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Automated Repair Service Bureau:

Mechanized Loop Testing Strategies and Techniques

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The Mechanized Loop Testing (MLT) system overcomes two long-standing inadequacies in the administration of loop repair: the lack of a single comprehensive automated testing device capable of analyzing the problems of loops having a wide variety of central office, outside plant, and terminating equipment installed; and the lack of a device of that type that could be integrated into the repair process in such a way as to provide for efficient administrative procedures. The MLT system meets these needs by means of a novel linkage with the Loop Maintenance Operations System (LMOS), which is the backbone support system for the repair process. The MLT system is unique in the way it makes use of information in the customer line records to configure tests and analyze their results. This paper outlines the means by which customer line record information is selected and processed for use in the test algorithms of MLT. It then discusses the general strategies used in the algorithms described, with some attention to the problems posed by inaccurate or incomplete records.

I. INTRODUCTION

The testing of a subscriber loop is presently undergoing a fundamental and dramatic improvement because of the introduction of the Mechanized Loop Testing (MLT) system. The MLT system is a recently integrated part of the Automated Repair Service Bureau (ARSB) described in detail in other articles in this issue. This article briefly outlines the operational changes in the ARSB attributable to the introduction of MLT and then goes into further depth in describing the advances in loop testing made possible by MLT's unique coupling to other ARSB systems and by its adaptive testing algorithms.

II. BACKGROUND

The backbone system of the ARSB is the Loop Maintenance Operations Systems, known as LMOS. The basic LMOS consists of a large host computer, such as an IBM 370, and several front-end (FE) minicomputers, PDP* 11/70s.

The host computer receives completed customer service orders for installing, deleting, or changing telephone services, creates a data base of records of those services ("line records") for maintenance purposes, and processes the line records into subsets ("miniline records") for download to the appropriate FE computer. In performing these functions, the host computer manages a large data base (typically millions of line records) composed of relatively slowly changing data. A typical rate of line record change is of the order of one or two changes per line per year.

The FE computers, on the other hand, process relatively fast-moving data. Each FE computer is the access point for a large group of users; it supports CRT terminals with the transaction programs necessary for tracking the progress of reported troubles. When a customer calls the ARSB to report a problem, a Repair Service Attendant (RSA) enters a trouble report via the FE CRT. Front-end programs provide line record and time commitment information for dealing with the customer, output paper trouble tickets that repair craft can take with them, and track the status of the repair process. The personnel of ARSBs can, for example, make use of FE transactions to find out which reported troubles have less than a specified percentage of their repair commitment time remaining.

The MLT system is an additional software and hardware system for which the FE computer provides the user interface. The MLT system consists of a PDP 11/34 computer controlling Loop Test Frames which comprise the loop access and test hardware. The bureau personnel enter test requests at FE cathode ray tubes (CRTs); the FE in turn sends the appropriate test and access commands to the MLT controller. The MLT controller causes the hardware to dial the desired line, and then the algorithm programmed in the controller controls the hardware test devices and analyzes their results. The results are then passed back to the FE for formatting and display for the user at the CRT or at a line printer.

Prior to the introduction of testing integrated with LMOS, the ARSB

* Registered trademark of Digital Equipment Corporation.

procedures had to be structured around a certain delay between the customer's call reporting the trouble and the actual tests performed on the affected loop. The usual procedure was as follows: The RSA would receive the report from the customer and enter it into LMOS. The resulting trouble ticket (known as the Basic Output Report or BOR) would be examined by a screener, whose function was to determine whether the trouble should be tested or sent directly to the dispatcher. The large majority of the troubles (about two-thirds) were sent to the tester. If the tester was unable to detect a problem with the loop, he or she would call the customer to negotiate a close-out of the trouble. If, however, a problem was found, then the tester would write the test results on the BOR and pass it on to the dispatcher for the necessary action. The time between the trouble entry by the repair service attendant (RSA) and the completion of testing was typically a half hour to two hours, depending upon the volume of reports.

In the procedure, useful diagnosis of the problem was made long after the customer's call, so that a call back to the customer was often required to provide a proper time commitment and to arrange for access to the customer's premises, if necessary.

Frequently, the tester would call the customer immediately after testing the line to confirm or clarify the problem; then, somewhat later the dispatcher would also call to finalize access arrangements. This succession of calls prior to accomplishing anything toward the actual repair tended to aggravate the already annoyed customer. Furthermore, many times the customer was simply not available after the initial call, so that any information that was not received from the customer at the first contact was not obtainable at all.

Integrating MLT with LMOS makes possible a streamlined procedure and allows the contact with the customer to be much more efficient (and more satisfying to the customer). In the combined LMOS/MLT system the trouble entry transaction is used to supply the troubled telephone number along with commands necessary to start tests to the MLT controller. Now, as soon as the customer gives the RSA the telephone number of the troubled line (the first thing the RSA asks for), MLT starts a test on the line. The MLT tests and analyses are usually completed in about thirty seconds, and a simple summary result is provided to the RSA *while the customer is still speaking to the RSA*. The RSA can then make an appropriate commitment to the customer.

For example, the RSA might get "C. O. FAULT" as an MLT result. This means that the tests show that the portion of the customer's loop that is outside the central office is good, but there is some malfunction that was detected with the central office wiring or switching machine functions. Such problems are normally quickly fixed, and because the maintenance force is already at the scene of the problem there is no delay because of travel. In this case, the RSA can inform the customer that no visit to the customer's premises is required, and that the probable time to complete the repair is approximately two hours.

If the MLT tests result in the message "CABLE FAULT" to the RSA, the customer will be given a much longer commitment time than in the previous example, because cable troubles are typically more difficult and time consuming to repair. "CABLE FAULT" also implies that the trouble is not likely to require entry to the customer's premises. This information is helpful to the RSA dealing with the customer, and it permits the customer to plan accordingly.

Both of these examples illustrate improvements brought about by integrating the testing system (MLT) with the administrative system (LMOS). Troubles are tested as soon as they are input into LMOS, instead of delaying for an hour or so in a paper queue at a screening or manual testing position. Furthermore, the RSA is given test results useful in dealing with the customer, while the customer is reporting the trouble, obviating the need to call the customer back in most cases until the trouble is repaired.

The function of the screener is also affected by the fact that tests are made at the time the customer reports the trouble. Within minutes after the RSA has completed the trouble report entry, the paper BOR is printed out. This report now has as an integral part a test summary and detailed results of the measurements and analyses performed by the MLT system. The screener can use them to decide whether or not to dispatch, and if dispatched, to which repair force. The screener may also decide that further MLT testing is desirable; this is immediately available via the CRT.

If the MLT results are not conclusive, or if the line is of a type too complex for present MLT tests (four- and eight-party lines, for example), the screener may refer the trouble for manual testing. However, manual testing is now required for only a very small fraction of the troubles reported.

The procedural improvements just described would have been possible with any test system triggered by trouble entries and automated to perform tests equivalent to the usual manual ones. The MLT system, however, is much more than an equivalent automation of a manual test system. MLT integrates the customer line record information into the testing process and makes use of the information in adaptive test algorithms to configure tests and analyze results. In this respect, the MLT system is unique among test systems, past and present. Furthermore, MLT commands an additional array of tests, not possible from the conventional, manual local test desk, to define precisely the condition of the tested loop.

Because the local test desk is a familiar and nearly universal equipment (at least within Bell System telephone RSBs), it may be instructive to compare its operation to that of MLT.

III. INSTRUMENTATION: THE LOCAL TEST DESK VERSUS MLT

The local test desk is basically a dc instrument; it is essentially a battery, a galvanometer, and a set of switches. Tests which involve ac characteristics of the subscriber loop are done by watching the "kick" of the galvanometer needle when a switch is thrown to produce a transient effect. Thus, while dc measurements are reasonably accurate, ac measurements are dependent upon the tester's experience and ability to interpret the transient response of the meter.

This is not to say that a tester and the local test desk are totally inadequate for the function. A tester is typically a highly skilled, experienced person who is able to detect quite a variety of loop problems with the relatively simple testing device. However, modern test hardware such as that included in MLT can provide precise measurements to replace the largely subjective ones of the tester. In addition, MLT measurements are repeatable, and this means that analysis and trend detection can be done.

The combining of the computer with the test hardware enables the use of test series, in which the results of several physically different tests may be combined to produce a diagnosis not possible from the isolated separate tests. In this way, the computer can supply the logical processing which formerly had to be done by the tester.

IV. LOOP INFORMATION NEEDED FOR PROPER TESTING

The tester provided another important ingredient in the loop fault analysis process, and that was to supply the knowledge of what equipment the customer's circuit had on it. From reading the paper line card or the LMOS computer line record, the tester determined the sort of termination and transmission equipment installed. He or she was assumed to know the expected electrical behavior of the desk meter for each type of loop equipment tested. The MLT system must also know the anticipated results of the measurements it makes. This information is supplied by programs which specially process the necessary LMOS line record information into the MLT system. The advantages of having the computer do this processing will become obvious later in the discussion.

Loop equipment which affects the results of manual or MLT testing may be divided into three categories:

(*i*) terminating equipment,
(*ii*) outside plant equipment, and
(*iii*) central office equipment.

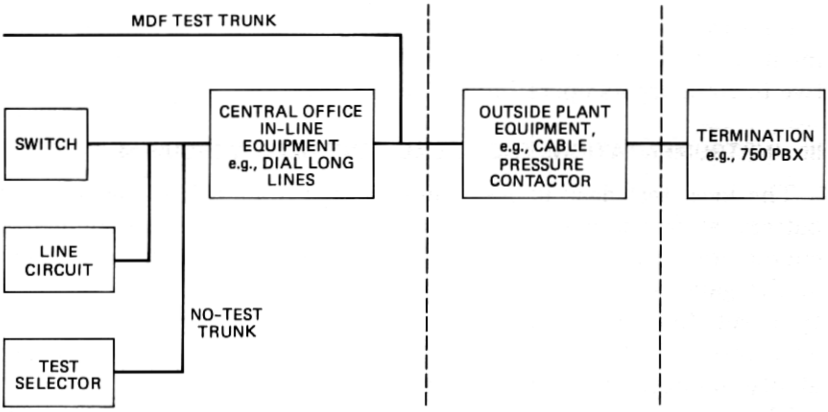

Fig. 1—Equipment affecting testing.

(In addition to equipment which is physically a part of the loop, there are sometimes other circuit features which affect test results. An example of such a "feature" is inward-only service in which dial tone is not provided, even if a tester were to try to draw it. The effects of a circuit feature are handled in essentially the same way as those of loop equipment as discussed in following sections.) Figure 1 is a block diagram of the equipment arrangement in a typical subscriber loop, showing the location of each category. By far the large majority of subscriber loops have only terminating equipment because no outside plant or central office equipment other than the switching machine is needed. The Test Selector with its No-Test Trunk* is the means of access to the circuit for most testing, although the Main Distributing Frame (MDF) test trunk may also be used for certain purposes.

If a test performed produces results characteristic of the loop plus the termination known to be at the end of the loop, then the loop is in good repair or has only minor faults. If the test fails to show results corresponding to the known termination, then most likely there is a fault to be evaluated. Recognition of the expected termination is, therefore, the key to loop testing, and this is true regardless of whether the testing is manual or performed by MLT. The presence of outside plant or central office equipment is important to the extent that it affects the test system's ability to recognize the termination or to detect and analyze a loop fault condition. The MLT system's means of acquiring the necessary loop equipment information will now be discussed.

* Reputedly, the "No-Test" Trunk is called that because the test probe is bridged onto the loop with "no test" performed by the switching machine to see if the line is in use by the customer. This is in contrast to "Regular" Test Trunks which will not bridge onto a busy line.

V. THE FLOW OF LOOP EQUIPMENT INFORMATION INTO THE MLT SYSTEM

The ultimate source of the loop equipment data is the Universal Service Order (USO) which provides information for installing the telephone service. The USO uses Field Identifiers (FIDS), FID code sets and Uniform Service Order Codes (USOCS), which are all codes from two to five characters long, to abbreviate the information about a customer's service and equipment required for the order. Field identifiers and code sets and USOCS indicate such things as the customer's name to be listed, the address, the cable and pair of wires to which the termination is to be made, the particular switching machine to be used, the type of termination, and so forth. There are many thousands of FIDS and USOCS which may be selected to make up a service order, and in fact there are several thousands of these which may be of significance to the MLT tests. Obviously, the customer's name is not required for analyzing test results, but the type of termination certainly is, and the USO is the vehicle for supplying that information.

It is important to recognize, however, that the MLT testing hardware is controlled by a small minicomputer which is intended to accept only a minimum of information about the line to be tested. The controller minicomputer cannot practically sort through all the data contained in a service order (or even the LMOS line record made from it) to glean the desired information. The process by which LMOS/MLT distills the USO information down to data useful for the testing algorithm and hardware is sketched in the following paragraphs.

The LMOS has a program called Automatic Line Record Update (ALRU). The function of ALRU is to read the service order and change or construct line records in the LMOS host computer. Because the service order is restricted to a certain format by the USO procedures, the resulting LMOS line record is highly formatted and amenable to automated searching. The data needed for MLT are retrieved by matching line record segments with a table of all the relevant FIDS, FID code sets, and USOCS. Each telephone company must maintain this table, because there is no one standard set of FIDS and USOCS that is applicable to all companies. (The USOCS, among other functions, are billing codes, and as such are subject to requirements placed by local public utility commissions.)

The host computer program which contains this table is called BINS (for binary search). When the host computer constructs a subset line record for downloading to the FE computers, the BINS program is run. The BINS program selects the FIDS and USOCS that were matched to its table, and assigns to each a simple numeric code which classifies the corresponding equipment. For example, all of the USOCS which correspond to a 701-type PBX may be given the code "20." There are hundreds of USOCs which apply to various ways of billing a 701 PBX, but because they all mean the (electrically) identical termination, the single code "20" is sufficient. Every terminating-, outside-plant-, and central-office-type of equipment has its own code assigned in the BINS table.

The FE line record (miniline record) thus has incorporated within it a set of codes corresponding to the three types of loop equipment shown in Fig. 1. Presence of this set of codes provides for two functions to be performed during FE transactions. First, the codes, translated into English by a simple table in the FE software, give the tester or screener a concise description of the testing obstacles. The user does not have to memorize or look up any of the thousands of applicable USOCs or FIDs to know what is installed. Second, and really their primary function, the codes list the equipment information needed to facilitate testing with MLT.

Merely knowing which equipment is present is not sufficient to run an intelligent test algorithm. It is necessary to know what *electrical effect* that equipment will have on a test result. Many types of equipment have identical electrical effects; for example, the 701-type PBX looks electrically identical to the 740, 756, 757, and 770 PBXs. Specifically, the 701 PBX may be installed so as to show one of two idle terminations, either a characteristic dc "signature" or a thermistor termination identifiable by a special test built into the MLT hardware. Electrical characteristics defined in this way are directly usable by a test algorithm, whereas the identifying code "20" is one step removed from usability. It is possible to resolve the several hundred equipment types or codes into about 30 distinct electrical effects. These electrical effects are called the "attributes" of the equipment, and it is these attributes which are used by the test algorithm to configure and analyze the test series.

The test algorithm resides in the MLT controller, while the equipment codes are stored in the FE. When the FE processes a request for test, it translates the equipment codes from the miniline record into the attributes appropriate for all the equipment on the subscriber loop. It passes those attributes along with the test access instructions to the MLT controller. In this way, the controller algorithm is kept independent of changes in the types of loop equipment or in their observed electrical characteristics. Similarly, the individual FE line records, with correct listings of the installed equipment codes, need not be changed if it is found that the attributes of the equipment are not as was expected. It is necessary only to maintain the small FE table of equipment code-attribute mappings, and this is efficiently done on a Bell System-wide basis.

VI. THE TEST ALGORITHMS

To appreciate the sophistication of the MLT system as compared to other means of testing loops, it is necessary to describe the function of attributes more fully. Attributes are the electrical characteristics of the loop that indicate the expected results of measurements made on the loop. They are used by the controller to configure all tests, analyze the test results, and even to decide whether or not to run a given test. This ability to configure tests according to the expected attributes of the line is very important. It ensures that every line undergoes a set of tests custom-tailored to produce the most useful and accurate information for the maintenance center.

As an example, consider the attribute assigned to any PBX which may be installed in a ground start mode. Presence of this attribute causes the controller algorithm to select a dc test specifically designed to avoid alerting the attendant as an incoming call would. To keep from alerting the attendant, signals of certain voltages and of only one polarity may be used. In contrast, if the ground start PBX attribute is not present, the controller is free to make use of results from any previous tests in the series it is running. It will choose the optimum voltages and polarities for the most accurate measurements under the observed conditions.

Another benefit of a computer-driven test series is that tests which would produce confusing or misleading results can be avoided. To accomplish this, the test algorithm will check intermediate results where prudent. An example of such a process occurs when attempting to count the number of ringers on a residence line. This cannot be done accurately if there is a resistive fault worse than a certain threshold value on the line. Therefore, the MLT system will run a dc test first and examine its results to see if the ringer count test should be attempted. If the ringer count test is not done, the user will be informed of that and of the reason for not doing it.

VII. AVAILABLE ALGORITHM CHOICES

The MLT system is intended for users of varying knowledge and responsibilities within the maintenance operation. In the normal course of events, it may be used by a near-entry level clerk who receives reports of troubled lines from customers, and it may be used by highly experienced testers to diagnose complicated loop problems. Therefore, there are different capabilities provided for the different users.

The test performed when a trouble report is being received by a clerk (the RSA) is the most restricted one, in the sense that the clerk has no control over what type of algorithm is used. The algorithm is a very general one, using the line record information as described above, and all the tests that are possible are actually performed. The objectives of this algorithm are to provide a simple statement of the loop problem for the RSA to use while making a commitment to the customer (while the customer is still on the line) and to provide for the screener, dispatcher, or any later user a comprehensive summary and detailed results of tests. This particular algorithm is known as the RSA/BOR series, because it is the series of tests that is initiated by the RSA and it produces the detailed test results on the BOR. The BOR is a paper record of all the data concerning a reported trouble, including much more than just test results, and it is produced *only* when a trouble is entered into the LMOS system.

A screener may wish to run another test after the initial trouble report processing. This is useful because customers frequently report trouble using the actual troubled lines. (Very little useful testing can be done on a line while it is in use because of the very low impedance of the station set during that time. The BOR test result summary for the line would be "SPEECH," and the detailed test results would be only "BUSY—SPEECH.") The screener would not want to use the trouble report transaction to initiate a test because to do so would cause another trouble report to be recorded by the LMOS trouble tracking system. Telephone company maintenance is evaluated in part by counting the number of trouble reports received, so to use the trouble report transaction would erroneously penalize the company rating. Therefore the MLT system is provided with an additional set of transaction options purely for testing under the TEST transaction. TEST transaction options do not generate trouble reports; they simply perform and analyze tests.

The "TEST" transaction includes the following options: FULL, VER, LOOP, RINGER, DIAL, MDFIN, and MDFOUT. FULL runs the RSA/BOR series to get a general diagnosis with output of detailed results. VER runs the same algorithm as FULL to output only the test summary or verification. LOOP is a fast algorithm intended to test only the loop part of the customer's circuit, omitting tests on such things as the line circuit. RINGER is a test to count the number of ringer-like terminations on the subscriber's loop. DIAL is a series of tests on the functioning of the rotary dial of the customer's station set. MDFIN and MDFOUT are algorithms used when manual test access is made at the main distributing frame (MDF), using access jacks wired for the purpose. To do these tests, the customer's line is actually opened at the point of access, so that the loop or switching machine part, respectively, of the line is physically disconnected. The disconnection may be necessary to isolate the cause of a particularly difficult problem. MDFIN is for testing in toward the switching machine from the customer side of the MDF, and MDFOUT is for tests outward from the MDF. Of course, the line record information used in the test algorithm is altered to suit the conditions; e.g., for MDFOUT information about range extension devices in the central office is not applicable because the devices are disconnected by the access jack; therefore, the algorithm excludes that information.

VIII. BASIC ALGORITHM STRUCTURE

The more general algorithms, such as FULL and LOOP, have a co nmon basic structure. This structure has the following steps:

(*i*) Provide access to the loop
(*ii*) Do preliminary screening tests
(*iii*) Do 3-terminal tests and analysis
(*iv*) Select further tests and analyze.

It should be noted that there is some analysis performed *during* virtually every test, as well as afterward, to ensure that each measurement is, in fact, performed successfully and with optimum parameters.

8.1 Access

The MLT system provides access by dialing the telephone number of the line to be tested. Normally, this is adequate for any type of testing, MLT or otherwise, but there is a significant number of cases where it is not. Typically, these are for circuits which either do not have a directory number or do have one, but it does not give physical access to the loop. The MLT system, however, is set up to provide for access in these cases without requiring the user to do cross-referencing for an access number or to provide any special manual signalling which may be required by the switching machine.

An example of a nondirectory number line is the so-called "extra number" provided in crossbar switching machines for use in hunt groups. Hunt groups are series of lines in which only the first line need be dialed from another telephone. If the first line is busy, the switching machine automatically connects the caller to the second line. To conserve directory numbers, the second line is not listed in a directory, hence the term "extra number." Extra numbers, in fact, have more than the usual seven digits. A caller cannot directly access the extra number by dialing. Special signaling to the switching machine is required before it will accept more than seven digits, even from a test-access device. The MLT system does this signalling automatically. If, for example, the first number were 555-3000, and the second number were 555-3000-0001, test access signals to the switching machine for the second number would be automatically provided for the MLT user who typed in 555-3000XN0001.

Another case in which the telephone number is not directly usable for test access is that of the local loop of an incoming Wide Area Telephone Service (WATS) line. In this case, the directory number might look like this: 800-555-3000. The 800-area code tells the switching machine that special logic is to be used to connect the caller. The actual number for test access, commonly called a plant test number, is likely to be quite different from 800-555-3000. (It could be, for example, 201-123-4567.) Because test access requests are treated differently from calls by the switching machine, MLT (or a manual test desk) must use the plant test number instead of the 800-number that was probably reported by the customer as having a problem. This is handled automatically by the MLT system because the cross-referencing of numbers is taken care of in setting up the MLT data base. The user types in the 800-number, and the MLT system automatically accesses via the plant test number.

Another access problem that is handled smoothly by the MLT system is the one in which it is necessary to ensure that the loop is not accessed accidentally. Some telephone companies have lines for which special permission from the customer is required for test access because of the extremely sensitive nature of the traffic on those lines. An example of a line like this might be an air controller circuit for a major airport; such a line might well be a dialable line which could be accessed if someone were to type in its number by mistake. In this case, the FE line record contains an entry which prevents the system from even accessing the line without the user's intentionally overriding the line record. Accidental access attempts cause a warning message to be displayed to the user, "TEST NOT MADE—PROTECTED SERVICE" for the RSA or "PROTECTED LINE—CUST PERMISSION REQ" for other users. The RSA cannot override the line record in the process of entering a trouble report; this capability is restricted to an option of the TEST transaction.

8.2 Preliminary tests

Preliminary tests perform several functions, the first of which is to determine if the line has a foreign voltage which is so high as to be hazardous to the test equipment or to personnel. If that is found, the algorithm terminates testing immediately with an explanatory message to the user. If no hazardous voltage is detected, the algorithm directs the hardware to check for a busy condition on the line. Busy lines should show a tip-to-ring voltage greater than about five volts. If a busy condition is found, a speech detection circuit is brought in to determine if the customer is talking on the line. This additional test is necessary because a dc voltage from an extraneous source or a short circuit on the pair could simulate the busy condition. If the line is found to have speech, the algorithm terminates the tests. At this point, no signals that are detectable by the customer will have been put on the line, so the service is not impaired in any way.

A busy line which does not show detectable speech may simply be the result of the customer's leaving an extension off the hook. Such a condition is electrically detectable by MLT for the station set terminations found on the vast majority of residence and small business lines. If the line record indicates an appropriate termination type, the Receiver-Off-Hook test is performed. Successful detection of a receiver left off hook offers an immediate savings to the telephone company, which can simply inform the customer reporting the trouble, rather than make an expensive dispatch of a repair person to put the receiver back on the hook. A receiver-off-hook indication causes the algorithm to terminate testing.

Lines with a busy condition which show neither speech nor a detectable receiver off hook probably have a foreign dc voltage on them. Alternatively, they could have terminations like ground start PBXs, which have a voltage supply at the termination. These lines are candidates for further testing to define the problem. In addition, of course, the lines which do *not* show a busy condition (i.e., they are in a normal idle state) will receive further tests.

At this point it is possible that there is a voltage at a lower than hazardous level but still high enough to render the more sensitive diagnostic MLT tests inaccurate. Two further preliminary tests are done to check for this condition. The MLT hardware is directed by the algorithm to measure the open-circuit voltage of the line and then to measure the short-circuit noise current. Either measurement has an upper threshold which will cause the algorithm to terminate testing.

8.3 Three-terminal tests

When the test algorithm arrives at the point of doing the 3-terminal tests, the really sophisticated diagnosis of the customer's line problem begins. Three-terminal tests (the "3 terminals" are tip, ring, and ground) are performed by the test hardware in such a way[1] that the customer's line and its fault, if any, can be modeled as three Thevenin-equivalent circuit elements.

The Thevenin-equivalent circuit elements assumed for modeling the dc measurements are arranged in a delta configuration as shown in Fig. 2. The dc "signature" of a fault condition or of a piece of loop equipment is defined by a set of limits on the values of the circuit elements. For example, the 800-type PBX would have a signature as illustrated by Fig. 3. Direct current results that fit this signature would indicate that the loop was certainly continuous out to the PBX termination and that no dc faults worse than about 120,000 ohms existed at the time of the test. (It is possible for a fault of higher

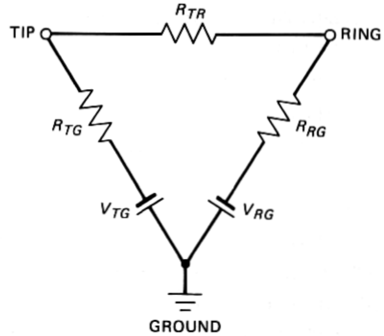

Fig. 2—Thevenin-equivalent circuit elements assumed for modeling dc measurements. Any or all of the five quantities R_{TR}, R_{TG}, R_{RG}, V_{TG}, and V_{RG} may be used to identify an equipment signature or fault condition.

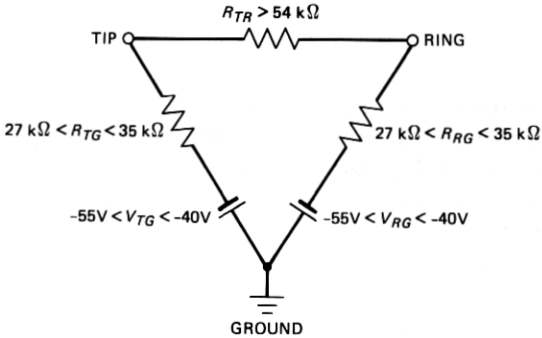

Fig. 3—Direct current Thevenin-equivalent circuit signature for the 800-type PBX idle termination.

resistance than 120,000 ohms to go undetected with this signature because there is a range of acceptable values necessary to allow for different loop resistances.) Note that five quantities must match the software values in order for the signature to be valid. This makes it very unlikely that a fault condition can simulate a good dc termination.

We can see the power of the 3-terminal model with the aid of a couple of examples. Referring again to Fig. 3, note that the circuit model shows a −48 volt supply in the PBX termination, just as it actually is. A 2-terminal measurement, such as that made from a test desk, would show *some fraction* of the −48 volt, depending upon the resistance of the loop and the termination itself. There are many different PBXs, with quite a range of resistances, hence widely varied 2-terminal signatures for the same voltage supply. However, there are only −48 and −24 volt supplies in PBX terminations; and because these show up explicitly in a 3-terminal Thevenin model of the measurements, they are well defined and extremely easy for the test algorithm (and the user) to recognize.

An even more obvious example of the advantages of the 3-terminal model is that of a customer's line which is in electrical contact with a second customer's line. This is known as a "cross" fault. It is characterized by the presence of the central office battery potential of the second customer on the first customer's tip or ring or both. The contact between the two lines may range in resistance from a "dead short" to a megohm or more. In a 2-terminal (unmodeled) measurement, this contact resistance and the resistance of the measuring device form a voltage divider, so that the resulting reading may be any fraction of the battery potential (−48 volt). High-resistance faults will, therefore, produce a negligible reading on a 2-terminal measuring instrument. The 3-terminal *model* produced by controller's computation, in contrast, separates the contact resistance of the fault from its foreign battery potential, displaying each explicitly, regardless of the value of the resistance. For example, the MLT results for a high-resistance cross might include "3 TERMINAL DC RESISTANCE = 600.00 KILOHMS T-G" and "3 TERMINAL DC VOLTAGE = −48.00 VOLTS T-G." The presence of the undesirable central office battery is immediately obvious. Lower computed voltages can result if more than two pairs are involved in the fault, but the cross is always more obvious using the 3-terminal model, because the voltage divider effect of the instrument is removed.

The Thevenin-equivalent circuit elements assumed for modeling the 24-Hz ac measurements are shown in Fig. 4. In similar fashion to the dc case, the ac "signature" of a fault condition or of a piece of loop equipment is defined by a set of limits on the values of the circuit elements. The signature for a typical 500-type set (the ordinary residence telephone) is illustrated in Fig. 5. Alternating current signatures are necessary because many terminations simply have no dc signature, i.e., they are open to dc. The 500-type set is one such termination. When it is on-hook, there is no dc path through the set between the

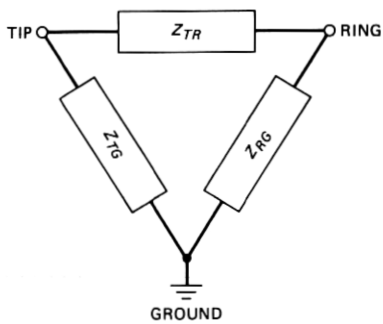

Fig. 4—Thevenin-equivalent circuit elements assumed for modeling ac measurements. Any or all of the six quantities (real and imaginary parts of the *Z*s) may be used to identify an equipment signature or fault condition.

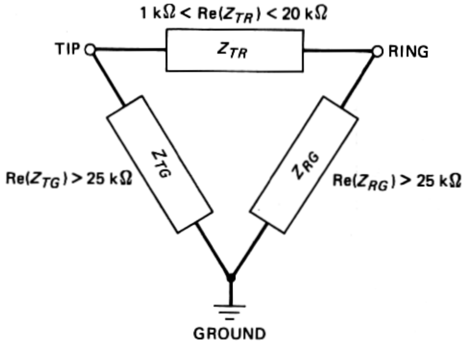

Fig. 5—Thevenin-equivalent circuit signature at 24 Hz for the 500-type residence telephone set. (The signature allows for several extensions.)

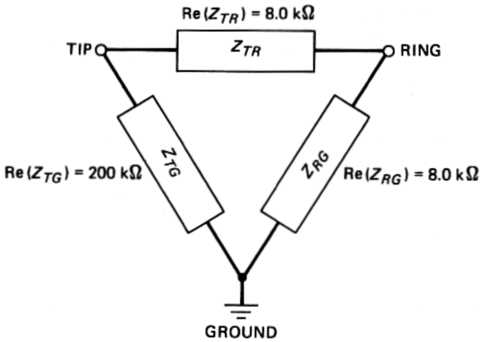

Fig. 6—Possible 24-Hz Thevenin-equivalent circuit signature for an improperly installed two-party line. The tip-to-ring and tip-to-ground impedances would be exchanged in a proper installation.

tip and ring conductors. However, because it is a resonant circuit at ringing frequencies (about 20 Hz), it has a readily detectable and characteristic real part impedance at the MLT measurement frequency of 24 Hz.

Here again, there are immediate advantages to the use of the 3-terminal model. Suppose an installer mistakenly connected the second party of a party line like a single-party service. The impedance of the first party would appear from ring to ground just as it was supposed to (see Fig. 6). The second party would appear on the tip-to-ring leg, cleanly separated from the other termination and obviously in the single party configuration. In addition to the measurement results, MLT analysis would provide the message "INVALID AC SIGNATURE" to highlight the improper termination configuration.

There is an additional type of termination which is not adequately defined by either the dc or ac 3-terminal tests. This is the termination in which thermistors are used as the sensing device for ringing signals.

The thermistors are capacitatively coupled to the tip and ring, hence appear open to the dc test. They present a rather high real-part impedance (25 to 100 kilohm) to the previously mentioned 24-Hz measurement technique, and this could be mistaken for a truly open circuit. Thermistors do, however, have a temperature dependent change of impedance when enough power is dissipated in them. The MLT system includes a special test capability to exploit this characteristic.

When the customer's line record indicates a type of termination which may have a thermistor in it, or when the dc and ac measurements show the possibility of a thermistor termination, the thermistor heating test is run. This test takes significantly longer than the dc and ac 3-terminal tests (which are run simultaneously), so it is not run by the algorithm unless it is needed. In this test, enough energy is supplied to the line to cause a measurable change of impedance in a thermistor station set, but the duration and magnitude of the signal is controlled so that it does not cause the set to ring. Thermistor terminations are found in many older PBXs and key systems, so it is particularly important that the ringing not be triggered by the test signals.

It will probably be noticed that no mention has been made of the use of the imaginary part of the 24-Hz measurement. The imaginary part of the measurement is particularly useful when an open circuit has been detected. Bell System cable leading from the central office to the customer's termination has a tightly controlled capacitance per unit length. The measured capacitance of the tip-ring, tip-ground, and ring-ground conductor pairs can be computed from the imaginary parts of the ac measurement results. Therefore, it is possible to determine the distance to the point where a wire may be broken from the ac measurement results. An obvious use of this measurement is to detect lines that are open in the central office by their very small computed length. A repair referred to the central office is much less expensive than a repair dispatched to the outside plant. The ability to distinguish open in (central office) from open out (a break outside the central office) gives the repair bureau direct guidance in the crucial dispatch decision, as well as assistance to the RSA in making a commitment to the customer. The MLT system has a built-in calibration method to ensure the accuracy of the open-in/open-out determination.

In cases of open out, the MLT system provides additional sophistication in the results reported to the user, again with the objective of facilitating accurate dispatch decisions. The imaginary parts of the tip-ground and the ring-ground measurements are compared for capacitive balance. If the balance is better than 99 percent (the two capacitances differ by less than 1 percent), then both conductors are probably broken at the same point. The messages to the user would be "OPEN

OUT" and "DISTANCE FROM C. O. = 10,400 FT." Experienced repair bureau screeners would know the approximate geographical location to dispatch outside plant repair craft to find the open at 10,400 ft from the central office.

If, however, the capacitive balance is between 95 percent and 99 percent, it is likely that only one wire in the pair is broken, and also that the break is quite close to the station set. In this case, the MLT results would say "OPEN OUT: NEAR DROP," and would in addition supply the information, "DISTANCE FROM C. O. = 10,400 FT" and "DISTANCE FROM STATION = 300 FT." If the capacitance of the tip conductor varies by more than about 5 percent from that of the ring, the MLT system will indicate (in addition to the distances to the open and station set in feet) that the open is in the cable, as opposed to the drop wire or station set. The user message would be "OPEN OUT: IN CABLE," enabling the repair bureau to assign responsibility for the repair directly to the cable repair craft, instead of station repair.

Similarly, MLT calculates the distance to a station set on a good line. This is useful as a sort of benchmark or as an aid to an inexperienced user. As mentioned above, MLT may detect an opened line for which the tip-ground and ring-ground capacitances are very nearly the same. Unless the total length of the line (hence its total capacitances) is known, it is not obvious from the measurement whether the line is broken at the end near the station set or somewhere back along the cable. Customer line record information does not include the length of the line to the station set. If the repair service does not have a good idea how long the line *should* be, the accurate distance to the open calculated by MLT may not be sufficient to determine whether cable or station repair craft should be dispatched. However, the repair service can test a good line to a neighboring telephone to get a length measurement for comparison.

The 3-terminal method of analysis has still another advantage over conventional techniques. This is the capability of doing ac analyses on lines which have dc faults. It frequently occurs that a dc-detectable fault (shorted or grounded conductors) is present along with an ac-detectable fault (open). This might be the case, for example, if the customer's drop wire were cut while digging for landscaping was being done. Here the effects of the resistive fault tend to overlay and mask the ac effects, making the open fault less detectable. However, the analysis provided in the MLT test algorithms is able to *isolate* the effects due to the simultaneously occurring but different faults. To the author's knowledge there is no test system, other than MLT, which provides this analysis. The MLT user is given a message like "RESISTIVE FAULT AND OPEN." This is a diagnosis which simply cannot be made by a tester using the local test desk. The local test desk can detect only the short or ground in this situation, and this limitation makes the information given to the dispatched repair craft less helpful.

At this point in the series of tests, most of the measurements necessary for the final analysis of the loop's problems may have been done. Intermediate analysis will have provided the algorithm with the reasons to terminate testing or to select other tests to refine the analysis. In the case that further tests are needed, the data already at hand allow the algorithm to decide if a test that is otherwise desirable can produce useful results in the face of the known line conditions. One such useful test is the longitudinal balance test* used to detect line conditions which are conducive to induced noise.

The test algorithm will examine the results of both the dc and ac 3-terminal tests. If the ac test has detected a possible open circuit or a termination type that will have an intrinsically bad balance in the on-hook condition (e.g., two-party service with only one party assigned), the balance test would produce no useful information and would not be done. Similarly, a previously detected dc fault would almost certainly guarantee a balance problem, hence the balance test would add no information to the analysis. Finally, the balance test might not be appropriate, even if the measurement data permit it, because of loop equipment known to be on the customer's line. Bridge lifters, indicated in the LMOS line record, will inhibit the balance test because of their known deleterious effects on that particular test.

This rather rigorous screening process, using both measurement and line record data, is typical for all MLT tests. The process has two significant effects: first, it causes the test series to be kept to the efficient minimum necessary for complete analysis; and second and very important, it ensures that all tests are run under conditions which deliver reliable and definitive results for the user.

The 3-terminal tests mentioned so far have all been performed with the customer's central office line circuit removed from the loop. This permitted an effective analysis of any problems associated with the portion of the line from the central office out to the station set. The next step in the general purpose algorithms is to reconnect the line circuit to the loop and test for central office problems. The MLT system automatically signals the switching machine to reconnect the line circuit.

The first test done with the line circuit present is a dc 3-terminal test, modified to make accurate measurements on the low resistance (about 200 ohm) elements of the line circuit. Line record information is needed here because the results for loop start and ground start line

* The test is performed by applying a 200-Hz signal simultaneously from tip-to-ground and ring-to-ground (longitudinally) and measuring the signal produced tip-to-ring. The test hardware is described in some detail in Reference 1.

circuits are different. (A faulty loop start line circuit may look like a good ground start line circuit.)

Successful completion of the line circuit test leads to the dial-tone analysis test. This is a test in which the MLT hardware simulates the drawing of loop current by a customer's station set going off hook. The time it takes the switching machine to respond with dial tone is measured, and the MLT user is given a message indicating whether or not the time is within specifications. Upon detecting dial tone, MLT attempts to break it like the customer would while dialing, and reports the result of that test also. Here again, the line record data are required, because not all customer loops are supplied with dial tone. Some loops, so-called "inward only," permit the customer to receive calls but not to originate them. An example of this type would be a business telephone used only to receive purchase orders; the business might well want to proscribe outgoing calls which would interfere with the order-taking process. This type of service obviously does not need the switching functions associated with dialing. Inward-only service is specified in the service order, hence in the LMOS line record; consequently, the correct MLT attribute can be set for the line in question.

8.4 Additional tests in the general algorithms

The above general algorithm path is essentially complete with respect to establishing whether or not there is a fault, and if so, of what kind. There are two more tests which may be run. One serves to assist in the dispatch decision for a dc fault by examining its behavior with time. The other is intended to help the telephone company detect unauthorized additional terminating equipment the customer may have attached to the loop.

The refinement on the dc fault measurements aims at coping with a frequently observed physical phenomenon where a resistive fault is detected, but by the time repair craft arrive to fix the fault, it has disappeared. This commonly occurs when pulp-insulated cable has a small sheath leak, so that a rainy night may produce the detectable resistive ground or short. As the cable gets warmer during the day, however, it dries out and the craft dispatched to repair the fault can no longer detect the problem.

The MLT system includes a test, called the "Soak" test, which applies a potential of approximately 80 volts for a period of about 2.5 seconds. While the potential is being applied, the leakage resistance of the loop is sampled periodically to determine its time behavior. If the resistance goes up by more than a threshold amount, then it is likely to indicate one of the "disappearing" type faults. The MLT user is given a message which indicates the result: "SWINGING RESISTANCE—DRIED OUT." The dispatcher can then make an intelligent decision based on the test results, the time of day, and local weather conditions. The expense of fruitless repair trips can be saved. Incidentally, the fact that a resistive fault is time-varying but does *not* dry out is also of aid to the dispatched craft, who can look for tree branches brushing drop wires or other conditions conducive to swinging faults. The MLT results would omit the "DRIED OUT" part of the results messages in this case.

Unauthorized terminal equipment is detected by the "Ringer count" test performed at the end of the test series on those customer lines which have ringer-like terminations, according to the LMOS line record. The number of station sets the customer is being billed for is counted in the line record and passed to the MLT algorithm for comparison with the measurement results. The discrepancy, if any, is noted in the detailed results for whatever action the telephone company policy requires. (In addition, the Ringer count test results are useful in detecting the type of line record error in which range extension equipment is installed but missing from the line record. Certain equipment types appear from the measurements to be thirty or forty ringers, an obvious impossibility.)

IX. ALGORITHM STRATEGIES FOR LINE RECORD INADEQUACIES

The preceding description has frequently pointed out the use of the LMOS line record information in the test algorithms. The line record is, of course, not perfect. It may be in error in data which affect the test algorithm; it may not be up to date because of the administrative delays inherent in service order processing; and in fact, it may sometimes simply not exist. Obviously, a practical test system must take account of these possibilities. The MLT system treats such situations by means of special sets of attributes supplied to the algorithms and by judicious use of the measurements obtained throughout the test series.

The most important principle in dealing with line record inadequacies is the fact that most fault conditions do not simulate valid termination signatures. This is so because the signatures tabulated in the MLT software always consist of at least three measurable parameters with severely restricted threshold values. It is simply very unlikely for a fault to fit all the requirements for a valid termination signature. The preceding paragraphs have shown how this fact facilitates the construction of an efficient and definitive algorithm. There is, in addition, a useful implication; that is, the algorithm becomes only slightly less efficient and precise if an additional valid termination signature which is *not* expected is allowed to be used. The algorithm still runs very little risk of a fault duplicating the additional termination signature, and the results supplied to the user should be the same as with the more restricted signature set in a correspondingly high percentage of cases.

9.1 The case of a nonexistent line record

When the line record is nonexistent, for whatever reason, the logical extreme of the above principle is applied. The MLT algorithms are supplied with the attributes appropriate for every known standard termination tabulated in its software. In addition to these "dummy" attributes, the system also includes an attribute to let the algorithm (and eventually the user) know that line record information was not used. This provides in a very straightforward fashion for the same test algorithms to be used regardless of the situation.

The ability of the algorithms to detect all possible faults is degraded somewhat, but not as much as might at first be suspected. A known possibility is that the customer's termination equipment might be a type of PBX for which the valid signature is identical to that for another type with an open fault on one wire. The MLT results for this case would indicate a good line, because *one* of the valid termination signatures would have been matched. In practice, this sort of problem is quite rare; furthermore, if it occurs, the customer reporting the trouble is very unlikely to be convinced by the RSA that the line is good.

Because a multiplicity of signatures are accepted in the case of nonexistent records, the number of paths through the test algorithms is greatly expanded. The attribute which signals the lack of a line record is continually used to avoid closing off possibilities before the fault diagnosis is absolutely conclusive. Nonetheless, the analysis of measurements provided at every step of the test series soon narrows the possibilities to a tractable minimum.

One reason for a lack of a line record is the day or so delay in completing service order processing. This is the situation just described, in which the dummy attributes provide for correct algorithm analysis. The customer's line is installed and should be working, but the record system has not yet received the notification of completion. There is, however, another frequently occurring case where no line record would be available. This is the situation in which the line has been disconnected or was never installed. The test is attempted on a telephone number which is not at the time serving a customer. Such lines are said to be "on intercept." The incoming calls are intercepted and transferred to a recording which tells the caller that the line is not in use. Up to 30 percent of the available telephone numbers in a switching machine are commonly on intercept, so that if there has been an installation error, it is possible that a test may be run on an intercepted line.

To handle this case, the MLT system includes in the algorithms a signature test for intercept in all Bell System switching machines. Electromechanical switching machines require a minor modification to provide a recognizable dc signature. In electronic switching machines, a combination of the dc signature and a tone detection is used. This capability completely removes the line record dependence from the identication of an intercepted line.

The MLT intercept detection capability has become very useful in dealing with the type of installation problem in which, for example, a translation error has been input to an ESS machine. The customer's telephone will not supply dial tone, and no incoming calls will be received because they will be intercepted. The customer may very well not know that incoming calls are getting the intercept recording. Nonetheless, the RSA, while taking the customer's trouble report, will be informed by MLT that the line is on intercept. Thus, either the RSA or the screener can deal effectively with the problem without causing a futile outside dispatch. The RSB can offer a much more palatable commitment time to the customer, secure in the knowledge that the trouble can be resolved on the telephone company premises.

9.2 The case of an erroneous line record

It is possible for a telephone number to have associated with it the wrong line record, as sometimes happens when the line record for a previous customer still exists when a new customer on the same number is installed, but before the updated line record is available to the computer. In this case, the line record data are not valid, including those of concern to the testing system. A more likely case is that where the proper line record exists, but some of its data are incorrect because of formatting or typographical errors propagated from the service order.

It would be difficult to give a concise description of the strategies used by the MLT algorithms to deal with these problems. Perhaps an example will serve to illustrate a typical approach.

Here the line record is present and must be assumed to be correct by the algorithms at the beginning of the tests. However, the algorithms are adaptive, and this means that data can be in effect discarded during the running of the algorithms if the data are clearly erroneous.

Assume that the line record shows an ordinary residence telephone, but the telephone number has been newly assigned to a business with a small ground start PBX. Assume the test series are performed with the line idle.

Upon accessing the line, a busy indication would be detected because of the battery voltage in the PBX termination unit. The speech detection circuit would find no speech, so the algorithm would proceed to call for the 3-terminal dc test. The results would be analyzed for the central office line-in-use signature because of the unexpected voltage. Since this would not match, and because the voltage is not a part of a residence telephone signature, the signature would be checked against the ground start PBX signatures, where a match would be found. Matching a valid dc signature would obviate the need to match the ac signature expected for the residence telephone. It would also preclude various other tests (longitudinal balance, for one) by means of their associated screening routines. Therefore, the algorithm would skip to the line circuit and dial tone tests and, upon completing them, terminate.

If the line were good, the results of the test would indicate that, but the discrepancy between the line record information and the measurements would be pointed out to the user. The test summary message would be "UNEXPECTED PBX TERMINATION," indicating the discovery of a good line with a valid termination and a discrepancy in the line record data. If there were a fault on the line, it would be detected via any of the possible paths in the algorithm, the path chosen depending upon the type of fault. A completely severed loop would obviously give no indication of the termination-type discrepancy, but the open fault would be correctly diagnosed. Simple resistive faults would be detected, and neither the dc nor ac termination signatures would match. The line record error is not so clear for these faults, so the message to the user would include the less specific statement "INVALID AC SIGNATURE."

9.3 The case of a line record with vague information

It is not always possible to abstract well-defined equipment information from the LMOS line record. Sometimes the customer has purchased a non-Bell System station set which is not in the software catalogue of terminations tabulated in the MLT system. Sometimes the termination USOC used in the service order is not yet included in the BINS table, so that no match can be found when the MLT information is being culled from the line record.

To cope with these situations, the BINS program includes a number of default procedures, so that the best available information is passed to the MLT algorithms. If the line record USOCS do not match anything in the BINS table, there still may be useful information in the record. Each line record is classified by its "class of service," which is a broad general category like "Residence," "PBX" or "Coin-Public." Some of these categories give no information about the terminating equipment. Residence, for example, covers a broad spectrum of possible equipment. Others, such as "PBX" and "Coin-public," do limit the possible terminations to more-or-less restrictive classes. The default procedures, therefore, examine the class of service to provide the most likely termination data.

For a Residence line record, the default is to specify an "Uncatalogued Termination" code. This code, just like the more specific "Single Party" code, causes certain attributes to be supplied to the algorithms. The attributes include signatures for thermistors and the ringer count test and also an indicator for the presence of uncatalogued equipment. Similarly, for a "PBX" line record, the default code is "Uncatalogued PBX," causing all PBX-related attributes to be supplied to the algorithms. The uncatalogued equipment attribute is included here also. Presence of this attribute always causes the message "UNCATALOGUED EQUIPMENT" to be displayed, so that the user is aware that unusual results may be expected.

9.4 Overriding the line record

Section 8.1 mentioned overriding the line record where test access was prevented by an entry in the FE line record. The override capability provides an important flexibility to the MLT system. Previous sections have illustrated the intimate connection of the line record data and the testing process. Several problems associated with erroneous or missing line record information have been discussed. In many cases the test algorithms themselves are comprehensive enough to handle the problems. Nonetheless, it sometimes occurs that a particular line record problem has a drastic effect on the analysis of a trouble. When this happens, it is important to be able to "get rid" of the offending information to make better use of the MLT testing capabilities. This ability is provided by the "override line record" option of the TEST transaction.

The implementation of the override option is quite simple; when the option is chosen on the TEST mask by a screener or tester, the algorithms are provided with the same dummy attributes as if there were no line record at all. The line record equipment codes are ignored. The dummy attributes are "permissive" in that they cause the algorithm to accept any valid tabulated termination type on a good line. A further latitude is provided in that the set of dummy attributes contains *no* outside plant or central office equipment attributes. The reason for purposely omitting outside plant and central office equipment attributes is that those kinds of equipment always represent a testing *obstacle* to some degree. They are always in the loop "in the way" of the terminating equipment and thus tend to restrict the types of tests which can be successfully run to diagnose loop problems. A well-known example is the Dial Long Lines (DLL) equipment used in the central office to boost the ringing range of the switching machine. The DLLs are electrically opaque to MLT tests, so the algorithms attempt to test only the line circuit and dial tone functions of DLL loop. A curtailment of the test process as severe as this is obviously to be avoided if useful information is to be gained from an override capability.

The DLL example also makes it clear why the override option is useful. Suppose the line record mistakenly showed a DLL, thus producing a very truncated MLT test. Simply choosing the override option of the TEST transaction allows the full gamut of the test series to be applied.

The override capability is also the means for accessing those previously mentioned very sensitive lines which have the line record "barrier" preventing accidental testing. Once the customer's permission has been received for testing, the powerful measurement and diagnostic capabilities of MLT are available through the simple device of overriding the line record. It should be noted that even if the test algorithms are not comprehensive enough to include every circuit configuration, they always provide the measurement results. The skilled user can, therefore, make use of MLT as a "meter" regardless of the type of circuit to which it is applied.

X. CONCLUSION

The MLT system is a comprehensive and sophisticated means of diagnosing loop problems in today's environment. Its improvements over the local test desk stem from the use of modern hardware and adaptive software. It is unique among loop testing devices in its integration of line record information with the testing algorithms. Extensive laboratory and field trial testing have helped to make it an extremely useful aid in the repair and maintenance of customer lines serviced by the Bell System.

XI. ACKNOWLEDGMENTS

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