenticeship basis, have until quite recently been limited to six or seven of the larger companies in the industry. These companies could not possibly hope to provide engineers for the whole industry, and for all the industries which are now employing electronics engineers. Fortunately, this situation was recognized and no less than twenty-four firms now provide craft, student and post-graduate apprenticeships. All these apprenticeships usually involve attendance at a technical college on part-time day release for at least one day per week. Craft apprentices normally study for qualifications intended for the technician, while the student apprentice is trained to become a professional engineer and would normally take a Higher National Certificate, or in some cases a university degree. A possible extension of this scheme which has been suggested by the Institution is the collaboration between two or more small companies who can each provide part of the practical training.*

It is extremely difficult to cover the syllabus of degree and professional examinations with one day of study per week, and this has led to the establishment of sandwich training schemes where alternate periods of about six months' duration are spent in industry and at a technical college. This type of training scheme provides an opportunity for earning while learning, and will undoubtedly increase in number.

Apart from its work in promoting training schemes for the professional radio engineer, the Institution takes an active part in the work of the Radio Trades Examination Board, which was formed in 1942, largely at the suggestion of the Institution. This body, which operates in conjunction with the City and Guilds of London Institute, has done much to promote formal training schemes both in the trade and in the technical college for the radio and television servicing technician. Representing as it does the professional engineer, the Institution must, of necessity, do what it can for the training of the technicians of the industry, without whose assistance the professional engineer would be unable to carry on.

All these training schemes and courses of study require a continuous and growing supply of recruits, and the Institution has an active careers advisory service which is used to a very great extent by schools and careers masters as well as for direct enquiries from parents and boys. What will affect the issue more than anything else is the gaining of boys' interest at an age early enough to ensure that they take science subjects. The problem of recruitment is national, and affects all branches of science and technology. There has been considerable comment at the very highest level on the need for more scientists and engineers†, while a large contribution towards financing science in independent schools is being made by industry through a recently-formed trust.‡

* "Industrial Apprenticeships," *J. Brit. I.R.E.*, **15**, page 129, March 1955.

† Since this meeting was held a White Paper on this subject has appeared—see page 113 of this issue of the *Journal*.

‡ *J. Brit. I.R.E.*, **15**, page 537, November 1955.

The Institution's new examination regulations show quite clearly the Council's decided views on the academic requirements for the professional radio and electronics engineer. Events have shown that training in the colleges and industry is following these lines more closely, and it is in this lead in education that the Institution plays an important role.

DISCUSSION

In the discussion which followed, one of the main points raised was the desirability of including radio and electronics subjects at an earlier level in the National Certificate Courses. Many speakers thought it desirable that a student should be able to study the principles of radio and electronics during the ordinary National Certificate course, rather than delaying the introduction of these subjects until the first year of the Higher National Certificate.

Reference was made to the considerable wastage of students taking the City and Guilds Telecommunications Certificate, as a large proportion did not proceed beyond the Intermediate level. Possibly the reason for this was that the City and Guilds courses were not available to any great extent to part-time day release students, with the exception of those employed in the Post Office, but even in this case release was not granted after intermediate level.

It was pointed out that many potential radio engineers did not have the opportunity of attendance at a technical college because of the lack of suitable courses in their area, and it might perhaps prevent such persons from qualifying if there were a rigid enforcement of the requirement for course work. The general feeling, however, was that the standards should not be reduced for the sake of a few who were handicapped.

In the discussion of basic education, it was suggested that Grammar Schools did not take applied science seriously. They took the view that this was handled by the Secondary Technical School, which, in the minds of the public, was of a lower level. It was suggested that this situation was being remedied to some extent by the introduction of Grammar-Technical Schools, which would stress technical education but would at the same time attract the Grammar School type of entrant.

On the question of recruitment to industry, a plea was made for greater co-operation between industry, schools and the Youth Employment Office. It was very necessary to make boys appreciate the opportunities offered to them, and the type of work on which they would be engaged. There was a tendency among the public to look upon the radio engineer as a person concerned only with domestic equipment.

Several speakers referred to the wastage of qualified engineers within the industry. It was thought that more attractive opportunities existed in the commercial rather than the technical field, and competent engineers were being lost from the development laboratories. It was also considered desirable that employers should reward examination successes, in addition to releasing apprentices and trainees for part-time training.

The discussion also covered the shortage of suitable part-time teachers. Whilst these were often well qualified, they lacked teaching experience and also had insufficient time for the preparation of teaching material. It was felt that this sometimes led to lax methods of teaching, unsupported by the proper use of facilities available to teachers in the form of visual aids and lecture room demonstrations. Reference was also made to the shortage of good text-books.

Bibliography

Other Institution discussion meetings on this general topic were held in Liverpool in 1953 (see *Journal* for January 1954) and in London in 1954, reported in the March 1955 issue of the *Journal*.

APPARATUS FOR THE MEASUREMENT OF PHYSICAL CONSTANTS BY THE ELASTIC VIBRATIONS METHOD*

by

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SUMMARY

This paper constitutes an elementary introduction to the technique of measurement of elastic properties of matter by ultrasonics, and is divided into three parts. The first part reviews briefly the classical theories of elasticity. In the second part, the more common methods of measurement are surveyed, with particular reference to the pulse method. Finally, a versatile equipment is described which has been used with satisfactory results for testing samples of gases, liquids and solids of several sizes ranging approximately from 1 to 5 cm. in length. The equipment is designed to cover a frequency range of from 0·5 to 50 Mc/s, a temperature range of from 0° to 100°C and pressures up to 10,000 kg/cm².

LIST OF PRINCIPAL SYMBOLS

- T Tension
- E Modulus of elasticity (Young's modulus)
- σ Poisson's ratio
- q Shearing stress
- G Rigidity or shearing modulus
- K Modulus of expansion in volume (bulk modulus)
- e Elongation or expansion
- L Lamé's elastic constant
- c Speed of an elastic wave
- θ Time
- t Temperature
- ρ Density
- **i**, **j**, **k** Orthogonal components
- ∇^2 Laplacian operator
- λ Wavelength
- f Frequency
- k Boltzmann's constant
- p Pressure

1. Introduction

While elastic waves have been used for some time to obtain interesting data concerning the fundamental properties of matter, it is only since the last war that pulse methods, directly derived from radar, have been extensively used to measure the velocities and attenuations of the elastic waves which can be propagated through various media. In the course of examining papers concerning measuring methods with the aid of ultrasonic waves, it seemed necessary to establish a synthesis of the methods employed, basing it on the fundamental theory of elasticity.

This investigation therefore commences with a definition of the elastic constants and the classic theory of elastic waves, and goes on to the consideration of ultrasonic waves, which are merely a particular case of the former. The relations between the rates of propagation of ultrasonic waves and elastic constants are established, as well as electronic methods of measuring velocities of propagation.

The special conditions governing the use of the equipment determine the procedure and frequency to be adopted, also the type of transducer and its assembly. The essential characteristics of the measuring equipment may thus be derived, and a specification is given for the minimum requirements of the components for a required degree of precision in the measurements. The method used employs ultrasonic pulses according to a principle derived from radar. The characteristics of the pulses used are established, which affect the accuracy of measurement according to the process adopted. The various methods of measurement are studied and their facility of use and intrinsic precision are compared, giving an indication of the methods best adapted to particular tests.

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The electronic and mechanical characteristics of the equipment used in the laboratory are then described. An account is given of how an aperiodic pulse transmitter may be operated with transducers of any frequency by the use of a shock excitation method. The three measuring methods available with the equipment are described, and the degree of precision attainable for each method is indicated.

2. Relations between Elastic Constants and the Velocities of Propagation of Elastic Waves

2.1. *Elastic constants*[4, 5, 6, 7, 8, 9]

If we consider a parallelepipedic elementary volume Δx, Δy, Δz of an isotropic body, and subject it to an axial tension T_x, the part will undergo a unit elongation given by

$$e_x = T_x/E$$

where E is the modulus of elasticity, or Young's modulus. The elongation in the x direction is accompanied by lateral contraction

$$e_y = -\sigma e_x = -\sigma T_x/E$$
$$e_z = -\sigma e_x = -\sigma T_x/E$$

where σ is a constant termed Poisson's ratio or coefficient. Within the limits of elasticity, E and σ are the same for pressure or tension and define completely the ratios between the stresses exerted and the resultant deformations.

If instead of being axial, the stress applied is transverse, we have the case of shearing, and the ratio is rather more complex between the shearing stress q and the resultant distortion.

$$R = \frac{2(1+\sigma)q}{E}$$

Here again, E and σ define the ratio between the stress exerted and the resultant strain. Assuming

$$G = \frac{E}{2(1+\sigma)}$$

we have $R = q/G$,

where G is the rigidity or shearing modulus.

2.2. *Expansion of Volume*

If instead of a single axial tension T_x we apply simultaneously three tensions T_x, T_y, T_z, three elongations will result:

$$e_x = \frac{1}{E}\left[T_x - \sigma(T_y + T_z)\right]$$

$$e_y = \frac{1}{E}\left[T_y - \sigma(T_x + T_z)\right]$$

$$e_z = \frac{1}{E}\left[T_z - \sigma(T_x + T_y)\right]$$

Assuming $e = e_x + e_y + e_z$, and $T = T_x + T_y + T_z$, we obtain

$$e = \frac{1-2\sigma}{E} \cdot T$$

which gives the ratio between the variations in volume and the sum of the tensions, T.

In the case of a uniform hydrostatic pressure p we have

$$T_x = T_y = T_z = -p$$

$$\text{and } e = -3\frac{1-2\sigma}{E} \cdot p;$$

or by assuming

$$K = \frac{E}{3(1-2\sigma)}$$

we have $e = -\sigma/K$, where K is the bulk modulus, or modulus of compressibility.

2.3. *Relations between elastic constants*[4, 5, 26]

From the purely physical point of view the modulus of expansion in volume K and the modulus of rigidity G can be regarded as fundamental elastic constants. K measures the resistance offered by the body to a change of volume without change of shape, and G measures the resistance offered by the body to a change of shape without change of volume.

Young's modulus E, and Poisson's ratio σ are used in practical problems, also the constants L (see below) and M, introduced by Lamé, M being equal to G. Young's modulus gives the ratio between the intensity of the stress exerted and the resultant deformation. Poisson's ratio is that between a change of width and the change in length that produces it. There are always two independent elastic constants, whatever the system of constants selected: either E and σ, or G and K, or L and G. Between these constants we have the following ratios deduced from the definitions:

$$\sigma = \frac{E-2G}{2G} \qquad \sigma = \frac{L}{2(L+G)}$$

$$L = \frac{2G}{1-2\sigma} \qquad L = \frac{\sigma E}{(L+\sigma)(1-2\sigma)}$$

$$G = \frac{E}{2(1+\sigma)} \qquad K = \frac{E}{3(1-2\sigma)}$$

$$E = 2G(1+\sigma)$$

2.4. *Equilibrium equations*[4]

Within the elastic limits, if a medium is continuous and in equilibrium, the deformations being proportional to the pressures, the forces involved are the inner pressures, the shearing stresses and the inertia due to accelerations of the elementary particles. Whatever the movement of an elementary particle, it is possible to resolve it into three components **i**, **j** and **k**, by reference to three orthogonal axes x, y and z. Equations determining the movements of the particles may be derived from the classical theory of elasticity.

The fundamental equations of equilibrium, in the absence of internal forces, are as follows:

$$(L+G)\frac{\delta e}{\delta x}+G\nabla^2\mathbf{i}=0$$

$$(L+G)\frac{\delta e}{\delta y}+G\nabla^2\mathbf{j}=0$$

$$(L+G)\frac{\delta e}{\delta z}+G\nabla^2\mathbf{k}=0$$

where L and G are Lamé's constants, and ∇^2 is the Laplace operator

$$\nabla^2=\frac{\delta^2}{\delta x^2}+\frac{\delta^2}{\delta y^2}+\frac{\delta^2}{\delta z^2}$$

and e is the expansion of volume.

By differentiating the three above equations with respect to x, y, and z respectively, and adding them, we obtain:

$$(L+2G)\nabla^2 e=0$$

In other words, the expansion of volume satisfies the equation

$$\frac{\delta^2 e}{\delta x^2}+\frac{\delta^2 e}{\delta y^2}+\frac{\delta^2 e}{\delta z^2}=0$$

2.5. *Movement equations*

In relation to the propagation of waves in elastic media, it is convenient to consider the equations that determine the movement of elementary particles. These movement equations are derived from the equilibrium equations by adding the forces of inertia, giving:

$$(L+G)\frac{\delta e}{\delta x}+G\nabla^2\mathbf{i}-\rho\frac{\delta^2\mathbf{i}}{\delta t^2}=0$$

$$(L+G)\frac{\delta e}{\delta y}+G\nabla^2\mathbf{j}-\rho\frac{\delta^2\mathbf{j}}{\delta t^2}=0$$

$$(L+G)\frac{\delta e}{\delta z}+G\nabla^2\mathbf{k}-\rho\frac{\delta^2\mathbf{k}}{\delta t^2}=0,$$

ρ being the density of the medium.

2.6. *Distortion waves*

If the volume of the body does not alter ($e=0$), the deformation is reduced to shearing distortion and rotation, and the equations become:

$$G\nabla^2\mathbf{i}-\rho\frac{\delta^2\mathbf{i}}{\delta t^2}=0$$

$$G\nabla^2\mathbf{j}-\rho\frac{\delta^2\mathbf{j}}{\delta t^2}=0$$

$$G\nabla^2\mathbf{k}-\rho\frac{\delta^2\mathbf{k}}{\delta t^2}=0$$

Such waves are termed shear waves.

2.7. *Expansion waves*

The deformation produced by the wave need not be accompanied by rotation. The rotation of an element in relation to the three axes is given by:

$$2r_x=\frac{\delta\mathbf{k}}{\delta y}-\frac{\delta\mathbf{j}}{\delta z}$$

$$2r_y=\frac{\delta\mathbf{i}}{\delta z}-\frac{\delta\mathbf{k}}{\delta x}$$

$$2r_z=\frac{\delta\mathbf{j}}{\delta x}-\frac{\delta\mathbf{i}}{\delta y}$$

The deformation will be non-rotational if the three components of rotation are zero, which occurs if **i**, **j** and **k** derive from the same function φ:

$$\mathbf{i}=\frac{\delta\varphi}{\delta x},\quad \mathbf{j}=\frac{\delta\varphi}{\delta y},\quad \mathbf{k}=\frac{\delta\varphi}{\delta z}.$$

In this case,

$$e=\nabla^2\varphi \text{ and } \frac{\delta e}{\delta x}=\frac{\delta}{\delta x}\nabla^2\varphi=\nabla^2\mathbf{i};$$

similarly for y and z, with **j** and **k**. The basic equations then become:

$$(L+2G)\nabla^2\mathbf{i}-\rho\frac{\delta^2\mathbf{i}}{\delta t^2}=0$$

$$(L+2G)\nabla^2\mathbf{j}-\rho\frac{\delta^2\mathbf{j}}{\delta t^2}=0$$

$$(L+2G)\nabla^2\mathbf{k}-\rho\frac{\delta^2\mathbf{k}}{\delta t^2}=0$$

These are non-rotational or expansion waves.

2.8. *Plane waves*

If the excitation takes place at any point in an elastic medium, elastic waves radiate out in all directions and the wave front is spherical. At a sufficiently great distance, however, the curvature of the wave front becomes negligible and it may be considered that plane waves are involved. The movement of the elementary particles may be in the direction of propagation, in which case we have longitudinal waves which are expansion waves. The movement of the elementary particles may also take place in a direction at right angles to the direction of propagation, giving transverse or shear waves.

2.9. *Longitudinal waves*

If we take the direction of propagation as the x axis, we have $\mathbf{j}=\mathbf{k}=0$, and the expansion wave equation is reduced to:

$$\rho\frac{\delta^2\mathbf{i}}{\delta t^2}=(L+2G)\frac{\delta^2\mathbf{i}}{\delta x^2}$$

So that if we put

$$c_1=\sqrt{\frac{L+2G}{\rho}},$$

$$\frac{\delta^2\mathbf{i}}{\delta t^2}=c_1{}^2\frac{\delta^2\mathbf{i}}{\delta x^2}$$

This equation is that of a wave which is propagated at the speed c_1, which may be expressed as a function of E and σ:

$$c_1=\sqrt{\frac{E(1-\sigma)}{(1+\sigma)(1-2\sigma)\rho}}$$

$$=\sqrt{\frac{E}{\rho}}\sqrt{\frac{(1-\sigma)}{(1+\sigma)(1+2\sigma)}}$$

2.10. *Transverse waves*

If we take the direction of propagation as the x axis, and the direction of transverse motion as the y axis, we have $\mathbf{i}=\mathbf{k}=0$. The equation of the shear waves is reduced to:

$$G\frac{\delta^2\mathbf{j}}{\delta x^2}=\rho\frac{\delta^2\mathbf{j}}{\delta t^2}$$

Or assuming

$$c_2=\sqrt{\frac{G}{\rho}},$$

$$\frac{\delta^2\mathbf{j}}{\delta t^2}=c_2{}^2\frac{\delta^2\mathbf{j}}{\delta x^2}$$

This equation is that of a wave which is propagated at the speed c_2, which can be expressed as a function of E and σ:

$$c_2=\sqrt{\frac{E}{\rho}}\sqrt{\frac{1}{2(1+\sigma)}}$$

2.11. *Ultrasonic waves*[1, 6, 26, 33]

Ultrasonic waves comply with the general laws governing elastic waves and in particular with the relations established, which connect the velocity of propagation with the elastic constants of the medium. They are readily obtained by means of standard oscillators, and for their introduction into a medium, or collection from it, use is made of transducers, the most usual types of which are the magnetostriction transducer and the piezoelectric transducer. Quartz is suitable for measurements on liquids and solids, as the high mechanical impedance of those media ensures good matching of the impedances, and therefore a good performance. The quartz plates used may emit longitudinal waves (Curie or X cut) or shearing waves (Y cut).

It is then possible, by means of either an optical method employing diffraction[32], an electronic resonance method[1], or a method for measuring the time of travel, to calculate the velocity of propagation c_1 of the longitudinal waves and the velocity of propagation c_2 of the transverse waves.

2.12. *Relations between elastic constants*

Knowing the density ρ of the body, and the two velocities of propagation c_1 and c_2, it is possible by using the above relations to calculate the fundamental elastic constants.[13, 26, 35]

We thus have the rigidity of shear modulus G, which is one of Lamé's constants, with the transverse wave equation

$$G=c_2^2\rho;$$

also, by assuming $\varkappa=c_1/c_2$, we obtain the second Lamé constant:

$$L=G(\varkappa^2-2), \text{ or } L=c_2^2\rho(\varkappa^2-2)$$

Similarly for Poisson's coefficient,

$$\sigma=\frac{(\varkappa^2-2)}{2(\varkappa^2-1)}$$

and for Young's modulus,

$$E=\varkappa^2\rho\frac{3\varkappa^2-4}{\varkappa^2-1} \text{ or } E=G\frac{3\varkappa^2-4}{\varkappa^2-1}.$$

It is therefore possible, by measuring the rates of propagation of ultrasonic waves, to deduce from them the elastic constants of a body.

3. Electronic Methods for Measuring Elastic Constants by means of Ultrasonic Waves

3.1. *Resonance method*[11-25]

In the resonance method of measurement, the excitation frequency is varied until the total path of the wave contains an integral number of half wave lengths.[32] It is possible to work on the fundamental by direct reading, or on consecutive harmonics by difference reading. In either case, the fundamental frequency is known and so is the distance covered. The velocity of propagation may thus be deduced.

The resonance may be detected by a receiver or simply on the ultrasonic transmitter itself, resonance corresponding to the minimum power supplied. If the medium does not unduly damp the transmitted wave resonance is acute and the accuracy of measurement depends essentially on the precision of measurement of the frequencies. This method has the advantage of relative simplicity; its drawbacks are due to the presence of a continuous wave which may on the one hand disturb the medium and on the other hand create interference resonance by stationary waves that are difficult to identify.

3.2. *Echo method*[1, 2]

In the echo method of measurement, an ultrasonic pulse of brief duration is applied to the specimen by means of a transducer-transmitter. This pulse passes through the specimen to a transducer-receiver. A variant of the method uses a single transducer; the ultrasonic pulse which it sends out is reflected at the end of the specimen and returns to strike the transducer, which then acts as a receiver.

The time of travel is measured, generally with a calibrated oscilloscope, and, knowing the distance covered, the velocity of propagation may be deduced. This method, which is derived from radar, calls for more complex equipment than the previous one, but it eliminates the difficulties due to standing waves. Its accuracy of measurement is essentially limited by the accuracy of the measurement of time, which may be high. Moreover, the pulse which returns after passing through the specimen, and is termed the echo, has undergone an attenuation which can be measured. For these reasons, the echo method appears to be the one best suited to the measurements envisaged.

3.3. *Choice of frequency*

Various considerations indicate the choice of a high frequency. Firstly, the energy radiated by a wave is proportional to the square of the amplitude of the vibrations, and to their frequency. Next, for the waves under consideration, the dimensions of the specimen must be large in comparison with the wavelength; the transverse dimensions must be equal to a large number of wavelengths, so that the specimen may be treated as an infinite medium. On the other hand, the greater the length of the sample, the greater the accuracy of measurement which is attainable. The dimensions of the test piece are limited by the internal bore of pressure cylinders to a few centimetres in diameter, so that the shorter the wavelength, the better is the approximation to an infinite medium. Finally, it is desirable to emit directional waves in the form of a narrow beam, so that they diverge very little, and, after being reflected, return to the transducer.

If D is the effective diameter of the transducer, the energy radiated is limited to a cone whose half-angle of opening is given by $\sin x = 1{\cdot}22\ \lambda / D$, λ being the wavelength. To obtain a concentrated beam, D must be large, or, due to the limitations stated above, λ must be small. Also, since the ultrasonic wave is pulse modulated, the slope of the sides of the impulse may increase with the modulated frequency.

By the same reasoning the receiver for amplifying the echoes must have a wide pass-band, which is easier to obtain if the modulated frequency is high. On the other hand, high frequency limitations are imposed by the fragility of quartz transducers, which become thinner as the frequency rises.

From the formula which connects the frequency f and the thickness d of X-cut quartz, with f in kc/s and d in millimetres, we have $d = 2{,}870/f$, i.e. for $f = 15{,}000$ kc/s,

$$d = 2{,}870/15{,}000 = 0{\cdot}19 \text{ mm.}$$

The thickness of the quartz plate is therefore less than two tenths of a millimetre for a frequency of 15 Mc/s. This might impose a practical limit, as very thin crystals require highly delicate handling if breakage is to be avoided. This difficulty could be obviated by the use of harmonic working frequencies, but this would entail a loss of efficiency, and the simple method of shock-excitation could not then be used.

Finally, attenuation increases very rapidly with frequency, and the number of conveniently measurable echoes diminishes simultaneously, impairing the precision of measurement. It must be emphasized that these factors are essentially practical ones applying to the particular case of a range from 0·5 to 50 Mc/s.

3.4. *Characteristics of the equipment*

The measurements under consideration must be capable of application to a wide variety of cases (solids, liquids, gases, under high pressures and at high temperatures), so it is essential for the measuring equipment to have the maximum flexibility of use without becoming unduly complex.

It is apparent from the previous paragraphs that the echo method, with a frequency of 1 to 15 Mc/s and a single transducer for the sake of simplicity, is the most suitable and this was the basis of the design of the equipment used.

Two distinct types of measurement are possible with the same equipment, based on the pulse method. By the first method, measurement of the time taken to traverse a known distance enables the velocity of propagation of the wave to be calculated. In the second, a comparison of the amplitudes of the pulse signal before and after the travel period makes it possible to measure the attenuation due to the medium employed.

3.5. *Principle of measurement*

The elements of the measuring circuit are shown in Fig. 1. A generator produces pulses, which are adjustable in duration and frequency, rectangular in shape and with steep fronts, and the same generator governs the horizontal scanning of an oscilloscope which is thus synchronized to the pulse repetition frequency.

The same pulse generator modulates a high frequency generator tuned to the frequency of the transducer or to one of its harmonics. The envelope of the high frequency pulses should have very steep sides, particularly the leading edge, which is used for determining directly or indirectly the departure and arrival times; its steepness therefore determines to a large extent the accuracy of measurement which may be achieved. It is desirable, with the times of travel which are possible in practice, to obtain a rise time of less than a tenth of a microsecond so that the relative precision is in the region of one tenth of one per cent.

The high frequency pulses are applied to a transducer which gives rise to the ultrasonic wave propagated in the specimen. The wave emitted is reflected on the opposite face of the sample and returns to the transducer, which then acts as a receiver. It should be noted that the distance covered by the wave is equal to twice the length of the sample. It is important to make a proper choice of the dimensions of the sample and the transducer, according to the wavelength, so that the wave propagated is essentially a plane wave. This avoids troublesome phenomena due to the spread of the beam or the appearance of waves of different types.

The reflected wave, on returning to the transducer, sets up an echo signal, which is delayed in time in relation to the emitted signal, and of lower amplitude. If the attenuation is not too great, this echo may accomplish a further journey, outward and return, in the medium under observation, and give rise to a second echo delayed with respect to the first one, and weaker. For small attenuations, it is thus possible to observe a whole series of regularly spaced echoes, whose amplitude decreases exponentially.

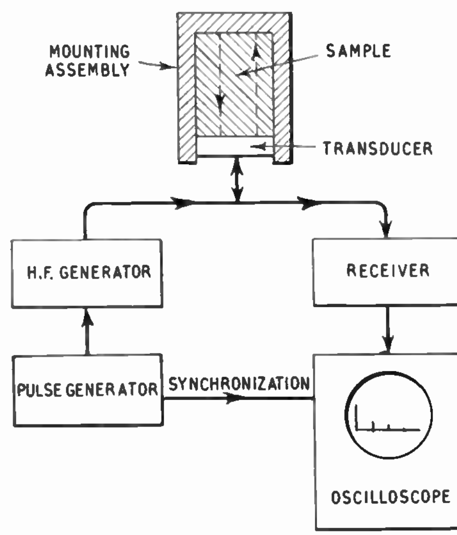


Fig. 1.—Elements of measuring circuit.

3.6. *Duration of pulses*

The minimum duration of the pulses used is fixed by considerations of the pass-band and the equipment. Let θ be the length of the impulse and B the pass-band: the noise output is given by Nyquist's formula[29] as

$$P = k\,t\,B,$$

where k = Boltzmann's constant and t = absolute temperature. On the other hand, the output of the required signal increases in the receiver with B up to a value of B which is roughly equal to $1/\theta$, after which it displays a gradual drop.

The best signal-to-noise ratio is therefore obtainable in the region of $B\theta = 1$. The maximum is not a very critical one, and the value of $B\theta = 1{\cdot}2$ is accepted in practice.

Mason has shown[28] that the band transmitted by a quartz fixed to the test piece is limited and determined primarily by the equivalent total loading of the transducer. For the purpose of this equipment, due to the variety of samples and transducers, it is necessary that the pulse generator be flexible enough to suit all cases. The generator employed furnishes pulses whose duration is adjustable between 0·2 and 10 μsec. It is therefore easily possible to exceed the minimum duration required to establish the permanent state. Also, in order to be able to transmit short pulses without distortion, it will be seen below that the equipment has been designed for a much wider pass-band than that determined by the above considerations.

3.7. *Pulse recurrence frequency*

The repetition frequency of the pulses is limited by the need to allow the echoes time to die out before the next period. The amplitude of the echoes decreases according to an exponential law which is fixed by the attenuation of the test piece, so that the number of echoes observable varies with the attenuation.

If we suppose that the amplitude becomes negligible after 50 echoes, it is possible to deduce the maximum p.r.f. For a specimen of 6 cm length and a velocity of propagation of 6 mm/μsec, the outward and return journey of the ultrasonic wave takes 20 μ sec, i.e., 1 millisec for 50 echoes. The corresponding p.r.f. is therefore 1,000 per second. The generator employed has a continuously variable p.r.f. between 50 and 5,000 per second and thus covers the necessary band. It should be noted that it is also possible to alter the length of the test piece.

3.8. *Utilization ratio*

In Fig. 2, let θ be the duration of the impulse and θ_r the period of recurrence, equal to the inverse of the p.r.f. The utilization ratio U is then given by:

$$U = \frac{\theta_r}{\theta}$$

The peak output P_c available during the pulse corresponds to the peak of the pulse. The mean output, P_m, on the other hand, is only $P_m = P_c/U$.

Provided the insulation is sufficient to withstand the high peak voltages corresponding to a large peak output, the valves employed for producing the pulses are limited not by the peak output but by the mean output. A high

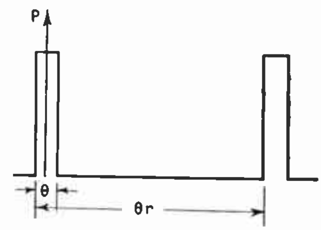


Fig. 2.—Diagram showing derivation of utilization ratio.

utilization ratio is therefore of importance, for it makes it possible to obtain considerable peak outputs with ordinary low-power valves. For instance, with impulses of 10 μsec and a p.r.f. of 1,000, i.e. with a period of recurrence of 1,000 μsec the ratio becomes $U = 1{,}000/10 = 100$.

3.9. *Pass-band*

The apparatus, as mentioned previously, must possess maximum flexibility in use, and some of the applications envisaged call for frequencies of 15 Mc/s or more, with consequent increase in the band transmitted by the transducer. The possibility of working on a harmonic of the fundamental frequency still further increases the possible range. The transducer is therefore the essential factor which limits the pass-band,

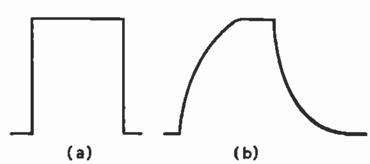


Fig. 3.—Rectangular pulse (a) undistorted, (b) distorted.

together with its method of mounting. It is desirable to reduce as far as possible the distortion of the pulse due to a finite pass-band, in order to be limited only by the unavoidable distortion due to the transducer. In practice, a pass-band of 10 Mc/s appears to constitute an acceptable compromise.

3.10. *Pulse distortions*

It is well known that the Fourier analysis of a rectangular pulse such as that shown in Fig. 3a leads to a frequency spectrum which extends to infinity (Fig. 4). Thus, if the pass-band is limited, the high frequency components disappear and the result is a characteristic distortion of the pulse (Fig. 3b). In particular

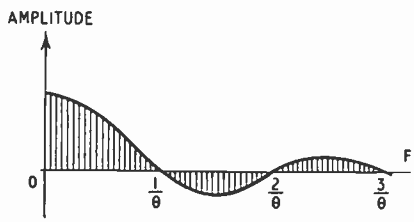


Fig. 4.—Frequency spectrum of rectangular pulse.

the steep front is replaced by a gradual rise, to which there corresponds a definite rise time, which is inversely proportional to the width of the pass-band.

The leading edge of the pulse is used as a datum for measuring times. To conduct these measurements with accuracy, the usual method is to expand greatly the horizontal sweep amplitude on the measuring oscilloscope. In the present case, the pulse envelops a high frequency oscillation, and the signal observed on the oscilloscope has the appearance of Fig. 5, with expanded horizontal scanning. The origin of the signal is rather ill-defined, and the precision of the measurement depends on the rate at which the oscillation is established, i.e. on the rise time of the modulating pulse, and therefore on the pass-band of the equipment.

3.11. *Measurement of time*

Besides the fundamental limitation due to the finite pass-band, the precision of the measurement of time depends on the method of measurement employed. Several procedures have been adopted.

It is not possible to effect a measurement of length on the screen of the oscilloscope and to transform it into a measurement of time, owing to the inaccuracies due to the non-linear scanning, the small dimensions of the usual tubes (useful diameter 10 cm), the thickness of the line (0·3 to 0·5 mm), and to calibration of the scanning time.

3.11.1. Marker signal method

A marker signal may be superimposed on the signal received, and may be moved on the screen with the aid of a calibrated control. The marker is made to coincide with the transmitted pulse, then with the echo, and from the difference measures on the calibrated control the time interval separating them may be deduced. The horizontal scanning may be extended to give greater precision, independent of the characteristics of the oscilloscope (non-linearity and approximate calibration).

3.11.2. Variable delay method

Another method is to use a calibrated variable delay, by means of which the origin of the transmitted pulse is made to coincide with a datum line on the screen. The delay is noted. The origin of the echo is then made to coincide with the same datum line, and from the delay measured the time of travel may be calculated. As before, the accuracy can be improved by horizontal extension of scanning, and is independent of the characteristics of the oscilloscope.

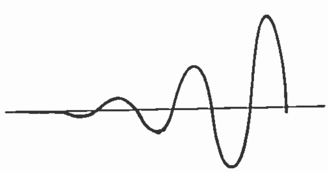


Fig. 5.—Signal obtained on oscilloscope.

3.11.3. Time-scale scanning

In a further method, a second scanning bearing a time scale, on which the time of transit is read directly, may be superimposed on the normal scanning which reproduces the signal. This method, borrowed from radar, utilizes a quartz generator for the time markers and an electronic switch to superimpose the two scannings. It is capable of high precision (if necessary with a variable interpolated marker) and does not depend on the characteristics of the oscilloscope. It does not appear to have been much used, doubtless due to the complex nature of the electronic equipment necessary.

It should be noted that with all these methods the existence of multiple echoes makes it possible to carry out a measurement of time relating to several intervals, with consequent improvement in the relative precision for the same absolute precision. To take advantage of this observation, the attenuation due to the medium must be low and the scattering must not unduly distort the observed pulses.

3.12. *Measurement of attenuation*

Attenuation may be measured by the standard methods to a precision of about 5 per cent. It is possible, with the aid of a calibrated attenuator or amplifier, to reduce the signals transmitted and received to the same amplitude· thus measuring the attenuation. As for the measurement of time, the presence of multiple echoes permits a more accurate measurement to be made. The direct observation of the echoes and the measurement of the successive amplitudes gives the envelope curve and the consequent attenuation, by direct means.

3.13. *Methods of coincidence*

A method due to Mason[30] and McSkimin[31] makes use of a modification of the pulse technique. The specimen is separated from the quartz by a silica rod (fused silica), which introduces a sufficient delay for the pulse emitted by the transducer to be very largely terminated before the first echo arrives (Fig. 6).

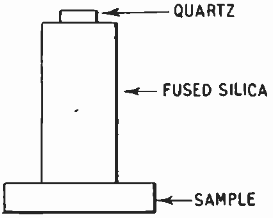


Fig. 6.—Assembly for measurement by coincidence method.

In addition, the length of the specimen and the duration of the pulse are selected so that the first echo returns to the input side of the specimen before the incident pulse is extinguished. At the input of the specimen there is thus superimposition of the incident pulse and of the succeeding echoes.

By altering the frequency of the incident waves, values are found for which the successive echoes are in phase or antiphase whenever

$$\lambda = \frac{2d}{n}, \text{ or } \lambda = \frac{2d}{2n+1}$$

where λ is the length of the incident wave, d is the thickness of the specimen, and $n = 1, 2, 3, \ldots$ This gives the characteristic configurations of Figs. 7a and 7b.

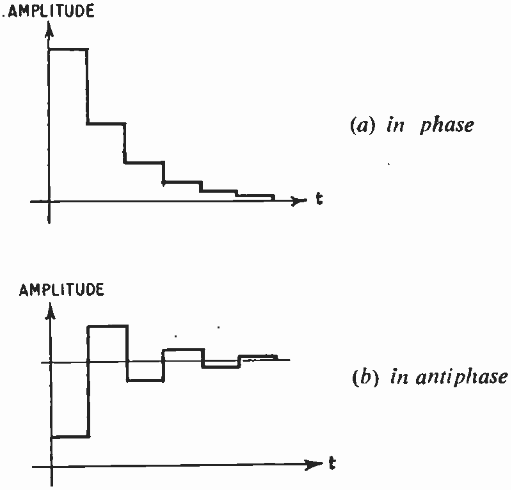


Fig. 7.—Signals obtained by coincidence method

Measurement of the frequency can be carried out with great accuracy, and the precision of the reading seems to depend essentially on the clarity and the precise identification of the characteristic figures. If the attenuation is low, the figures converge only slowly. If the attenuation is high, passage through the characteristic figure may be imprecise with the change of frequency. In addition, this method calls for an equipment that is capable of covering, with the same transducer, a whole range of frequencies. This makes it necessary, with quartz, to work below the resonant frequency.

4. Description of the Equipment used in the Tests

The equipment used comprises:

Rectangular signal generator, C.R.C. type G.I. 52.

Oscillo-Synchroscope, Du Mont 256 F.

Ribet-Desjardins Oscilloscope type 263 B, modified by replacement of the vertical

amplifier to pass a wider band, and used to control the pulse shapes.
Pulse transmitter.
Apparatus for the mechanical assembly of the transducer and the sample.
Echo-receiver/amplifier.
Two stabilized supplies, for the receiver and the transmitter.

The last four items on the above list were made in the laboratory, and are assembled on a standard 2 metre rack. The transmitter has been built in compact form to be placed in the immediate vicinity of the sample and reduce the length of the connections, which are made by coaxial cables and connectors.

4.1. *Rectangular signal generator*

The pulse generator, C.R.C. type G.I. 52, furnishes pulses of length varying from 0·2 to 10 μ sec in steps of 0·1 μsec. The output signal is supplied at 75 Ω impedance with a maximum voltage of 50 V: the step attenuator covers 30 db in steps of 6 db. It is completed by a 10-db continuous attenuator. The output signal is available in positive or negative phase; there are also positive or negative synchronization signals whose advance or lag in relation to the pulse may vary from 0·1 to 10 μ sec.

The amplitude of the synchronization signals is adjustable between 0 and at least 50 V, their rise time is less than 0·05 μsec. A stabilised supply is used with the generator and an additional external attenuator enables 30 or 60 db more attenuation to be added as required.

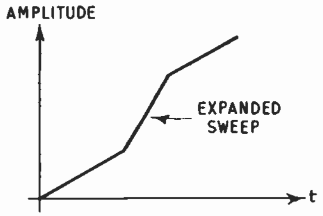


Fig. 8.—Expanded sweep provided by variable slope.

4.2. *Oscilloscope*

The Du Mont oscilloscope type 256 F is designed for testing and adjusting radar equipment, and is used for a number of functions. Its vertical amplifier has a pass-band of 12·5 Mc/s at 6 db. It handles voltages between 0 and 600 V peak, an input voltage of 0·1 V r.m.s. giving at least 1 cm deflection with maximum gain, i.e. about 125. A compensated 5-way attenuator reduces the input signal in the ratios 1/1, 3/1, 10/1, 30/1 and 100/1.

The time base is either free running or triggered by an external synchronizing signal. It provides six scanning rates, with respective times of 4,500, 1,000, 100, 25 and 4 μsec. In addition, scanning of 4, 10 and 25 μsec with variable lag can search any part of the previous scannings and present it considerably expanded on the screen (Fig. 8).

4.3. *Time Measurement*

The three methods of time measurement mentioned in Sect. 3.11 may be used with the oscilloscope 256 F.

In the method outlined in Sect. 3.11.1, an adjustable marker signal is supplied by the apparatus, whose accuracy is 0·1 per cent. of the maximum period. This marker is not, however, very sharp and is preceded by a slight parasitic oscillation, which limits the accuracy of marking. Its lag is read directly off a scale which is accurate within 0·1 per cent. The same scale is used for shifting at will one of the expanded scannings along a normal sweep. It is then possible to expand the useful part, on which an echo appears, and read off the lag on the dial. This is a variation of the previous method, the marker pip being replaced by the origin of the expanded sweep.

For the method described in Sect. 3.11.2, the same calibrated time delay device is used, as well as the graticule placed in front of the screen of the cathode ray tube. Scanning is delayed so that the commencement of the pulse transmitted coincides with the zero line (datum line). The dial reading is noted. The delay is then increased until the origin of the echo signal coincides with the datum line, and the second reading of the calibrated dial is noted. The difference between the two readings gives the time interval separating the emitted pulse from the echo. The intrinsic accuracy of the oscilloscope is the same as before.

For the method of Sect. 3.11.3, two sets of quartz-controlled markers are available, with respective spacings of 10 and 50 μsec. The accuracy attainable is ±0·02 per cent. Nevertheless, the marker pips last roughly 1 μsec and are not extremely sharp. In addition, their amplitude is very low, in the region of 1 mm, and the direct reading of the time scale is difficult due to the poor luminosity of the tube, especially at high scanning speeds. The tube employed is of the blue fluorescent type, highly actinic and suitable for photography, but ill-adapted for visual observation, for which an additional green fluorescent tube may be employed, giving improved visibility. The two tubes, differing only in the screen, are directly and rapidly interchangeable.

An additional improvement is in process of being installed, in the form of a quartz electronic time scale with variable phase, appearing on a second scan by the aid of an electronic switch. This will permit the use of high-amplitude markers. The variable phase replaces an interpolation, and can be calibrated. The position of the second scan can also be modified so that the reading of the coincidence of the marker and of the beginning of the signal takes place with maximum precision, the top of the marker being adjusted to coincide with the leading edge of the signal.

The above methods and their variants, separately or in combination, may be used with the existing equipment. The quartz marker incorporated is especially useful for checking the calibration of the variable delay. Whichever method is used, the intrinsic precision of the oscilloscope is in the region of 0·1 per cent., which is sufficient for the initial work under consideration. The factor limiting precision is, as has been shown, the visual identification of the exact moment of commencement of the pulse or echo signal.

4.4. *Pulse transmitter*

The transmitter is designed to supply a high frequency pulse which is applied to the transducer at its resonant frequency, for the maximum efficiency. It is controlled by the pulse generator.

A normal method is that shown in Fig. 9[2, 27]. The valve V2 is a cathode-coupled oscillator. The frequency of the circuit LC is variable for tuning to the resonant frequency of the transducer. V1 is, in rest condition, highly conductive. Its cathode impedance appears across the terminals of the circuit LC. It is nearly equal to $1/g_m$, g_m being the mutual conductance of the valve, and is very low so that the circuit LC is below critical damping, and cannot oscillate.

The arrival of a negative pulse of sufficient amplitude at the grid of V1 cuts that valve off; its cathode impedance becomes very high, and the circuit LC begins to oscillate for the duration of the pulse. This oscillation commences and is extinguished very quickly, according to the damping (Fig. 10). The transducer is excited directly or through amplification or buffer valves, by the voltage which appears at the terminals of the circuit LC.

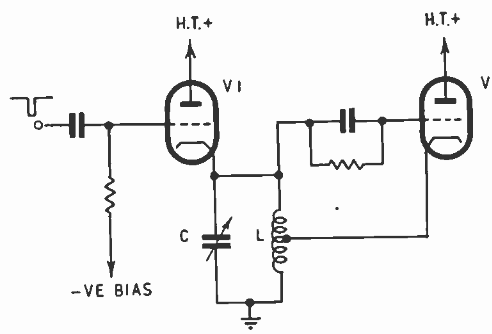


Fig. 9.—First circuit for pulse generator.

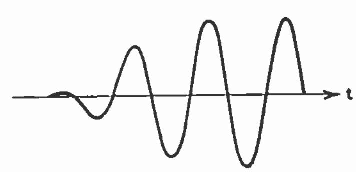


Fig. 10.—Damped oscillation from pulse generator.

Nevertheless the distortion of the pulse due to inertia (Q factor) of the oscillating circuit is added to that of the transducer. Also, the LC circuit must be tuned to the transducer frequency, which may entail switching operations if it is desired to use a wide frequency band. An assembly dispensing completely with the oscillating circuit LC would therefore have advantages. For such a method, the oscillation of the quartz is shock-excited with the aid of a steep-fronted pulse of great amplitude. Working is independent of the frequency of the quartz and calls for no tuning. The only distortion of the pulse is the unavoidable one due to the quartz. To supply the exciting shock pulse, Bradfield used a thyratron.[27] However, the instability of gas-filled valves may cause an erratic variation in the signal.

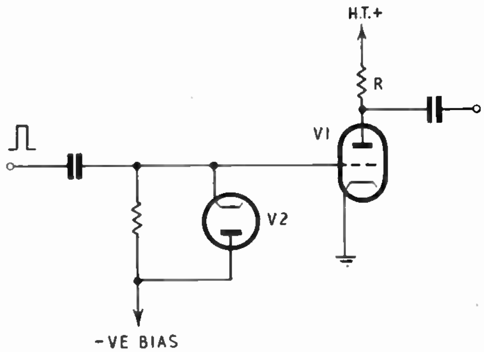


Fig. 11.—Improved circuit for pulse generator.

The method which we have used is given in Fig. 11. The valve V1 is normally blocked by the adjustable negative voltage applied to the grid. The arrival of a positive pulse, supplied by the pulse generator, unblocks the valve and creates a considerable rectangular voltage drop across the terminals of the load resistor R. It is this voltage which excites the quartz.

A diode, V2, aligns the zero of the pulses and ensures regularity of the signals supplied, the amplitude of the pulse on the grid being sufficiently large to switch the valve from cut-off position to that of maximum conductivity.

The magnitude of the output voltage is dependent upon the quartz and the conditions of the experiment. The assembly used furnishes rectangular pulses of variable amplitude between zero and more than 300 V.

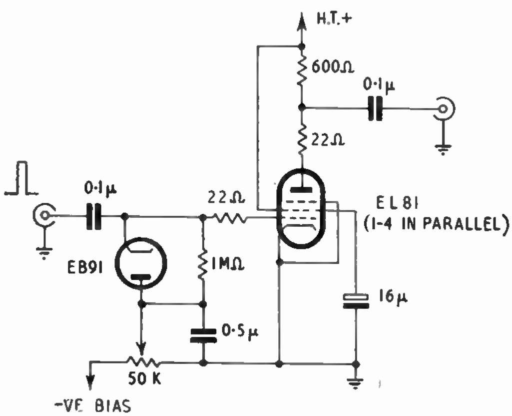


Fig. 12.—Connections for pulse generator.

V1 is in practice a power pentode. The assembly provides for four pentodes in parallel, from one to four being used according to the output voltage required.

The value of the resistor R is limited by the pass-band, which is fixed at 10 Mc/s. It is readily interchangeable, but the value of 600 Ω ensures suitable results. To obtain 300 V at the 600-Ω terminals, a current variation of 500 mA is needed, which makes it necessary to connect the power valves in parallel. The circuit diagram of the transmitter is given in Fig. 12. The voltages are supplied by a separate stabilized source.

4.5. *Amplifier-receiver*[38]

The amplifier-receiver must be capable of giving a gain of about 100 db with a pass-band of 10 Mc/s. This is obtained with the circuit shown in Fig. 13. Four high-slope pentodes, mounted as a wide band amplifier (anode-to-anode negative feedback quadruplet) provide a gain of about 60 db. If observations are to be taken of the v.f. wave shape, the output signal is taken from the coaxial jack J 3, the signal having been detected and undergone additional amplification in the region of 40 db in two wide-band video-frequency stages.

The four negative feedback amplification stages are tuned to a frequency providing for the quartz, i.e. 15 Mc/s; the signal input is at J 1 on a coaxial jack. Provision has been made for the use of higher frequencies. In order to avoid modifications to the receiver described, the amplifier tuned to 15 Mc/s has been completed by a frequency changer stage with double triode, designed to reduce by heterodyning the incident frequency to 15 Mc/s.

Frequency changers have a high noise level. Therefore, to improve the signal-to-noise ratio, a preliminary amplification stage has been provided, tuned to the incident frequency, which in this case comes in on the coaxial jack J. The inputs have been provided for an impedance of 75Ω, in order to be adapted to the impedance of the coaxial connecting cables. Supply to the receiver is from a highly stabilized source.

Further modifications have recently been made to the assembly, due to the attenuation caused by the oscilloscope, whose amplifier only passes 12·5 Mc/s at −6 db. The incoming signals are reduced by heterodyning to a constant frequency of 8 Mc/s, to which the i.f. amplifier of the receiver is tuned. The amplifier

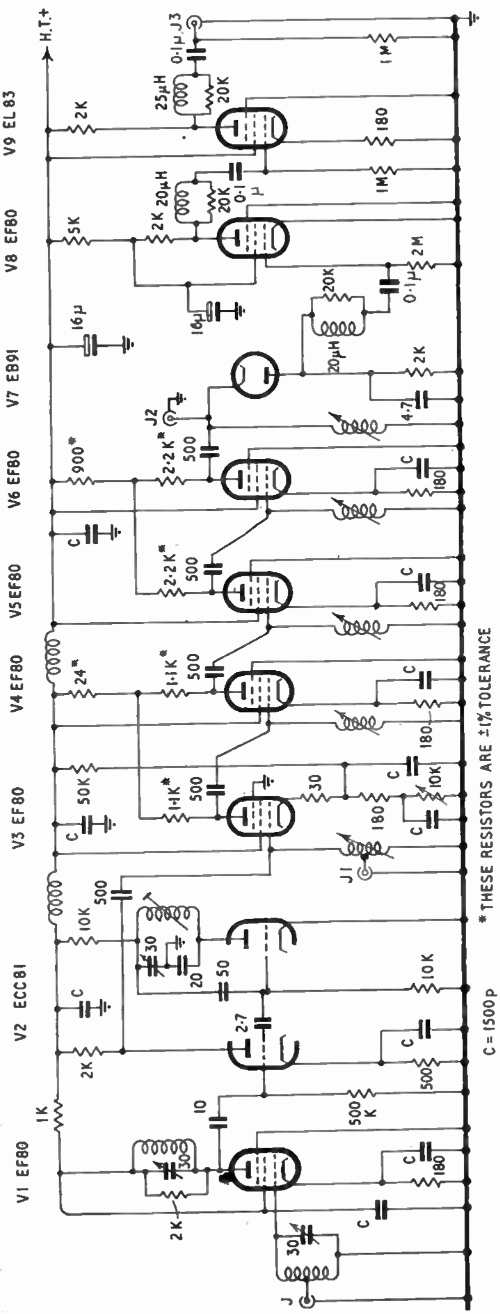


Fig. 13.—Receiver circuit.

uses stagger-tuned circuits, which are easier to adjust than the negative feedback type. As the pass-band is an important fraction of the i.f. central carrier frequency, the approximation generally used for calculating staggered circuits no longer applies, and the best procedure is to adjust the response curve of the receiver with a frequency-modulated signal generator.

This arrangement makes it possible to use the vertical amplifier of the oscilloscope, which brings in an additional gain of 125. In addition, the oscilloscope amplifier can be used to observe the detected pulses, and to observe the r.f. pulses direct.

Finally, as it is desirable for certain measurements to have a reserve of amplification, the receiver is completed by a two-stage r.f. amplifier fitted with high slope pentodes of type EF 80. A switch has been added at the level of the detector EB 91, and this makes it possible to supply the vertical amplifier of the oscilloscope, either with r.f. or with detected pulses.

4.6. *Stabilized supplies*

Two stabilized supplies are provided, one for the transmitter and the other for the receiver. They employ the well-known form of series valve stabilization and are designed for high voltages and currents varying within very wide limits. The stabilized supply circuit for the transmitter is capable of supplying a stabilized voltage which can be regulated between 200 and 400 V with an output of 0 to 250 mA. At 400 V, a variation in drain from 0 to 250 mA involves a voltage variation of less than 1 per cent. In addition, the stabilized source furnishes the filament voltage and a negative bias voltage, also stabilized. The stabilized current supply to the receiver has a much higher rate of stabilization, due to the high amplification of the receiver which makes it sensitive to variations in the supply voltage. It has the same characteristics as the transmitter supply, with a short and long term stabilization rate better than 0·2 per cent.

4.7. *Mechanical assembly*

The mechanical assembly of the test-piece and the quartz has been designed with a view to its introduction into a pressure cylinder, or bomb, whose internal bore does not exceed 40 mm. In order to facilitate assembly, the diameter of the test-pieces has been standardized at 20 mm, which is suitable for high frequencies.

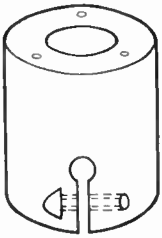


Fig. 14.

Simplified mounting used in preliminary tests on solids.

The mounting for the test piece is illustrated in Fig. 14. It measures 38 mm in diameter by 40 mm in height, and has a 20 mm eccentric drilling to accommodate the test-piece, which is inserted at the bottom and locked into position by a screw in the slot provided.

A circular piece is attached to the top of the test-piece by means of three screws, and carries the coaxial connecting jack, which is connected to the quartz by a contact spring and backing piece.

In the preliminary tests, a simplified assembly as shown in Fig. 15 was used with satisfactory results. It consists of a simple clamp fixed to the test piece by a locking collar. Attached to the clamp is a coaxial jack fitted with a T piece for the intake and output of pulses. Contact with the quartz, which is gold-plated, is ensured by a spring and contact washer.

By applying sufficient pressure to the quartz when merely laid on a polished section of the test-piece, it has been possible to obtain echoes. The assembly is, however, difficult to reproduce, and the arrangement is critical, when there is no cement between the quartz and the metal. The quartz has therefore been attached to the test piece with the aid of a thin layer of phenyl salicylate[11]. The whole is heated to about 70° C and the section of the test-piece is lightly

(a)

(b)

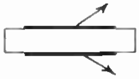


Fig. 16

Metallization of quartz electrodes.

sprinkled with phenyl salicylate, which melts at 42° C and wets the surface. The quartz is placed in position, and the assembly completed so that the spring presses on the quartz. It is then allowed to cool. A variant of this method is to apply the quartz to the test-piece with the aid of a 5–10 kg weight, assembly being completed once the whole has cooled.

In order to have access to the two quartz electrodes, metallization was at first carried out in the form indicated in Fig. 16a. The lower plating comes on to the free surface of the quartz, where it is possible to make the two contacts required. This method, which has the drawback of reducing the active surface of the quartz, has been abandoned in favour of the simpler one shown in Fig. 16b, which is satisfactory, the return taking place through the mass of the test-piece. The metallization on the back of the quartz plate is stopped 1 or 2 mm from the edge to prevent a spark from jumping the edge.

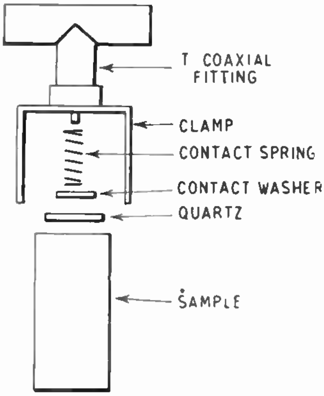
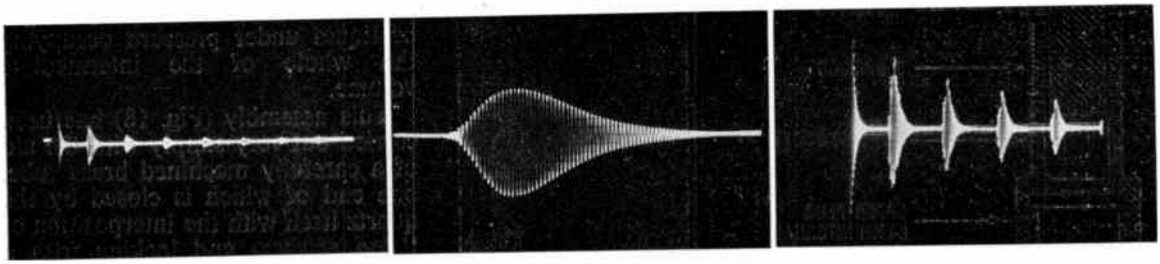


Fig. 15.

Assembly used for preliminary tests on solids.

Fig. 17.—Waveforms of typical echoes obtained with the equipment.

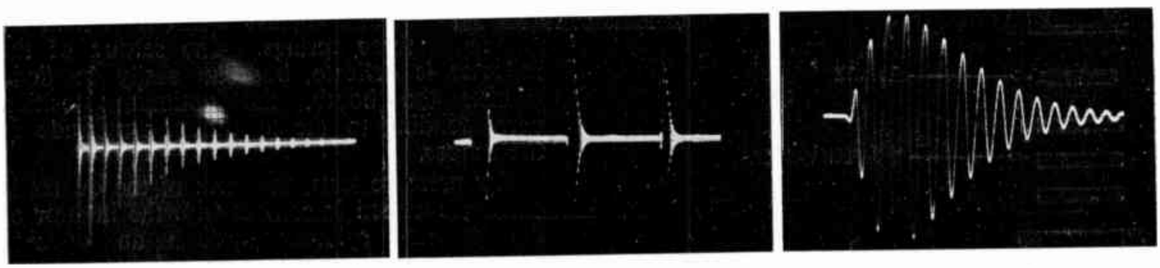


(*a*) (*b*) (*c*)

(*a*) *Series of echoes in a solid (Aluminium C). Sweep length* 1,000 *μsec, temperature* 20°*C, quartz* 15 *Mc/s.*

(*b*) *One echo amplified. The beginning of the pulse is rather ill-defined, and it is difficult to ascertain with precision the time of arrival of the echo.*

(*c*) *Series of echoes in a liquid (benzene). Sweep length* 100 *μsec, temperature* 25°*C, barium titanate* 5·4 *Mc/s.*

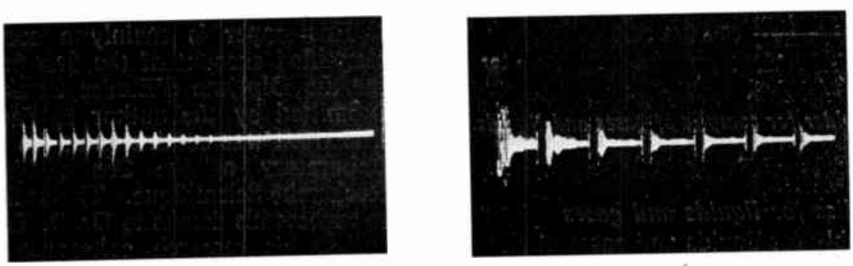


(*d*) (*e*) (*f*)

(*d*) *Series of echoes in distilled water. Sweep length* 1,000 *μsec, temperature* 25°*C, barium titanate* 5·4 *Mc/s.*

(*e*) *Transmitted pulse and first two echoes in distilled water. The high writing speed spoils the quality of the photograph, but is not objectionable on direct visual observation of the oscilloscope. This remark also applies to the following photographs.*

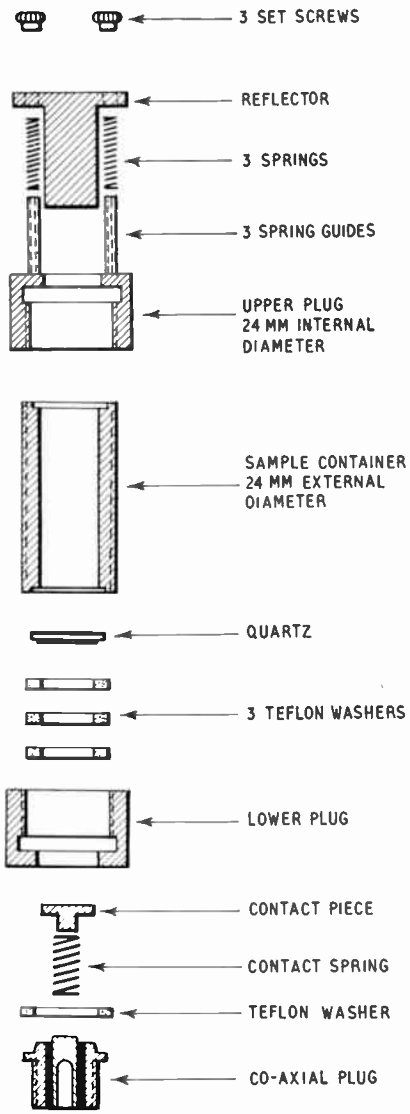
(*f*) *One echo amplified. The beginning is quite well-defined and allows a good precision in the measure of time.*



(*g*) (*h*)

(*g*) *Series of echoes in a gas (nitrogen purified). Sweep length* 1,000 *μsec, temperature* 25°*C, pressure* 1,000 *kg/cm*², *barium titanate* 5·361 *Mc/s.*

(*h*) *First echoes, as above, but time scale* 100 *μsec.*



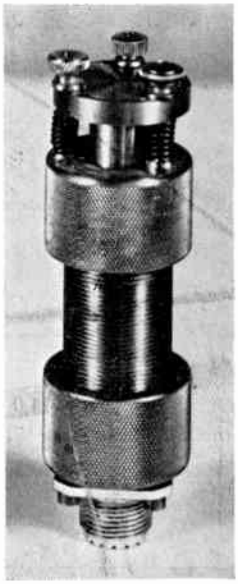


Fig. 18.—Holder for samples of gases and liquids.

4.8. *Assemblies for liquids and gases*

The assembly for liquids and gases obviously differs from that used for solids. With solids, the test-piece is placed in the cylinder and the hydrostatic pressure is applied by means of a suitable liquid. In the case of liquids, it is the body itself which receives direct pressure. It is sufficient to have inside the pressure cylinder a mechanical assembly which ensures the parallelism of the transducer and the reflector, the gas or liquid under pressure occupying the whole of the intermediate volume.

This assembly (Fig. 18) has been carried out very simply with the aid of a carefully machined brass tube, one end of which is closed by the quartz itself with the interposition of teflon washers and locking with a threaded cap. This cap bears the coaxial plug, connected to a pressure-tight passage provided in the construction of the pressure cylinder. At the other end of the brass tube, an identical cap bears a metal reflector which may be orientated by means of three set screws against which it is held by three springs. The setting of the reflector is delicate, but can easily be done outside the bomb, the optimum position corresponding to the maximum amplitude of the echoes.

For pressure tests, the back of the quartz is of course placed in contact with the interior of the pressure cylinder through an opening provided for the purpose to balance out the pressures on either face of the quartz.

This assembly is also used for measurements at normal pressure with liquids, the brass cylinder being filled with the liquid to be tested and the quartz providing the seal at the lower end of the tube.

5. Acknowledgments

This paper is mainly a summarized and simplified account of the first part of a thesis for the Diplôme d'Etudes Supérieures (Phys.) submitted by the author to Paris University. The work was conducted at the High Pressure Laboratory of the Centre National de la Recherche Scientifique. The author would like to express his thanks to Dr. B. Vodar, Director, and to his research colleagues at the High Pressure Laboratory, as well as to Messrs. G. Bradfield and H. Pursey of the National Physical Laboratory, Teddington, for the valuable advice which they have generously given.

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. . . Radio Engineering Overseas

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

534.844.1/2:621.396.712.3

Pulse techniques for acoustical measurements in broadcast studios.—R. K. VEPA and N. K. TRIVEDI. *Indian J. Physics*, **29**, pp. 369-79, August 1955.

In recent years, the concept of reverberation time as the sole criterion of good acoustics in a test enclosure has yielded to an emphasis on the manner of sound decay in the enclosure. New techniques using short impulse sounds have been developed for this purpose, and this paper describes the particular method employed in All India Radio for the acoustic testing of broadcast studios. Results obtained in a typical studio are described and are interpreted on the basis of the acoustical treatment employed in it.

621.317.336

New diagram for solving impedance transformations.—R. GUILLIEN, *Onde Electrique*, **35**, pp. 1164-70, December 1955.

After recapitulating the classical Smith diagram, a diagram shows a plot of the complex logarithm of the reflecting power of a line. Its properties are explained, with particular reference to impedances of lines. The two essential advantages of this diagram are first, that a simple translation will give results which, in the Smith diagram, require a rotation or a rotation plus a translation, and secondly, that it gives a large scale representation of the impedances near the characteristic impedance.

621.319.4

The impedance of a wound capacitor with extended foil electrodes.—H. HEYWANG. *Archiv der Elektrischen Ubertragung*, **10**, pp. 29-44, January 1956.

It is known that, because of its inductance and its losses, the impedance of a capacitor departs increasingly with frequency from the value corresponding to its capacitance alone. This phenomenon is first derived from the electric and magnetic fields of the capacitor for units of different geometry, disregarding all losses, and subsequently transferred to capacitors with losses in the dielectric and in thin (evaporated) metallic films. The eddy currents in the contacting layer at the front-end and in thicker metallic foils call for a separate discussion. This analysis starts from capacitors with a cylindically symmetrical layout, while the practical capacitors consist of strips of foil wound in helical fashion. The resulting deviations in the impedance are usually negligible. In an appendix, the results found are used to determine the transfer impedance of lead-through capacitors.

621.375.2 + 621.375.4

A comparison of the behaviour of a junction transistor and an amplifier tube.—G. LEDIG. *Archiv der Elekt. Ubertragung*, **10**, pp. 1-9, January 1956.

The linear behaviour of a junction transistor is compared with that of an amplifier tube. The quadripole equations are developed for various customary transistor and vacuum tube circuits. All data of interest concerning the linear properties of these circuits are shown in tabular form.

621.396.677,2.029.54

Standardized transmitting aerials for medium-frequency broadcasting.—S. F. BROWNLESS. *Proc. Instn. Radio Engrs, Aust.*, **16**, pp. 383-96, November 1955.

A range of aerial systems suitable for transmitting stations of powers from 200 W to 50 kW in the frequency range of 540-1600 kc/s has been developed for the Australian National Broadcasting Service. The aerial systems fall into two classes: "high" aerials having special anti-fading properties, usually near half-wavelength in height, and "low" aerials less than a quarter-wavelength in height. This paper traces the development of the designs, with special emphasis on low aerial systems suitable for construction by Departmental staff. Here the application of practices well established at v.h.f. leads to structures believed to be novel for m.f. broadcasting. Charts and diagrams are given from which aerial structures suitable for any particular application may be readily selected.

621.396.962.33:557.594.5

Radar echoes from the aurora and the use of Doppler techniques.—A. G. MCNAMARA. *Engineering Journal of Canada*, **39**, pp. 31-33, January 1956.

The author discusses the theories of radio reflection from the aurora, which has been studied extensively by radar and Doppler techniques only in very recent years. It is concluded that auroral radar observations can provide information not only about the aurora itself, but also about the physics of the upper atmosphere and radio propagation in the ionosphere.

621.396.963.325

A shore based surveillance radar.—A. LECONTE, *Onde Electrique*, **35**, pp. 1147-52, December 1955.

A radar set designed for Dunkirk harbour according to the specifications of the Service Technique des Phares et Balises is described. It operates in the 3 cm. band with peak output of 30 kW; it uses pulse lengths of 0·2 and 0·5 μsec. at a p.r.f. of 1,000.

Correction

January 1956, page 60, second abstract: Title *should read*: "Variations in the phase constant of ground waves."

Last sentence of abstract *should read*: Curves are calculated showing the variations of field strength and equivalent phase constant at different frequencies for soils of different conductivities.