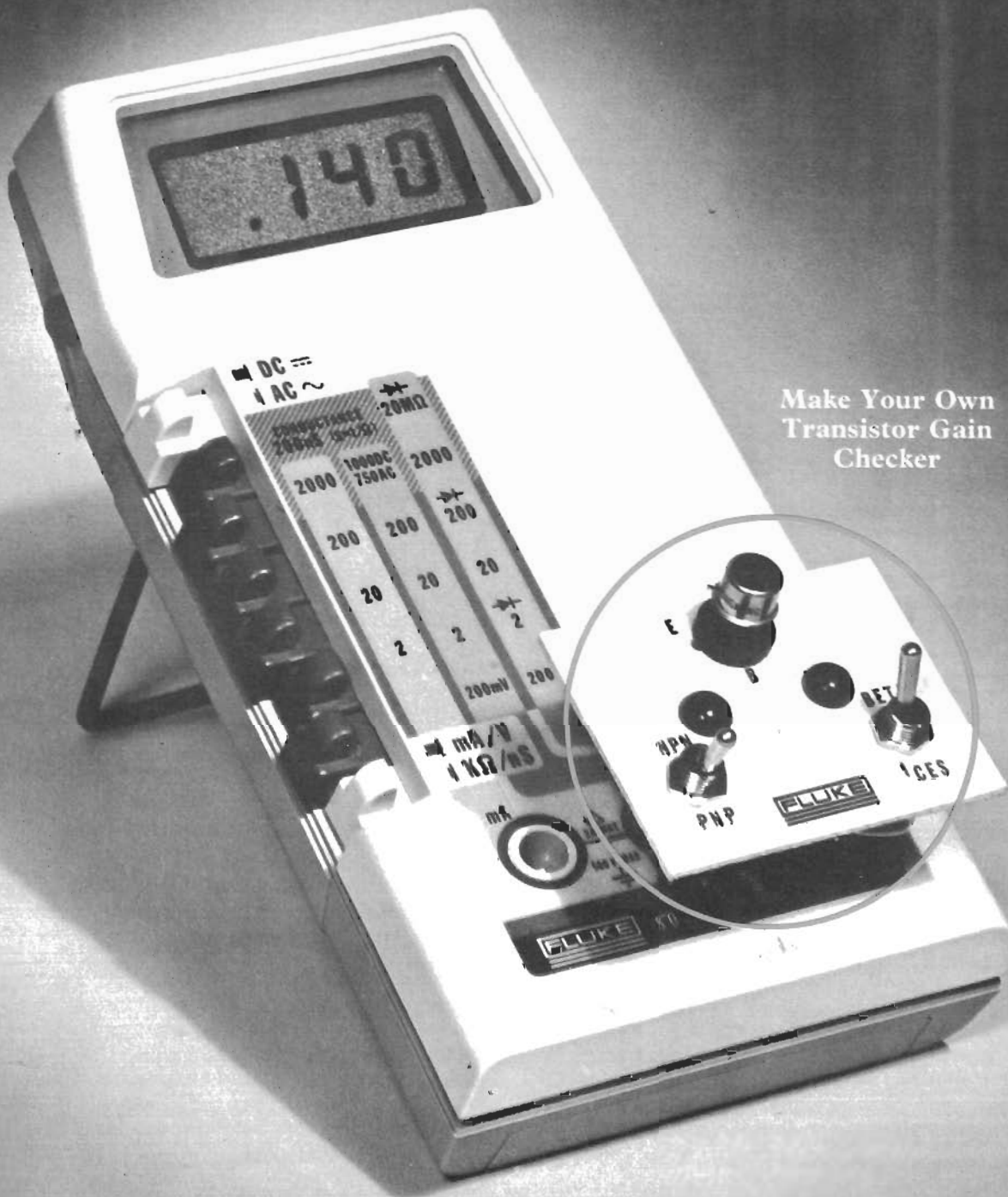


## USING CONDUCTANCE TO CHECK OUT ELECTRONIC COMPONENTS (and just about anything else)



Make Your Own  
Transistor Gain  
Checker

## Introduction

The purpose of this application bulletin is to show how common electronic components, such as transistors, capacitors and diodes can be functionally checked for proper operation. Ordinary checks using a digital multimeter can frequently be misleading because the common DMM only goes to 20 MΩ. This is not high enough for a complete checkout since many components function properly only when their resistance is in 100's of MΩs.

The procedures to be described are based on a new "conductance function" in the Fluke 8020A, 8010A and 8012A Digital Multimeters. Conductance allows measurements equivalent to a total resistance range of 0.5 kΩ to 10,000 MΩ. By allowing measurements equivalent to 100's of MΩs and reading out in units different from ohms, conductance makes possible tests that were difficult if not impossible to do before. The 8020A has two ranges of conductance: 2 milliSiemens full scale (equivalent to 0.5 kΩ - 1 MΩ), and 200 nanoSiemens full scale (5 - 10,000 MΩ). The 8010A and 8012A have an additional range: 20 microSiemens (0.05 MΩ to 100 MΩ). Note that the procedures to be described are intended as "general checks for component operation". They are not meant to replace formal acceptance procedures which require sophisticated and expensive equipment (e.g. curve tracer, wheatstone bridge, etc.).

What is this new function called conductance? The easiest way to understand it is to think in terms of resistance which we are all familiar with. A unit of resistance is a unit of opposition to current flow. Conductance by definition is the opposite (i.e., inverse) of resistance. Hence, think of conductance as being a unit expressing the ability of a material to **allow** current to flow **instead of opposing** it. When resistance decreases, conductance increases and vice versa. The unit of conductance is the Siemens (S), and it is a simple matter to move from conductance units to resistance units since  $S=1/\text{ohm}$ . Hence, resistance and conductance can be thought of as two different ways to express the same electrical concept. Shown in Figure 1 are conductance-to-resistance graphs for the three ranges.

Since conductance requires the use of Siemens units, a common question is why not measure high resistance directly instead? There are three problems with this direct approach. First and most importantly is direct high resistance measurements require very special parts. Most ohmmeters use a ratio ohms technique which compares the unknown resistor  $R_x$  with a known value  $R_{ref}$ . The catch is that to maintain accuracy for high resistance ranges,  $R_{ref}$  becomes prohibitively expensive. This is the primary reason that digital multimeters do not go up to 10,000 MΩ. A second problem with the direct approach is that noise becomes a problem as the unknown  $R_x$  increases in value. Because resolution decreases at higher resistance equivalents, this noise is not a problem with

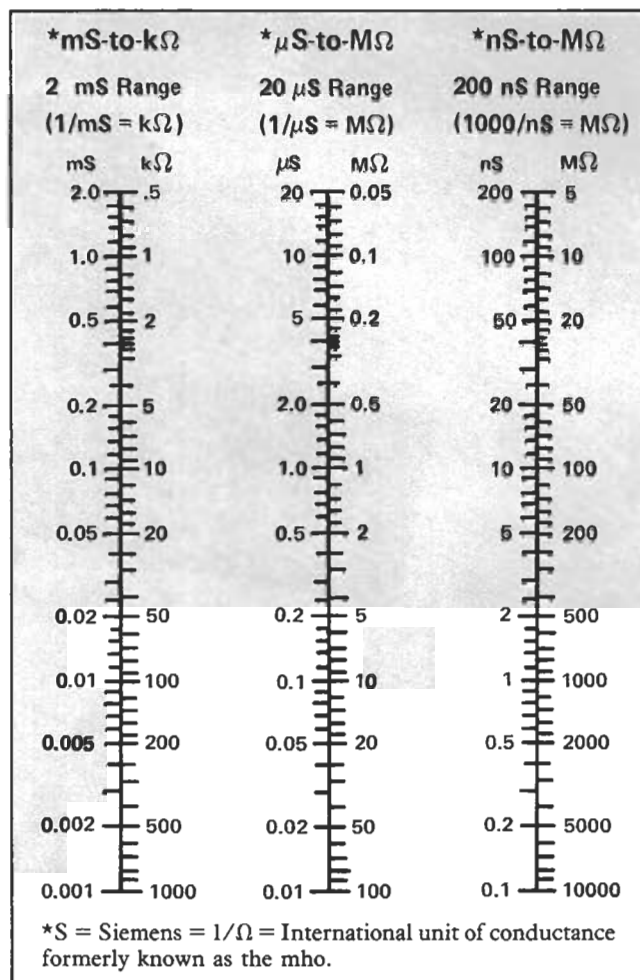


Figure 1. CONDUCTANCE-TO-RESISTANCE CONVERSION

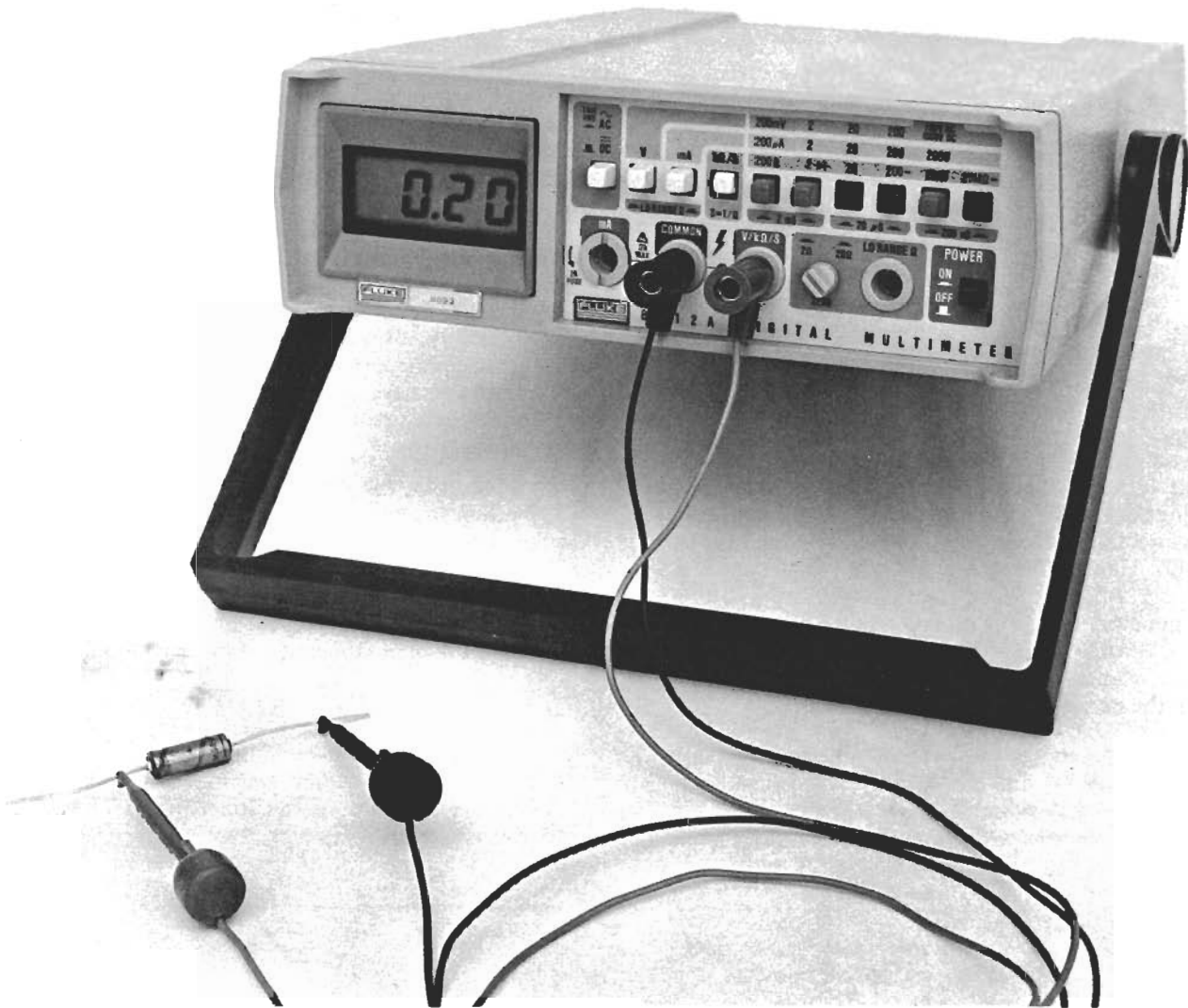
conductance measurements. The final reason for measuring conductance is that many parameters vary directly as the Siemens units do. For example, increasing light on a photoresistive cell results in a higher conductance reading. An ohmmeter would indicate a smaller reading for increasing light, hence giving a confusing indication to the operator.

## Capacitors

Capacitors have a nasty way of partially failing by developing a high leakage resistance. This leakage is seen by associated circuitry as a very high resistance in parallel with the specified capacitance. The results can be disastrous in common direct coupled circuits which treat the additional leakage resistance as a change in bias. The effect multiplies when there are several stages. Timing circuits also suffer since the RC time constant is now shortened. A change in a circuit's RC master clock will throw an entire circuit off.

Manufacturers test for capacitor leakage by actually measuring the associated leakage current that flows after allowing the capacitor dielectric to form at its rated voltage and temperature. This test can be approximated by measuring a capacitor's conductance value. The lower the conductance is, the lower the leakage current is, and hence

the better the capacitor. Because of typical  $\pm 20\%$  tolerances and characteristic differences between types (e.g. aluminum vs tantalum), measured conductance will vary somewhat even between good capacitors that have the same specified capacitance value.



**Figure 2.** THIS 47  $\mu\text{F}$  CAPACITOR INDICATES 0.20  $\mu\text{S}$ , AN UNACCEPTABLE LEAKAGE

Begin the test by shorting the capacitor leads together to get rid of any charge. For capacitors up to 1 mfd, set an 8020A or 8010A DMM to the 200 nS range. Connect the DMM test leads to the capacitor observing proper polarity for polarized capacitors. The reading will start at some high value, perhaps even overrange, and gradually decrease to the final leakage value in conductance units (i.e. nanoSiemens). Typical leakage values for good capacitors will be between 0.5 nS and 0.1 nS with the smaller capacitors tending toward the 0.1 nS number. Note that this equivalent to a leakage resistance of 2000 to 10,000 M $\Omega$  way above the capability of an ordinary 20 M $\Omega$  ohmmeter.

Capacitors between 1 mfd and 100 mfd are best checked using the 8010A or 8012A's 20 $\mu\text{S}$  range. Again be sure to discharge the capacitor then connect it to the DMM observing the proper polarity. Typical leakage values for good aluminum caps will be below 0.05  $\mu\text{S}$  with good tantalums even reading 0.01  $\mu\text{S}$ . Aluminum caps vary widely in quality and "cheapies" will generally have leakage notably greater than 0.05  $\mu\text{S}$ . It is not always necessary to wait for a large value capacitor to settle to its final leakage value since an appropriate rate of value change generally indicates it will get there. Capacitors larger than 100 mfd take a reasonable amount of time to settle to their final value, hence this procedure is recommended mainly for smaller value caps.

The technique for measuring capacitors between 1 mfd and 100 mfd is somewhat different when using an 8020A. Since this instrument does not have the optional 20  $\mu$ S range and the 200 nS range is slow, it is necessary to speed things up by precharging the capacitor with the 200  $\Omega$  range. After this has been done, switch to the 200 nS range and allow the reading to stabilize. Note that when using this technique, the 8020A readings will start out near zero and gradually **increase** to the final leakage indication. This is because of the precharging, and is opposite to the decreasing indications obtained in the test procedures described previously.

## Diodes

A properly functioning diode will conduct heavily in the forward direction (i.e. when the anode is biased positively with respect to the cathode, and very little in the reverse direction (i.e. anode negative and cathode positive). The ratio of forward conduction to reverse conduction should approach 1000:1 and is easily checked using the 2 mS range of an 8010A or 8020A. Connect the red input (V/k $\Omega$ /S) to the anode and the black input (common) to the cathode of a good diode. The cathode end is usually marked with a black or white band. Depending upon the diode type, a reading of about 0.700 to 1.2 mS of conductance should be obtained. Reversing the test leads to reverse bias the diode gives a readout of .000 mS. Calculating the ratio of forward-to-reverse conductance is made easier if the reverse reading, .000 mS, is assumed to be .001 mS. Hence 0.700 mS/0.001 mS = 700:1 and 1.2 mS/.001 mS = 1200:1. Both are acceptable values. The ratios do not even have to be calculated each time. Merely look for a reading of 0.700 to 1.2 mS in the forward direction, a reading of 0.000 mS in the reverse direction and move the decimal to the left three digits.

This test operates in the proper conductance units and provides visibility for high forward-to-back ratios. The more common "high power ohms test", by measuring

0.600 k $\Omega$  in the forward direction and overrange in the reverse direction, can only indicate forward-to-back ratios of 3.3 maximum (2.000 k $\Omega$  overload max/0.600 k $\Omega$ ). This is inadequate for excessively leaky diodes or diodes that have a partial junction breakdown.

Although the preceding checkout is adequate for 98% of the applications, sometimes it is necessary to look at the reverse conductance (i.e., formally  $I_R$ , leakage current) more closely. Such is the case in high voltage power supplies where reverse conductance should be minimized and matched for the individual diodes in a "series stack". The 20  $\mu$ S and 200 nS ranges are ideal for this. A random sampling of small signal silicons and stud mounted rectifiers yielded readings of about 2 to 10 nS.

## Transistors

Two transistor parameters critical for most applications are current gain (beta), and leakage ( $I_{ces}$ ). Circuits are typically designed to operate properly over a certain range of beta; substitute a transistor with a beta outside of this range and the circuit may not operate properly. Leakage is just as critical and may result in dc offsets in direct coupled circuits along with upsetting bias calculations.

The 2 mS range in the Fluke 8020A and 8010A/8012A DMM's provides a convenient way to approximate these critical parameters. Figure 3 diagrams a tester which measures beta at a VCE of about 2V and a  $I_c$  of approximately 200  $\mu$ A. The cover of this bulletin shows a transistor with a beta of 140. The tester is easily constructed with a minimum of components. Data provided include:

1. Transistor type (NPN or PNP)
2. Collector-to-emitter leakage ( $I_{ces}$ )
3. Beta from 10 to 1000 without changing range
4. Shorted collector-to-emitter junction
5. Open collector-to-emitter junction

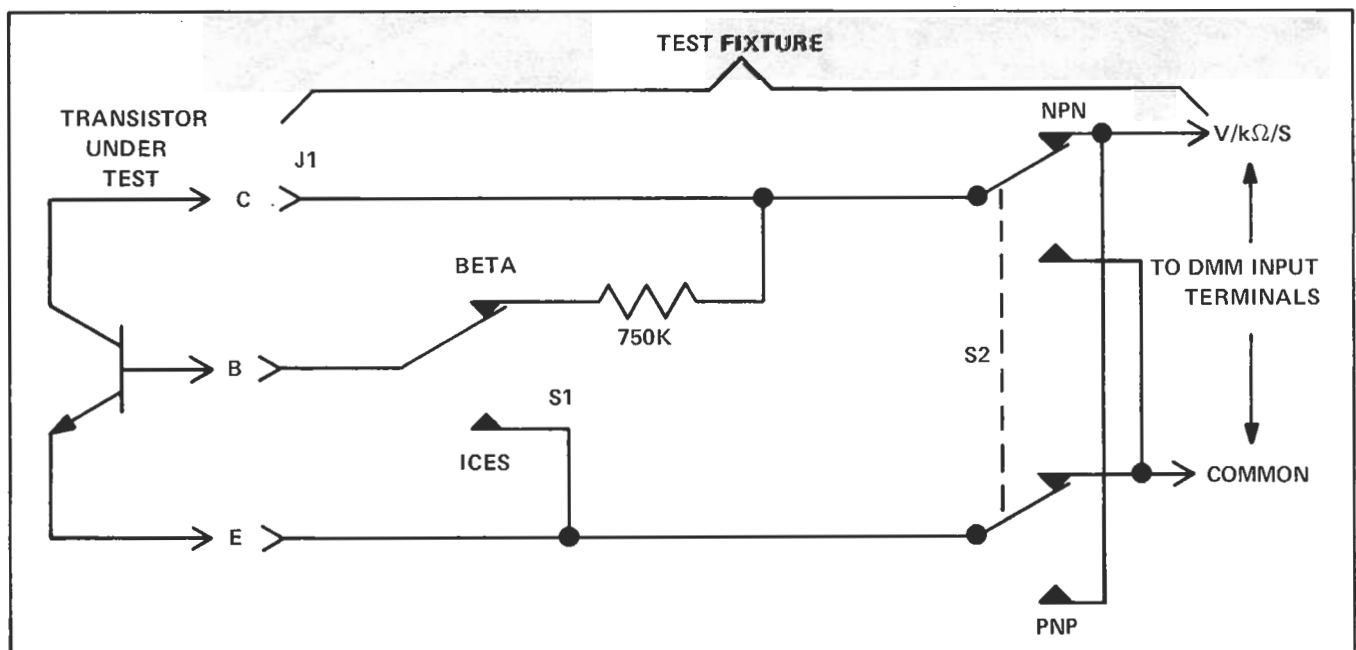
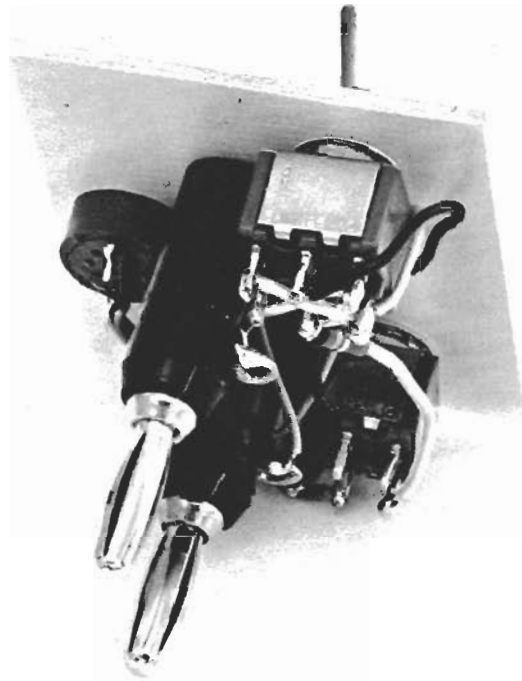
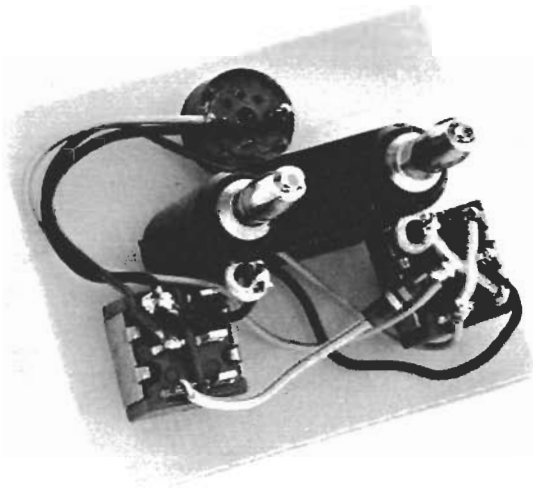


Figure 3A. TRANSISTOR BETA TEST FIXTURE



**Figure 3B.** DETAILS OF TEST FIXTURE CONSTRUCTION

Select the 2 mS range and plug the tester into the V/K $\Omega$ /S and common input terminals. Plug a transistor into socket J1 being sure to observe proper lead orientation. To determine transistor type, set S1 to beta and observe the DMM display. If a very low reading ( $\leq 0.010$ ) is obtained, move S2 to the opposite transistor type. When a significant reading is obtained, the switch will indicate the proper type (i.e. NPN or PNP). The reading may typically be from 0.050 to 0.650. This is the transistor's beta and is read by mentally moving the decimal point three places to the right. For example, a display reading of 0.650 indicates a beta of 650. Note that beta is a temperature sensitive parameter and that the transistor case should not be touched with your fingers during the reading. If the transistor is shorted, an overload (i.e. 1) indication would be displayed regardless of what transistor type switch S2 indicates. Likewise, an open transistor would always read about 0.001 or less.

To test for leakage, S1 is set to the Ices position. The transistor is turned off in this test (base shorted to emitter), and should appear as a very low conductance (high resistance) from collector-to-emitter. Therefore, the lower the reading the lower the leakage. Silicon transistors that read more than 0.002 (6  $\mu$ A) should be considered questionable.

### Cables

Cables are susceptible to much physical abuse during their lifetime. Unless they are buried deep inside a chassis or part of a semipermanent setup, they are going to be bent, twisted, run over and subject to changing environmental

conditions. If a cable is shorted or open, it can be checked using a regular 20 M $\Omega$  ohmmeter. This does not work, however, for faults in between the open and shorted conditions.

Fortunately, an unterminated cable behaves very much like a capacitor. Like the capacitor, it has two plates and a dielectric. These are respectively the center conductor, the shield, and the insulating core. Capacitance is typically on the order of 30 to 100 pF per foot of cable since the capacitance determining "plate area" is very small. Using this analogy, cables and connectors can be checked for high resistance leakage with the 200 nS conductance range.

The 200 nS range will respond to a minimum of about 50 pF of cable capacitance or about one foot. Note that wire manufacturers usually give these numbers, although you will not need them for this test. To get a feel for how different lengths of cable should respond, you might try checking a few capacitors from 50 pF to 1000 pF in the normal manner. A very short cable, like the 50 pF capacitor, will display about 0.1 nS for a second, then go to 00.0 nS upon full charge. The 1000 pF responding to 20 feet of 50 pF cable will start at 1.0 nS and quickly display 00.0 nS when fully charged.

To begin the check start by making sure the cable is unterminated. For rf applications certain types of antennas with coupling coils will have to be disconnected from the output end of the cable along with the xmitter end. If this is not done, the DMM will see a "shorted" cable.

Touch the common probe to the cable shield. It might be necessary to wait for the DMM to stabilize a couple seconds since the test impedance is so high (10,000 MΩ!). Now touch the hot probe to the center conductor. A short length cable should read a few nS and rapidly go to 0.00 nS. Longer lengths with more capacitance will start at a higher value and go to 0.00 nS more slowly. Note that an electrically shorted cable will indicate an overload, and than an open cable will not exhibit capacitor action. The latter is particularly useful when checking long lengths of cable which cannot be rolled up so as to have access to both ends at the same time. Besides loss in coax, this check has been used to look at salt water corroded connectors which may have high leakage resistance.

## Resistors

The typical DMM gives out trying to measure resistors above 20 MΩ. Although a few go higher, they are usually plagued by noisy readings and long settling times. The 200 nS range of the Fluke 8020A and 8010A/8012A are ideal for making this measurement. This range provides conductance readings equivalent to 10,000 MΩ. Conductance readings are readily converted to equivalent ohms by the graph shown previously using the 1000/nS reading=MΩ rule. The ability to read above 20MΩ can be very useful for common circuits such as in HV power supplies, TV's and FET designs.

## Printed Circuit Boards

It is relatively easy for a circuit board to become contaminated. In the production process this can occur in one of the many steps that start with a copper-clad laminate and end with a functional board loaded with components. For operational circuitry contamination can result from a hot or burned out component that leaves carbon deposits. Whether this contamination becomes a serious electrical leakage problem or not depends upon a number of factors including the relative impedance of the circuitry, the associated voltages, and the relative humidity. Leakage resistance can upset the accuracy of high impedance instrumentation, or cause an arc over in high voltage power supplies. Humidity is very important since a normally acceptable level of pcb cleanliness frequently will cause serious problems under a combination of high temperature and high humidity.

The 8020A and 8010A/8012A 200 nS range will indicate to 0.1 nS or an equivalent leakage resistance of 10,000 MΩ. This is a middle of the road figure for acceptable common board leakage and makes an excellent good/bad indication.

Sample unloaded production boards can be checked by attaching the leads from a conductance DMM to parallel circuit traces. The board should be placed in a chamber and run at the desired humidity and temperature. From the dimensions of the pcb trace area, a standard figure for nS per square area can be calculated. For example, assume two parallel traces are 0.2 inches apart and running parallel for one inch. One inch divided by 0.2 inches equals 5 square units of area. If the corresponding conductance indication is 0.5 nS, then the leakage for the board is 0.5 nS/5 squares = 0.1 nS/square. This type of

test may be done as a contamination check on previously burned boards that have been washed. This assumes, of course, that components that would shunt the parallel traces have been removed. It is important to note that most boards will have to be tested under high humidity and high temperature conditions to get a valid reading. It is pretty hard to see a board leak under typical bench conditions.

## Anything Else

The previous sections have described in detail functional checks that most people would find useful for common electronic components. Those applications just scratch the surface of the many possible uses for conductance. To illustrate, the following list points out some of the more unusual and varied applications our customers have reported for this new function. Because of their unusual nature and limited application, we have not attempted to verify each customer's results. They are given here mainly to provide stimulus for other possible applications.

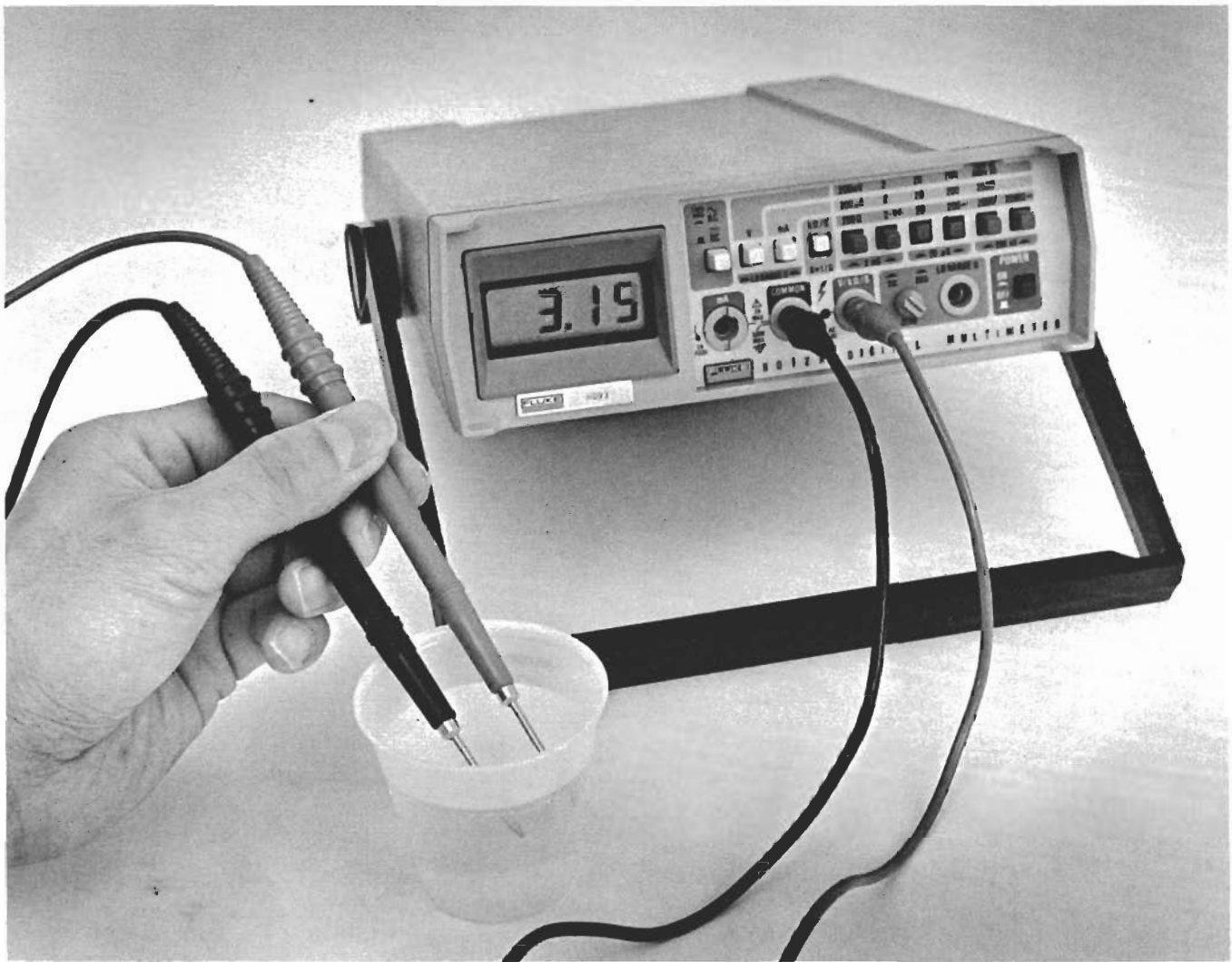
**1. Wood Moisture Content.** The customer reported using conductance to determine the moisture content of cabinet quality wood. Wood of this grade is kiln dried so it might be easier to measure the moisture in the lower grades which are only "S-Dry".

**2. Inverse Resistance.** Certain electrical devices, such as photoresistive cells and thermistors, exhibit an inverse resistance effect. When the temperature or light get greater, the device resistance decreases. This can be confusing since it is easier to think of both numbers going in the same direction. Use of the conductance function allows direct readout of photoresistive cell and thermistor outputs. (The inverse of an inverse gets you a direct reading.) When the light level increases, your reading increases. Scaling or a calibration table would be necessary if you need actual values.

**3. Nondestructive Isolation Resistance.** The application called for measuring the isolation resistance of mounted strain gauges. Initially a 500V megger was used, but the high voltage frequently broke down the extremely thin dielectric and destroyed the element. The 8020A conductance function with a maximum voltage of 3.5V, proved to be safe, nondestructive means of making the test.

**4. Fouled Sparkplugs.** It's pretty difficult to come up with typical values. A comparative check should be able to indicate any plug out of line with the others.

**5. Electrolytic Conductivity.** Customers report using the 8020A to measure the conductance of solutions. For this application the 8010A and 8012A are better suited because of an additional range. Noncritical measurements that don't require calibration can be done by merely placing the tips of a pair of test probes into the solution. Serious work, however, will require the use of a conductivity cell to hold the solution since the readings are proportional to the electrode surface area and spacing. A cell with a constant of 1.0 will give direct readings.



**Figure 4.** MEASURING THE RELATIVE CONDUCTIVITY OF WATER

Conductivity is typically given referenced to 25°C; readings at other temperatures should be adjusted back to 25°C. The temperature coefficient is quite large, being about 2% per degree. The better conductivity meters use a temperature compensated cell to do away with the conversions. In addition, they use an ac measuring circuit to avoid the electrolysis and gas evolution problems associated with dc measuring circuits.

### Concluding Comment

It is hoped that this bulletin has given you some concrete ideas on how to check some common electronic components. As has been pointed out, the traditional methods have many limitations. In conclusion just about anything can be checked using conductance!

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Check Out Electronic Components  
In This Bulletin Using These Conductance Measuring DMMs



8020A

- 2 Conductance Ranges
- Unique One Hand Operation
- 200 Hours Battery Life
- Transient Protection
- Diode Test
- Rugged Construction



8010A/8012A

- 3 Conductance Ranges
- True RMS AC Measurements
- 50 kHz Bandwidth
- Nicad Pak Available
- Extensive Input Protection
- Touch and Hold Readings
- 10A Current (8010A only)
- 2/20Ω (8012A only)
- Diode Test
- 0.1% Basic Accuracy



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