The Lenkurt Demodulator

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Maintenance of Transistorized Communications Equipment

In May, 1957, The Lenkurt Demodulator discussed "The Effect of Transistors on Carrier Maintenance". The article stressed several advantages and apparent limitations of transistors, and attempted to predict their impact on the communications industry. Since that time, transistors have come into their own; very little communications equipment is now being designed with electron tubes if transistors will do the job. In the light of more recent experience, this article reviews the basic differences between transistors and electron tubes and how they affect the testing of equipment.

The obvious advantages of transistors — reliability, small size, and low power consumption — have resulted in their wide-spread use, even in applications and environments where their vulnerability to temperature and voltage extremes are most likely to cause trouble. Pole-mounted cable repeaters are often housed in small enclosures, subject to the burning sun and chilling winds. Voltage surges abound not only in remote locations, but also in large, central installations.

The contrasts between electron tubes and transistors are quite impressive. Almost all physical and electrical characteristics of the two are opposite. Electron tubes are essentially voltage amplifiers, while transistors are basically current amplifiers. This shows up in the radically different range of impedances that each exhibits when used in similar circuits.

Electron tube operation is almost unaffected by temperature. Some electron tubes, using ceramic envelopes instead of glass, have been operated at temperatures in which the entire circuit glowed red hot! By contrast, transistor performance and operating characteristics are very sensitive to temperature, so much so that elaborate temperature-compensating measures must be built into most circuits employing transistors.

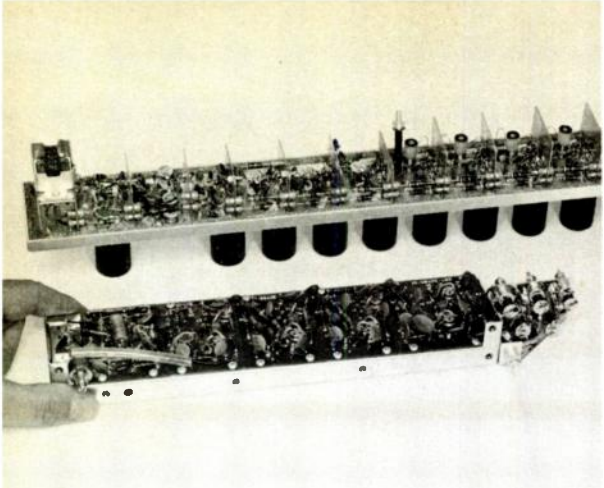


Figure 1. Dramatic reduction in size and complexity made possible by transistors is demonstrated by comparison of electron-tube IF amplifier, and its transistorized equivalent used in Lenkurt 76A microwave. Low voltages and impedances simplify maintenance, but increase the need for care in testing.

Transistors, particularly those designed for very high frequency operation, show a similar sensitivity to improper voltages; changes of only a very few volts may be enough to destroy a transistor. Electron tubes, however, are relatively rugged; very wide voltage excursions can be tolerated so long as they do not last long enough to melt parts of the tube. The very modest voltages present in transistor circuits eliminate the hazard present in electron tube circuits, but may breed a disrespect that could be hazardous for the transistors. Careless testing of the equipment may not provide shocks or electrocutions, as in the case of electron tube equipment, but may too easily destroy one or more transistors.

Soldering Techniques

It may be necessary to remove and replace a defective transistor or to unsolder one or more transistor leads for testing. Special precautions must be taken to avoid ruining the transistor during the soldering operation. Transistors are especially vulnerable to high temperatures, and the soldering and unsoldering operation itself may heat the semi-conductor material enough to destroy or seriously impair its function. This is particularly true when the leads of the transistor are cut short for the sake of compactness.

A widely-used method of reducing heating during soldering is to interpose some sort of "heat sink" between the transistor and the soldering point, as shown in Figure 2. Long- nose pliers, alligator clips, and even hemostats are used for this purpose, usually with excellent results. Another technique illustrated in Figure 2, is to mount the transistor on an insulating spacer. This allows longer leads without permitting movement of the transistor or play in the leads; the spacer itself may divert some of the heat in the leads. Some circuits permit the transistor to be mounted by the top of its case, with the leads fanned out. This allows the leads to be much longer. In all cases, the lightest-duty iron available should be used to minimize heating and restrict it to the immediate area of the solder joint. If a heavy iron must be used, restrict the heat applied to the transistor leads by using heavy copper wire, tinned at the tip, as an extension of the iron, as shown in Figure 3.

Leakage potentials from the heating element to the soldering tip may occur in electric soldering irons, and can

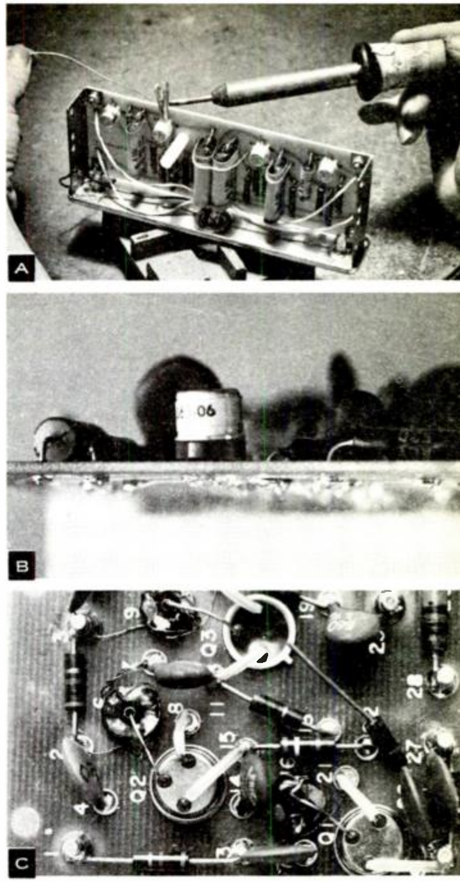


Figure 2. Typical ways of avoiding heat-damage when soldering transistor leads: (A) Alligator clip serves as heat sink on lead; (B) Insulated spacer supports transistor, increases lead length, absorbs some heat; (C) Case-mounting permits longer leads.

swiftly destroy transistors upon contact. Electric soldering irons may be tested during operation by connecting a sensitive a-c voltmeter between the soldering tip and ground. If there is no indication, reverse the soldering iron plug. If there is any doubt about leakage currents, bring the iron up to heat, then disconnect it long enough to solder or unsolder the connection. The iron may also be used if the tip is grounded, or if it is isolated from line by a transformer. Although leakage may still occur, there will be no direct path through the equipment.

The fact that transistors are vulnerable to surge currents should always be remembered when checking voltages. Many of the components in modern equipment are so closely spaced that a voltmeter probe may accidentally touch an adjacent terminal or ground point, unless care is taken. This could easily place excessive potentials on the transistor, thus destroying it. By contrast, electron-tube circuits are much more rugged, and, in most cases, would not be damaged by brief slips of this sort because of its inherent surge-withstand capability. In such cases, however, a transistor is usually the first circuit component to be damaged, as reflected by the occasionally-expressed thought, "transistors are the most effective devices known for protecting fuses!"

Testing Transistor Circuits

If servicing procedures for transistorized circuits were identical to those used for electron-tube circuits, the first item to be checked in a defective circuit would usually be the transistors themselves. However, since most manufacturers of transistorized equipment now wire the transistors directly into the circuit, it is usually quite impracticable to remove and test each transistor. The servicing of transistorized equipment, then, should begin with an effort to localize the trouble to a particular circuit or section of the equipment. As in electron-tube circuits, measurement of operating voltages, and signal tracing techniques are the most successful methods of narrowing down the uncertainty to a given circuit stage.

The technique of using voltage measurements in testing a transistorized circuit requires knowledge of the transistor's function in the circuit and its

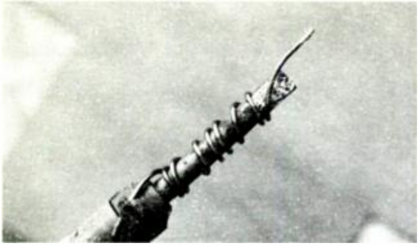


Figure 3. Excess heat from large irons can be reduced by technique shown. Number 10 or 12 gauge copper wire serves as soldering tip.

electrical characteristics. A little time spent in recording voltages and signal levels when the circuits are working properly will repay the effort many times over when trouble occurs. The chances are increasing rapidly that in a defective stage, it may not be the transistor that is faulty, but some other circuit component.

In signal tracing, it is possible to destroy a transistor by overloading the circuit with too strong a test signal. Any signal tracing should begin with the injected signal at a very low level, gradually increasing the test signal until *normal* levels are obtained for the particular circuit under test. Strong signals should never be injected at any low-level stage; a loose coupling between the signal source and the equipment under test is preferred to a direct connection.

If a direct connection must be used between circuit and signal generator, a d-c blocking capacitor should be placed in series with the test probe to prevent the possibility of forming a parallel path across a biasing resistor through the internal circuitry of the test instrument. In such cases, the bias voltage on the transistor might be altered, with subsequent damage to the transistor. Most test oscillators have this capacitor built into the output circuit; however, if in doubt, use an external capacitor of appropriate value (determined by circuit characteristics).

A transistor's direct current gain or "beta" is the most significant single factor in determining its condition, since it provides a direct indication of the transistor's ability to amplify. In certain circuits, such as in conventional common-emitter, resistance-coupled amplifiers, a quick in-service check of the current gain can be made with a voltmeter. This is done by short-circuiting the base to the emitter and noting the resulting drop in collector current, which should fall to almost zero under these conditions. This change of current can be readily checked by a voltage reading across a resistor in the collector circuit. A transistor that will not cut off in this manner is probably defective and should be replaced. This same test, if applied to a switching circuit or a direct-coupled circuit, however, can cause damage to a following stage, and is therefore unsuitable.

Ohmmeter Tests

Surprisingly accurate transistor tests can also be performed with an ohmmeter. These tests can be applied to loose transistors, or to "in-circuit" transistors, but always with operating power removed from the equipment. Since a conventional transistor behaves like two diodes of opposing polarities connected in series as shown in Figure 4, the conductivity of the individual diodes can be checked with an ohmmeter. In performing an in-circuit test with an ohmmeter, it is important that no secondary electrical paths exist across any of the transistor elements. A resistor or an inductance connected from base to emitter, for example, may cause an incorrect reading by effectively paralleling the internal resistance of the emitter-base

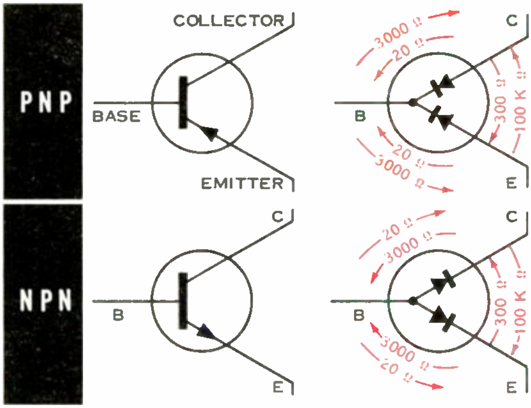


Figure 4. PNP and NPN transistors and their diode equivalents; typical internal resistance values are shown. Before measuring, be sure that ohmmeter voltage is lower than the peak ratings of the transistor under test.

junction. However, it is usually a simple matter to open the secondary path temporarily.

Measuring from base to emitter, the meter will read, perhaps, from 10 to 150 ohms; with the test probes reversed, a high resistance of several thousand ohms should be present. Similar results are obtained when measuring across base and collector. A measurement between the collector and emitter, however, may yield somewhat different results. Diode action should still be present, but should be at a higher resistance than in the previous test, since a fairly high resistance is in series with the diode. Thus, there may be a reading of several thousand ohms in both directions, but a good transistor will show a lower resistance in one direction. Although the ohmmeter test provides no direct information about transistor gain a change in diode action will generally result in a corresponding change in gain. Therefore, if the circuit has operated properly, the transistor is probably good if it shows normal rectification or diode characteristics.

When testing with an ohmmeter, it is important to use one of the higher resistance meter scales, since the internal resistance on the higher scales effectively limits battery current. Be certain that the internal meter battery does not exceed the peak voltage rating of the transistor. With most low-frequency transistors it is generally safe to use an instrument having an internal battery of 3 volts or less. Ohmmeter tests should never be made on high-frequency transistors because of their small junction area, nor on certain diffused-base power transistors which have a very low emitter-to-base breakdown voltage in the reverse conduction direction. The transistor's electrical characteristics should always be verified from the manufacturer's data sheets if there is any doubt.

Where more information is needed about a transistor's condition, it is necessary to use more elaborate equipment. Most simple transistor testers provide a current gain test as well as a current leakage test. These two checks are usually incorporated into the simpler, commercially available static testers.

Leakage is generally measured between the collector and emitter elements only, with the base circuit open. This test is known as the I_{ceo} test, where *I* is the current passing through the collector (c) and emitter (e) elements, with the base open (o). Maximum leakage current is not always quoted in

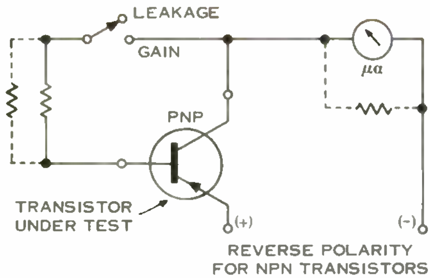


Figure 5. Simple tester for leakage or gain. Shunt resistors (shaded) increase testing range for power transistors.

transistor data sheets, but is roughly the product of collector cut-off current (I_{cbo}) and current gain (beta). Transistor leakage current can be checked in a test circuit as in Figure 5, and if in excess of the calculated value, the transistor is defective. If the transistor passes the leakage test, the same circuit can be used to check gain, simply by closing the base collector circuit. If the transistor is normal, the collector current indicated on the meter will increase. If a meter is used in the base circuit as well, the exact transistor beta can be calculated from the measured base and collector currents:

$$Beta = \frac{collector\ current}{base\ current}.$$

Dynamic Testing

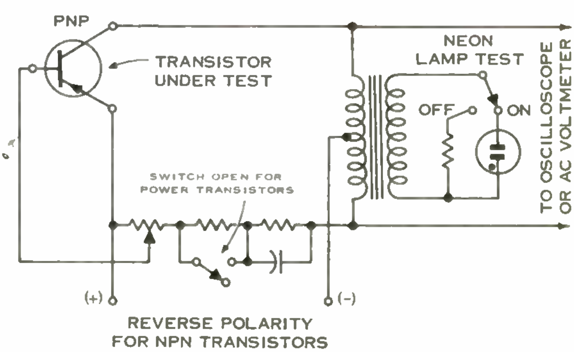
Static tests are usually adequate for most routine equipment servicing. However, a transistor may pass the d-c tests and still be deficient in high-impedance or high-frequency circuits, or in high-speed switching applications.

In one type of dynamic tester, the transistor is operated as an oscillator, as indicated in Figure 6. At least one commercially available checker uses this principle, and the output is measured with an a-c voltmeter or an oscilloscope. Another type of dynamic tester (Figure 7) permits in-circuit testing of transistors by using the transistor under test as an amplifier. A signal is applied to the transistor, and gain is measured by comparing the input and output signal levels, using a tuned a-c voltmeter.

Either type of dynamic tester can be used for in-circuit tests, with interconnections made by clip leads. In-circuit testing is usually possible without disturbing surrounding circuit components because of the low-impedance input and output of the tester, although it may sometimes be necessary to open d-c or a-c return paths for maximum accuracy.

Although the testers described are adequate for normal maintenance work, dynamic testers permitting much more sophisticated checks are available for

Figure 6. Oscillator-type test circuit. Neon lamp glows if transistor is shorted, open, or has excessive leakage. Output can be measured for more exacting tests.



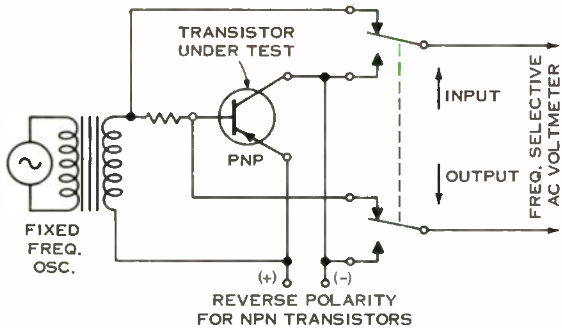


Figure 7. In-circuit amplifier-type tester. Gain is determined by comparing input and output levels. Low impedances reduce effects of external components when used for in-circuit tests.

laboratories or servicing centers. In addition to providing gain and leakage tests, such testers check input impedance, voltage feedback ratio, alpha cut-off, beta cut-off, collector capacitance, and the like.

Transistor Substitution

After other circuit components are found to be in working order, it may be feasible to substitute transistors, as is done with electron tubes, for a more positive test. If the trouble persists, the original transistor is probably good, and the fault lies elsewhere. For a quick check, it is not always necessary to use an identical transistor, provided that a unit of the same general type is used and is of the same polarity configuration. The chances are that in a substitution of this nature, circuit performance will be degraded by the new transistor. However, the fact that there is any output at all generally indicates a satisfactory circuit.

When making a permanent replacement, the new transistor should be *exactly as specified* by the equipment manufacturer. This is because there is often a substantial difference in the characteristics of "identical" transistor types made by different suppliers. Even when built to identical specifications, transistors can exhibit considerable differences in performance. These variations are noticed most often in the high-frequency response characteristics. Therefore, if an equipment manufacturer specifies, say, a 2N-1776 transistor of a certain brand as the recommended replacement, there is a distinct chance of poor performance if the product of another manufacturer is used.

Conclusions

A working knowledge of the transistor's advantages and limitations will yield big dividends to the maintenance force. Although today's transistors possess outstanding reliability, efficiency, and life expectancy, these features cannot be attained without a full understanding of semiconductors by those who use them and maintain them.

Just as the "direct-current" workers in the earlier days of telephony faced a major re-education process when the electron tube made its debut, the telephone man of today must accept the necessity of familiarizing himself with the properties of the transistor, since the transistor is here to stay!

The tremendously varied uses of transistors in modern communications equipment preclude a detailed, comprehensive discussion in a publication of this size. The test and maintenance hints discussed in this article are intended only to provide a foundation in developing good maintenance practices. •

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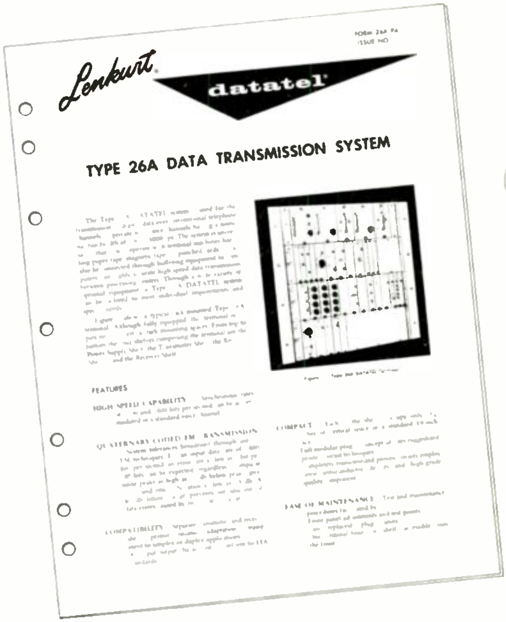
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