# Automatic Manufacturing Testing of Relay Switching Circuits

By L. D. HANSEN

(Manuscript received May 18, 1956)

*The large variety and quantity of shop-wired relay switching equipments produced by the Western Electric Company lead to the use of comprehensive and flexible manufacturing testing facilities to insure quality of product and to reduce costs. An older manual type test set is briefly described and used to illustrate the functions and operation of two automatic test sets designated as Card-O-Matic and Tape-O-Matic respectively.*

## INTRODUCTION

Early telephone central office installations were of the manual switchboard type which were relatively simple and required few relay circuits other than those located in switchboards themselves. Installation effort, in addition to actual erection of the switchboards, equipment frames, fuse boards and the like consisted largely of running and terminating the central office cabling. As the telephone art grew, both with the introduction of the dial telephones, and carrier and repeater equipments for long distance calls and the consequent need for interconnection of these various types of systems, a considerable variety of relay switching circuits was required.

To reduce the installation time and effort the practice of doing as much circuit wiring in the factory as possible was introduced. Relay switching units are now completely assembled, wired to terminal strips and tested in the shop. Since these are in effect working circuits the installation testing effort, after the connection of office cabling, consists largely of overall tests required to insure the proper functioning of the entire office.

Due to the wide variety and complexity of these units, many of which have optional circuit conditions that can be supplied on order and few of which have sufficient demand to justify specially designed high pro-

duction test sets for their exclusive use, adaptable manually operated test sets were first used. These sets required a high degree of flexibility in interconnecting the terminals of the circuit under test to those of the test set and in applying the proper potentials in sequence that would insure putting the circuit through its paces and checking that the switching functions are properly performed.

It should be stated here that since all apparatus components of these circuits such as relays, transformers, capacitors, inductors and resistors are tested and inspected for their respective electrical and mechanical requirements when manufactured, except in the case of some types of relays which require adjustment to meet their particular circuit requirements, the testing of switching circuits is largely confined to verification of the circuit wiring with normal voltages. Although marginal component tests are not normally applied, operation tests will, of course, detect defective apparatus components which cause malfunctioning of the circuit.

## MANUAL TEST SET

Fig. 1 shows a representative manual type test set that was extensively used for wired relay unit testing before the introduction of the automatic test sets to be described later. On the left side is a pin jack field into which the numbered wires of the connecting cable can be individually plugged in order to connect the test set terminals to the proper terminals of the relay unit under test. The other end (not shown) of the cable is equipped with a contact fixture arranged to give quick electrical connections to the terminals of the wired relay unit. The plugging of the pins into the proper pin jacks is a feature needed to provide flexibility in a test set arranged to test many types of circuits and is a part of the setup operation for any one circuit. It is a slow and time-consuming operation since each lead has to be identified and plugged into the proper pin jack. The pin plug setup must be taken down and rearranged in order to test any other type of relay circuit.

The test set is equipped with signal lamps for visual response indications and manually operated keys for the use of the tester in performing the test operations. Separate power cords are plugged into power distribution jacks which supply the various potentials commonly used in telephone central offices.

After the initial setup the tester operates the numbered keys and observes the lamp signal responses in accordance with the chart clipped to the front of the test set. Failure to get a particular lamp indication

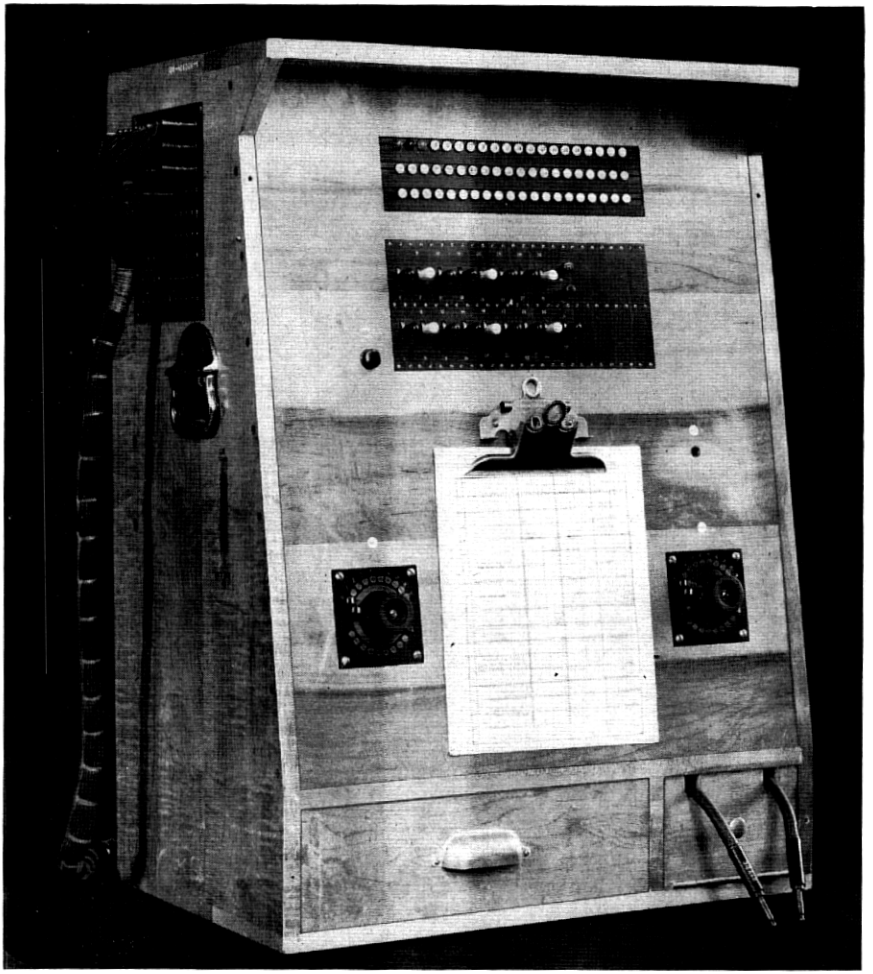

Fig. 1 — Manual wired unit test set.

requires that he analyze the circuit conditions and locate the cause of the trouble. Usually a circuit fault must be corrected before testing can proceed.

Fig. 2 shows a small portion of a simplified circuit test arrangement for such a manual test set. In this illustration a single key, when operated, supplies battery and ground potentials to the winding of a relay in the circuit under test. Assumption is made that the three relay contact terminals are wired directly to the relay unit terminal strip so that

they can be connected to ground and to battery through lamps for circuit closure indications. The switching functions of the relay can then be checked by operating the test key and observing that signal lamp (1) extinguishes and that (2) lights.

While such an arrangement can adequately test most switching circuits of any complexity by further extension of the basic scheme, when supplemented by internal circuit connections where necessary, the

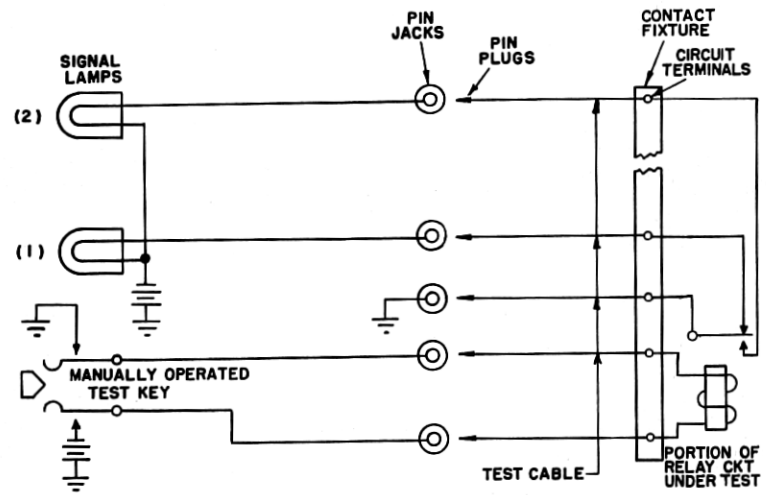


Fig. 2 — Simplified circuit sketch for manual test operation.

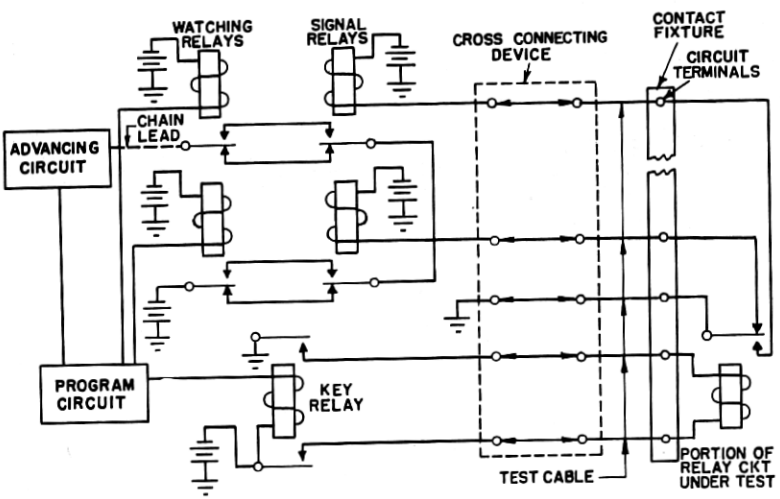


Fig. 3 — Simplified circuit sketch for automatic test operation.

system is at best a slow and laborious one which is subject to human error. Wages for testers are determined not primarily on their ability to operate keys and check the indications of lamps but on their skill in analyzing and clearing trouble conditions. If some quick and automatic means could be devised to make the initial cross connection setup, apply the potentials in the proper sequence under control of some programing device and check the circuit responses at each step a real advance in speeding up tests and reducing human errors would be accomplished Such an automatic set ideally should have improved response indications to aid the the tester in locating circuit troubles when the test set stops on the failure of meeting any test requirement.

## THE AUTOMATIC TEST SET

The key and visual lamp indicating functions of the manual test set can be replaced by relays in an automatic test set which perform these operations if they are under control of suitable programing and advancing circuits as shown in Fig. 3. Here the "signal" relays operate through the contacts of the relay under test and their operating positions are checked by the "watching" relays whose contact closures must match those of the signal relays. The series path through the contacts of all signal and watching relays is called a chain lead. The program circuit establishes the positions of the watching relays to meet the expected conditions prior to operating the key relay and then any lack of continuity through the chain lead caused by failure to satisfy test conditions halts the progress of the tests under control of the advancing circuit. At this point additional contacts (not shown) on the signal and watching relays may be used to light signal lamps to convey information to the tester as to which portion of the circuit failed to operate properly.

For quick setup a pre-wired multi-contact adapter plug may be used as a cross-connection device to permit establishing the proper test connections to the unit under test. One will be required for each type of relay circuit to be tested. These, together with some means whereby the sequential operation of the programing circuit can be controlled, constitute the essential features of an elementary automatic relay switching circuit test set. How these basic features can be extended into practical embodiments will be explored further below.

## THE CARD-O-MATIC TEST SET

Key equipment relay units are small switching circuits used as circuit building blocks to provide the desired optional features in conjunction with the key boxes or key-in-base telephones often seen in small

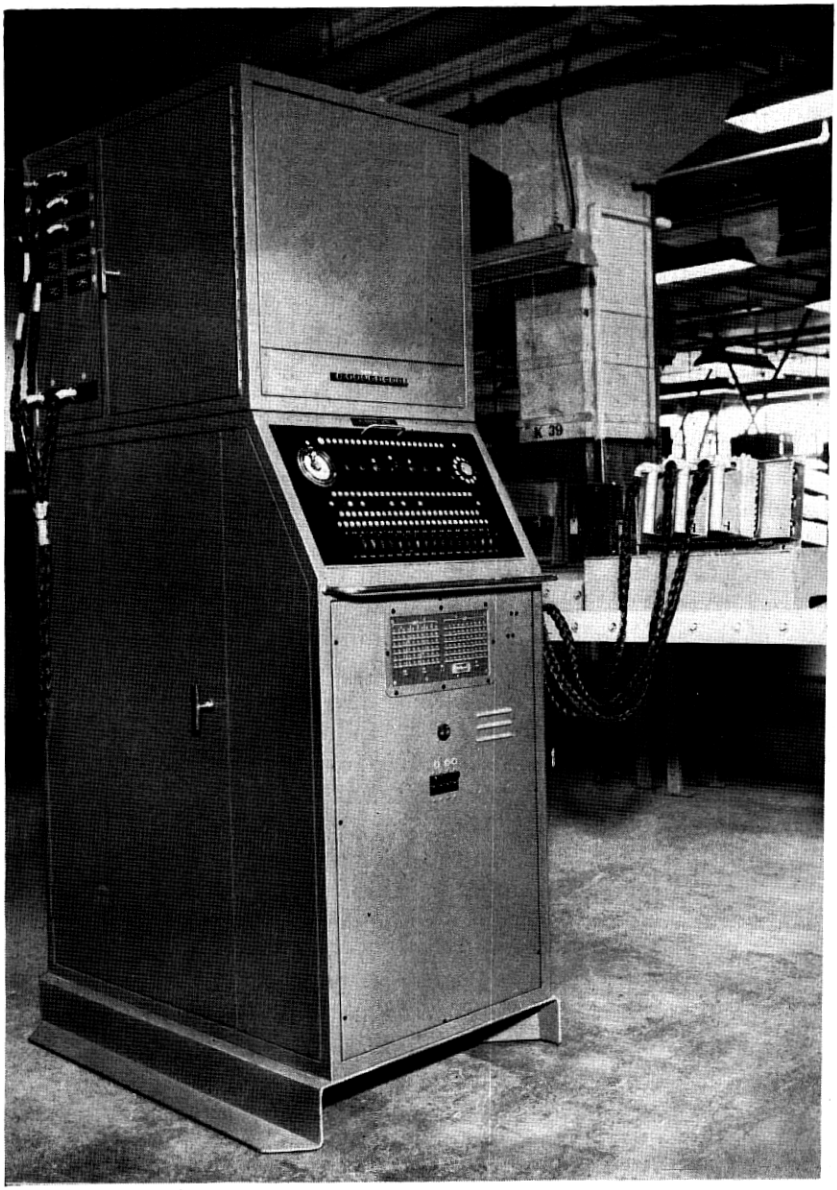

Fig. 4 — Card-O-Matic test set.

business offices to furnish the flexibility needed in answering and transferring calls. These systems are used where the number of telephones served does not warrant the use of a regular PBX switchboard.

These circuits are relatively simple but their large scale production warrants the use of high speed automatic test sets to perform the test functions and to indicate circuit trouble.

Fig. 4 shows the operating position of the Card-O-Matic* test set which was developed to test such unit assemblies. The keys shown are used to initiate and control the automatic operation of the test set and in trouble shooting. They are not to be confused with those that perform the actual testing functions described previously for the manual test set. The lamps provide indications of the progress of the tests and of the positions of the watching relays which are also needed to aid in determining the point of circuit failure. The meter type relay in the upper left corner of the operating panel provides a sensitive checking device for audio frequency tests through the voice transmission circuits. The telephone dial affords a simple means of generating any required number of pulses for operating stepping selectors on some types of units. The terminal field in the lower front of the cabinet gives the tester access to the circuit terminals of both the unit under test and the test set for his use in analyzing and locating faults. The upper cabinet was a later addition and contains the multi-contact relays needed to permit testing units with more than one circuit. The row of push buttons are used to select the circuit to be tested.

Fig. 5 is a rear view of the set that shows the perforated insulating card from which the set derives its name. The coded card controls the sequence of test operations and is hung on pins over the field of 1,000 spring plungers (20 × 50) as a part of the setup operation for a particular relay unit. Closing the door and screwing up the hand wheel, which is necessary to provide the force required to depress the plungers, will ground those which coincide with holes in that particular card.

Cross-connection setup of the test leads is achieved by the use of a plug-board such as is commonly used for quick change over on perforated card type business machines. Fig. 6 shows the plug board being inserted into the transport mechanism. The relatively large number of terminals are required because each of 60 test leads must be capable of being patched in to an equivalent number of terminals on a maximum of ten different circuits. Not all of our test sets are equipped with the upper cabinet since most key units have only one circuit and on these a simpler

* Patent No. 2,329,491.

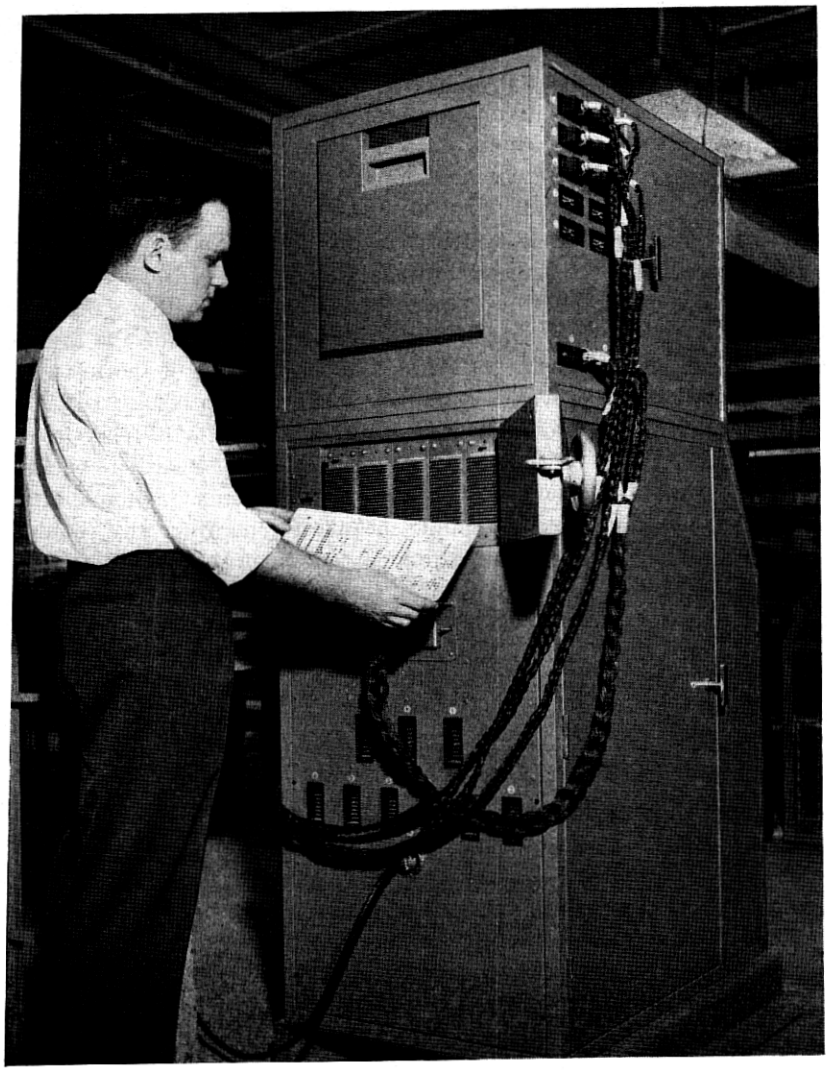

Fig. 5 — Rear view of Card-O-Matic test set showing insertion of perforated card.

cross connection fixture is plugged into the location where the lower end of the cable joining the two cabinets is shown terminated in Fig. 5.

A side view of the test set is shown in Fig. 7 to give an indication of the amount of switching equipment and wiring necessary for an automatic test set of this sort. The set is powered from a 120-volt 60-cycle

source from which are derived the 24-volt dc, 90-volt 20-cycle ringing current and 600-cycle audio tone supplies that are required. The test circuit features include tone transmission checking, dial pulsing, 90-volt 20-cycle ringing and ground and battery supplied either directly or under relay control. Other battery and ground relays are available for checking the response of the circuit under test.

These test features have been sufficient to perform operation tests on most relay units associated with key telephone systems. The test cycle is fast and the twenty test steps can be performed in approximately ten seconds. The lamp indications given when the test is interrupted by an open-circuited chain lead, convey information to the tester as to which test step is involved and when any pairs of signal and watch relays fail

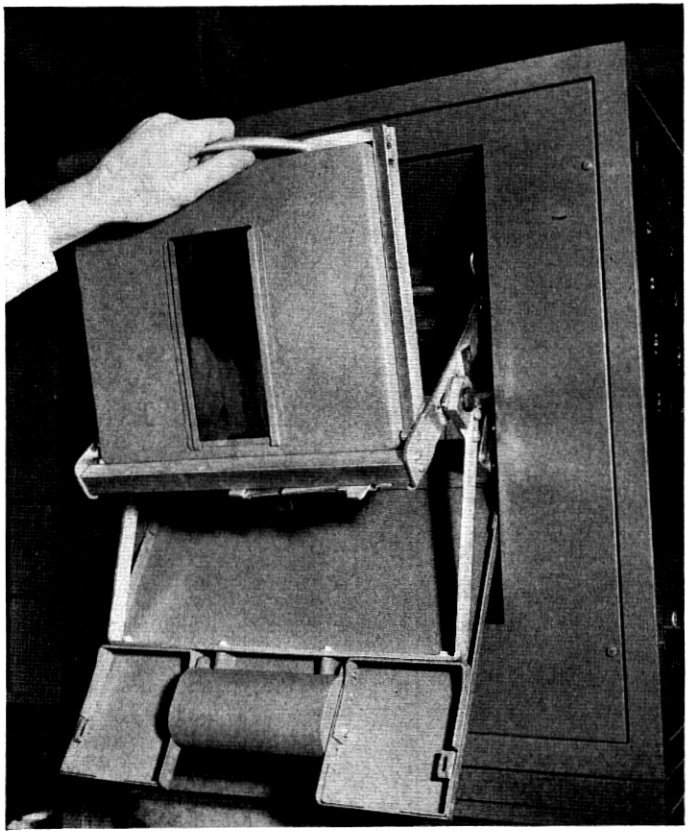

Fig. 6 — Insertion of cross-connection plug board into Card-O-Matic test set.

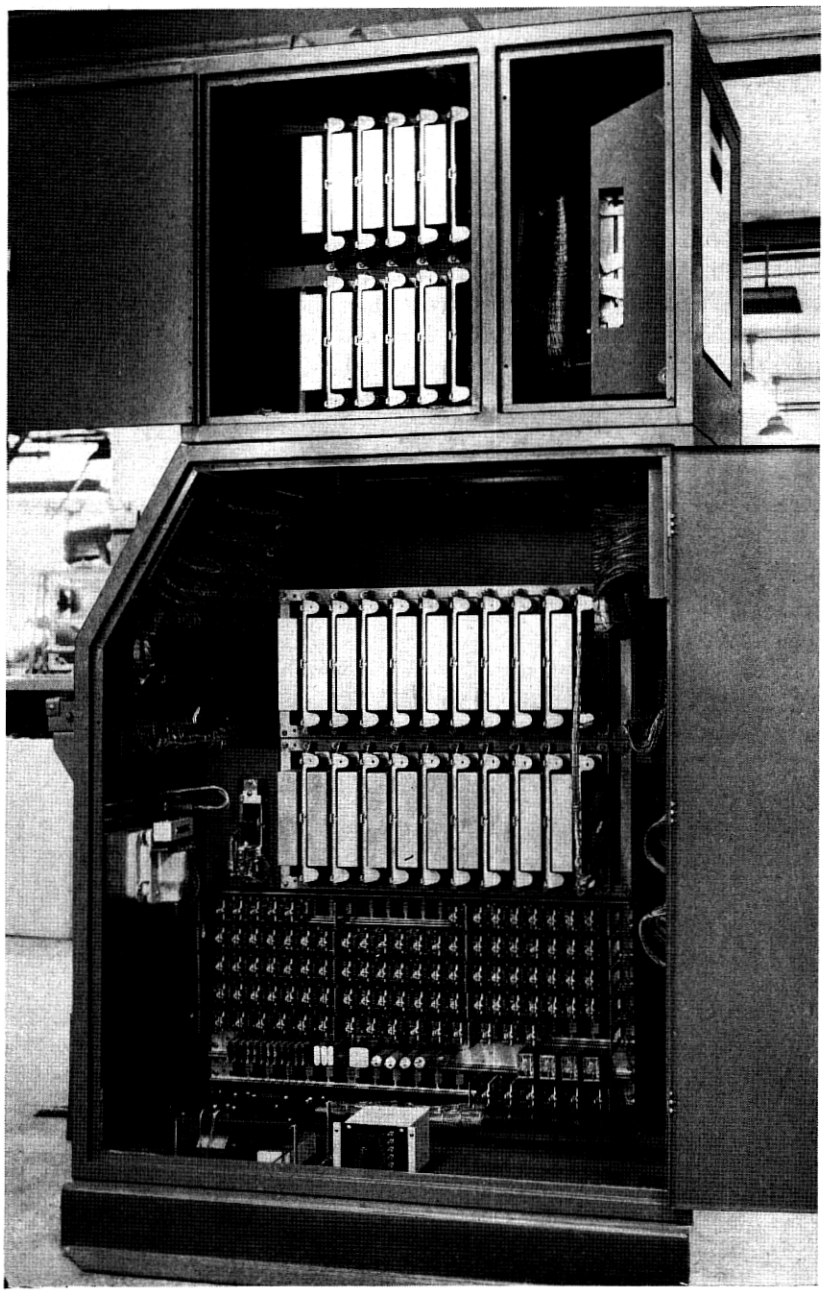

Fig. 7 — Interior of Card-O-Matic test set.

to match each other. Simplified circuit sketches which show the interconnection of test set and wired unit circuits are provided to enable the tester to determine quickly the cause of the failure.

The Card-O-Matic test set, while performing admirably on the relatively simple relay circuits within its range and capabilities, falls down on the more complicated relay switching circuits used in telephone central offices for several reasons. The most important of these are:

1. A fixed cycle within a maximum of twenty steps with any one coded card.

2. No provision for alternate or optional circuit conditions on a card.

3. The only power supplies provided to operate relays are negative 24-volt dc and 90-volt 20-cycle ringing whereas telephone office units frequently also require negative 48-volt and positive 130-volt dc as well as positive or negative biased ringing currents for party line ringing.

4. The increase of either test steps or features would increase the size of the perforated card beyond a practical size.

### THE TAPE-O-MATIC TEST SET

The experience gained in the design and successful operation of the Card-O-Matic test set led naturally to the exploration of ways and means whereby a more versatile and comprehensive set could be devised. The five hole coded perforated teletype tape was selected as a cheap and flexible programing device. It afforded a means of providing a test cycle of any required length and, since the perforating and reading mechanisms were already available, it appeared to be nearly ideal for its purpose.

Consideration was given to the following desirable features all of which were incorporated in the design of the new set:

1. Provision for cross-connecting (under control of the coded tape) any test set circuit to any terminal of the circuit under test for as long as necessary and then disconnecting for reuse in later testing steps if required. This would greatly extend the range and capabilities of the set.

2. Provision for several power voltage sources which could be selected as required to meet the normal telephone office voltage requirements of the unit under test.

3. Provision for alternate or optional tests to be coded into the tape to meet the various circuit arrangements that may be wired into the unit as required by the Telephone Company who is our customer. Such optional test arrangements could be applied by the test set under the control of keys to be operated by the tester as part of the setup at the start of the tests.

4. Provision for stopping the test cycle to enable the tester to perform manual operations such as inserting a test plug in a jack on the unit or insulating relay contacts in order to isolate portions of the circuit for test simplification and to obtain a more detailed test.

5. Provision of improved lamp indications to aid the tester in clearing wiring faults or in locating defective apparatus. These would include the necessary information as to which test set circuits are connected to which unit terminals as well as which relays of the wired unit should be operated at that stage of the test cycle.

6. Provision for connecting several terminals of the unit under test together as a means of providing circuit continuity where required.

7. Provision for measuring resistance values of circuit components.

8. Provision for insertion of various resistors in battery or ground leads to control currents to desired values.

9. Provision for checking voice transmission paths through non-metallic circuits such as transformers or capacitors.

10. Provision for measuring circuit operating times in steps of approximately 100 milliseconds.

11. Provision for sending and receiving dial pulses.

12. Provision for a single code for releasing all test connections and conditions previously established by the coded tape as a means of quick disconnect. This is in addition to the release of individual connections mentioned in (1) above.

13. Provision for audible and visual indications of completion of a successful test cycle.

Through the use of two letters (each of which has its own combination of the five holes) for each signal it was possible to obtain the over 500 codes required to control all test and switching functions even though the teletype keyboard has only 32 keys. The only Teletype transmitter (tape reader) available when the test set was first designed operated at a speed of 368 operations per minute and was arranged for sequential read out on two wires by means of a commutator. Conversion to five wire operation and removing the commutator permitted reading each row of holes simultaneously. The gearing was also changed to permit 600 operations per minute but even so the hole reading contact dwell time was increased from approximately 20 milliseconds to 70 milliseconds for more reliable operation with ordinary telephone relays.

The machine which was designated as the Tape-O-Matic* test set, is shown in Fig. 8 in operation on a typical wired relay unit mounted in its shipping frame. The contact fixture is attached to the unit terminal

* Patent No. 2,328,750.

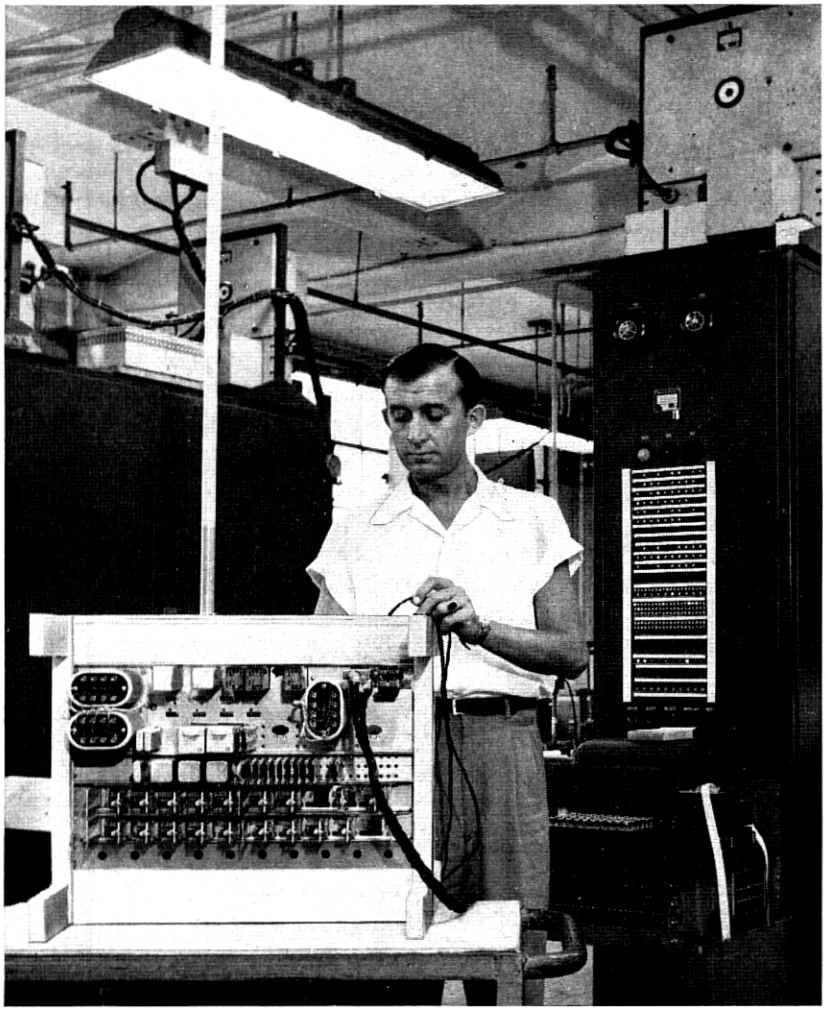

Fig. 8 — Tape-O-Matic test set in operation.

strip and cabled to a gang plug which in turn is plugged into a receptacle behind the operator. These leads are extended through a duct to the metal enclosure at the base of the set for entry to the test set proper. The coded tape is dropped into the receptacle at the side of the key shelf to which it returns after its traverse through the reader. A row of circuit breakers on the end of the key shelf control the application of

and provide protection for the various power supplies. Two of these supplies are mounted on the top of the set.

The rows of vertical push button keys on the key shelf afford the tester a means of determining (for trouble shooting purposes) the association (through lamp display signals) of the wired unit circuit terminals with those of the test set and the corresponding test voltages which are connected at that particular stage of the test. The lamp display panel also indicates which test set circuits are in use and through fast or slow (0.5 or 1 second) flashes whether the fault thus indicated is the result of a failure to meet either an expected condition or the occurrence of an unexpected condition. This feature is illustrated in Fig. 9 which shows one link of the chain leads which extend through all pairs of signal and watching relays for the check of satisfaction of all test conditions and the application of steady or interrupted ground to the associated test feature lamp. The operating condition of all test set key relays as previously established by the tape is also indicated by the display lamps. Another type of information obtained from the lamp display panel which is valuable to the tester in trouble clearing is the indication of the particular unit relays which should be operated at that part of the test cycle. By checking the lamps against the operated or non-operated position of the relays he can frequently localize the fault in a minimum of time.

As mentioned above an important part of the test set flexibility is the ability of the tester to set up the test set to test only those optional circuit arrangments which are provided in any particular unit ordered

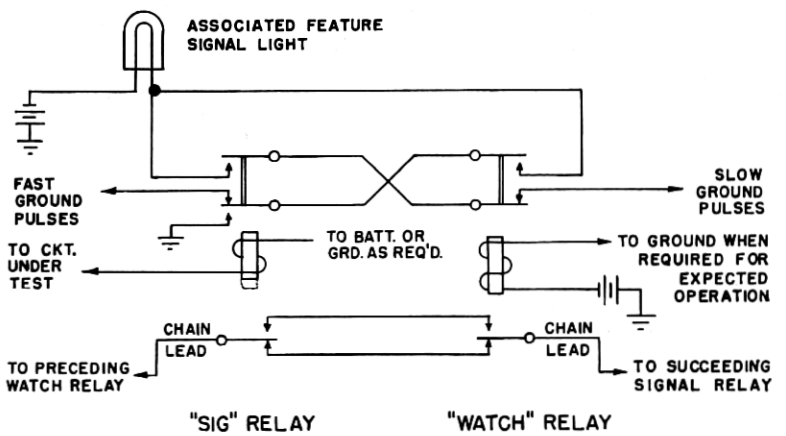


Fig. 9 — Chain circuit showing watching relay function.

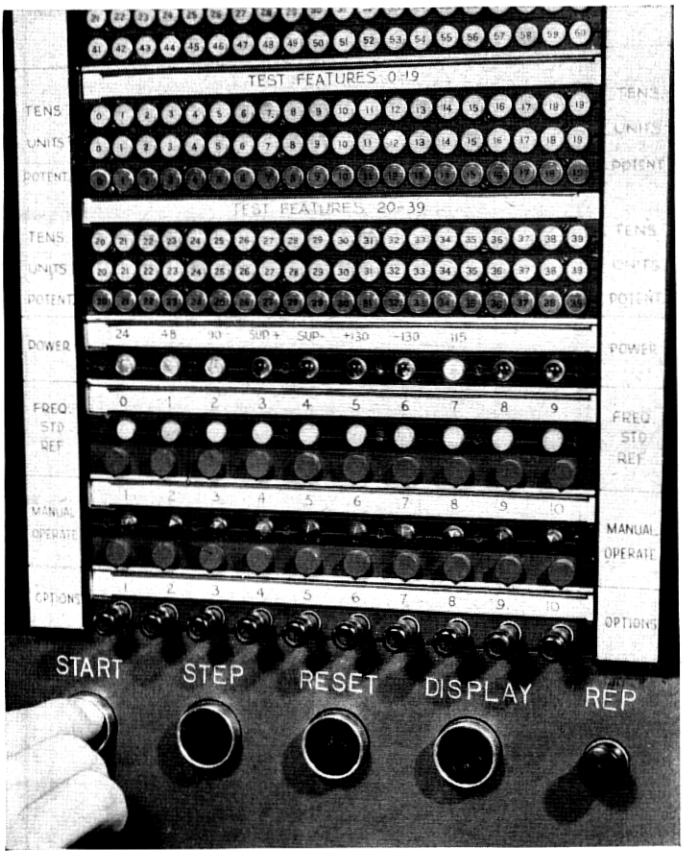


Fig. 10 — Lower portion of lamp display panel.

by the customer. Failure to provide this would result in fixed test cycles and many more tapes, which might be similar but varying only in regard to the options, would have to be prepared. Figure 10 shows the lower portion of the lamp display panel with the push-pull option keys on the bottom row. Directly above are the manual operation keys with their associated lamps which the tester must operate to cause the test set to resume the testing cycle after it has stopped for him to perform a manual operation.

A side view of the interior of the set is shown in Fig. 11. Two bays each facing the oppcsite direction from the other are housed within the cabinet and are used for mounting the crossbar switches and telephone type relays which are the principal circuit components. Two doors on

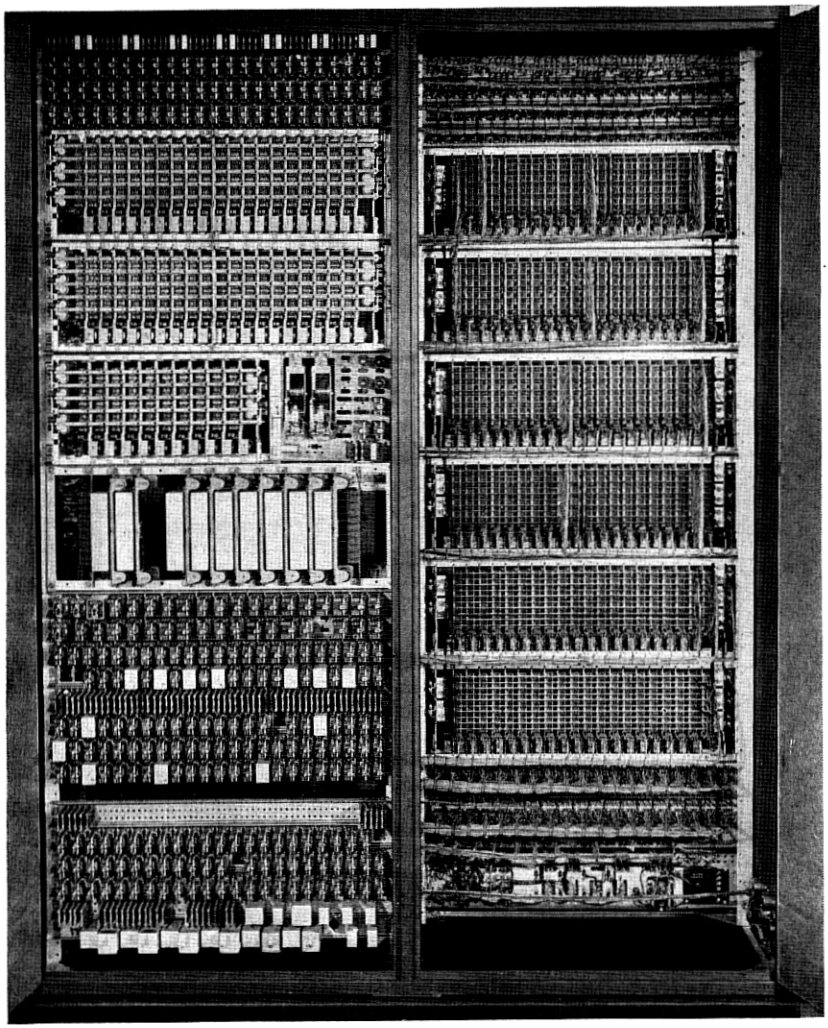

Fig. 11 — Interior of Tape-O-Matic test set.

each side give convenient access to all wiring and apparatus for maintenance purposes.

A fairly large portion of the mounting space is occupied by the crossbar switches which perform the functions of interconnecting the circuit terminals of the unit under test and those of the test set. They also connect the proper voltages to these circuits. The switching plan Fig. 12

shows in abbreviated diagramatic form that the unit terminals 0-99 appear on the horizontal inputs of the two 10 × 20 and one 10 × 10 switches that comprise the primary group. The horizontal multiple of these switches are split so that each section runs through five verticals to afford connection to each of the hundred unit terminals.

The vertical outputs of the primary switches are connected to the horizontal inputs of the two 10 × 20 secondary switches. The horizontal multiple of these switches are split so that each section runs through eight verticals. The verticals of the secondary switches are linked to the horizontals of the two 10 × 20 tertiary switches which have their

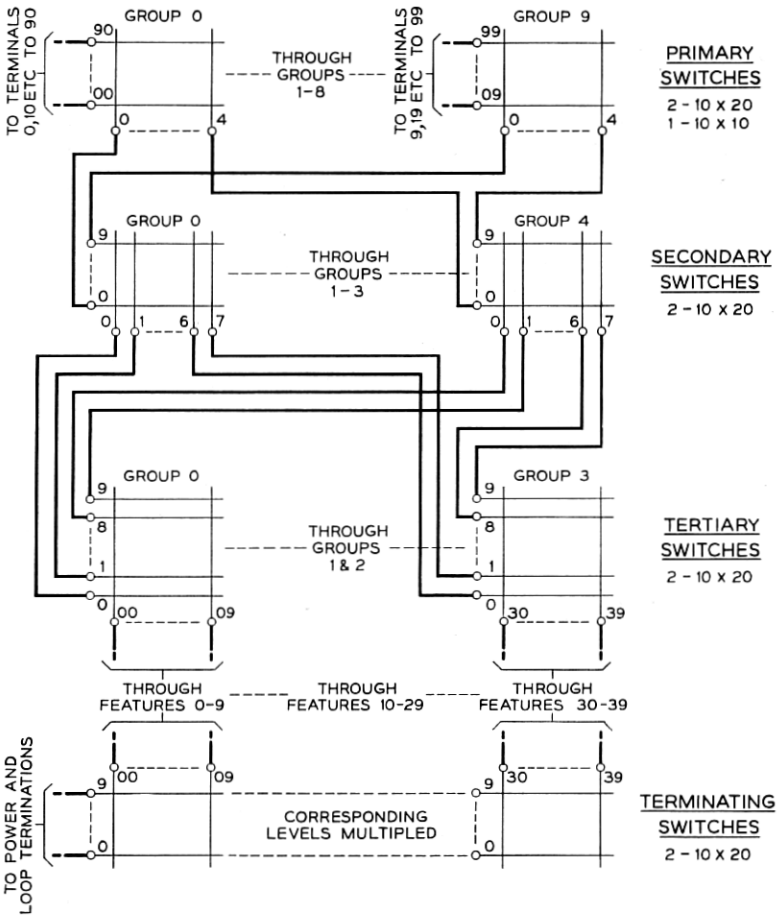


Fig. 12 — Switching plan.

multiple split into groups of ten. The 40 verticals of the latter are connected directly to the 40 test set feature circuits designated 0-39.

Two additional 10 × 20 crossbar switches perform the function of connecting any of the five power or five multiple terminations to any of the forty test set features. These terminations are comprised of 5 loops and one each of ground, negative 24 volts, negative 48 volts, 90-volt 20-cycle ringing current and positive 130 volts.

Thus it can be seen that, through proper operation of the primary, secondary, tertiary and terminating crossbar switch cross points, a path can be established from any circuit terminal to any test set feature and supplied with any of the available power or loop terminations. It is

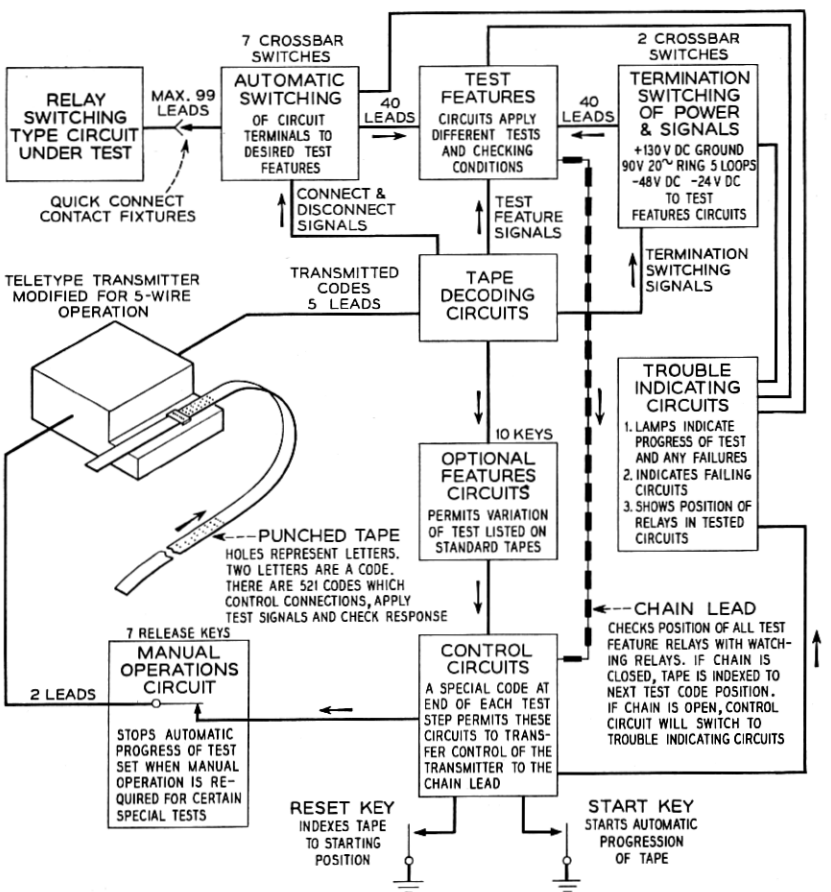


Fig. 13 — Block schematic.

also apparent that several paths can be found that will satisfy any one switched connection. Paths are assigned in sequence by a series relay loop circuit. The entry point on this circuit is changed periodically to distribute wear on the relays and switch cross points.

Although only one lead for the switched circuit is shown for each cross point in Fig. 12 there are actually four leads through corresponding pairs of contacts through each cross point. The remaining leads are associated with the holding and signalling functions of the switch.

The block schematic (Fig. 13) shows the principal functions which must be included in an automatic test set of this sort. A somewhat more detailed schematic is presented in Fig. 14 in order to show the functions of the forty test features 0-39. These are tabulated in Table I.

The coding of the two letter combinations in the tape must follow a definite sequence in order that the machine may recognize and act on the information it receives. This sequence is as follows:

1. Code FW to stop the tape at the end of the reset cycle after which tests will proceed when the start button is pressed. This is the first code on all tapes.

2. Codes to set up crossbar switches to connect each circuit terminal to its proper test set terminal and the proper termination. Knock down or release codes may also be sent.

3. Codes to operate or release "Key" relays. These relays are shown without windings in Fig. 14.

4. Codes to operate or release the watching relays associated with the "Signal" relays which are shown with windings in Fig. 14.

5. Codes to operate or release relays controlling the lamps associated with relays in the circuit under test to aid in trouble shooting.

6. Codes to delay the timing out interval up to a maximum of ten seconds.

7. Code FJ which checks the matching of all signal and watching relays through the chain circuit for satisfaction of all test conditions being applied.

In addition to the above, additional codes can be inserted after each FJ test signal to stop progress of the test to permit the tester to perform some required manual operation. After completion of this step he presses a button associated with that operation and the test proceeds. Option codes can also be inserted at the beginning and end of each testing step to permit bypassing of that part of the tape if the corresponding option keys are operated at the beginning of the test. A common knock down code FR can be inserted at any time to release all connections and relays for a quick disconnect and make all test set features available for

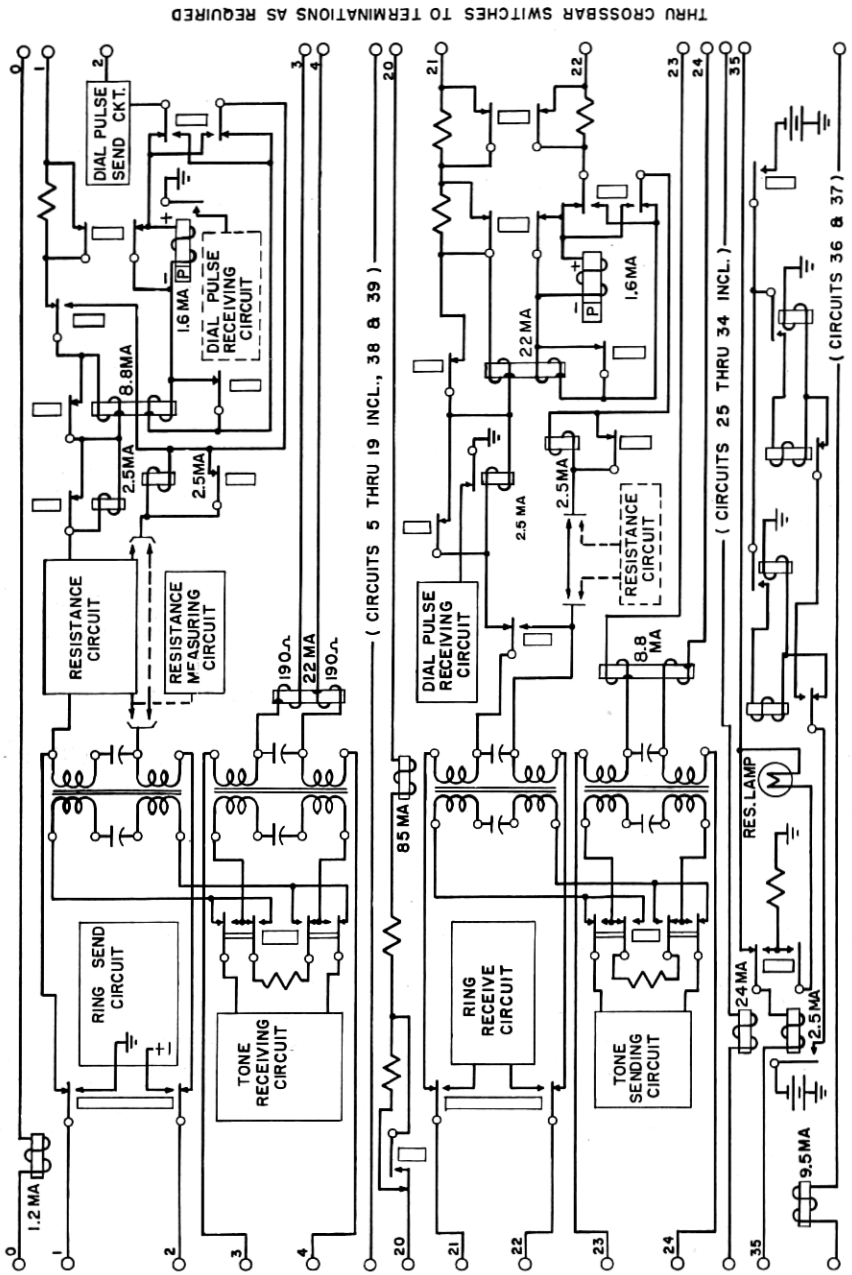


Fig. 14 — Functional schematic.

reuse. A final code SC must be put in every tape to operate the OK lamp and gong if a successful test cycle has been performed or conversely to indicate that the tape should be re-run if trouble has been found and cleared during the test cycle to be certain that no new faults have been introduced.

Preparation for testing a particular wired relay unit requires only the selection of a test cable one end of which is equipped with a suitable contact fixture for attachment to the unit terminal strip and the other with a gang plug for connection to the set. The proper tape is selected from a nearby file cabinet and inserted in the gate of the tape reader as shown in Fig. 15. The tape is stored in a cardboard carton $3\frac{3}{4} \times 4$

TABLE I

| Feature Numbers | Description of Functions |
|---|---|
| 0 | High sensitivity relay circuit. Simulates 1,800-ohm sleeve circuit for busy test and general continuity through high resistance ciruits. |
| 1 and 2 | Simulates the distant tip and ring terminations of a subscriber or exchange trunk. Provides for ringing, tone receival, dial pulse sending, line resistance, high-low or reverse battery supervision, pad control, continuity, and resistance verification. |
| 3 and 4 | Auxiliary tip and ring circuit for holding, checking continuity, receival of tone on four wire or hybrid coil circuits. Loss range of less than 0.5 db, 0.5 to 1.5 db, 1.5 to 6 db and 6 to 15 db can be checked. |
| 5 through 19 | Direct connections for supplying any of the ten terminating conditions. |
| 20 | Simulates low or medium resistance sleeve circuits for marginal tests. |
| 21 and 22 | Simulates the local tip and ring terminations of a switchboard or trunk circuit. Provides for ringing and dialing receival, high-low reverse battery supervision, transmission pad control, tone transmission, continuity and resistance check by balance. |
| 23 and 24 | An auxiliary tip and ring circuit for holding, checking continuity, tone transmission on four-wire hybrid coil circuits. |
| 25 through 34 | Low sensitivity relay circuits for general continuity checking. |
| 35 | A circuit for checking balance on the (M) lead of composite or simplex signalling circuits and for checking receival of none, one or two pulses. |
| 36 and 37 | Medium sensitivity relay circuits for continuity checking. |
| 38 and 39 | Direct connections for supplying any of the ten terminations. |

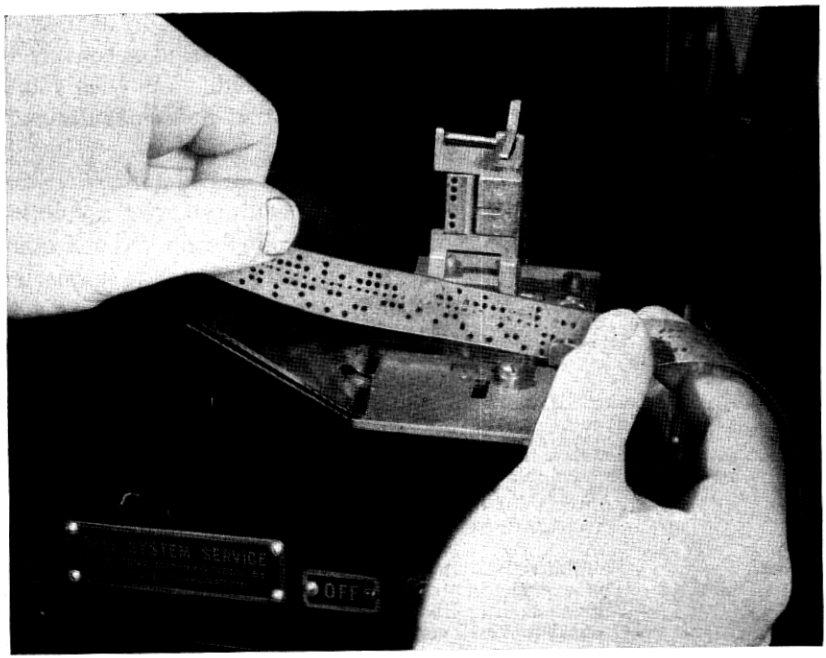


Fig. 15 — Perforated tape being inserted in reader.

inches in size, the label of which carries all pertinent information required for setup of the option keys, preliminary tests and manual operations during test. A separate 12 conductor cable equipped with individual test clips permits connection to internal parts of the circuit if needed for adequate tests. No other information than that on the box label, the circuit schematic and the lamp panel display is needed by the tester to operate the test set and to analyze and locate circuit faults when they occur.

With the tape inserted, the test connections established and any preliminary operations performed the tester has only to push the RESET button to index the tape to the initial perforation on the tape and the START button to initiate the test cycle. The set will continue to operate until either a circuit trouble is encountered or a manual operation must be performed. After a defect has been repaired, the automatic progression of the tape is again started by the momentary depression of the STEP button. When a manual operation is performed the tape is restarted by the momentary depression of the red button associated with the lighted manual operation lamp signal.

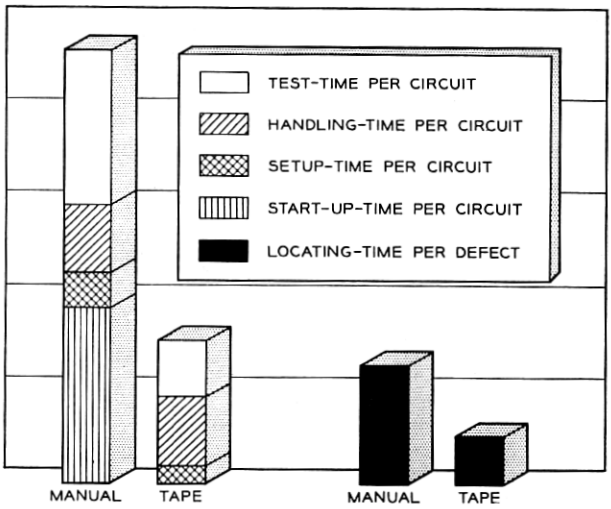


Fig. 16 — Comparison of manual and Tape-O-Matic test operation times.

As might be expected the easy setup, automatic testing and superior trouble indicating features of the Tape-O-Matic test set have materially improved the quality and reduced the testing time and effort required for wired relay units as compared to the older manually operated sets. The average time per circuit for six representative units are shown graphically in Fig. 16. One time consuming operation on manual testing is the start up time allowance for reading and understanding the written test instructions which has no counterpart in the Tape-O-Matic tests and this alone represents a sizeable gain. The handling time of the unit itself is the only operation which is not reduced in automatic testing.

## HISTORY

The initial Card-O-Matic test set was installed in 1938 in the Western Electric, Kearny, New Jersey plant. Post war and subsequent expansions of production levels have necessitated construction of six more sets of improved design of the type described earlier in this article.

The first three Tape-O-Matic test sets were built in 1942 for the Wired Relay Unit Shop and additional sets have since been constructed to bring the number to twenty-six including six that are used in testing trunk units in the Toll Crossbar Shop. They have performed admirably with few changes from the initial design. They have been used to test well over a million wired units with a minimum of maintenance. This

may be accounted for, in part, by the fact that most of the component parts are telephone type apparatus designed for heavy duty use.

A maintenance feature is the use of 18 specially coded tapes which, together with a properly strapped input plug, permit the maintenance technician to obtain indications on the lamp display panel of the performance of the set.

Nearly three thousand tapes have been coded to date. Of these approximately two thousand are in active use on the many types of wired relay units made at the Kearny plant. More tapes are being added weekly as the Bell System telephone plant grows in size and complexity.

## CONCLUSION

Automatic testing of wired relay switching circuits has been successfully applied to the manufacture of these equipments at the Kearny, New Jersey, plant of the Western Electric Company for a number of years. Even though the total production is large, manufacture is essentially of a job lot nature due to large number of types made and is further compounded by the optional circuit arrangments that may be ordered. The solution to the problem was found through provision of flexibility in programing and cross connection leading to quick setup, rapid testing and improved transmittal of essential information to the tester to aid him in clearing circuit faults.