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A CENTRALIZED SUPERVISORY AND CONTROL SYSTEM FOR WATERWORKS

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The System described makes available to water distribution authorities the advantages of centralized supervision and control.

With an ever increasing demand for water and with progress towards a national grid the introduction of more sophisticated methods of control than those in general use is essential.

Although primarily designed for the needs of the Water Boards, the system can be readily adapted for other liquid or gas distribution networks.

CENTRALIZED control has been commonplace for a number of years in the electrical distribution industry but it was much later introduced into the gas industry and only recently into the water distribution field.

The storage of a reserve supply—which is denied to an electrical distribution network—allows the tempo of control operations in gas and water networks to be somewhat leisurely. The effect of the demand upon the supply is always delayed by the reserve.

The average daily domestic consumption of water in this country is probably of the order of 30 gallons per head, with industry using the equivalent of an equal amount, so millions of gallons are required to satisfy the needs of even a small urban community. This water is obtained from rivers, catchment reservoirs or from deep wells and is distributed by pumping stations through a network of storage reservoirs and booster stations interconnected by high and low pressure mains. The level of water in the storage reservoirs is maintained by pumping operations to ensure that an adequate supply is available to meet all expected demands at all points of the network.

A pre-determined pumping plan for each day may be formulated from a long-term study of the daily pattern of demand and the daily checks on the storage reservoir levels made by a visit or, perhaps, by a simple telemetering installation.

However, with consumption showing an ever increasing upward trend, the cushioning effect of existing storage capacity is diminishing, making it necessary to couple the supply more closely to the demand. This entails a more frequent checking of the storage reservoirs and a pumping plan more responsive to level changes. An increased labour force may be a temporary solution but is not economic as a long-term policy.

Centralized Control

A system has been produced which makes centralized control of distribution now available to Water Undertakings and permits the existing storage capacity to be used at its maximum efficiency by providing a constant watch on, and for the recording of, reservoir levels and a close control of pumping.

A typical control board is shown in Fig. 1. The basic section on the left contains the control and alarm indicating equipment. The other sections which house the telemetering recorders and indicators are provided as necessary to meet the requirements of the distribution network.

Line Plant

To ensure that the provision of the wires for the transmission of data to the control room offers no practical difficulties, the system is designed to use one common pair of wires to connect all reservoirs and pumping stations to the control room. This is achieved by the use of switching centres, each serving a group of reservoirs. The switching centres or, as they are termed, way-stations, are connected to the control room by the common line. Each reservoir is connected to its associated way-station by a pair of

Fig. 1—Typical Water Supply Control and Indicating and Recording Equipment Panels

independent direct wires. Hence the use of individual wires is restricted to the relative short distances between reservoirs and way-station.

The preferred maximum number of way-stations is six but may be increased to ten if certain limitations are accepted.

Usually a pumping station is sited within a group of reservoirs and the way-station is located within the pumping station buildings. The way-station equipment is housed in a steel dust-proof cabinet which also accommodates apparatus for the remote control and indication of the pump motors, valve postions, etc., of the station.

Where no suitable shelter exists, an outdoor cabinet is available and in these circumstances the way-station is concerned only with reservoir levels.

The power for the way-station equipment is obtained from the mains, but a battery of dry cells housed within the cabinet takes over automatically in the event of mains failure.

The control room equipment can be made to act as the way-station for any reservoirs in its vicinity.

Multiplex Working

The information displayed on the control board serves to confirm the accuracy of the estimated daily pumping plan. Should an unpredicted demand prove the plan inadequate, the falling reserves give a warning which becomes apparent some time before an emergency exists. Continuous reservoir level indication is not therefore necessary and a periodic inward transmission of level data is quite sufficient.

The system employs a sequential time basis—or the multiplex principle—for the collection of data, and scans the whole of the common line and way-station networks at pre-determined intervals.

Each scanning operation commences with a test on the continuity and insulation of the common line. The spur lines from the common line into the way-stations are included in the test.

The line test is followed by the scanning of each way-station network. At the control room, the equipment steps in synchronizm with the scanning operation to connect in turn to the common line, the indicators, recorders and pump indications on the control board. Thus each reservoir, pump, etc., has for a short period during the scan, exclusive use of the common line to transmit its data to the control board.

A scan can cover up to a preferred maximum of forty indications and these can be distributed over the way-stations as required.

Periodicity of Scanning

The scanning cycles are initiated by a synchronous motor-driven timing device in the control room. The device has also a reserve spring-operated drive which takes over during mains failure. It can be adjusted to give a time between scans of from five minutes to one hour in steps of five minutes.

The period between scans should be as long as possible to reduce wear in the equipment but not long enough to produce appreciable steps on the recorder charts of reservoirs with normally widely fluctuating levels.

Telemetering

To avoid the provision of a power supply at the reservoir site—which may be an expensive item—a Wheatstone bridge principle is used for level data transmission. The transmitter at the reservoir consists simply of a resistance, its value being controlled by the water level.

A copper float is connected to one end of a stainless steel perforated tape, and a counter weight to the other end. The perforations in the tape engage with the teeth of a sprocket wheel mounted on the driving spindle of the transmitter. As the float moves with the water level to turn the driving spindle, internal gearing positions the wiper arm of the variable resistance.

The receiver at the control board is a 12-inch diameter circular chart recorder. If desired, an easily read indication can also be given on a meter type receiver with an 8-inch scale. Within both instruments is a low voltage a.c. reversible motor which drives the wiper arm of a variable resistance. Attached to the wiper arm is the pen of the recorder or the needle of the indicator. The chart of the recorder is driven by a separate electrical or clockwork mechanism.

During the scan the variable resistances in the transmitter and associated receiver are joined in series over the common line. At the same time, the control equipment interposes a self-balancing Wheatstone bridge circuit between transmitter and receiver so that the two variable resistances form one arm of the bridge. If their combined value does not equal the value of the fixed arms of the bridge, the unbalance causes the operation of a very sensitive moving-coil relay in the diagonal of the bridge.

This relay—which is centre stable—moves in one direction or the other depending upon whether the combined resistance is greater or less than the fixed resistance. Its contacts drive the receiver motor to increase or decrease the receiver resistance so that balance is obtained. Once balance is achieved the scan is continued, and the next transmitter and receiver are coupled through the bridge circuit, except where a transmitter is associated with both a recorder and an indicator. In this case, the balancing

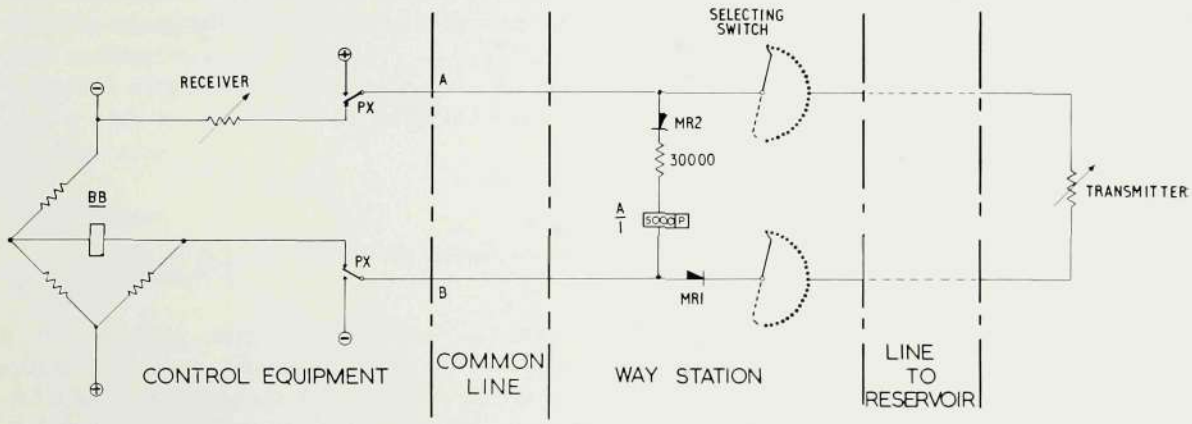


Fig. 2—Path Differentiation for Telemetering and Pulsing

of the indicator follows that of the recorder and then the transmitter is transferred back to the recorder. If re-balancing of the recorder is necessary it indicates that the position of the transmitter is changing and so the control equipment connects alternatively the recorder and indicator to the transmitter until stability exists for a defined period of time.

Line Transmissions

Over the common line the system transmits from the way-stations to the control equipment :—

1. The telemetering data.
2. The pump, valve, etc., indications.

And from the control board to the way-stations :—

3. The scanning control pulses.
4. The pump, valve, etc., control signals.

The telemetering data is transmitted as an analogue and as such its accuracy is determined by how much the common line characteristics mask from the bridge the full effect of a change at the transmitter.

As the line resistance and leakance increase, the accuracy may be maintained by increasing the sensitivity of the bridge relay and by using higher transmitter and receiver resistances. When the bridge relay becomes so sensitive that contact adhesion troubles are met, or the resistances employed are so high that a change in line leakance appears as a change of reservoir level, further line increases can be met only by less accurate telemetering.

The system has been designed to give an accuracy of within 1% of full scale over a line of 2000 ohms loop and 10000 ohms insulation resistance. (The maximum line resistance of 2000 ohms consists of a 1000-ohm common line and a 1000-ohm direct line between way-station and reservoir).

This accuracy is obtained without lowering our accepted factors of safety and as a further safeguard the bridge relay is fitted with a magnetic contact blow-off device.

It is essential that the way-stations shall be able to receive the scanning control signals at all times. This means that the receptive devices for these signals at the way-stations must remain connected to the common line during the transmission of telemetering data. They must not, however, contribute to the masking of the data and to avoid this, separate transmission paths are provided by rectification. The circuit arrangement is shown in Fig. 2 in which the transmitter resistance and the scanning control relay A at the way-station are electrically separated by rectifiers MR1 and MR2.

During telemetering, the bridge is connected with the negative potential to the A wire of the common line. The bridge is therefore affected by the transmitter resistance only.

The pulses controlling selection during scanning are applied by contacts PX with the positive potential on the A wire. Relay A of the way-station responds and is not shunted by the path through the transmitter resistance.

In practice, however, the separation is not complete. The leakage in the ' no-go ' direction through rectifier MR2 must be considered as this tends to reduce the telemetering accuracy. The MR2 rectifiers at all way-stations are across the line and their effect on the telemetering is additive, so the permissible leakage through each must be very low. Selenium rectifiers are used with an individual leakage current of not greater than 0.5 micro-amps. Their rated forward current is correspondingly low and should not exceed 1.5 milli-amps which is, therefore, the maximum operate current that can be offered to

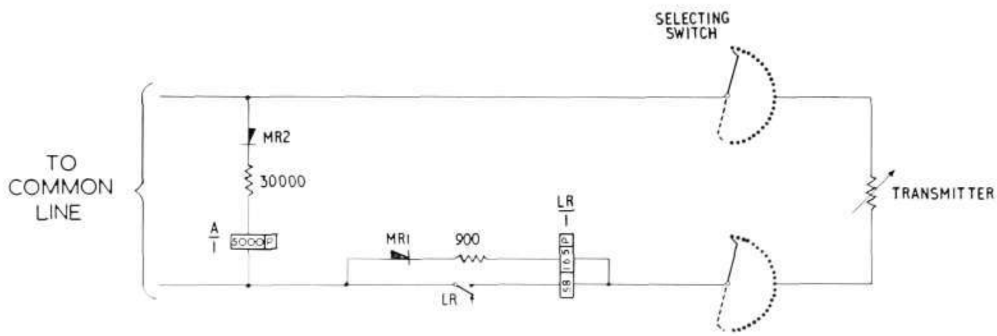


Fig. 3—Dynamic Rectifier Circuit

the A relay. To provide a factor of safety, the operate current is restricted to 0.5 milli-amps, and one-side-stable polarized relays in sealed cans are used.

The sensitive A relays are guarded against spurious operation and pulsing instability by using reverse current pulsing. The MR2 rectifiers are polarized by the reverse voltage so that the A relays are 50-volt biassed towards their stable side during quiescent periods and they release under virtually open circuit conditions during pulsing.

The leakage current of rectifier MR1 does not affect the pulsing of the A relays because there can be only one reservoir and, therefore, one MR1 rectifier connected to the line at any time, and the design of the pulsing elements allows satisfactory working with a shunt resistance as low as 2000 ohms across the line. (The actual purpose of this rectifier is to allow the A relay to function when the transmitter resistance connected to the line falls below this figure). Rectifier MR1 is a normal copper-oxide rectifier with a relatively low reverse resistance, nevertheless its forward resistance introduces a difficulty because, as a non-linear device, its value varies with the voltage across the rectifier. This non-linearity is in the telemetering path and would preclude accurate data transmission.

Rectifier MR1 is therefore associated with a polarized relay so that the combination forms the equivalent of a rectifier with a stable forward resistance. This circuit element is shown in Fig. 3, in which relay LR is operated under the conditions existing during telemetering by its 165-ohm winding via rectifier MR1. It is then held operated through its own contacts by its 58-ohm winding until telemetering is ended by the next selection pulse. The current reversal through the 58-ohm winding brought about by the pulse forces the relay contacts to open. The combination appears to the telemetering path as a rectifier with a stable 58-ohm forward resistance and a back resistance 1065 ohms higher than its inherent value.

Way-Station

An outline of the way-station circuitry is shown in Fig. 4.

The scanning control pulses operate and release polarized relay A. Relay A merely controls relay AA which is a high speed relay and, as such, is of low inductance, throwing no destructive load on the contacts of sensitive relay A. On the first pulse of the scan, relay AA operates relay C which in turn operates slow releasing relay D. The selecting switch is on its first outlet contact when the first pulse arrives, and relay B is operated in series with the driving magnet. Relay B locks relay C through the interrupter springs of the switch. At the end of the pulse, relay AA releases to hold relay B and to close the circuit of the magnet. Energization of the magnet breaks the interrupter contacts and relay C is released to break the magnet circuit. The magnet thus steps almost at the speed, and under the conditions, of self-drive.

Relays B and D hold during pulsing and, at the end of a selection, relay B is held by relay AA normal but relay D is released.

If the selected position is concerned with telemetering, then, on the release of relay D, the reservoir resistance is connected across the line.

If the selection is for the purpose of control, the appropriate control relay is operated in the selected control circuit and the associated indicate circuit is connected to the line. The indicate circuit is a two-state element that signals its condition back to the control board by connecting a high resistance loop to the line for one state and a low resistance for the other. The pump or valve is controlled by the control circuit and its response is transmitted back by a change in the indicate circuit.

Should the selecting switch get out of step during pulsing, it moves to a parking contact and remains there until it is returned to normal on the cessation of pulsing. The effect of pulsing failure is thus corrected before the next scan commences.

At the end of a scan, a long signal is sent from the control equipment. This clear-down signal operates relay A for a sufficient time to release relay B. The homing circuit of the selecting switch is closed, hence the clear-down signal is followed by the restoration of all way-station circuits.

Control Equipment

The fundamentals of the control board circuitry concerned with the common line signals are shown in Fig. 5.

Guard Circuit

The drive potential of the scanning pulses is applied by relay PX, and the reverse polarizing potential for the release of the A relays of the way-stations by relay PY. The

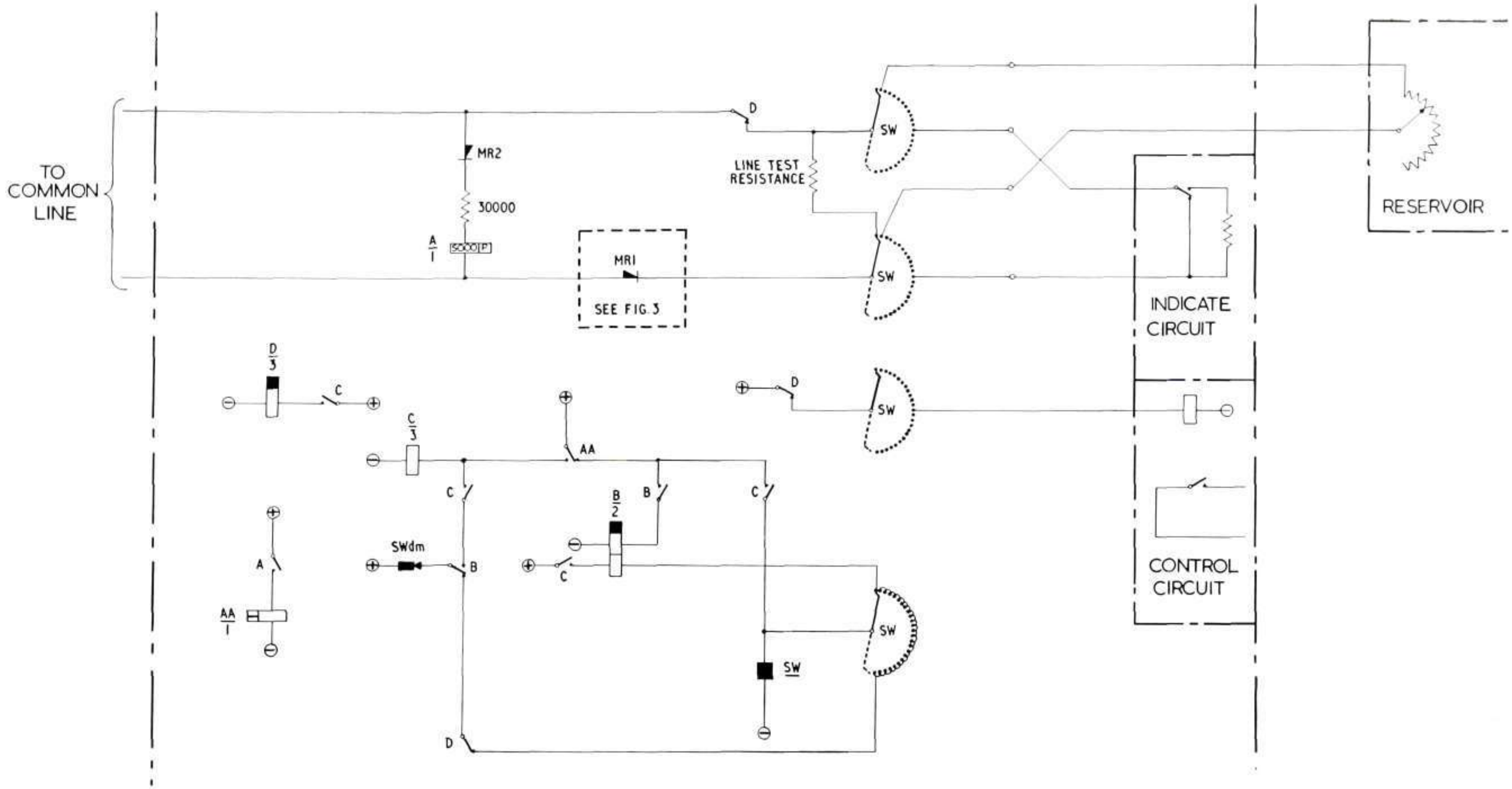


Fig. 4—Way-station Circuit Fundamentals

degree of polarization depends upon how much of the potential gradient appears in the actual line. To achieve the maximum polarization, the positive battery is fed direct and the negative through a low resistance of 25 ohms derived from the guard circuit. In the event of abnormal conditions arising, the guard circuit operates within 0.5 milli-seconds to protect the line and all contacts concerned by restricting the current to a maximum of 45 milli-amps.

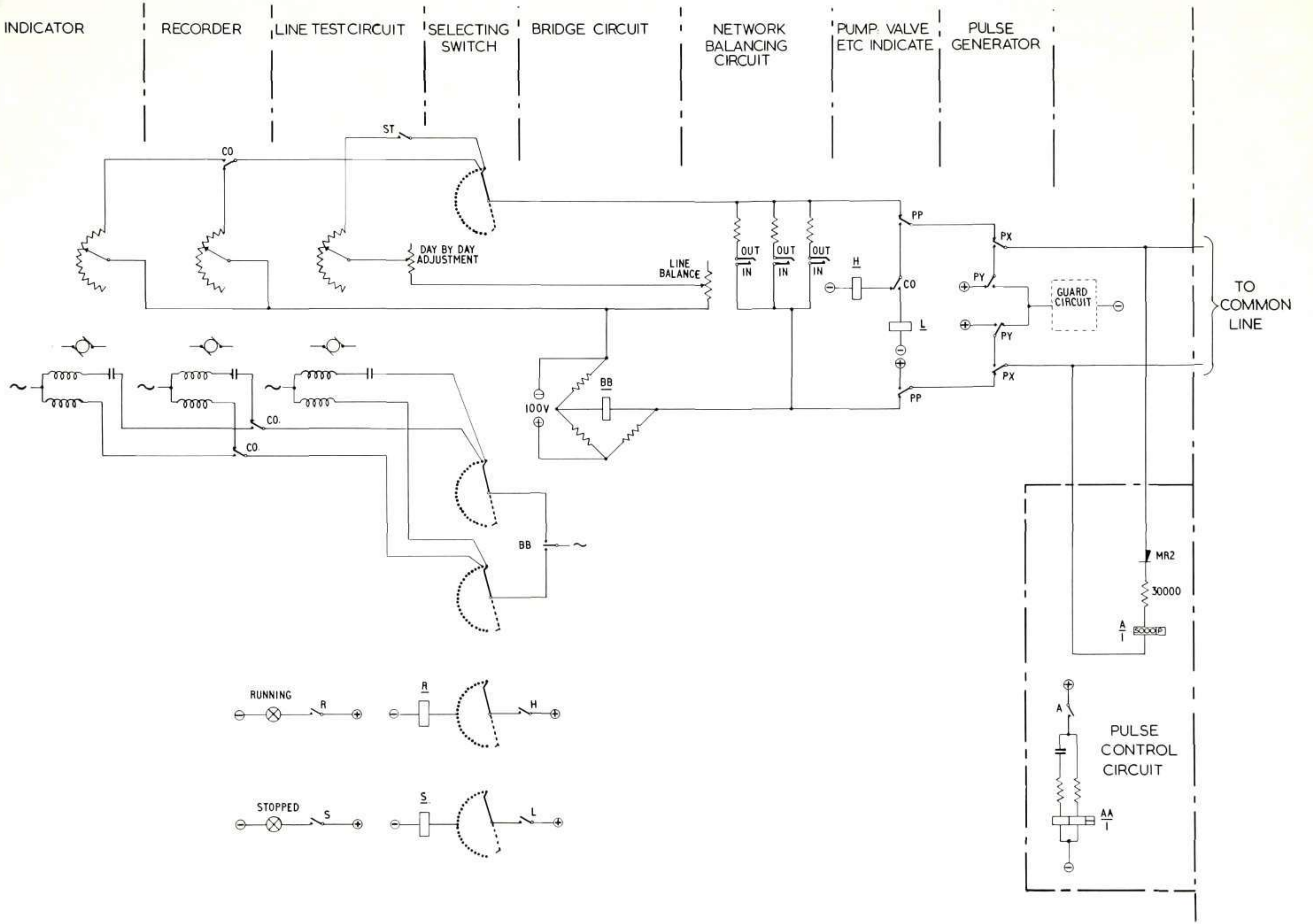


Fig. 5—Control Panel Circuit Fundamentals

Pulse Control Circuit

The pulse length is governed by the pulse control circuit. This circuit is similar to a way-station circuit but with added weighting factors so that its response time is that of a way-station working under the most unfavourable line conditions and with its relays adjusted to the tolerances which affect most adversely the working of the circuit.

The build-up and decay time of the line is simulated by relay AA, which is a high speed relay used differentially with one winding controlled by a non-inductive circuit and the other by capacitance.

The stepping response time of the pulse control circuit measures the minimum pulse length necessary to ensure satisfactory stepping under any distribution pattern of the way-stations along the line.

Selecting Switch

This is stepped by, and interlocked with, the pulse control circuit so that during a scan, the selecting switch of the control equipment and those of the way-station move in unison.

Line Test

When relay ST operates at the commencement of a scan, the line test indicator is connected into the unknown arm of the bridge circuit. The indicator is a mechanism similar to that of a reservoir level indicator and is controlled in a like manner by relay BB of the bridge circuit. The unknown arm also includes the variables of the network balancing circuit and is completed by all way-station line test resistances (see Fig. 4) in parallel.

The line test detects any deviation of the line network from its normal characteristics and which may be detrimental to the performance of the System. This can range from a decreasing insulation resistance, which would impair the accuracy of the level data, to the disconnection of one or more way-stations.

The line network can present a resistive value within the limits given by a zero-ohm line with six way-stations to a 1000-ohm line with one way-station. During the line test, the resistance of the bridge arms is changed in value so that the bridge circuit has its maximum sensitivity within these limits.

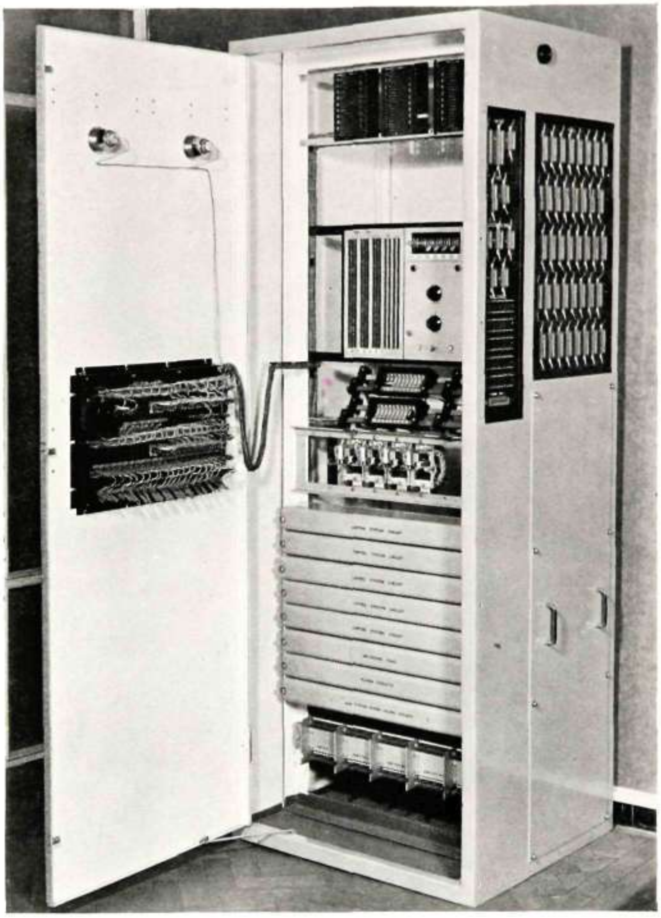


Fig. 6—A Control Cabinet Equipment including plug and socket field

When the System is initially set up, or following upon a subsequent alteration of line network, the characteristic resistance of the line network is matched to the bridge arms by setting the variables on the line-balancing panel. This panel is mounted within the control cabinet as shown in Fig. 6 and is on the right-hand side in the enlarged view, Fig. 7.

Each of the six keys at the top represents a way-station line test resistance and is mechanically locked into the ' in ' or ' out ' position depending upon whether or not the way-station represented exists in the line network. The panel circuits are made effective by pressing the adjust key, and the bridge is then balanced by use of the coarse and fine adjustments. The lamps at the top of the panel indicate when the bridge is unbalanced ; the direction of unbalance is shown by one lamp or the other being lit, so adjustment is made until both lamps are extinguished.

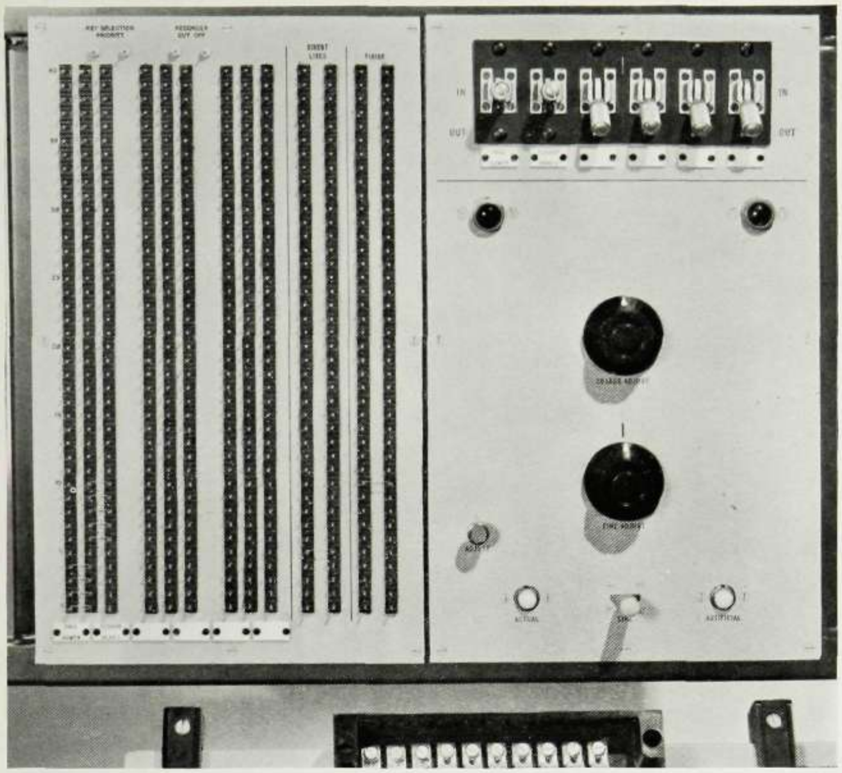


Fig. 7—Enlarged View of Line Balancing Panel in Fig. 6.

Should the pointer pass beyond the extreme of the 'adjust' sectors, a line fault alarm is given and the scan is abandoned.

Reservoir Position

When the selecting switch reaches a contact associated with a reservoir, the variable resistance of the recorder is connected in series with the line. The recorder motor is driven by the bridge relay BB until balance is obtained. Relay CO then operates to connect the associated indicator and when this is brought into balance relay CO releases to reconnect the recorder. The operation and release of relay CO continues until no movement of either the indicator or recorder occurs in a pre-set period of time. With stability achieved, the scan is continued.

An artificial line with characteristics of mean value can be connected to the bridge instead of the actual line by the key at the bottom of the panel. By eliminating the unknown, the artificial line facilitates preliminary balancing and checks the functioning of the panel.

Upon the release of the adjust key, the line test indicator is brought into action and it moves its pointer to a position on its scale representing the approximation of balance. The pointer should then be moved to within a defined central sector of the scale by using a set of controls associated with the indicator which give a final delicate adjustment to the balancing of the bridge.

The width of this sector covers the permissible day-to-day variation in the line characteristics due to weather conditions. Outside this sector, the scale is labelled 'adjust', and if the pointer should wander into these parts of the scale it can at any time be re-centralized by using the sensitive controls.

Once set, the line test circuit stores this normal resistance value of the line network and when brought into use at the commencement of each scan, the indicator pointer should remain within the central sector of the scale.

Pump Position

On a contact associated with a pump or valve, relay PP is operated and relays H and L are connected successively to the line. These relays are operated in accordance with the indicating resistance applied by the indicate circuit at the way-station. Relay R or relay S is operated to give a permanent visual indication of the state of the pump or valve.

MANUAL CONTROL PANEL

Under the normal routine scanning cycles, the System supervises the water distribution network and presents and records on the central control board a general picture of the conditions existing at the moment. To permit modifications or closer scrutiny, a manual control panel is mounted under a bureau cover on the control board. As shown in Fig. 8, this panel is divided into a number of sub-panels, those in the lower part being mainly concerned with selection and in the upper part with control.

Key Selection

On the larger sub-panel at the bottom are up to 40 keys, each associated with a selection in the

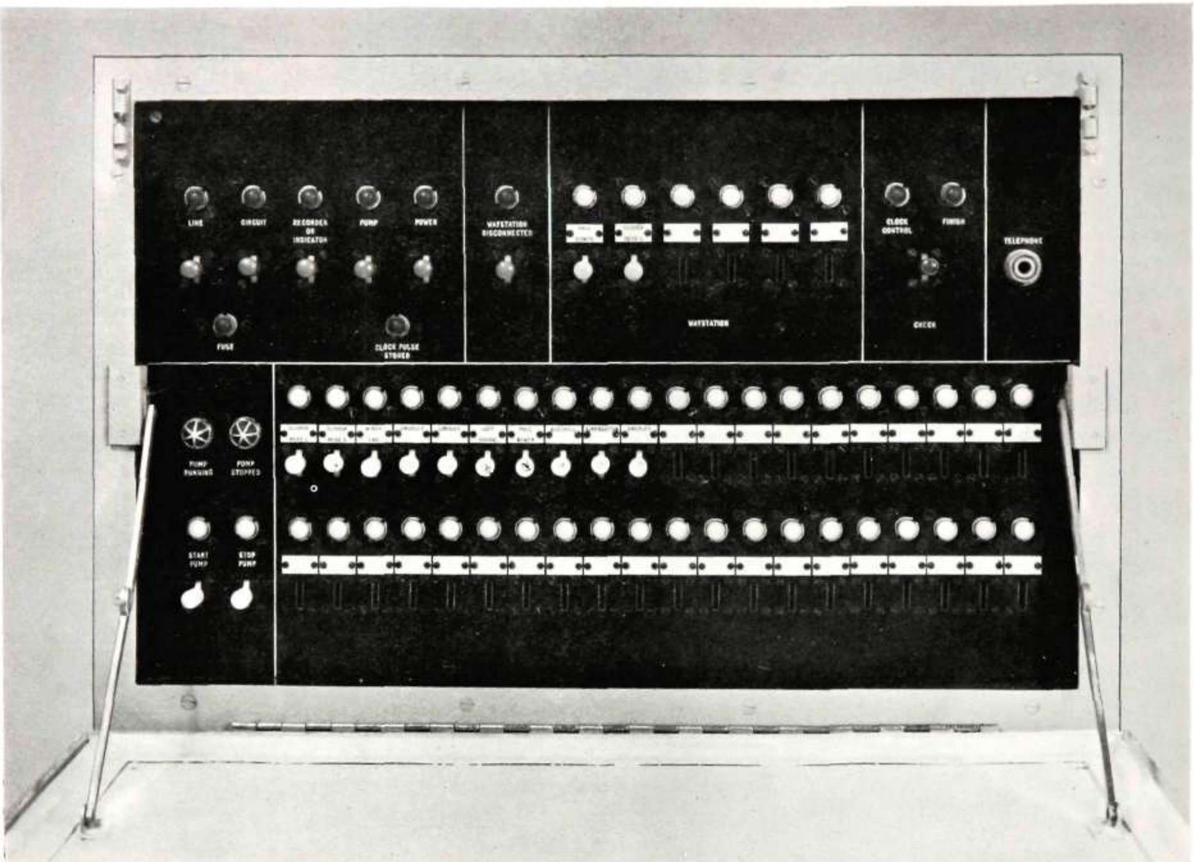


Fig. 8—Typical Panel for Manual Control of Water Distribution

scanning cycle. If one of these keys is operated, a scan is immediately commenced but all selections except the one chosen are ignored. The lamp above the operated key is lit when the scan reaches and stops at the selected point. If a reservoir is selected, then, as long as the key remains operated, the associated indicator and recorder will react immediately to any change in level. This condition is identical to that of direct line telemetering.

If the key is associated with a pump, then the normal visual indication of the state of the pump, on the control board, will be directly controlled from the way-station concerned.

Restoration of the select key returns the System to clock controlled scanning.

Pump Control

To change the state of a pump, valve, etc., the control signal is sent to all way-stations by operating either the ' start ' or the ' stop ' key on the smaller bottom sub-panel. The control signal is stored at each way-station until the pump concerned is key selected. Only the way-station concerned with the selected pump reacts to the control signal and changes the state of the pump accordingly. The response of the pump to the control signal is indicated by the two lamps above the control keys.

The control signal is cancelled at all way-stations if it is followed by any signal other than a pump selection.

Way-Station Supervision

The two top centre sub-panels are concerned with supervision of the way-stations. They indicate when a way-station is working on its standby battery because of a mains failure, or has become disconnected from the line. Each way-station can be key selected for individual checking purposes.

Check Scan

The top right-hand sub-panel allows the scanning cycles to be manually started at any time and its functioning checked. The progress of the scan is indicated by the lamps over the select keys lighting as each selection point is reached. The check facility cannot interfere with a clock-controlled scan that is already in progress.

If a clock pulse originates during a check scan the pulse is stored and its presence indicated by a lamp. At the end of the check scan, the stored clock pulse is released to initiate its own scan.

Alarms

The top left-hand sub-panel accommodates the alarm lamps and associated individual 'acknowledge' keys. These cover a line fault, a circuit fault within the control equipment, a recorder or indicator that has failed to respond correctly to the telemetering data, and an indicate circuit that has failed to respond to its incoming signals.

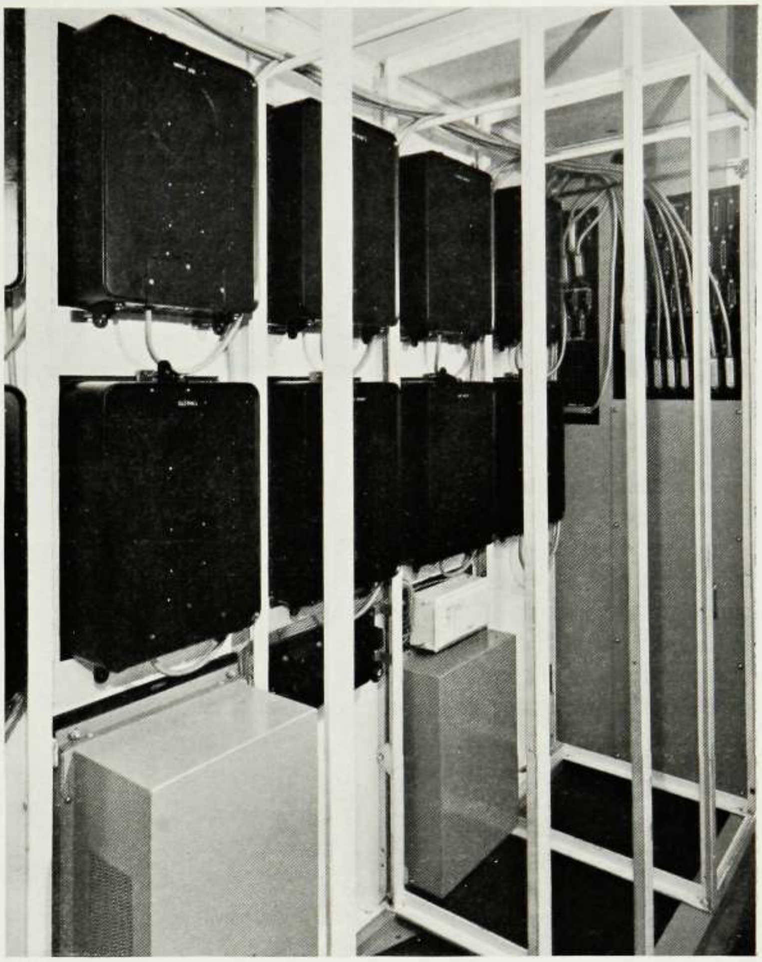


Fig. 9—Internal View showing plug and socket connections to indicating and recording apparatus

Scan Allocation Panel

The terminals of this panel (mounted on the left of the balancing panel in Fig. 7) are strapped so as to present to the control board circuitry the distribution pattern of the forty selections over the way-stations.

Other terminals enable the recorders to be omitted from a check scan if required, thus avoiding the inclusion of extraneous information in the permanent records.

Provision is also made for the operation of a select key to over-ride a scan already in progress. The scan cycle is abandoned and the selected point connected to the control board. This allows emergency manual control to be effective without delay.

Interconnection of Control Board Panels

The basic control cabinet is connected to the control board panels by plugs, sockets and flexible cords.

The sockets can be seen on the side of the cabinet in Fig. 6, and the plugs and cords in situ in Fig. 9, which is a view inside a control board. The plugs are locked into the sockets and cannot become detached accidentally. The System thus provides for the future growth of the water distribution network without difficulty, since an extension of the control board is merely a matter of plugging-in an extra panel. The plug wiring conveys to the control equipment circuitry all necessary information about the additional panel, such as whether it is equipped or not with indicator, recorder and pump control.

U.D.C.621.395.26

P.A.B.X. TYPE ET. 4

E. C. Dyson — Circuit Development Engineering Department

A technical description of an extensible P.A.B.X. with a cordless manual board appeared in Bulletin No. 33, July 1956. The following article describes a recently developed version of this P.A.B.X. employing floor pattern switchboards with press-button controls. The facilities provided conform to the requirements for use in the United Kingdom and the system has received British Post Office approval.

P.A.B.X. type ET.4 is also suitable for overseas Administrations due to the wide range of facilities available.

IN a manual private branch exchange the onus of restricting the service given to an extension line is vested in the operator, but a P.A.B.X. allows any extension to be provided with service facilities suited to the status of the user. P.A.B.X. type ET.4 gives complete flexibility so that every extension can be given any of the following facilities by adding or removing wire straps on the extension line circuit connection strips.

1. *Barred Access to or from the Public Exchange*

   Extensions in this category are unable to be connected to the public exchange under any circumstances whatsoever, but calls to and from other extensions can be dialled in the normal manner. Access to private wires and the P.A.B.X. manual board can be permitted or barred in accordance with the customer's wishes.

   This classification is sometimes required for extension telephones accessible to the general public where stringent measures are necessary to prevent fraudulent exchange calls. In some countries, a reduced rental is charged for extensions in this category.

2. *Barred Direct Access to the Public Exchange*

   These extensions have all internal services, but exchange calls must be extended via the operator or transferred from another extension.

3. *Direct Access for Public Exchange Local Calls*

   A considerable proportion of lines usually fall into this category which provides all the facilities of (2) above, with the addition of direct access to the public exchange by dialling '9'. The barring of trunk calls is effected by segregation of lines in the public exchange or, alternatively, by the provision of equipment in the P.A.B.X.

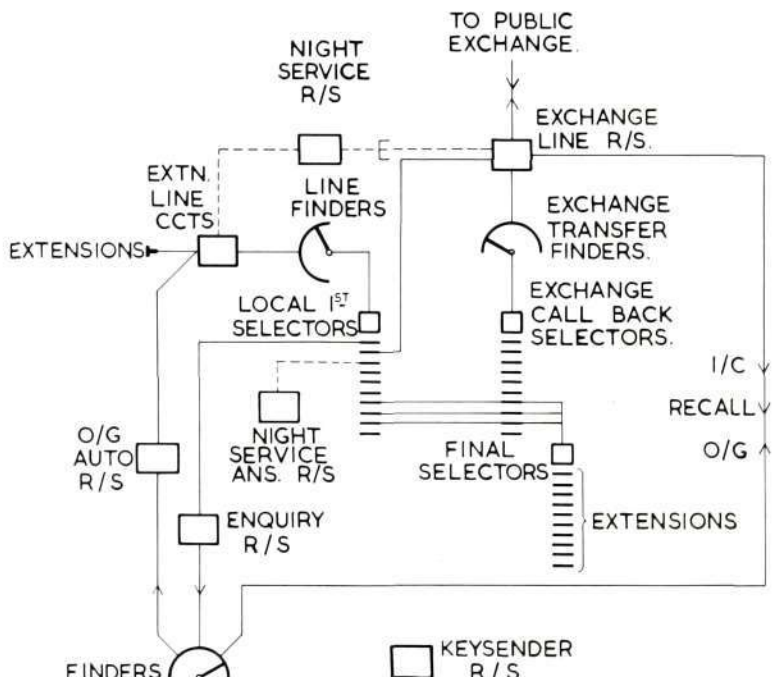


Fig. 1—Typical P.A.B.X. ET4 Trunking

exchange line circuit which checks the code dialled. The call is disconnected if the code is barred and 'number unobtainable' tone is transmitted to the caller.

4. *Direct Access for Public Exchange Local and Trunk Calls*

In this case the user has all the facilities of (3) and is not prevented from dialling trunk calls or the public exchange operator.

5. *Priority Extensions*

This classification is usually reserved for Executives. Such extensions have all the facilities of the preceding classification and the ability to intrude into existing extension-to-extension calls, but not into public exchange calls. If the need to contact an extension engaged on an exchange call is sufficiently urgent, the P.A.B.X. operator must be called and she will either pass a message or request the engaged extension to clear. When specially required, it is possible to arrange for an extension to intrude into exchange line calls, but this facility is not usually permitted by the British Post Office.

TRUNKING

The manner in which traffic is routed is shown in Fig. 1. Conventional Strowger switching via group and final selectors is used for extension-to-extension traffic ; exchange line calls are routed to final selectors via transfer finders and call back group selectors. These selectors are taken into use only when the operator actually extends a call to the local extension.

Fig. 2A—Operator connected to Exchange

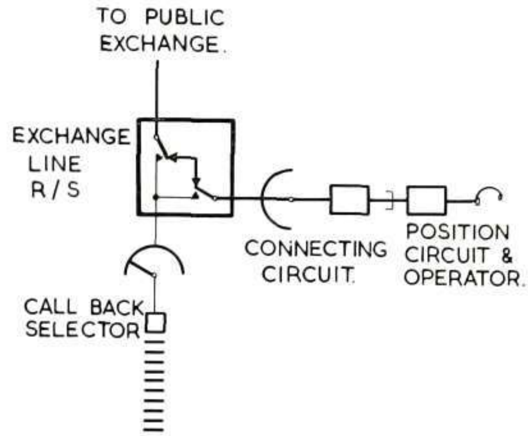


Fig. 2B—Operator connected to Extension (Exchange held)

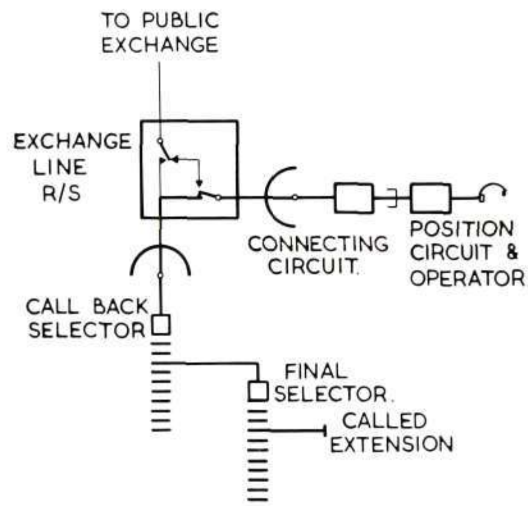
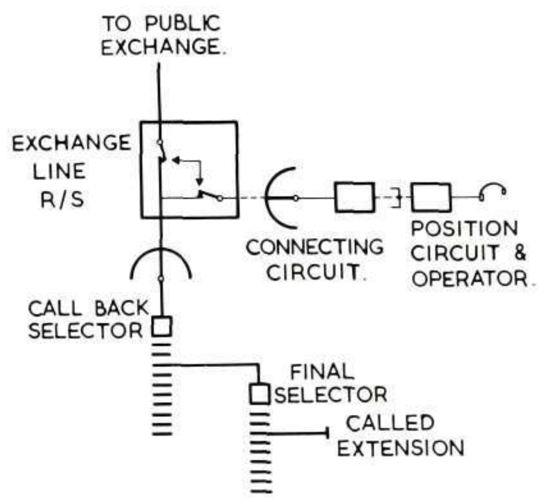


Fig. 2C—Extension connected to Exchange



Figs. 2A-C—Routing of Incoming Exchange Calls.

The connecting circuits are of a type which replace conventional cord circuits and they serve as control links between the operator and the relay sets.

Fig. 2A shows the condition existing when the operator is answering or originating an exchange line call. When the call is to be extended, her speech circuit is diverted to the call back selector and, as illustrated in Fig. 2B, by using the key-sender or dial, she may establish contact with an extension. In this condition a lamp, designated ' internal ', glows on the switchboard. Since the speech path between the exchange line and the extension is split, the operator has the benefit of both lamp and tone supervision over the internal call, and neither tones nor speech between operator and extension can be overheard by the public exchange.

The next stage is shown in Fig. 2C where the extension is connected to the exchange line. Normally the connecting circuit is released at this juncture but if the operator so desires, she may momentarily operate a ' hold ' button and the connecting circuit will remain held for the duration of the call. This is shown by dotted lines. Outgoing trunk calls may then be timed, and on exchanges provided with Subscriber Trunk Dialling (S.T.D.) facilities, the call charge can be ascertained from a connecting circuit meter on the switchboard. Extensions can still transfer exchange line calls even though they may be held, and the operator receives an indication to enable her to allocate call charges appropriately.

The operator may monitor the circuit at any time but she cannot effect control without consent of the extension, and her presence on the line is indicated by a rhythmic 400-cycle intrusion tone. Battery feed to the extension and, for all practical purposes, the transmission level of the call are unaffected.

Two other circuits shown on the Trunking Diagram, Fig. 1, may be mentioned. Firstly, the O/G Auto relay set which enables operators to contact extensions and secondly, the Enquiry relay sets which carry traffic in the reverse direction and are mainly used for booking purposes. Unless specially requested, provision is not made for completing calls over the Enquiry relay sets on a demand basis.

The Console Switchboard

On the previous P.A.B.X., small desk type switchboards were used. Due to the greater quantity of face equipment necessary on the ET.4 version,

Fig. 3—Manual Switchboard

a console switchboard (including provision for eight connecting circuits) as shown in Figs. 3, 4 and 5 has been adopted.

The console is constructed of light oak and stands on a plinth faced with black Warerite. The writing shelf (finished in grey Warerite), provides ample space for tickets or writing pads and an extension of the side members separates adjacent positions to prevent papers falling to the floor or being inadvertently pushed on to neighbouring positions. This extension can be provided on cordless positions because operators are not required to reach over to other positions.

A matt dark green finish is normally applied to the steel control and display panel, which is shaped to raise the most frequently used buttons to a convenient level for operation.

The control panel is hinged so that all maintenance work can be undertaken from the front, thereby permitting positions to be installed either side by side or back to back. This freedom of location means that switchboards may be positioned singly, in groups or even backed against a wall. The possible saving of space over cord equipment which requires cable turning sections, or a straight line layout for the benefit of the multiple, with freedom of access to the rear, can be appreciable. Apparatus racks for

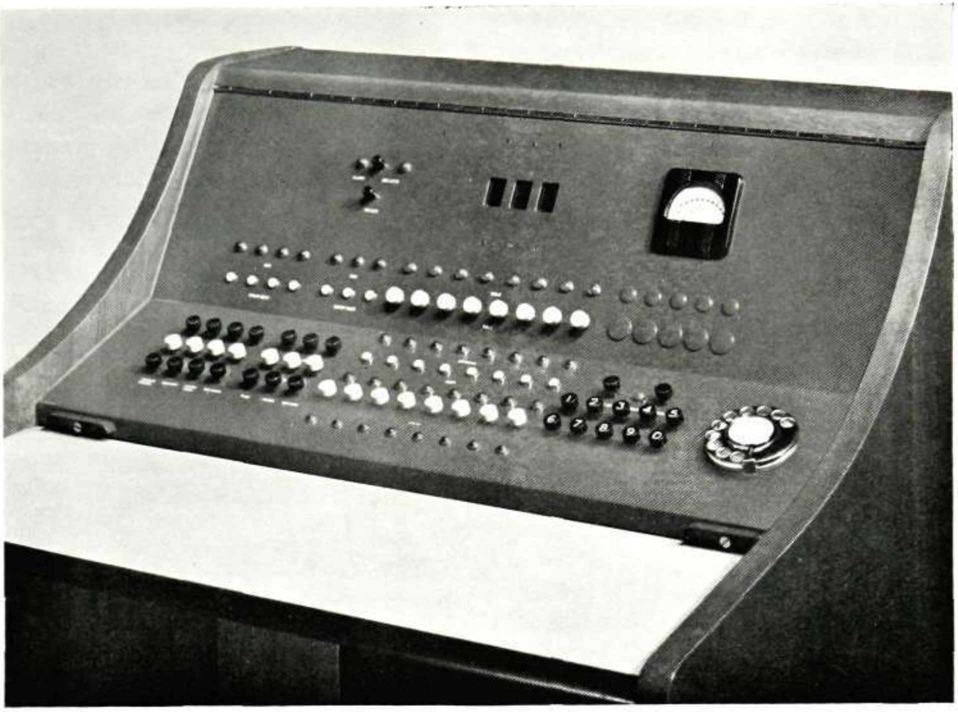


Fig. 4—Switchboard Control Panel

cordless systems frequently occupy more space than the equivalent racks for cord systems, but an overall saving is usually effected because fewer manual positions are required and less space is required per position.

There are no relays accommodated within the switchboard ; only components for the operator's telephone circuit and an alarm buzzer, thus avoiding the need for frequent maintenance.

The Waiting Calls meter shown in Fig. 4 registers the number of incoming exchange calls awaiting answer although it can, in addition, be arranged to indicate other types of traffic. This meter is positioned on the right-hand side of the switchboard and is easily visible from an adjacent position, but if necessary, up to about 15 meters can be connected without circuit modifications. The standard calibration registers from 0 to 10 waiting calls and the circuit adequately compensates for variations in exchange battery voltage.

The indicators in the centre of the switchboard panel, when illuminated, display bold letters and figures 1 in. (25 mm.) in height. The operator brings the indicators into use whenever she wishes to identify a private wire, exchange line, enquiry or other circuit connected to the banks of the connecting circuit finders. For example, an operator engaged on an exchange line might momentarily press the ' identify ' button and a display of ' E.21 ' would appear if she were dealing with Exchange Line 21. To cancel the display, the ' display cancel ' button is momentarily pressed.

Detailed layout of the keys can be studied more easily from Fig. 4 although the key colouring, an important aspect, is not apparent.

The buttons in the centre are white and, with associated lamps, are arranged in eight vertical columns serving eight connecting circuits. Black denotes buttons common to the position, and includes the keysender controls on the right and the bottom horizontal row on the left of the connecting circuits. Above this latter row will be found fourteen ' class of call ' buttons used when answering or originating calls.

An incoming call will be signalled by the glowing of a red lamp, there being a different red lamp for each class of call, such as ' enquiry ', ' incoming exchange ', ' operator recall ', etc., and the operator answers the selected class of call by momentarily pressing the red button immediately below the red lamp. To originate an outgoing call the operator presses a white button associated with the appropriate circuit group. Should all circuits in the required group be engaged, a white lamp glows to warn that operation of the button will be ineffective.

As stated earlier, all control buttons including 'speak' are non-locking. The circuit arrangements leave the operator's telephone and the position controls switched to the connecting circuit associated with the 'speak' button which was last pressed. The 'live' circuit is indicated by an amber 'speak' lamp adjacent to the button and depression of a second 'speak' button automatically restores the one previously operated. To effect release during light traffic periods a common 'restore' button is provided.

INCOMING EXCHANGE CALLS

A cord switchboard operator usually has a plug in her hand whilst awaiting the next call. The equivalent to this in the ET.4 system is to have already pressed a 'speak' button so that when an 'exchange call' lamp glows all the operator has to do is to press the corresponding red 'answer' button.

A uniselector associated with the connecting circuit then hunts for the calling line and the connecting circuit 'busy' lamp glows on seizure. Next, the operator ascertains the caller's requirements and if the call is to be extended she presses a 'transfer' button to seize a call back selector and switch the connection into the condition shown in Fig. 2B. The wanted extension number is now keyed up and when the necessary digits are stored (indicated by the glowing of the blue 'send' lamp) the operator's duties are normally complete. She is free to attend to the next call whilst the establishment of connection between the exchange and extension, and the ultimate release take place automatically.

If she wishes to introduce the call, the operator remains in circuit and the answering extension is prevented from connection with the exchange line until the operator withdraws.

Should the wanted extension be engaged, the internal switching train need not be released. A 'park on busy' facility ensures that the call will mature in the usual manner when the extension does become free. However, the connecting circuit supervisory lamp flashes when a busy line is encountered, and the rate of flashing indicates whether the extension is engaged on an exchange or internal call. Thus operators are restrained from offering public exchange calls to extensions already so engaged. The operator uses her discretion as to whether or not intrusion is warranted and if she decides to intrude she keys 'O'. A speech circuit with intrusion tone superimposed is then completed between the three parties and the operator may request the extensions to clear.

The wanted extension is re-rung immediately it becomes disengaged and is connected to the incoming exchange line when the handset is again removed.

If the call has not been established and the operator wishes to ring another extension, she operates the 'transfer' button twice and then keys the second extension number. The first operation releases the first call back selector and restores her telephone circuit to the exchange line whilst the second operation seizes a second call back selector. The

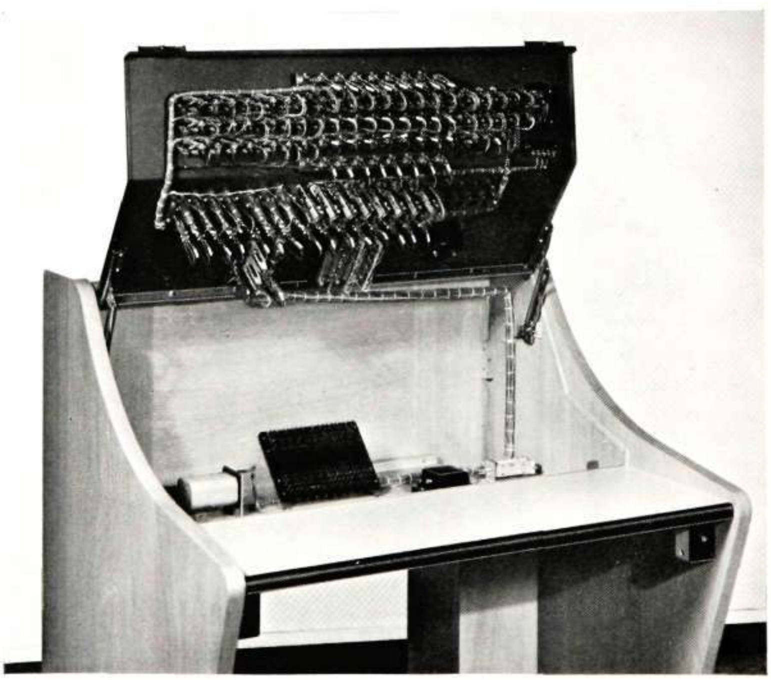


Fig. 5—Switchboard Control Panel raised

' internal ' lamp indicates the routing of the circuit at any instant.

Should the called extension be barred from exchange service, the operator can converse but transfer is impossible. During the conversation a ticker signal warns that transfer is not permissible and the operator's supervisory lamp flashes as a further warning.

When an extension cannot be obtained immediately in either ' busy ' or ' no reply ' circumstances, the operator can advise the public exchange party of the situation on pressing the ' refer back ' button. This diverts her telephone circuit to the exchange line without releasing the internal switch train.

On all types of call it is fundamental that the operator speaks to one party or the other, but never to both, unless her presence on the line is accompanied by intrusion tone. Thus, the system is inherently secret.

Call Back Enquiry Calls and Call Transfer

Extensions engaged on exchange lines may call other extensions or the operator without releasing the exchange line. One depression of the instrument transfer button causes a second call back selector to be seized and dial tone returned. The extension may now dial the appropriate number to obtain the necessary information. A further depression of the transfer button restores the connection to the exchange line, releasing the internal connection. But if the first extension should wish to transfer the exchange line to the second extension he should notify the latter of his intention and replace his receiver. The call is transferred automatically and, if necessary, may be transferred again to other extensions.

Busy tone is returned if a number dialled on an enquiry call is busy but, unlike an ordinary internal call, busy tone will change to ring tone and the call will mature when the called line becomes free. A certain amount of repeated dialling of busy numbers is thus avoided, although the originator of the enquiry call must use his discretion and not wait unduly long.

When the called line is engaged on an internal call, priority extensions can intrude by dialling ' 0 '. They will realize that the call is internal by listening to the cadence of busy tone which is doubled for exchange calls. Some Administrations also allow priority extensions to gain access to extension lines employed on an exchange call and this facility can be incorporated when required.

Operator Recall

' Operator recall ' is a term covering a class of inward call to the operator from extensions engaged on exchange lines or private wires. It includes not only enquiry calls to the operator but also calls diverted to the operator by reason of mis-operation on the part of the extensions. With the previous cordless P.A.B.X., mis-operation, such as clearing from a call-back to an extension by replacing the handset, resulted in recall of the erring extension. On this P.A.B.X. such calls are routed to the operator who is thus brought into circuit by an extension :—

(*a*) dialling ' 0 ' on an enquiry call,

(*b*) pressing his ' transfer ' button and immediately replacing the handset,

(*c*) attempting to transfer a call to a barred extension, or to an extension who also has replaced his receiver, or under other abnormal conditions.

Usually (*b*) is effected purposely ; the extension notifies the other party of his intention, presses the button and replaces the handset, thus avoiding the need to wait until the operator answers. Under both (*b*) and (*c*) conditions an operator answering the call is connected to the public exchange.

In case (*a*), however, the operator is connected to the extension, who still has control of the call and may press his ' transfer ' button to revert to the exchange line or replace his handset to transfer the call to the operator. If he reverts to the exchange line, intrusion tone will be applied to the circuit until the operator clears.

From the extension user's point of view, the recall procedure is unaffected whether the connecting circuit is held or not, but operation differs on the manual positions. When the call is not held, the recall produces a general signal which may be answered by any operator, whereas, if the call is held on a connecting circuit, that operator alone is signalled by rapid flashing of the relevant supervisory lamp. In both cases an audible alarm can be given.

Operator-Controlled Outgoing Calls

Extensions barred direct access book exchange calls over the ' 0 ' level enquiry circuits ; the

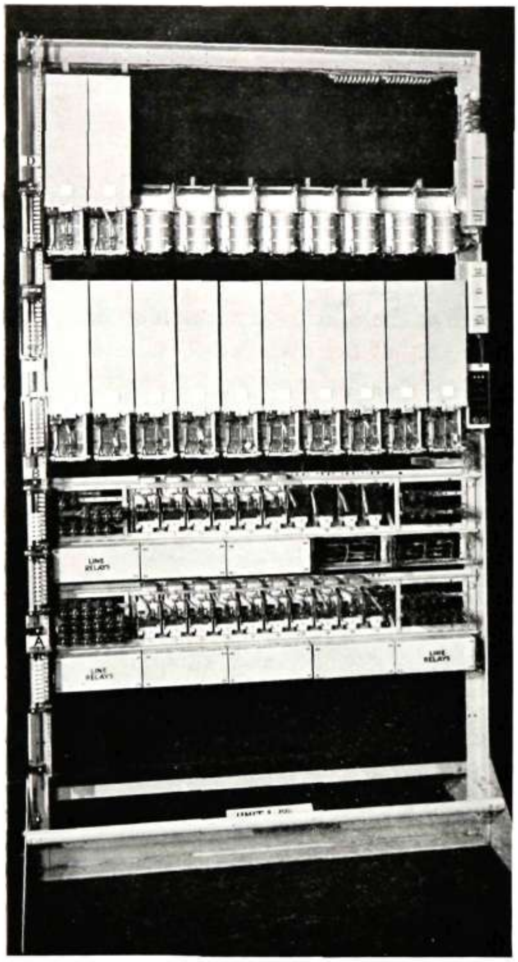


Fig. 6—Rack for 100 Extension Lines

operator records the requirements and recalls the extension after having obtained the distant subscriber. It is not usually desirable for extensions to wait on enquiry circuits whilst the operator completes calls on demand, since the practice leads to unnecessary waste of the extension user's time. Nevertheless, reversion (i.e. the re-ringing of the extension after having seized an exchange line) can be immediate even to the extent of transferring the exchange line to the extension before dialling and allowing him to dial his own number. However, the general procedure will be for the operator to press the appropriate outgoing ' class of call ' button, whereupon she will receive dial tone and then key or dial the public exchange number. Keysenders may be equipped to meet only the extension numbering scheme or provided with up to 10 digits capacity to cater for national numbers. When the distant subscriber has answered, the operator presses her ' transfer ' button, keys the extension number and normally retires from the circuit, the procedure being identical for incoming and outgoing calls.

Concentration and Night Service

Since the manual positions are identical, any position can deal with any type of call and concentration occurs automatically as positions are vacated in periods of light traffic.

When the last operator leaves the switchboard the removal of the headset plug automatically switches the exchange into the night service mode of operation.

Night service in a cordless P.A.B.X. with transfer facilities can allow a very much improved degree of service over conventional equipment, because the answering extensions have normal P.A.B.X. facilities when not dealing with incoming calls and can transfer incoming calls to the appropriate extension.

The ET.4 system permits alternative schemes. Firstly, Class I night service in which any extension may be connected to receive the incoming calls from exchange lines and, if required, calls from private wires or enquiry circuits. All traffic may be routed to one telephone or divided between a number of telephones and, when essential, individual exchange lines may be connected to separate extensions.

Secondly, in the Class II scheme, conveniently situated alarm bells are rung by incoming calls which may be answered by any non-restricted extension dialling a code digit, usually ' 8 '.

In both schemes, extension lines used for night service answering can be provided with facilities for intruding into established calls during night service periods when extending incoming calls. They are thus enabled to cope with a considerable volume of traffic and moreover are warned by a suitable tone when further incoming calls await attention.

Additional Facilities

In this article it is impossible to cover adequately all variations and extra facilities which can be provided but several of the more outstanding features may be mentioned.

Cyclometer type meters with facilities for manual re-setting can be provided on the console positions to register S.T.D. meter pulses, thus enabling individual call charges to be obtained. Meters can also be provided to give a totals indication on each exchange line or may even be fitted on individual extension lines.

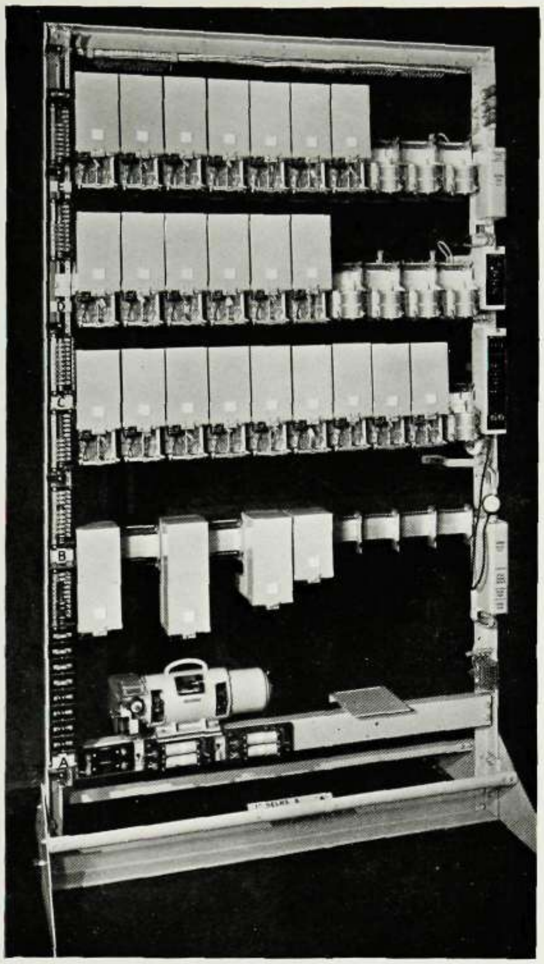


Fig. 7—Group Selector Rack with ringing machine

Manual extensions arranged to call the switchboard directly for call booking and similar purposes can be provided. Such extensions also have access to the automatic equipment to enable the user to originate extension-to-extension calls and obtain service when the manual board is not staffed. Where the number of manual extensions required is greater than the number of buttons which can be accommodated on the positions, group calling is adopted and a lamp indicator displaying the extension number glows for 3 to 6 seconds when a call is answered.

It is also possible to provide a similar arrangement for answering exchange lines and other services. One common answer button then replaces a number of ' class of call ' buttons and when the call is answered the class of call is displayed.

Apparatus Racks

The equipment design follows established B.P.O. 2000-type practice. Dimensions of the racks are normally 7 ft. 9 ins. x 4 ft. 6 in. (236 cm. x 137 cm.), although racks of a different height can be supplied to suit building requirements.

Rack layout generally conforms to a pattern utilizing three basic rack types, the line rack, group selector rack and relay set rack ; typical examples of each type of 7 ft. 9 in. (236 cm.) rack are depicted in Figs. 6, 7 and 8 respectively.

The line rack accommodates 100 extension line circuits, 20 linefinders and 20 final selectors together with connection strips providing for numbering flexibility and extension classification strapping.

At the bottom of the first group selector rack, two battery driven ringing machines can be accommodated. When two machines are fitted, either can serve the exchange and arrangements are provided to change over automatically to the idle machine in the event of failure. The first group selector rack also accommodates the pulse relay sets and these too can be supplied in duplicate with changeover facilities which operate if the pulse uniselector should cease to rotate with a start condition applied. In small installations all alarms have an auxiliary centralized display on this rack but in larger exchanges a fault supervision panel with writing desk can be supplied.

The remaining space on group selector racks is occupied by shelves of call back and local group selectors of which the appropriate quantities are supplied to meet the requirements of individual exchanges.

In designing P.A.B.X. equipment, it is always a problem to attain a satisfactory basis of provision between exchange lines, private wires, extensions and manual positions because the ratios of these circuits vary so much from one installation to another. The system finally adopted allows extension line capacity to be extended without regard to other circuits, and group selector racks to be added in accordance with traffic. With the Exchange Line R/S and Position Circuit racks however, the layout is based on an assumption regarding the number of exchange lines and private wires which an operator can handle. This is dependent on the business conducted by the P.A.B.X. user, the extent to which an operator is expected to answer callers' queries, and the number of difficult time-consuming calls which an operator must originate on behalf of her extensions. Under optimum conditions an operator may be able to handle 20 exchange lines but in a P.A.B.X. of this size a second position is nearly always specified.

Hence, the basis finally adopted for equipment is a maximum of 15 lines for the first position and an average of 25 lines per two positions in bigger installations where by virtue of the larger circuit groups the traffic per circuit is higher. The Exchange Line and Position rack illustrated has capacity for all relay sets associated with one position (including eight connecting circuits) together with 15 exchange lines and miscellaneous circuits such as night service, O/G Auto and ' O ' Level relay sets.

Supplementary relay set racks may sometimes be needed for Direct Access O/G Only exchange lines, which add little to the operator's load and can be provided without regard to the basis of provision mentioned above. Auxiliary private wire relay sets and junction relay sets to satellite exchanges would also be provided on these additional relay set racks.

CONCLUSION

It will be seen that the ET.4 is a flexible P.A.B.X. system which, although based on well-established principles, provides a number of new facilities, including provision for Subscriber Trunk Dialling.

The new facilities promote speedy and efficient service and the many additional features which can be incorporated should make the system suitable for most Administrations.

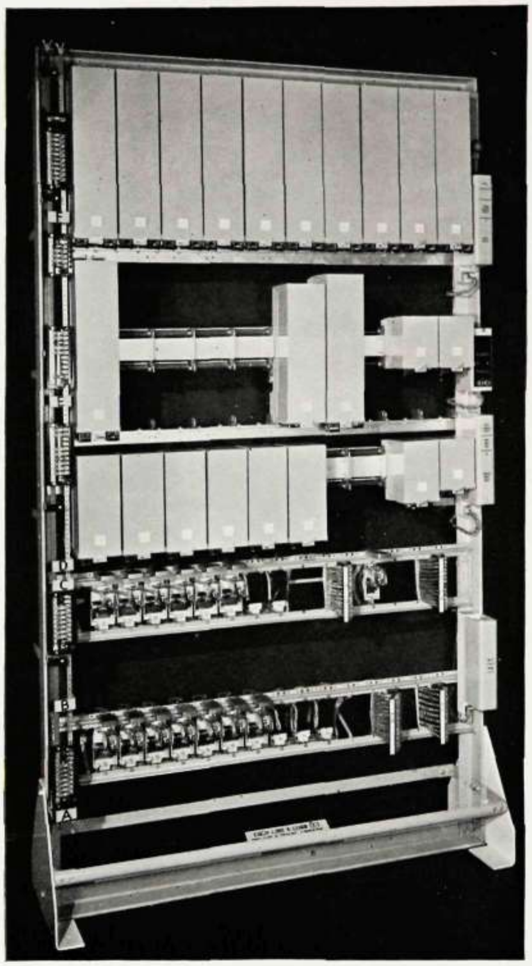


Fig. 8—Exchange Line and Position Equipment Rack

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THE ETL-NPL AUTOMATIC POLARIMETER

A. W. PALMER — Instrument Division

Measuring instruments, particularly automatic recording instruments, employing electronic techniques are of increasing importance to many industries ; the polarimeter described is a good example of the application of electronics to optical measurements thereby providing facilities for automatic recording. In its operation, the rotation of an optically active substance is compensated by a counter rotation produced by a Faraday cell connected to a feedback amplifier. The current required for compensation is proportional to the optical rotation and can be displayed on a meter, chart recorder or digital instruments, or used for servo control systems. A particular installation is described for carrying out routine measurements in sugar beet tarehouses where automatic digital records on punched cards are required.

THE PROPERTY OF OPTICAL ACTIVITY

MANY organic substances exhibit the phenomenon of optical activity, i.e. when a beam of plane-polarized light is allowed to pass through them, the plane of polarization undergoes a rotation or twist. The instrument which measures the amount of twist is known as a polarimeter. A version used to assess the strength of sugar solutions is referred to as a saccharimeter. In its simplest form a polarimeter consists of two polarizing filters, usually nicol prisms. One of these, called the polarizer, has a fixed position, whereas the other—the analyzer—is mounted in an angularly divided disc which can be rotated. The polarizer and analyzer are separated by a trough used for supporting a tube to contain liquid specimens. When a light source is viewed through the polarizer and analyzer in the absence of a specimen, a position can be found, by rotating the analyzer, where the transmitted light is seen to be extinguished. If this extinction position is noted and a specimen (e.g. a solution of sugar and water) is introduced between the polarizer and analyzer, the latter must be rotated to find a new extinction position. The angular difference of the two extinction positions is a measure of the optical activity of the specimen.

HISTORICAL DEVELOPMENT

During the period 1815-1840 the French physicist Biot established those fundamental relationships in polarimetry which are the basis of modern practice. In 1845 Soleil introduced a system of compensation using a wedge of quartz. Quartz crystal, if cut at right angles to its axis, is optically active ; the degree of rotation depends upon the thickness or optical path-length. Soleil used this property to compensate the rotation of a specimen by a counter-rotation in the quartz wedge, by moving the wedge into the field of view and thus adjusting the path-length to achieve extinction. This is the principle of modern quartz wedge instruments in which the position of the wedge is calibrated in terms of twist, rotation, or in the sugar industry, directly in units of sugar concentration.

In 1860 the Rev. William Jellet produced an improved form of polarimeter by introducing a photometric principle. In his version, the beam of plane-polarized light in the polarimeter was split into two halves whose planes of polarization differed by a small angle, and the instrument was balanced by matching the two halves, seen through an eyepiece, for equal intensity. This method provided a more accurate means for setting the analyzer than the extinction method, and is still employed in visually balanced polarimeters.

Since the middle of the nineteenth century, improvements to the polarimeter have been in the main due to more precise engineering or to the introduction of new materials. Polarimeters have a circularly divided scale in degrees of angular rotation, require a monochromatic light source, and are used for fundamental laboratory measurements. Saccharimeters are used for measuring sugar concentrations, are calibrated in terms of a sugar scale and are found in two basic forms. One which measures the angular twist expressed in sugar degrees is a sugar polarimeter and requires a monochromatic light source. The other is the quartz wedge compensating instrument which does not require a monochromatic light source. Both are in use, although the sugar polarimeter is used more for precise measurements and the quartz wedge type now mainly confined to process control.

Fig. 1—The ETL-NPL Automatic Polarimeter Type 143A

PHOTOELECTRIC POLARIMETERS

With the development of photoelectric devices sensitive to variations in intensity of illumination, and of electronic measuring techniques, considerable effort has been devoted in recent years to applying these devices and techniques to the field of polarimetry. The ETL-NPL Automatic Polarimeter Type 143A described below is the first fully automatic recording instrument in commercial production. In the development of photoelectric polarimeters one approach was the logical one of replacing the eye by two matched photo-electric detectors, each directed at one half of the split field, and balancing for equal illumination as before. A subsequent stage was to use one photo-electric detector and provide alternating signals to it by modulating the beam, that is, splitting the beam in time as opposed to splitting it in space by Jellet's method. Instruments have been made using a vibrating quartz segment or rotating disc fitted with quartz segments[1] for modulating the beam. The ETL-NPL Automatic Polarimeter makes use of the magneto-optic or Faraday effect, which appears to have seen little practical application since Faraday discovered it in 1845. Faraday placed a piece of optical glass between the polarizer and analyzer of a polarimeter and induced a controllable magnetic field in the glass in line with the beam of light by means of an electro-magnet. He found that the glass became optically active under the influence of the magnetic field, and that the rotation so produced was directly proportional to the strength of the applied field, and hence to the current producing the field.

By placing a Faraday cell, that is, a piece of glass in a solenoid, between the polarizer and analyzer and applying an alternating current to the solenoid, the plane of polarization of the beam can be made to rotate first in one direction and then the other, following the applied alternating current. A beam of light passing through this system becomes modulated in intensity. Electronic methods can now be applied for conversion of the alternating signals derived from photo-electric detectors. At balance with the polarizer and analyzer at the crossed or extinction position, the detector receives a symmetrical signal, commonly sinusoidal but dependent on the form of modulation employed. Introducing a specimen disturbs the symmetry of the signal, so the analyzer must be rotated manually, or automatically by means of a motor, to achieve a fresh balance point.

THE ETL-NPL AUTOMATIC POLARIMETER TYPE 143A

The ETL-NPL Automatic Polarimeter is based on an original design by the National Physical Laboratory, Teddington, described by Gillham[2] and Gates[3].

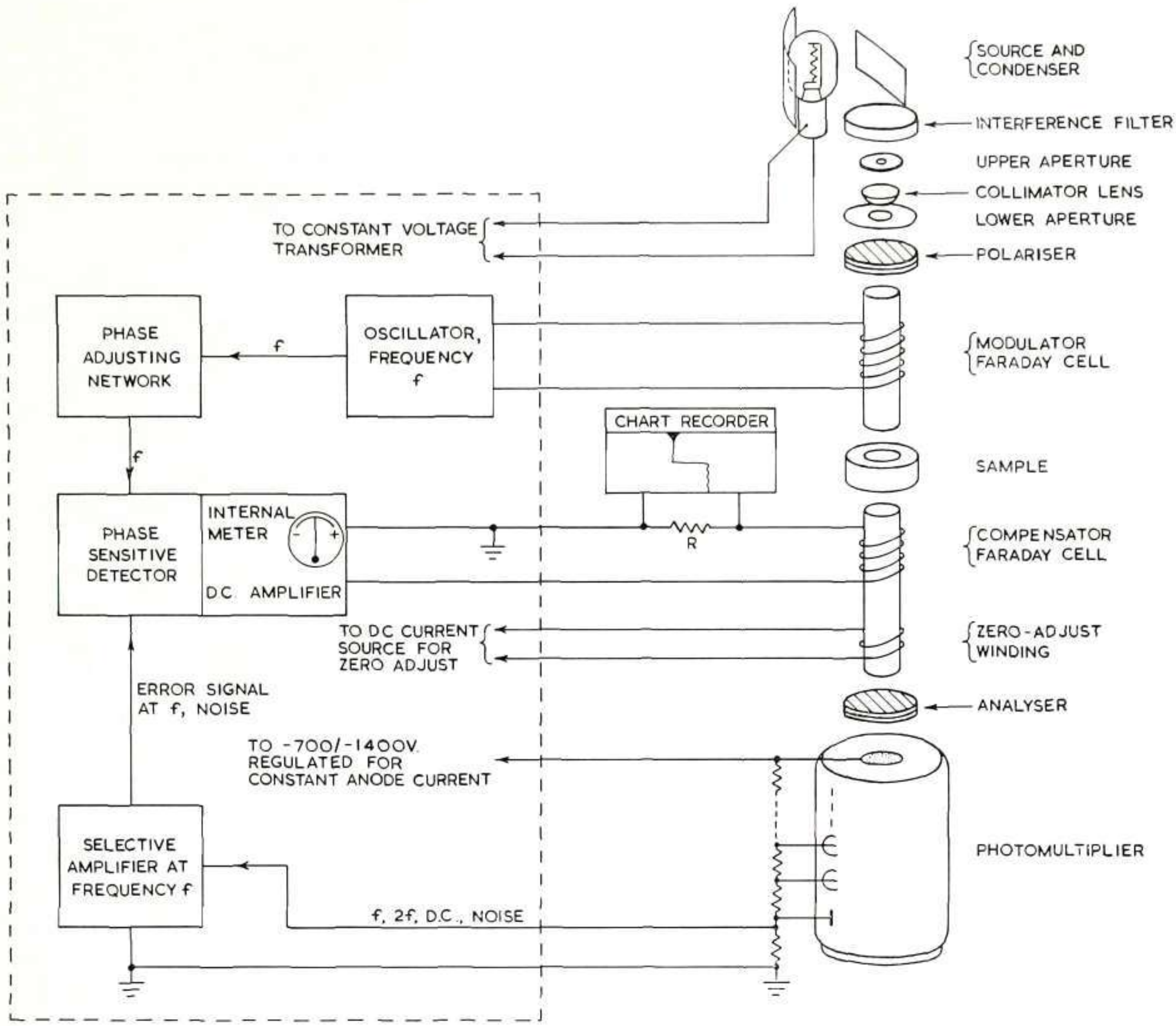


Fig. 2—Block Diagram of the Polarimeter

In this instrument the principle of compensation is employed by introducing a second Faraday cell between the polarizer and analyzer and applying a direct current to the solenoid to produce a counter rotation exactly equal to that of the specimen. This compensation current is provided automatically by using electronic techniques, the current giving a measure of the rotation of the specimen.

Fig. 1 is a view of the instrument showing the Optical Unit with a sample cell and the Electronic Control Unit. Fig. 2 is a block diagram showing the arrangement of the principal optical components. With the polarizer and analyzer in the crossed or extinction position, an alternating current at a frequency *f* is fed to the modulator from an oscillator. The photo-multiplier used as the detector receives light having an intensity which varies with time at a frequency of 2*f*, since for every complete cycle fed to the modulator the light beam passes through the extinction point twice, thus there are two maxima and two minima. The anode of the photo-multiplier is directly coupled to the input of the a.c. amplifier, which receives an alternating signal 2*f*, noise, and a steady d.c. component. The signal at frequency 2*f* is unwanted and is rejected by the system. When a specimen is introduced, the alternating signal from the photo-multiplier contains in addition a component at the modulating frequency as depicted graphically in Fig. 3. The component at frequency *f*, which is usually very much smaller than that at 2*f*, is the error signal which is accepted by the system, amplified, and fed to a phase-sensitive detector which receives its timing wave at frequency *f* from the modulator through a phase adjusting network. The rectified error signal passes through a d.c. amplifier, which passes a current through the compensator Faraday cell of polarity tending to compensate for the rotation of the specimen, and of a magnitude which reduces the component at the frequency f practically to zero.

With this system, very small rotations, below one second of arc, can be detected, the sensitivity being limited only by the noise level, which under normal conditions is of the order of 0.0001° arc r.m.s. Such sensitivity permits the use of path-lengths for the specimen tube or cell a factor of 10 shorter than those used in visual instruments without loss of relative precision. The use of short path-lengths has the advantage that it is possible to measure the rotations of solutions which, because they transmit so little light in the long path-lengths necessary in visual measurements, are difficult to measure. This is because the light transmitted by an absorbing solution increases exponentially with decreasing path-length, while the optical rotation decreases linearly. Thus, a sample transmitting 50% in a 10 mm. path-length which is easily measured in this instrument, would transmit only 0.1% in the 100mm. path-length which would be required for use in a visual instrument to obtain the same relative precision. The high voltage supply to the photo-multiplier is automatically regulated to maintain a practically constant current through the photo-multiplier, thus permitting the measurement of solutions with transmissions as low as 10% in the path-length chosen. This is achieved however at the cost of some increase in the noise level.

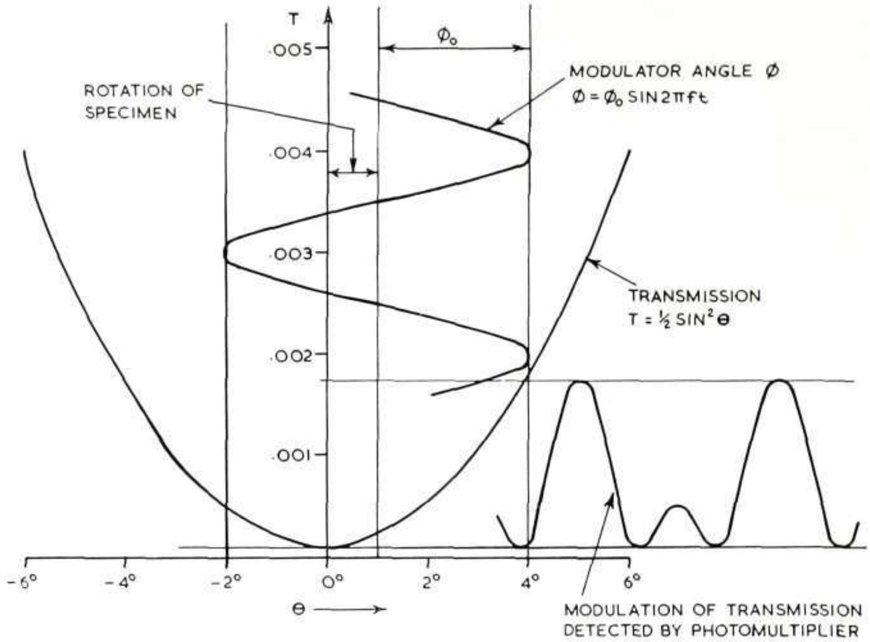


Fig 3—Diagram showing light transmission to photo-multiplier

The angle of rotation from the compensator Faraday cell is limited in part by heat dissipation in the solenoid when current is passing through it. With a sensitivity of 0.0001° arc r.m.s. a range of ± 0.5° arc was chosen for the instrument, the heat dissipation being low enough to cause no thermal stress birefringence in the glass core of the Faraday cell. The rotation, in terms of the current producing it, depends upon the physical properties of the cell, the number of turns in the solenoid, the optical path-length and magneto-optic or Verdet constant of the glass. Generally, a glass with a high Verdet constant has a relatively high density or a high refractive index. The compensation current can be measured by using any of the conventional methods of measuring direct current, such as a pointer type meter, chart recorder, or digital techniques. Since the rotations measured are in electrical form, the instrument lends itself admirably to automatic recording or servo-systems for process control.

Details of the Design of the Instrument

The Optical Unit, evolved from the prototype made by the National Physical Laboratory, has a vertically oriented axis, as seen in Fig. 1, whereas most polarimeters and saccharimeters have a horizontal or diagonal axis. The advantage of the vertical arrangement is that not only is stress distribution due to the weight of the optical components and heating effects kept symmetrical about the axis, but also the effect of the Earth's magnetic field is constant and not dependent upon the orientation of the instrument on the bench. The effect of the vertical component of the Earth's field in Nottingham (where our Instrument Factory is located) has been found to be about -0.013° arc, which is 2.6% of the full scale deflection of 0.5° arc.

Since the Faraday cells are sensitive to magnetic fields, it was decided to make the Optical Unit entirely of non-ferrous materials rather than attempt to shield it. The difficulties occasioned by the remanent magnetization of a shield and especially its effect upon the field distribution in the Faraday cells have thus been avoided. The presence of magnetically permeable material near the Faraday cells would be expected to affect the proportional relationship of the polarizing current to the optical rotation produced. For the same reason, the Faraday cells are not shrouded or designed with magnetic cores, which would in any case only slighly reduce their magnetic reluctance. In practice, however, the instrument can usually be sited at an adequate distance from large moving ferro-magnetic objects.

The vertical orientation also permits an arrangement of components such that the greatest power is dissipated at the top, thereby minimizing the conduction of heat downward towards the sample space. A further advantage is that temperature distribution throughout the frame of the instrument is symmetrical about the axis, which would not be the case were it horizontal. During operation, the temperature of the Optical Unit in the vicinity of the sample cell space is about 0.5°C above ambient. This is largely due to the power (about 2 watts) dissipated by the modulator Faraday cell, and to a lesser extent to the heat transferred by conduction from the lamp. The maximum dissipation in the compensator is only 300 mW.

Due to the high sensitivity of the instrument, the mounting of the two polarizing filters, which are glass-laminated Polaroid, has been the subject of detailed investigation ; as a result, mechanical joints between them have been eliminated as far as possible, and all the mechanical components linking them are made of the same aluminium alloy. The optical components are contained in two castings separated by a yoke which holds the specimen tube or sample cell. The upper casting contains the collimator assembly, the polarizer, its clamp in the form of a locking ring, and the modulator. The lower casting contains the compensator, the analyzer and the photo-multiplier. The analyzer uses a fixed polarizing filter, for convenience, since the polarizer is more accessible. The polarizer is mounted in an aluminium alloy ring which can be seen through the lower of the two cut-outs in the upper casting, just below the lamp housing in Fig. 1. The ring holding the polarizer is clamped by end pressure through a Teflon ring when the locking ring in the upper cut-out is screwed downwards. Since it is very difficult by mechanical means to adjust the azimuth angle of the polarizer better than ± 0.02°, an electrical fine adjustment having that range has been provided, using a Faraday cell and potential divider as shown in Fig. 2.

The upper aperture of the collimator assembly has a diameter of about 1.1 mm. (0.045 in.), and is focussed on to the cathode of the photo-multiplier which is an EMI type 6094 B, 11-dynode end-on tube with a 10 mm. (0.390 in.) diameter photocathode. The beam, where it crosses the sample space, has a diameter of 7 mm. (0.276 in.).

The space in the yoke for holding the sample cells is 38 mm. (1.5 in.) wide and about 76 mm. (3.0 in.) high. In the floor of the yoke is a recess 1.6 mm. (0.063 in.) deep with a diameter of 30 mm. (1.178 in.) which is the standard diameter for practically all visual polarimeter specimen tubes, and so many of the accessories used with the automatic instrument can be used in a visual instrument. A sample cell of the flow-through type for repetitive measurements is shown in Fig. 4. It consists of a stainless steel spacer lapped plane-parallel 20 mm. (0.780 in.) in length, having a clear aperture of about 8 mm. (0.315 in.), with channels cut to permit the flow of solutions, and end windows which in this instance are microscope cover glasses. Banjo-type manifolds at the top and bottom conduct the solutions in and out of the cell. The whole assembly is in a container of 30 mm. (1.178 in.) external diameter. It is shown in Fig. 4 clamped in a base ready for insertion in the instrument. The cell is filled by syphon action and has been found to require a volume of 30 ml of solution to completely replace the previous sample. Cells with path-lengths of 5 mm. and 10 mm. are also being made as standard items. One purpose of the base in which the cell is shown clamped, is to permit the cell to be inserted and removed from the instrument without altering its azimuth orientation. In setting-up, the procedure is to insert the cell filled with distilled water, and then adjust the polarimeter to read zero, in this way balancing out any birefringence which may be present in the cell.

Concerning birefringence ; if a piece of glass which is normally not optically active is strained, placed

Fig 4—A Sample Cell (New type)

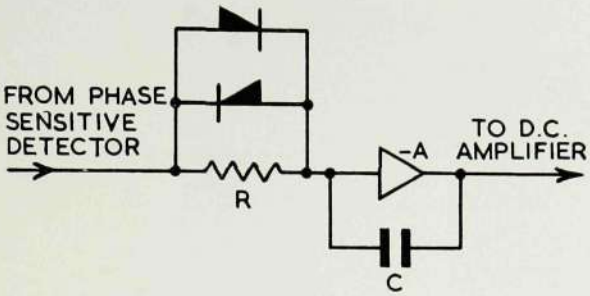
between the polarizer and analyzer in a polarimeter and slowly rotated about the optical axis, it will appear to have optical activity varying in degree with its azimuth position, and is said to exhibit birefringence. With the very small angular rotations being measured, birefringence, which in visual instruments would pass unnoticed, becomes a factor of considerable significance in an instrument as sensitive as that being described. In practice it is extremely difficult to avoid its presence entirely. During experiments with microscope cover glasses for use as cell windows it was found that methods of cleaning or wiping the glasses affected birefringence, and that one method for keeping it to the minimum was to wipe the glass in a circular motion, having cleaned it (or even flamed it) beforehand. Since birefringence cannot be avoided entirely, it is essential to balance out its effects before measurements are made.

The light source in the standard instrument is an incandescent lamp, shown in Fig. 2, with interference filters transmitting mercury green light. The lamp is energized by a constant voltage transformer operated from the mains supply, and, to keep the size of this transformer to the minimum, a 6 watt lamp is used. To fill the optical system with light from such a relatively small source, it is necessary to use cylindrical mirrors to magnify the elongated filament shape anisotropically so that its image upon the input pupil is square. By this expedient a maximum of energy is transmitted through the upper aperture and is limited only by the filament temperature. Were a larger lamp and consequently a larger transformer used, a simpler condenser system could probably be employed, but the brightness of the system would remain practically the same. A feature of the design is that the input pupil is made readily accessible so that an external light source or other filters may be used.

The electronic control unit is shown in the diagram, Fig. 2, but in addition it energizes the lamp through a constant voltage transformer and provides the small (about 1mW max.) but constant and adjustable magnetic bias by which the zero position is given fine adjustments.

The local oscillator, which provides both the phase-reference signals to the synchronous detector and drives the modulator Faraday cell, delivers rather more than two watts at about 380 c.p.s., a frequency which is chosen because it is a harmonic of neither 50 nor 60 c.p.s. Apart from shielding problems, it appears that the modulator could be run at almost any convenient frequency ; both 50 and 400 c.p.s. have been used experimentally. The choice of 380 c.p.s. was governed also by convenience and the future possibility of using a semi-conductor photo-detector which would give a good signal-to-noise ratio at this frequency. The signal from the photo-multiplier is amplified, as shown in the diagram, until the noise component at 380 $\pm$ 10 c.p.s. is about one-half of the amplitude which would saturate the amplifier feeding the phase-sensitive detector. It appeared to be most practical to limit the bandwidth (and hence reduce the noise) not by more selective filtering in the a.c. amplifier, but by suitable integration of the noise in a d.c. amplifier following the phase-sensitive detector.

A feature of the Miller-integrator which has been used to smooth the noise by such time-integration, is the way its time constant depends upon the size of the



$\tau(t) = AC(1-A)$, $t \to \infty$ OR AT EQUILIBRIUM,

$\tau(t) \to 0$, $t=0$ OR AT AN INPUT STEP.

Fig. 5—Miller Integrator Circuit (Ref. 4)

signal[4]. The circuit is shown in outline in Fig. 5, and exploits the non-linear characteristics of semiconductor diodes. When a large signal step is applied to the integrator circuit, the resistance of one of the diodes in parallel with R falls to a low value. A large charging current is passed to C, and the effective time-constant is short. As C becomes charged, the voltage across R falls, and the effective resistance of the diode pair increases. In the final steady-state condition the resistance of the diodes is so high that the time-constant, limited by R, becomes RC (1 + A.) By this means, when a sample is introduced to the polarimeter, the reading will reach within 0.001° of its final value in a second or so, and will reach within 0.0001° in a further 25 seconds.

The output of the d.c. amplifier passes into the 8,000Ω load of the compensator Faraday cell; this current is proportional to the optical activity and is in the range ± 6 mA for ± 0.5° arc.

Performance of the Polarimeter

Although the Electronic Control Unit is provided with a meter to indicate optical rotations, the available relative precision of 1:2500 (max.) is better exploited by measuring the compensator current using a shunt resistance and external potentiometric means. With a recording potentiometer it is found that noise limits the useful sensitivity, and corresponds to an r.m.s. angular fluctuation of 0.0001° arc. Thus, more than 95% of the instantaneous readings made for a given sample (measured with a digital voltmeter, for example), would fall within ± 2s ; an interval of ± 0.0002° arc.

The range of the instrument is ± 0.5° arc from any pre-set position of the polarizer and analyser.

The Measurement of Sugar Concentrations

Polarimetry has probably reached its highest degree of refinement in the sugar industry, for no commodity has been scrutinized more closely with respect to its optical activity than sucrose. The International Commission for the Uniform Methods of Sugar Analysis (I.C.U.M.S.A.) first met as long ago as 1900, and has maintained international agreement on practices employing polarimetric measurements for the determination of sugar concentrations. Commercial transactions in bulk sugar rely on polarimetric measurements to determine the sucrose content of consignments and hence the price. It is not surprising therefore that the industry should take a keen interest in the development of photo-electric polarimeters and that the British Sugar Corporation should provide the first application of automatic polarimetry in sugar beet reception tarehouses.

Sugar concentrations are usually expressed in degrees of an arbitrarily defined sugar scale, of which there are two now in use ; that used only in France and her colonies, and the International Sugar Scale which has found general acceptance elsewhere.

At the 1932 meeting of the I.C.U.M.S.A. the 100° point on the International Sugar Scale was agreed to be the rotation of 26.00 gm. of pure sucrose (weighed in air with brass weights) made into a solution of 100 ml at 20°C, viewed through a tube having a path-length of 200 mm. The angular rotation corresponding to the 100°ISS point was taken to be 34.64° arc when the wave-length of the light source was sodium yellow at 5893 Å, and 40.69° arc in mercury green at 5461 Å. Quartz plates are used as reference standards of rotation for calibration purposes, being a more convenient form than standard solutions.

Sugar Beet Tarehouse Practice

Growers are paid for sugar beet according to the sugar content and the clean weight of beet delivered. Sampling is thus necessary, and in this country is carried out on each load of beet as it is delivered to the factory. A factory processing, say, 2500 tons of beet a day would expect about 400 loads to arrive daily. A representative sample is first taken from each load to assess the clean weight of the delivery by weighing the sample before and after washing. The sample is then put into a multiple saw machine which rasps off a portion from each beet to produce a finely shredded mass known as ' brei '. This is thoroughly

Fig 6—Automatic Polarimeter installation for British Sugar Corporation factory, Wissington

mixed to make it representative of the batch, and 26 gm of the brei is made up into a 200 ml solution with distilled water to which basic lead acetate has been added as a clarifying agent. The mixture is put into a metal beaker, covered with a rubber seal, and the sugar allowed to diffuse into the solution for at least 10 minutes. It is then filtered to remove fibrous matter and precipitated lead salts. The sugar content of the clear liquid is then read on a polarimeter calibrated in degrees ISS and using a tube with a path-length of 400 mm. Tarehouse solutions are half strength, 26 gm being made up to a solution of 200 ml instead of 100 ml, and so the path-length must be doubled in order to use the same scale. The smallest division on the vernier scale of visually balanced instruments is 0.1°ISS, but 0.05° ISS can be estimated. Sugar contents are, by agreement between growers and processors, expressed to the nearest 0.1°ISS.

Each measurement entails the balancing of the half shades for equal intensity, reading off the vernier scale and making a record. Any lapse of concentration on the part of the operator dealing with 400 samples in an 8-hour working day could be significant. To safeguard his financial interest against such errors, the grower has a representative who makes a separate analysis of about 5% of the total number of samples.

Automatic Digital Recording Polarimeter

It has long been thought that some device was needed to reduce the human element in the procedure described above. One solution to the problem would

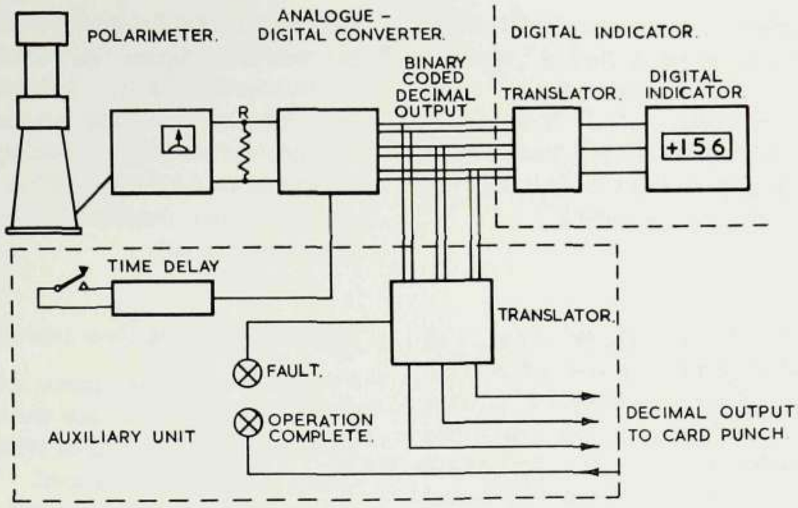


Fig. 7—Block Diagram of the Wissington installation Fig. 6

be an automatic polarimeter which would also record the sugar content automatically, preferably with digital indication as well. A system using the ETL-NPL Automatic Polarimeter was devised and installed at the Wissington, Norfolk, factory of the British Sugar Corporation for trials at the beginning of the 1958/59 beet campaign. The equipment, shown in Fig. 6, measures the sugar content of the solutions, displays the rotations in digital form, and feeds the digital information to a Hollerith card punch for recording. The whole operation is automatic from the filling of the sample cell to the punched record, the time cycle for the complete operation being approximately 45 secs. The units contained in the cabinet shown in Fig. 6 are :—

(*a*) Digital Indicator Type 157A (top)

The measured sugar content is directly displayed in numerals representing degrees ISS on our Digitron* numeral indicating tubes, type GR10G. The size of the numerals is approximately 1.2 x 0.67 in. (30 x 17 mm.).

(*b*) Industrial Analogue-Digital Converter Type 154A

This instrument is essentially a self-balancing potentiometer matching an internal voltage to the applied external voltage. It employs the 8, 4, 2, 1, binary-coded decimal system which can easily be translated into a pure decimal one-out-of-ten form for purposes of display or recording. Its function is essentially that of a digital voltmeter.

(*c*) Auxiliary Unit Type 143A.

This unit contains all the control circuitry for the system, and the binary-coded decimal-to-decimal translator which feeds the Hollerith card punch.

(*d*) Electronic Control Unit of the Polarimeter Type 143A (nearest the table).

The system employed is shown in the block diagram, Fig. 7.

The polarimeter compensation current is converted into a voltage by the inclusion of a resistor, the resultant voltage being fed to the Analogue-Digital Convertor. The ohmic value of the resistance is such that the digital output from the Convertor represents degrees ISS. The binary-coded decimal output from the Convertor is fed to the Digital Indicator where it is translated to decimal form for the display, and to the Auxiliary Unit, where another translator prepares the signals for the Hollerith punch card. The Analogue Digital Convertor does not monitor continuously but requires a control signal to make it operate. As the polarimeter requires some 30 seconds from the introduction of a sample to reach the correct reading, a time delay is incorporated in the Auxiliary Unit to initiate the Convertor after a fixed delay period from the time the operator

* *Registered Trade Mark.*

depresses the ' Initiate ' key on the front of the Auxiliary Unit. The operation of this key also clears the previous reading from the Digital Indicator and the translator for the card punch. A switch is provided to eliminate the delay period when setting up. There is also a lamp indicator to show that the card punch has completed its operation.

Setting Up

With the sample cell inserted and filled with distilled water, the polarimeter is adjusted to read zero, thus balancing out any birefringence which may be present in the cell. Calibration is accomplished by means of standard solutions, any adjustment required being made by means of the ' Calibrate ' control on the Analogue Digital Convertor.

Operation

The cell used is fitted with a funnel and is of the flow-through type. The operator fills the funnel with a sample and releases the syphon clip on the outlet tube. A discharge volume of 30 ml is required to ensure complete displacement of the previous sample. The operator then depresses the Initiate key, which clears the previous reading and starts the time delay. After the pre-set period the Analogue Digital Convertor is initiated, and the result of the measurement is displayed on the Digital Indicator and is fed through to the Hollerith machine. During the delay period, the operator inserts a plastic disc bearing the identification number of the sample into a Hollerith reader, so that the completed card bears the sample number as well as its rotation.

During the trials at Wissington, a total of nearly 30,000 samples were first tested by the visually balanced instrument and then by the Automatic Polarimeter. 96.4% of the measurements by each method agreed to within ± 0.1°ISS. It should be borne in mind that the degree of accuracy in this comparison depended upon the human element for the visual determinations, and upon the fact that the Analogue Digital Convertor used was a 3-digit model giving readings in steps of 0.1°ISS, i.e. to ± 0.1°ISS accuracy. At the Bury St. Edmunds factory, where an ETL-NPL Automatic Polarimeter is installed without digitizing equipment (a precision meter being used instead for indication), over 12,000 comparative tests were made. Of these, 80% produced identical results and over 97% gave figures within ± 0.1°ISS of each other. The results of these trials were so promising that a number of new installations are to be completed before the commencement of the 1959/60 beet campaign. It is worth noting that the only addition to normal tarehouse practice in the treatment of samples for automatic polarimetry is the inclusion of a fine mesh filter in the funnel of the cell, to exclude fragments of brei and filter paper fibres from the cell.

Modifications for New Installations

A number of improvements and modifications will be incorporated in the new installations to be completed during the autumn of 1959, although the basic system will remain unaltered. The dimensions of the equipment will be reduced by combining the Digital Indicator and the Auxiliary Unit.

The Analogue Digital Convertor Type 154A will be a 4-digit instrument (similar to the one shown this year at the Physical Society's Exhibition) giving readings down to 0.01°ISS, but as, by agreement, the sugar content is to be expressed to the nearest 0.1°ISS, a rounding-off operation is necessary. This can be accomplished automatically with the 4-digit Convertor if the zero position (i.e. with the cell in place filled with distilled water) is offset to + 0.05°ISS. If during operation the fourth digit is blacked out, the remaining three figures will be automatically rounded off to the nearest 0.1°ISS.

In the Auxiliary Unit a scanner is included after the translator (which at Wissington fed digital information to the Hollerith machine) to permit the attachment of print-out units or other recording devices which require information to be fed serially. The sample cell has a path-length of 20 mm. instead of the 10 mm. length previously used for tarehouse samples. The 100°ISS point, measured at a wavelength of 5461 Å mercury green and using a path-length of 200 mm., is 40.69° arc. For a path-length of 10 mm., a solution of 100°ISS would have a rotation of 2.0345° arc, thus 20°ISS in the same path-length corresponds to 0.4069° arc, whilst 0.01°ISS is equivalent to 0.0002° arc. When tarehouse solutions are half-strength, twice this path-length is required, i.e. 20 mm., to enable the same orders of rotation and precision to be maintained.

The new cell shown in Fig. 4 has an inlet probe with a mesh filter to suck up the sample, instead of the funnel.

We are indebted to the British Sugar Corporation whose constant interest in this instrument has greatly stimulated its development, and who have given the early installations critical appraisal in their factories. It is understood that it is intended to publish a paper[5] in the *International Sugar Journal* reporting the results of a season's work with the Wissington installation as it has been outlined here.

More detailed papers on technical aspects of the instrument will appear in specialist journals in due course.

References

[1]Gillham, E. J. *J. Sci. Inst. 34*, pp. 435-439 (1957)

[2]Gillham, E. J. *Nature* (London) *178*, pp. 1412-1413 (1956)

[3]Gates, J. W. *Chemistry & Industry*, pp. 190-193 (1958, Feb. 15)

[4]U.K. Patent application No. 34262/58

[5]Parker, Wm. H. *International Sugar Journal* 61, pp. 231-235 (1959)

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TRANSISTOR MULTI-CHANNEL CARRIER EQUIPMENT

(PART 2)

H. T. GOACHER AND G. ASHMORE — Carrier and H.F. Development Department

Part 1 of this series of articles described the twelve channel unit, type TCS 12, *used as the basis of the Company's multiplex systems. Part 2 outlines the means by which the necessary carrier supplies are generated. An effort has been made to provide carrier generating equipment of high performance and which is sufficiently compact in its basic form for economical use with small systems, but which can be readily extended for use with all installations up to the largest size.*

DESIGN CONSIDERATIONS

THE requirements to be met in the design of carrier generation equipment for frequency division carrier systems are mainly those of complete reliability and high standards of both short and long term frequency stability. It is also an advantage from a manufacturing point of view, where a whole range of carrier systems is produced, if the generating equipment can be easily adapted to all sizes of installation.

It is not possible to guarantee absolute reliability, but by sound design, conservatism in the rating of components, care in manufacture and the provision of standby equipment, which is automatically brought into use in the event of a failure, a very high grade of service can be given.

It will be readily appreciated that the greater the number of channels, and consequently the higher the frequencies involved, the greater must be the stability of the carrier supplies. The relative

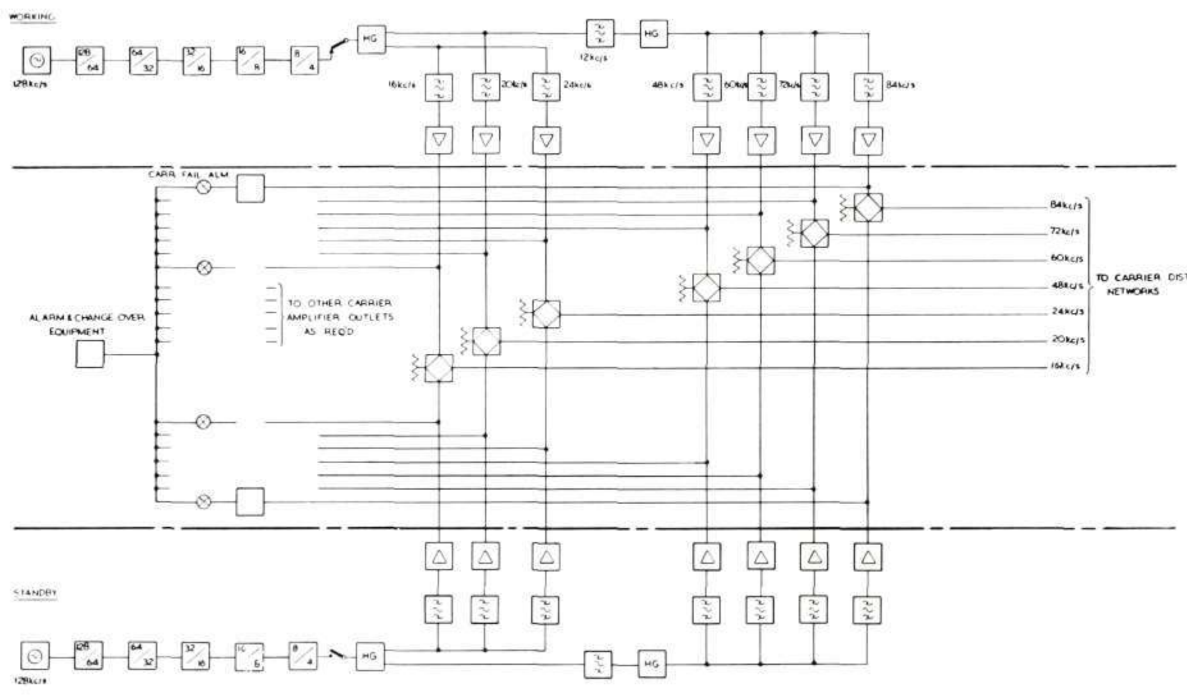

Fig. 1—Frequency Generating Equipment, Channel

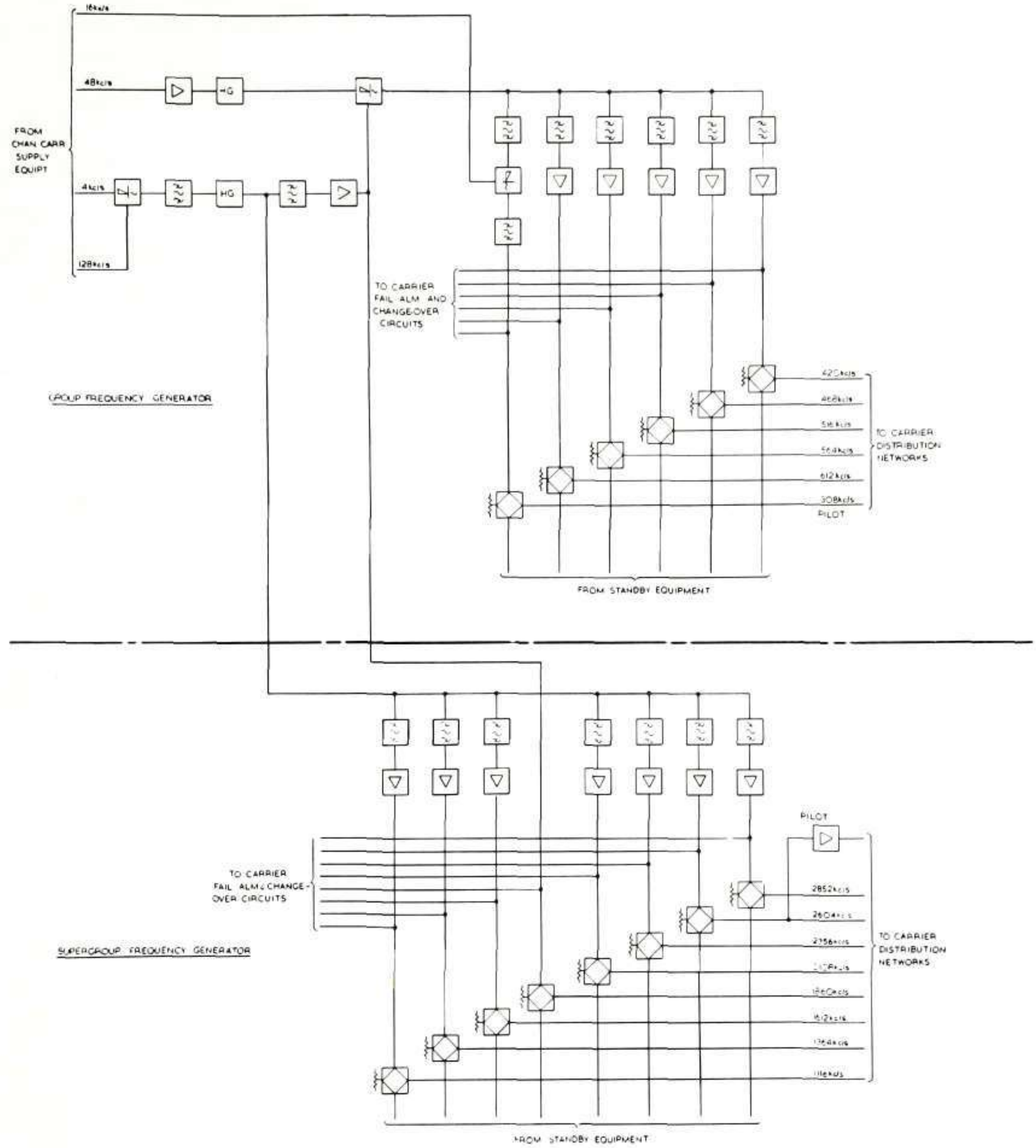

Fig. 2—Frequency Generating Equipment, Group and Supergroup

stabilities between the two ends of a link are particularly important, since any frequency difference of the corresponding carriers at the transmit and receive terminals will result in an audio shift of the received signals. The amount of asynchronism that can be tolerated depends upon the type of signal being transmitted. For example, a smaller frequency difference can be allowed for a high quality programme circuit than can be accepted for normal speech. Moreover, where a number of links are operated in tandem, frequency errors may add, and in consequence the stability requirements become more severe. The C.C.I.T.T. stipulate that carrier stability should be of such an order that an audio frequency transmitted through a link, or series of links, shall not change by more than two cycles per second. This means that over a single 12 or 24-channel link using an upper carrier frequency in the region of 100 kc/s, the stability of the carrier supply need not be greater than 1 part in 10^5 to comply with these requirements. In larger systems employing group and super-group modulation, the maximum frequency error which can be tolerated for each carrier may be only two parts in 10^7.

Carrier power is also a variable quantity. A TCS 12 terminal providing a twelve-channel group in the 60-108 kc/s band requires carrier power for 16 modulators and 16 demodulators (12 channels and 4 sub-groups). A 600-channel terminal however employs fifty such 12-channel groups, a total of 1600 modulators and demodulators, in addition to which carrier frequencies are required for group and super-group modulation stages. This varying range of frequencies and of carrier power levels can most economically be met by generating equipment which is used alone for simple systems, but which can be extended as required for more complex installations. For this reason the scheme described below has been developed.

General Circuit Arrangements

Figs. 1 and 2 show in block form the method by which the carrier frequencies are generated. Fig. 1 includes the generating equipment which produces the seven carrier frequencies, 16, 20, 24, 48, 60, 72 and 84 kc/s, required by the channelling equipment. Fig. 2 shows additional items which are added when group and super-group working is required.

Referring to Fig. 1 it will be seen that all carrier frequencies are determined by a single master source. The frequency of the master supply is controlled by a quartz crystal, cut to a frequency favourable for optimum stability (128 kc/s in this instance) and maintained at constant temperature. The oscillator output drives a chain of simple binary divider circuits which reduce the frequency to 4 kc/s. Series of odd and even harmonics are derived from this 4 kc/s source by a harmonic generator, and the third, fourth, fifth and sixth harmonics, 12, 16, 20 and 24 kc/s respectively, are then selected by inductor-capacitor type narrow-band filters. The 16, 20 and 24 kc/s frequencies are amplified and fed to distribution networks for use as channel carriers. The 12 kc/s signal drives a further harmonic generator from which are selected the remaining carriers, 48, 60, 72 and 84 kc/s, used by the sub-group modulators. These latter frequencies are derived from 12 kc/s rather than 4 kc/s mainly to simplify filtration requirements by the elimination of closely-spaced harmonics.

With any suppressed carrier type of transmission system it is of course desirable to provide means for comparing the synchronism of the carrier frequencies at the two ends of a link. A portion of the 60 kc/s carrier is used for this purpose ; it is fed through a constant voltage amplifier and is available for transmission as a pilot frequency over the link. The manner in which the frequencies are checked is outlined later in this article.

Carrier Supplies for Groups and Super-groups

In large multiplex systems employing super-group working, blocks of five 12-channel groups are assembled into 60-channel basic super-groups, which are then translated by super-group modulation stages into their final positions in the frequency spectrum. The super-group carriers are spaced at intervals of 248 kc/s and are odd harmonics of a fundamental frequency of 124 kc/s. This frequency is generated as shown in Fig. 2 by mixing 4 kc/s from the basic carrier generator with the 128 kc/s supply from the master oscillator. The 124 kc/s lower sideband is selected and drives a harmonic generator. The required harmonics appear at the generator output and are filtered and amplified in a similar manner to the channel carrier supplies.

The group carrier frequencies required for the formation of a basic super-group are, 420, 468, 516, 564 and 612 kc/s. They are produced by intermodulating the 48 kc/s sub-group carrier from the basic carrier generator panel with the 1860 kc/s super-group carrier, as shown in Fig. 2. Before modulation, the 48 kc/s carrier is distorted to render it rich in harmonics so that the modulator output will contain, among other products, frequencies of 1860 kc/s minus the 26th to 32nd harmonics of 48 kc/s, i.e. 324, 420, 468, 516, 564 and 612 kc/s. The frequencies 420-612 kc/s are filtered, amplified and used for the basic super-group carriers. The 324 kc/s output undergoes a further modulation with 16 kc/s, the difference frequency of 308 kc/s being used for pilot purposes.

Master Oscillator Synchronization

A frequency comparison panel enables the local and remote master oscillators to be checked and synchronized with each other and against external reference standards. A beat method is used whereby harmonics of the 60 kc/s pilot supplies are modulated together and the frequency difference is displayed as a beat on a meter. Direct comparison of the 60 kc/s pilots would produce too slow a beat for convenience, and consequently the error is first multiplied by using the 16th harmonics of 60 kc/s, i.e. 960 kc/s, to give a higher beat rate. The frequency difference is determined by counting the number of beats during a short period, the difference between the 60 kc/s inputs is then $\frac{n}{0.96\,t}$ parts in 10^6, where n = number of beats and t = time in seconds. In the event of a frequency error, it is desirable to know whether the frequency being checked is on the high or low side of the reference supply. A ' sense ' key is fitted to introduce a network into the ' reference ' side of the modulator. When the key is depressed and the network switched into circuit, the phase shift produced by the network momentarily retards the phase of the 960 kc/s supply to the modulator. If the frequency being checked is lower than the reference, then a momentary slowing down of the beat will be observed when the key is thrown. Conversely, the beat rate will increase if the frequency is higher than the reference.

A frequency deviation alarm is given by feeding the modulator output into a frequency discriminating circuit which produces an output voltage directly proportional to the input frequency. This voltage is applied to a detector circuit which gives an alarm when a pre-determined level is exceeded. The alarm can be pre-set to give indications when frequency differences greater than 2.5 parts in 10^5, 10^6 or 10^7 occur.

Stand-By Equipment

To safeguard against any interruption of service, the entire carrier generating equipment is duplicated. The output from each carrier amplifier is monitored by a transistor which is maintained in a non-conducting condition by the carrier supply. In the event of a carrier falling below a pre-determined level, the transistor conducts, lights an alarm lamp in its collector circuit, indicating that the particular carrier has failed, and operates a common transistor relay combination. This in its turn initiates change-over to stand-by and gives a general alarm. A key is provided which permits changeover to be performed manually when desired.

Both working and stand-by equipments are continuously energized ; the output circuits of each pair of carrier amplifiers are connected through hybrid transformers to provide mutual isolation. The changeover operation is effected by switching the 4 kc/s drives to the inputs of the basic carrier harmonic generators.

Master Oscillator

This uses a 128 kc/s GT-cut quartz crystal maintained in oscillation by a transistor drive circuit. In the interests of frequency stability, the amplitude of oscillation is kept to a minimum. A three-stage buffer amplifier employing OC 45, OC 71 and OC 72 transistors is used to raise the oscillator output to the required level. The complete oscillator is mounted in a cylindrical oven. This is maintained at constant temperature by an arrangement in which two windings having dissimilar resistance/temperature coefficients and forming the ratio arms of a bridge are wound on the outside of, and in direct thermal contact with, the oven. The bridge is supplied with current at 300 c/s from a small oscillator, and the output from the bridge is amplified and rectified to operate a relay controlling the oven heater circuit.

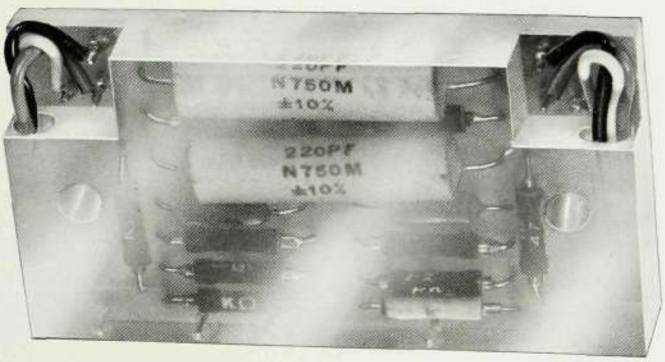

Fig. 3—Frequency Divider

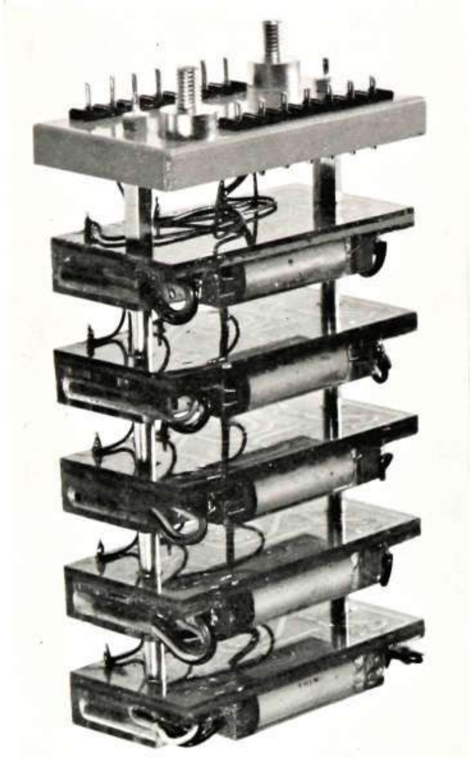

Fig. 4—Complete Frequency Divider Assembly, less cover

As the oven is heated, the bridge approaches balance and its output current decreases. When balance is attained the bridge output disappears, causing the oven control relay to release and disconnect the oven heater current, so limiting the oven temperature. The arrangement is sensitive to very slight changes in temperature at the balance point, and controls the temperature of the oven to within $\pm$ 0.5°C. An over-riding mercury thermostat is fitted as a safeguard against overheating in the event of a failure. The frequency stability of the oscillator is better than $\pm$ 1.5 parts in 10^7 over one month. Where stability requirements are less stringent, as for 12 or 24-channel systems, substantial saving can be made by replacing the oscillator by one of lower stability, for example $\pm$ 5 parts in 10^6.

FREQUENCY DIVIDERS

A divider unit consists of two OC 45 transistors arranged in a standard Eccles-Jordan circuit to give 2:1 division ratio. Each assembly is in the form shown in Fig. 3 and measures approximately 3 x $1\frac{1}{2}$ x $\frac{1}{2}$ in. (76 x 38 x 13 mm.). Printed wiring is used and the divider unit is encapsulated in resin. All five dividers are mounted together in a single unit can, as shown in Fig. 4. The total current consumption is approximately 5 mA. The final divider forms part of the 4 kc/s harmonic generator, since its output is of square waveform and is very rich in odd order harmonics of 4 kc/s. This waveform is supplied to an OC 71 transistor operating in the common collector mode, to provide an output circuit of low impedance. A rectifier bridge connected across the transistor output serves as a frequency doubler from which a series of even harmonics is obtained. The harmonic generators used for the production of sub-group, group and super-group carriers are of conventional type, using high-gain amplifiers and saturable inductors.

Fig. 5 shows the master oscillator frequency divider and generator panel.

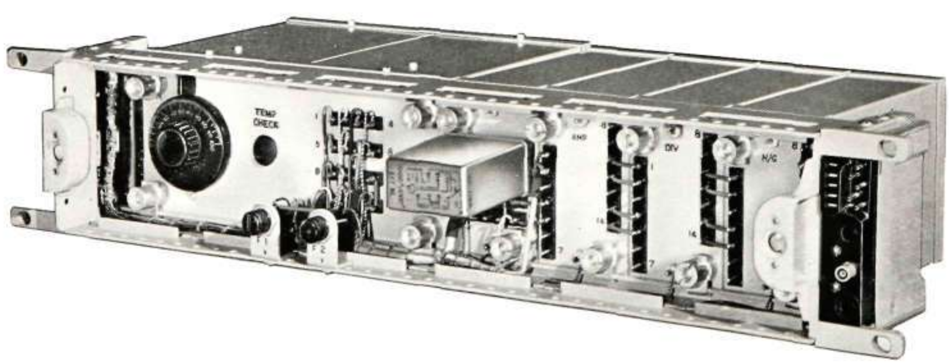

Fig. 5—Master Oscillator, Frequency Divider and Harmonic Generator Panel

Amplifiers

All channel carrier amplifiers are of identical construction. Each uses two OC 44 transistors as a voltage amplifier followed by a power stage consisting of two GET 105 type transistors operating in push-pull. Negative feedback is used to stabilize gain and give a low output impedance. Two working and two stand-by amplifiers together with their respective carrier filters are accommodated on a panel 3½ ins. (89 mm.) deep, and each set of amplifier panels supplies sufficient carrier power for 60 channels. Where equipment exceeds this figure, further sets of amplifiers consisting of an output stage only, are fitted at the rate of one set per additional 60 channels.

The sub-group carrier amplifier panels are of similar construction, but the amplifiers are of single-ended design due to the lower power demand.

Mechanical Construction

Construction is on similar lines to the channel equipment rack previously described in Part 1. Certain panels, however, require a different form of mounting, due to the large number of screened conductors which have to be brought into these panels. The rack cable is wired directly to the panel, which is hinged at one end so that it may be swung forward for maintenance purposes.

A typical rack of carrier generating equipment is shown in Fig. 6.

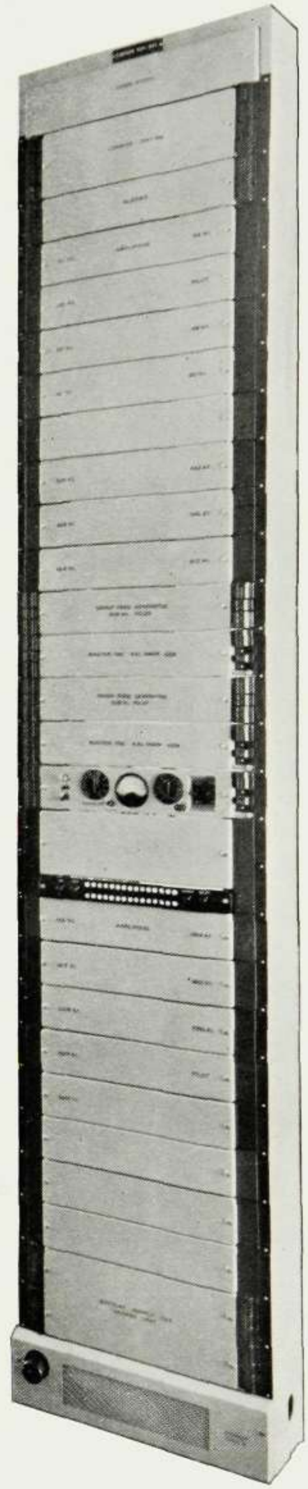
Fig. 6—Carrier Generating Equipment Rack

Power Consumption

The use of transistors has resulted in very low power consumption compared with the equivalent valve type apparatus. In consequence there has been a considerable reduction in heat dissipation which is particularly advantageous where large amounts of equipment may be assembled in a confined space. As an example, a typical carrier supply rack for a 60-channel terminal requires approximately 14 watts at 24V.d.c. This compares most favourably with the older type equipment which requires an input of some 200 watts.