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Paper 12

System Tests: Instrumentation and Measurements

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1. Introduction

This paper describes the instrumentation for the System Tests programme described in Paper 2.

The tests involve the measurements at fixed points and on moving trains. The frequency of the 50 cycle supply forms a convenient time scale to synchronise all records and observations.

Most of the measurements were electrical, but others such as speed and distance required transducers to convert them into electrical signals.

All instrumentation was aimed at producing permanent records for the application of computer technique in the evaluation of results.

2. General

Three main groups of recorders were used:—

(*a*) High Speed, e.g. oscillographs.
(*b*) Fast, e.g. electronic digital 12-channel recorders.
(*c*) Slow, e.g. pen recorders.

While (*a*) and (*c*) are of the most modern type they follow in the main conventional patterns but the electronic digital recorder is a new instrument using components of well-established performance, in a combination which hitherto has not been applied to electric railway testing.

3. Electronic Digital Recorder

The electronic digital recorder (E.D.R.) designed and built by Microcell Ltd, is in effect an analyser sampling up to 12 different events at the rate of one analogue event every 160 milliseconds and records such events in digital form on Creed tape in the International 5-unit Teleprinter Code.

The equipment operates from 50 c.p.s. mains or from batteries as required and is therefore capable of installation in moving vehicles or at ground stations.

The details of an analogue to digital converter capable of being automatically and continuously connected to 12 different inputs can best be described by its use in evaluating recording data at a railway feeder station. The general appearance of the instrument is illustrated by figs. 5, 6 and 7.

3.1 *Logical Layout*

The schematic diagram in fig.1 shows the type of unit used in each section of the instrument and the flow of information is as follows:—

The rotary sampling switch 'A', feeds an analogue to digital converter with a range of 0 – 100V. The output of this is in binary code and each sample is expressed with an accuracy better than ± 1 per cent. on three decades, tenths, units and tens. Following this, rotary switch 'S' (electronic as its speed is 25 points per second) feeds the information, via a code converter consisting of diode matrices, to five power amplifying valves energising the Creed punch coils.

As the Creed code is difficult to read for those unfamiliar with it, a visual monitor is provided consisting of a tape hole sensing unit, connected by a suitable code changing matrix to three numerical display tubes (dekatrons).

A subsidiary device added to this information chain is an electrically driven synchronous clock 'C' which, when triggered, issues in binary coded form the time expressed in hours, minutes and seconds. As this information is injected into the main information stream, analysing is automatically stopped during this recording period.

The manual switches ('M') are incorporated to enable any type of number to be inserted on the tape, either before or after running, to record the calibration factors by which the recorded figures are to be processed to give real values.

The Master Timer (fig.1) consists of some 40 valves wired to issue appropriate impulses.

3.2 *Electrical Details and Circuits*

Sampling switch 'A' is a standard heavy duty rotary line switch energised at a rate of 6·25 impulses per second by a pair of 12 E1 power valves in parallel capable of safely supplying the 400 M/A required by the coil.

The impulses are produced by a scale of eight countdown circuit deriving its input from 50 cycles ($\frac{50}{8}=6{\cdot}25$).

The voltages to be recorded are connected to the fixed contacts and the rotating arm connected to the input of the analogue to digital converter.

The unused banks of this unit are utilised in connection with the visual monitor strobe circuits (3.4).

3.3 *Analogue to Digital Converter*

The A.C. outputs from the instrument transformers are converted to D.C. voltages by the translators shown on the right of fig.1 and are presented in turn to the input of the A/D Converter, e.g. 25 kV A.C. could be presented as 25V D.C. at the input to the Converter.

Similar translators are used to present as D.C. voltage, other measurements such as speed and distance. This D.C. voltage is measured and displayed on the analogue/digital converter which also provides a binary coded output.

The input gate is fed with 100 kc/s pulses; when a measurement is required, the ramp generator is started and as the ramp voltage passes through zero potential, a comparator operates which opens the input gate enabling the 100 kc/s pulses to reach the counting units. The unknown input voltage and the ramp voltages are compared and at coincidence a second comparator operates, producing a pulse which closes the input gate (fig.2).

The counting units will thus display the analogue voltage directly, and in the example taken, the indicated count would be 250. The impulses which initiates the ramp is derived from the master timer.

3.4 *Visual Monitor*

The information punched on the tape is in the form of 5-hole international teleprinter code and placed in groups of three digits separated by a single space, where the first set of holes after the space is the tenth of units followed by units and tens.

As the tape is fed to a teleprinter for tabulating, circuits have been provided which cause symbols for 'paper feed' and 'carriage return' to be inserted automatically after every twelfth group. Further provision is made to insert four paper feeds at pre-set intervals so that the blocks of figures printed on the page are broken up for indexing.

As the tape emerges at a rate of 25 digits per second it passes over a row of 5 holes illuminated from underneath; these small holes project an image on five photo-electric cells. These cells feed, via amplifiers, a diode matrix (fig.3). The output of this matrix can be connected to any one of three dekatrons by means of three diode coincidence-gate switches (G1, G2, G3).

It can be seen that if the matrix translates from 5 input Creed code to 10 output decimal code, then by opening the appropriate coincidence gate in synchronisation with the tape movement, the glow on the selected dekatron can be made to jump to the appropriate cathode which will have the same numerical value as that punched on the tape.

The dekatrons act as storage as well as display tubes.

A close look at the overall system reveals that, unless special precautions are taken, the high rate of digit flow (25 per second), coupled with the fact that the main sampler never rests on any given path for more than 160 milliseconds, will produce a quite unreadable blur in the display tubes.

To overcome this a strobing technique has been included, whereby the dekatron display tubes will only be influenced by the sensed holes if a triple coincidence is found between (1) a manually positioned switch ('S' fig.3) called 'Select Channel' to be displayed, (2) the position of the main sampling rotary and (3) the four position electronic decade switch. Diode switches ('C') therefore act as triple coincidence gates.

It can be seen from the foregoing that, providing the photocell sensing unit is a whole multiple of groups displaced from the punch position, then whichever channel has been selected for display will appear in the correct order on the three display tubes (in our example, 25·0).

To check that the digits monitored are in fact of the value being presented by the translator, a volt meter is provided which is automatically switched to the correct channel by a spare bank on the Channel Select switch.

3.5 *Contacting Synchro-Clock*

Because the system would be recording events over long periods and the time that some event of interest occurred has to be accurately determined when the tape is later analysed, the time is punched automatically into the tape at regular intervals.

This is arranged by a self-contained unit deriving its initial timing from the mains or from a stable oscillator. In the case where 50 cycle mains timing is sufficient a divide by two circuit is followed by two dekatrons both arranged to scale at 5, giving a total demultiplication of 50 ($2\times5\times5$) and therefore issuing impulses at one second intervals.

These impulses feed a rotary line switch whose contacts, suitably coupled in groups of 10, issue a carry pulse every 10 seconds. This in turn feeds the next rotary line switch whose contacts issue a carry every fifth operation, that is, R.L. switch 'A' scales at 10, R.L. switch 'B' scales at 6, giving 59 seconds.

The next two R.L. switches are similarly wired, giving 59 minutes and the next R.L.S. is arranged to count to 23.

This simple arrangement, which is novel and has been patented, provides a 24-hour clock capable of issuing from the spare banks any code which one cares to wire to it (in this case, binary) and having an accuracy only dependent on the type of oscillator feeding it (in this case, 50 cycles).

To provide a visual indication of the time, a spare bank on each R.L.S. is wired to a numerical display tube on the front panel or remote panel as required.

Any of the R.L.S. can be pre-set to any given position by means of an impulsing switch provided below the display.

3.6 *Operating Features*

The speed of operation of the entire instrument is limited by the Creed punch which, in this case, has a maximum safe operating speed of 25 impulses per second. As it is intended that the apparatus should continue to record during and after a mains failure, the whole equipment is capable of being battery-driven and the mains synchronising is replaced by a high stable oscillator which continues to oscillate at close to main frequency.

So that a number of installations may be started and stopped together, remote control facilities are provided, such that one pre-designated machine earmarked as a Master Unit emits a half-second impulse (via land line or carrier frequency) to start all units and a three-second impulse to stop. This same Master Unit is also arranged to emit synchronising impulses at five-minute intervals. These impulses are similar to the 'Start' pulse. As the first recording after a 'Start' signal is a 'Time', then it follows that on receipt of each synchronising impulse, normal data recording will be interrupted and a 'Time' record substituted for two seconds.

The E.D.R.s installed on the electric vehicles are mounted on rubber shock absorbers to mitigate the effect of vibration.

4. Translators

The electronic digital recorders require that the input signals are in the form of D.C. voltages in the range of 0–99·9V, with a ripple not exceeding 1·0 per cent, and since the majority of the data to be recorded was not in this form, translating equipment was necessary. This translating equipment, which was specially developed for the recorders, is of several types. Translators are provided to convert A.C. currents and voltages, kWs, D.C., amps., speed, etc. and in certain cases, psophometric measurements, where the energy content is so low that the translator incorporates an amplifier. The majority of the translators required an input of some 5 V.A. Very compact equipment was developed and generally it was possible to locate them close to the circuits being measured, in many cases within the relay panels of the equipment cubicles.

The translators were mainly designed and built by the main contractors for the electrification works.

5. Current Transformers (Instruments)

In many cases, it was possible to utilise the current transformers already provided as in the case of the H.V. feeder equipments, but for measuring the return currents in the running rails special encapsulated transformers were made. These had the novel feature of being provided with protective devices in the form of a pair of backed rectifiers across their secondary terminals, designed to break down and seal the circuit in the event of the secondary becoming open circuited.

6. Calibration

Prior to the start of testing the calibration factors to be applied to the digitised values of the recorded quantities were determined. The factors were punched out on the test tape together with the code number of the quantity in the same order in which the related quantities would be recorded on the tape.

All relevant identifying information was also marked clearly at the commencement of each tape.

7. Continuous Display Wave Form Analyser

Normally wave form analysis is a slow and laborious process but for the analyses made during the tests, a new instrument developed by the P.O. was used. These instruments were made for the British Transport Commission by the Telephone Manufacturing Co, Ltd.

The instrument is provided with indicating meters but by means of the output terminals provided, the outputs were fed through a translator for record by an E.D.R.

To extend the scope of the instrument, use was made of magnetic tape recorders to store wave form signals for subsequent analysis by means of the wave form analyser.

7.1 *Logical Layout of the Continuous Display Wave Form Analyser*

The analyser is designed as a portable battery driven instrument to measure and display simultaneously the fundamental and 11 selected odd harmonic components of 50 c.p.s. voltage or current wave forms.

The 11 selected odd harmonics have frequencies of 150, 250, 350, 450, 550, 650, 750, 950, 1,150, 1,350 and 1,550 c.p.s. as these frequencies are known from previous measurements to be those of principal interest in the tests.

Even order harmonics, although present, are generally of sufficiently low level to be ignored. The equipment is transistorised throughout and operated from a 15V battery formed of ten 1·5V dry cells, the continuous current drain being of the order of 35 m.a. The instrument is fitted with range switches. At its most sensitive setting the input voltages required to give full-scale deflection is 100 mV for the fundamental frequency and 10 mV for each harmonic frequency. The range switches provide for these voltages to be increased by the following factors:—

For all components simultaneously 1, 10 and 100.

In addition,

For the fundamental, 1, 2, 5 and 20 and for each harmonic separately 1, 5, 10 and 50.

The system on which the instrument operates is based upon direct filtering to remove all but the particular harmonic of

interest and the inclusion of attenuators to enable voltage range switches to be used. The input impedance is 10,000 ohms. The general layout of the instrument is shown on fig.4. The attenuators and filters shown on the diagram perform conventional functions but additional discrimination is obtained from the measuring unit at the end of each chain. This measuring unit is a frequency selective feedback amplifier of high stability. In the feedback circuit a bridge rectifier and a milliameter is included. By using the high-pass filter of a previous chain, the rejection of all lower order harmonics is maintained. Finally, after amplification, a low-pass filter is fitted to remove nearly all the higher order harmonics leaving the measuring unit to select and display the voltage of the particular harmonic of interest. The completed instrument is designed for use in fixed positions as well as on moving electric trains and suitable for working satisfactorily at ambient temperatures in the range of 10 – 30°C. For calibration purposes pre-set controls are incorporated to enable the wave analyser to be adjusted to give correct readings when known voltages at each of the 12 frequencies in turn are applied to the unit. A separate source of known voltages was used originally but on later constructed instruments an oscillator and calibration unit has been fitted integrally with the instrument.

8. Measurements

To provide for the easy identification and required after treatment of measured quantities, schedules of every item were prepared beforehand giving in tabulated form all the detailed information such as origin of the measurement, form of input signal calibration factors and so on, each item being given an item number which it retained throughout.

The following table gives an extract from a section of one of the schedules of the tabulated items.

Item No.	*Quantity*	*Range*	*Method of Measurement*	*Type of E.D.R. Translator*	*Input to Translator*	*Output from Translator— Input to E.D.R.*	*Digitised Range of Recorder Output and Calibration Factor*
			132/25 kV Transformers T.1, T.2				
304	No. T_{1c} primary current	0 – 150 amps.	C/T.75/1	C.1/30	0 – 2 amps. A.C.	0 – 60V D.C.	(000–600) × ·25
306	No. T_{1c} sec./volts	0 – 28·75kV	P/T.26400/110	D.110/26·4	0 – 120V A.C.	0 – 28·7 V D.C.	(000–287) × 100
308	No. T_{1c} sec./amps.	0 – 600 amps.	C/T.300/1	C/1/30	0 – 2 amps.	0 – 60V D.C.	(000–600) × 1

9. System Tests

Particulars of the way in which the instruments described above and others, including the method of synchronising reading at fixed sites with those on moving vehicles will be found in Paper 2. The arrangements for decoding and evaluating the results are given in Paper 13. Particulars of associated tests on permanent way, on rolling stock and on overhead are given in Papers 21 and 22.

SUMMARY

This paper concerns the instrumentation and measurements required in connection with the System Test programme described in paper No. 2.

It describes the electronic digital recorders by which the bulk of the measurements were recorded. The electronic digital recorder is a new, fast recording instrument which produces its records for ready assimilation by computer equipment for the evaluation of results. The recorder, whilst formed of components of well proved performance uses them in a combination new to the testing of an electric railway system and greatly extends the scope of testing possible. The recorder is capable of sampling up to 12 different electrical inputs and its output is produced in digital form to the International Teleprinter code on punched tape. The recorder is arranged to accept inputs as D.C. voltages and is used in association with translators where the inputs originate in other forms.

The paper also describes a portable battery-driven continuous display wave-form analyser which is a new instrument developed by the P.O. The instrument measures and displays simultaneously the fundamental and 11 selected odd harmonics of the wave form submitted to it. This instrument greatly facilitates the wave-form analysis of quickly changing phenonema.

The paper concludes with brief descriptions of the translating units and of some other special measuring devices developed for these tests.

RÉSUMÉ

Cet exposé traite des instruments et des mesures des essais décrits dans le rapport No. 2.

Dans la présente note on décrit les enregistreurs électroniques digitaux au moyen desquels le grand nombre des mesures ont été effectuées. Ce sont de nouveaux enregistreurs rapides qui produisent leurs enregistrements tout prêts pour être appliqués à la calculatrice pour l'évaluation des résultats. Bien que toutes les parties de l'enregistreur aient des performances bien connues, elles n'ont pas été employées auparavant dans cette nouvelle combinaison pour essayer un réseau ferroviaire électrifié. Ces dispositions contribuent puissamment à l'augmentation de la portée des essais. Cet appareil est capable d'enregistrer 12 mesures différentes au maximum et l'enregistrement s'effectue sur une bande perforée sous forme digitale conformément au Code International des Téléimprimeurs. L'appareil est prévu seulement pour la mesure des tensions continues et on l'emploie conjointement avec des convertisseurs statiques dans le cas où les quantités à mesurer ne sont pas des tensions continues.

L'exposé décrit aussi un nouveau instrument portatif développé par l'Administration des Postes; il s'agit d'un appareil alimenté par des batteries qui indique continuellement les harmoniques. L'instrument mesure simultanément l'harmonique fondamentale ainsi que les 11 harmoniques de rang impair et facilite beaucoup l'analyse des phénomènes qui changent rapidement.

L'exposé se termine par une description brève des convertisseurs statiques et d'autres dispositifs de mesure développés tout spécialement pour ces essais.

ZUSAMMENFASSUNG

Der vorliegende Bericht behandelt die Instrumente und Messmethoden des " System-Testprogrammes ", das bereits in Bericht No.2 beschrieben wurde.

Der Bericht beschreibt zunächst die elektronischen Registrierapparate mit deren Hilfe der grösste Teil unserer Messergebnisse in Form von Ziffern festgehalten wurde. Die Aufzeichnungen dieser elektronischen Höchstleistungs-Instrumente können von normalen elektronischen Rechenmaschinen direkt assimiliert und ausgewertet werden. Obwohl die Registrierapparate durchwegs aus wohlerprobten Teilen hergestellt wurden, können sie wegen deren neuartiger Kombination und wegen ihrer erstmaligen Anwendung auf dem Gebiete des Eisenbahnwesens als neuartige Instrumente angesehen werden, zumal durch ihren Einsatz der Bereich der Prüfmöglichkeiten entscheidend erweitert wurde. Der elektronische Registrierapparat nimmt 12 verschiedene elektrische Grössen auf und liefert die Ergebnisse – gemäss dem Internationalen Fernschreibeschlüssel – in Ziffern auf Lochstreifen. Da das Instrument für den Empfang von Gleichspannungen ausgelegt ist, arbeitet es mit Uebersetzungsgeräten zusammen, welche die andersartigen Grössen in Gleichspannungen umwandeln.

Das zweite in dem Bericht beschriebene Instrument ist ein tragbares Gerät mit Akkumulatorenspeisung, das kürzlich von der Postverwaltung für Wellenformanalysen entwickelt wurde. Das Instrument ist so ausgelegt, dass eine Grundwelle und 11 ausgewählte, ungerade, Harmonische der zu untersuchenden Wellenform gleichzeitig gemessen und angezeigt werden. Es erleichtert daher wesentlich die Durchführung von Wellenformanalysen rasch veränderlicher Erscheinungen.

Der Bericht schliesst mit einer kurzen Beschreibung der Uebersetzungsgeräte und anderer Messeinrichtungen die für die Prüfverfahren besonders entwickelt wurden.

RESUMEN

Este artículo trata de los instrumentos y de las medidas que se necesitan para el programa de ensayos descrito en el artículo No.2.

Se describen los registradores electrónicos por medio de los cuales la mayoría de las medidas se han efectuado. Este aparato es un instrumento rápido que produce sus registros listos para colocar en la máquina de calcular para la evaluación de los resultados. Aunque todos los componentes del registrador están bien comprobados, no se han empleado antes en tal combinación para el ensayo de una red electrificada; tal disposición alarga mucho el alcance de los ensayos. El registrador es capaz de seleccionar de hasta 12 entradas distintas, y sus resultados se producen en cinta perforada en forma numérica conforme al Código Internacional de Teleimpresión. Puede aceptar entradas en forma de corriente contínua y se emplea con traductores cuando las entradas se originan en otras formas.

El artículo trata también de un instrumento portátil desarrollado por el Correo Británico. Este aparato se acciona por baterías y analiza los perfiles de onda; mide y muestra simultáneamente la armónica fundamental así como 11 otras armonicas elegidas del perfil de onda, y facilita el analizar fenónemos que siguen modificándose.

El artículo concluye con una descripción breve de las unidades traductoras y de algunos otros dispositivos de medida destinados especialmente a estos ensayos.

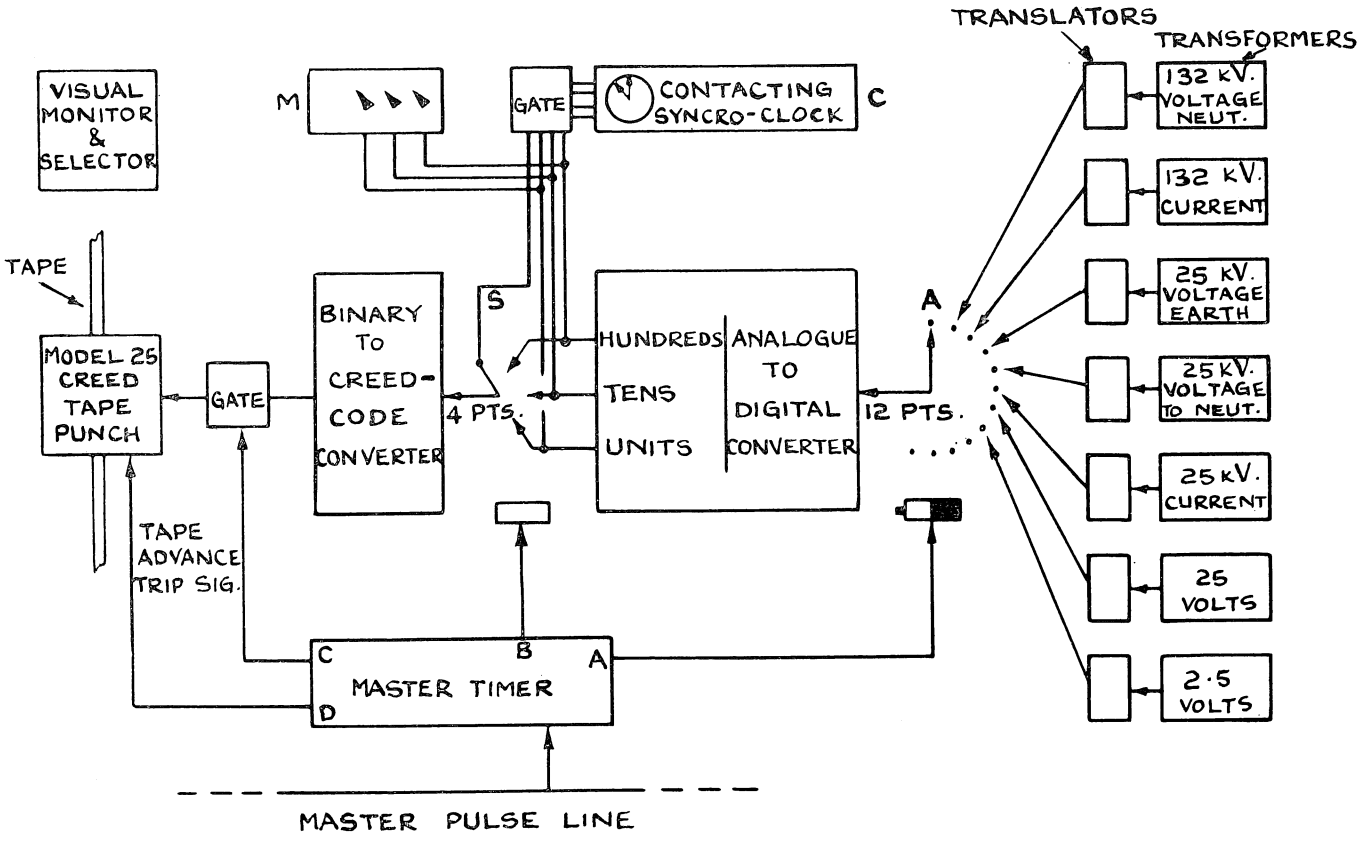

Fig.1 Block Schematic Diagram – Railway Feeder Station

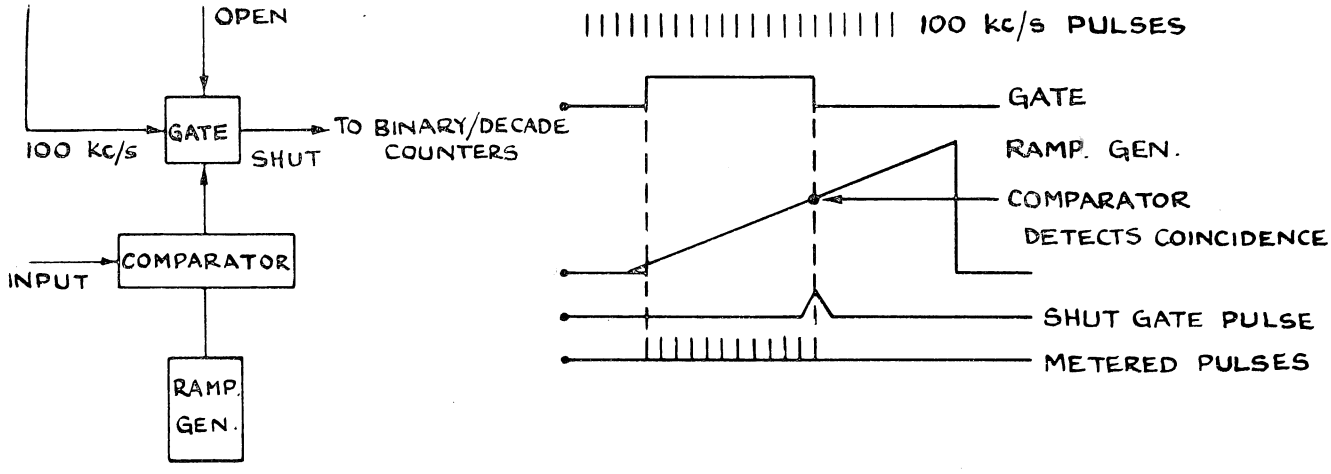

Fig.2 Analyser Technique

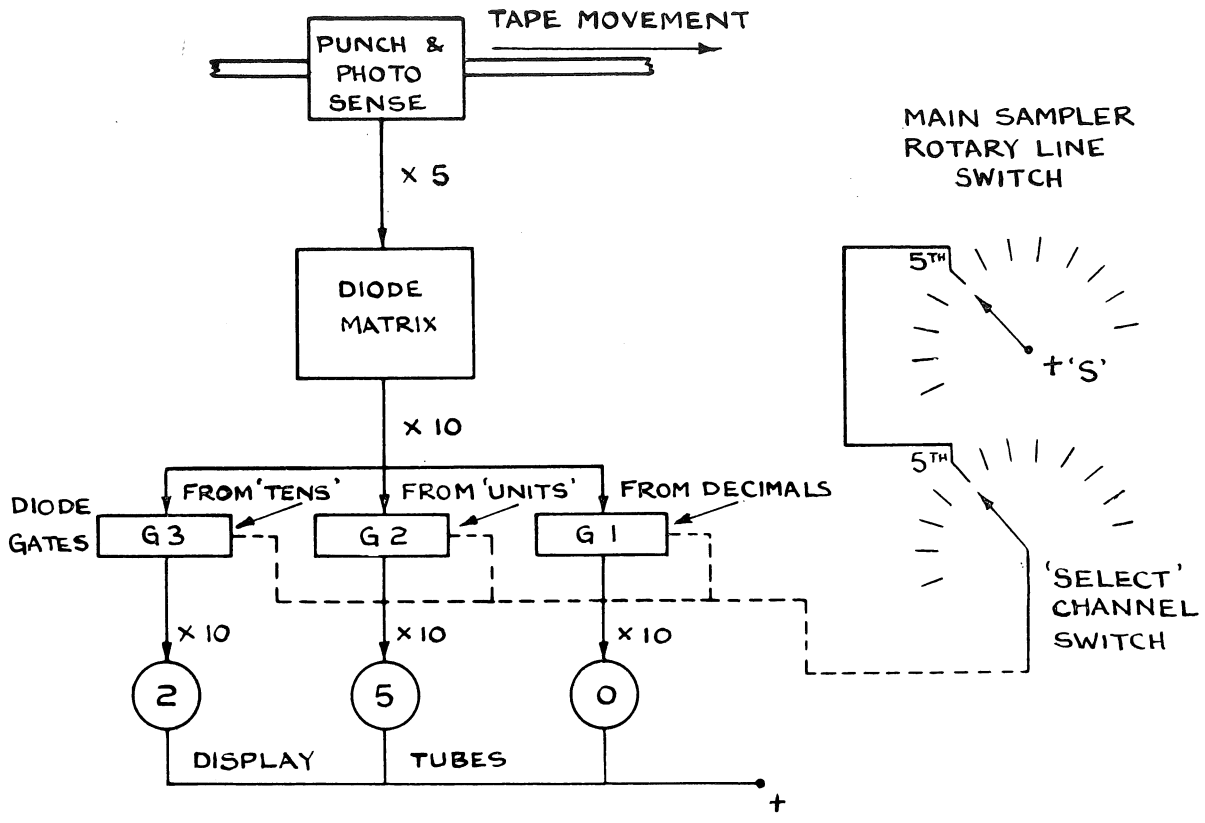

Fig.3 Block Schematic Diagram for visual monitor

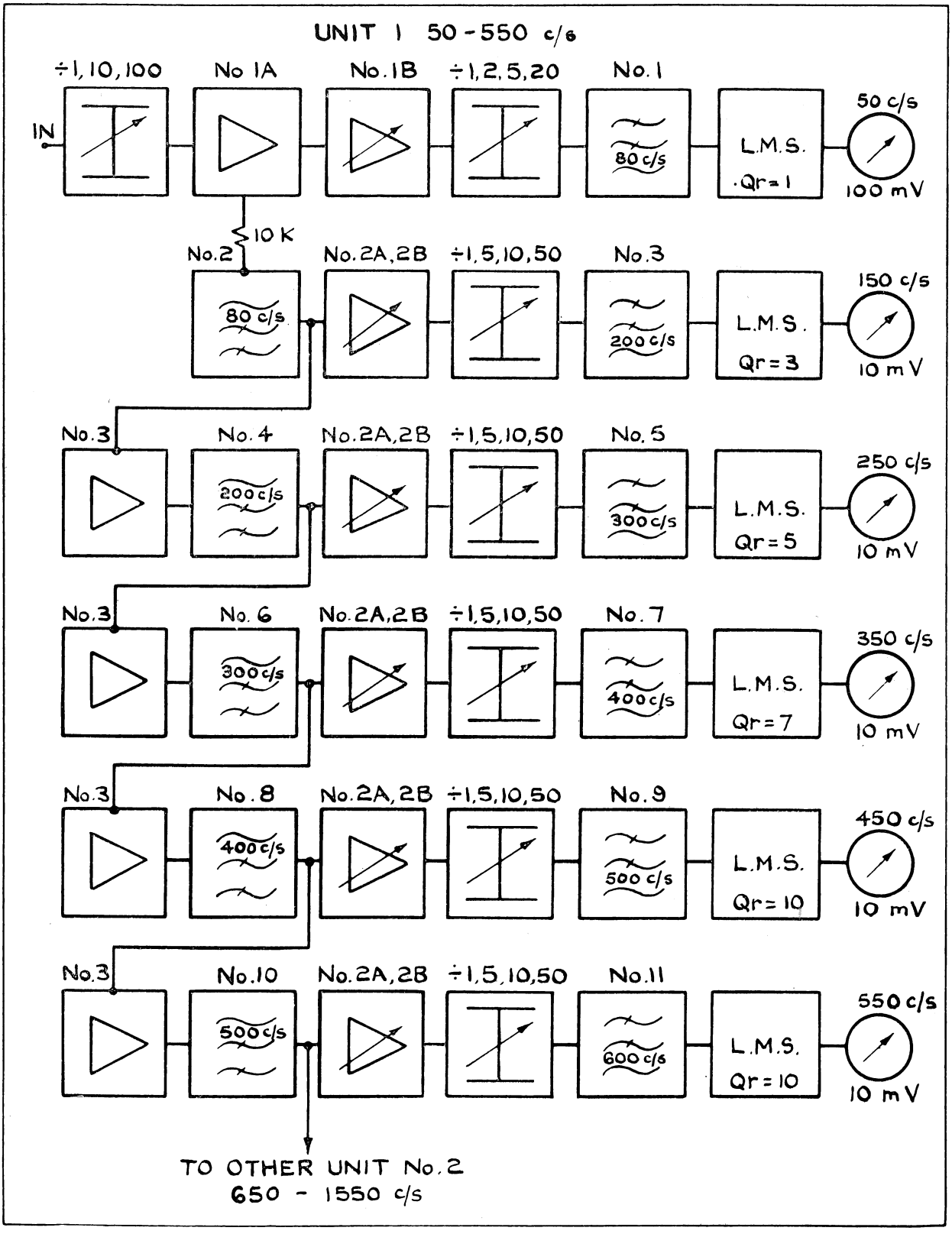

Fig.4 Continuous Display Wave Form Analyser Block Schematic

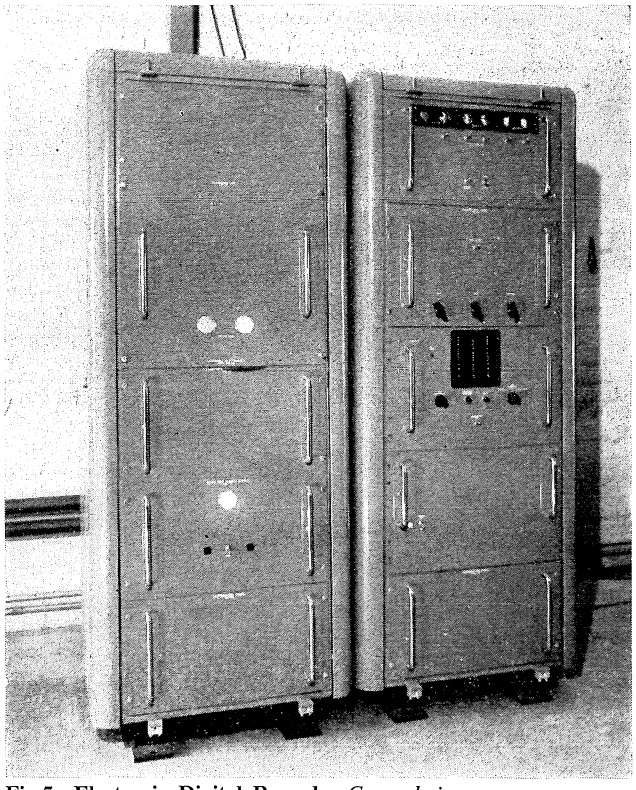

Fig.5 Electronic Digital Recorder *General view*
Left-hand cabinet contains Creed tape Punch and power supply stabilising units. Right-hand cabinet contains analogue/digital converter unit and electronic clock.

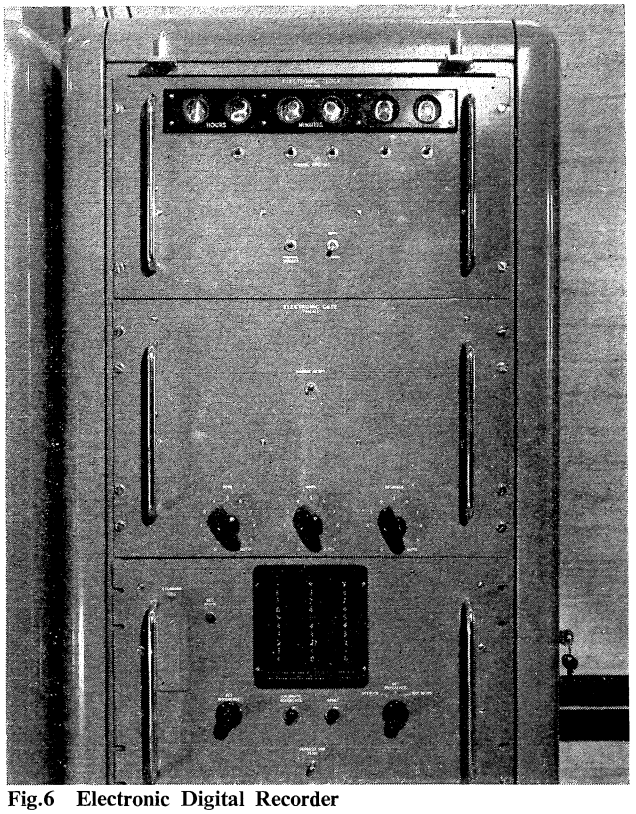

Fig.6 Electronic Digital Recorder
Detail of cabinet containing analogue/digital converter unit showing 3 digit indicator panel, control switches and (top) electronic clock.

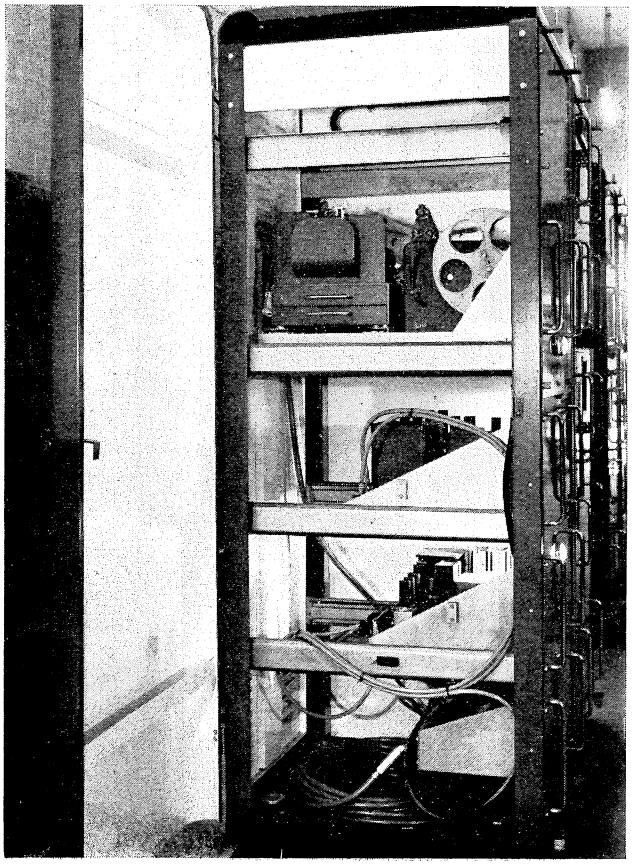

Fig.7 Electronic Digital Recorder
General view of interior of cabinet containing Creed tape Punch and power supply stabilising units.

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