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BENCH BRIEFS

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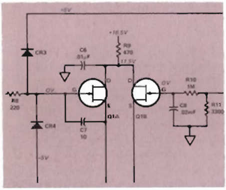
TESTING THE FIELD EFFECT TRANSISTOR



Field Effect Transistors (FETS) present a unique challenge when you try to test them as there are three basic categories and two subcategories (N and P) for each of the three. This article describes each type, then tells you how to build a FET checker that dynamically tests all the types of FET's, and gives advice on how to find and fix a major FET problem without unsoldering.

by George Stanley, Group training Manager for Hewlett-Packard's instrument-producing divisions. Mr. Stanley may be familiar to many of you as the author of the widely-distributed transistor book: Transistor Basics: A Short Course, *Hayden Book Co. Inc., NYC, HB 5819.*

FET Types

The three basic types of FET's are known as Junction Gate, Insulated Gate (non-enhanced) and Insulated Gate (enhanced). They are referred to in this article as J-FET's, enhanced MOSFET's and non-enhanced MOSFET's. (The designations J and MOS refer primarily to the method of construction, but they also involve different electrical characteristics.) The similarities and differences between the three basic types of FET's are described in Table 1.

The FET symbols and a schematic equivalent of what is actually inside the devices are shown in Figure 1. Also shown is why FET's are hard to test. For example, a dc ohmmeter could be used to check the J-FET diode but would not work on a MOSFET device.

In addition, a non-enhanced MOSFET will show a resistance from source to drain while an enhanced MOSFET will not. However, between substrate and source or drain in both MOSFET's you will essentially see a diode. Incidentally, *enhanced* as used here means a channel must be "created" by the gate field to allow carriers (electrons in N channel, holes in P channel) to move from the source to the drain. Therefore, in an enhanced MOSFET you would have to *forward bias* the gate/source to start conduction. Thus you can see that enhanced MOSFET's are bascially *OFF* devices, while non-enhanced MOSFET's and J-FET's are basically *ON* devices.

Testing FET's—In Circuit

Before removing any FET from its circuit, try these in-circuit test tips: *J-FET*—Short the gate to source and the device should start conducting heavily, as you have removed the field which pinches the channel. You can check this by monitoring either the dc source voltage (it will go up) or the dc drain voltage (it will go down). *MOSFET Non-enhanced*—Short the gate to source, or gate to substrate. Usually you will find the source and substrate connected together. As with the J-FET, the non-enhanced MOSFET will conduct more heavily. *MOSFET Enhanced*—Short the gate to source, or gate to substrate. As mentioned above, the source and substrate are usually connected together. In this case the device should turn off, since the enhancing field has been removed. Check by monitoring the dc voltages on the source or drain.

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TABLE 1. Principal FET Categories

The Three Basic FET's:	Junction Gate (J-FET)	Insulated Gate-Non-enhanced (MOSFET)	Insulated Gate-Enhanced (MOSFET)
Type of Channel	Can be either N or P channel	Can be either N or P channel	Can be either N or P channel
Condition of channel	High conduction (ON at zero bias)	High conduction (ON at zero bias)	Low conduction (OFF at zero bias)
Comments:	Similar to vacuum tube *pentode*	Insulation is between gate and channel, comparable to a delicate capacitor. Input resistance can be as high as 10^{15} ohms. Also similar to pentode.	

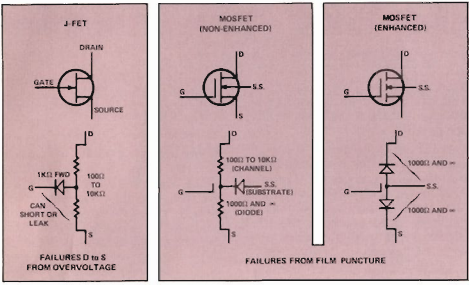
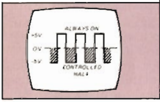
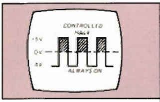


Figure 1. FET Symbols and Schematic Representation (Examples are all N Channel).

Table 2. Examples of Good Waveforms Using FET Checker.

	J-FET	MOSFET (non-enhanced)	MOSFET (enhanced)
			
	P channel	P channel	N channel
	N channel	N channel	P channel
	3 Leads (4 with case) controlled half does not go all the way to zero	4 Leads controlled half does not go all the way to zero	4 Leads controlled half goes all the way to zero

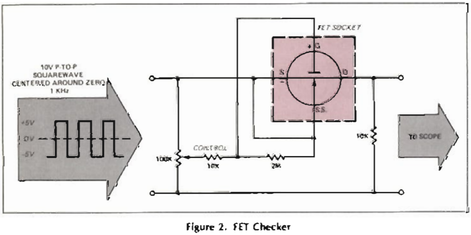


Figure 2. FET Checker

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Testing FET's—Out-of-Circuit

For an out-of-circuit tester to be really useful, it must be able to test both P and N junction-gate and insulated-gate FET's, plus have the ability to test enhanced as well as non-enhanced FET's. Figure 2 shows the schematic of a FET checker that will test all of these types, including the enhanced MOSFET in the test socket. This is a dynamic checker that uses a 1-kHz square wave to provide both signal and "power" to the device under test. Table 2 describes the waveforms you should see on the scope when testing good FET's. Let me explain using the example shown in Figures 2 and 3. Table 2 shows that for a good N-channel, enhanced MOSFET, the control should not affect the top half of the squarewave but should make the bottom half vary in value from normal, that is from −5V, to zero. (Now you can see that your squarewave input signal must swing between a positive voltage and a negative voltage to cover all FET types.) With an enhanced MOSFET, N channel, we have to put a positive on the gate with respect to the source, to make the FET conduct. This happens when the bottom of the potentiometer is more positive than the top of the pot, that is, whenever the squarewave input is in the region below 0 volts. This is the region where you would have control because by varying the position of the pot wiper you vary the amount of *enhancement* voltage applied to the source.

The reason the top half of the squarewave is always on is because the FET diode between substrate and drain is forward biased during this time. The diode between substrate and source is shorted out by the jumper wire on the tester socket. This jumper provides a reference point for the substrate so it won't float around. While we're on that subject, the 2-meg resistor provides a bleed path for any charge that might build up on the gate if the wiper accidentally lifts off the pot. The 10K resistor is a current limiter needed only for J-FET's and then only when the pot wiper is at the maximum to forward bias the gate/source diode. Without the 10K limit resistor you would see ampli-

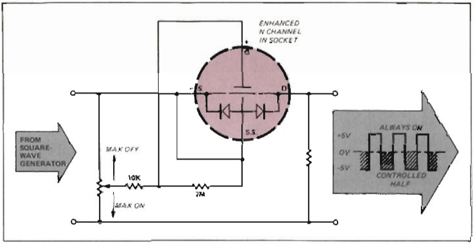


Figure 3. Tester Redrawn to Show FET Diode Equivalent and How Control Affects Output.

tude loading on the squarewave generator. The important thing about the generator is that the output be symmetrical around zero and that you can get a 10V peak-to-peak output. You can verify Table 2 by doing a similar analysis for a J-FET and a non-enhanced MOSFET. The oscilloscope display should look like what is shown in Table 2, plus if you have leakage in the FET you will have rounding on the trailing edge of the squarewave. Obviously, with a completely defective or shorted gate, you won't get any gate action so you won't get any change when you vary the control. After you have built your checker, you had best experiment to learn the subtleties of what represents good and bad.

When you begin constructing a checker of your own, I would recommend installing four 4-pin sockets in parallel to cover the many different FET socket configurations. The ones I recommend are shown in Figure 4. Once you have these configurations identified, you can use the checker, along with Table 2, to identify unknown FET's.

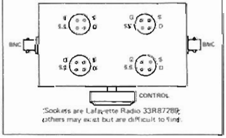


Figure 4. FET Tester (Top View)

Replacing FET's

Many FET's are changed that are really good but behave as though they are defective. The trouble is leakage *external* to the FET on the printed circuit board. Remember FET's can have high input impedances, as high as 10^{15} ohms. External leakage can build up because moisture tends to be absorbed in the solder flux that remains on the PC board under the lacquer sealer. This lacquer sealer is not a 100% moisture barrier, so over a period of time moisture seeps through the lacquer and collects in any residual solder flux. Therefore, before changing a FET take either a stiff fiberglass brush or a gray typewriter eraser (not the red gummy kind) and thoroughly clean around the FET. Clean enough to cut through the lacquer. You can tell when this is done as the finish will be dull rather than shiny. Retest the circuit and if everything is OK, spray the local area with lacquer sealer from a pressurized can and you should be home free. You may be surprised but this quick procedure may cure over 50% of your "defective" FET's. (See also article on page 5, Solder Flux Removal.)

If you decide to build the FET checker and then through using it come up with something I haven't covered, please drop me a line in care of the Editor, BENCH BRIEFS, 1501 Page Mill Road, Palo Alto, Calif. 94304. I can then share these in some future issue with all our readers. Cheerful Checking!

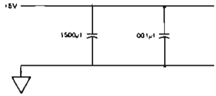
CIRCUIT BOARD EXCHANGE SAVES YOU TIME AND MONEY

Many circuit boards for HP instruments are available on an exchange basis at reduced costs. For example, the A1 Sweep Generator Board Assembly in a Model 8620A Sweep Oscillator can be purchased for $78 exchange where the list price for this board is $168. These exchange boards are made available to help minimize repair times when downtime is critical or in those cases (*such as intermittent dogs*) where troubleshooting to a component is apparently not the best strategy.

Boards available as an exchange item are listed in the HP Replacement Parts & Supplies, Master Price List. If you don't have one, consult your purchasing department or call your local HP Sales & Service Office for assistance.

ELECTROLYTIC FILTERS

Why is an electrolytic capacitor often paralled with a small by-pass capacitor as shown below?



Electrolytics generally do not filter out high frequency signals very well. Thus if just an electrolytic were used, it would be quite easy for high frequency signals (noise pulses and oscillations, for example) to get fed around the instrument on the power supply lines.

Installing a small by-pass capacitor squelches the high frequency signals and it thus becomes an excellent complement to an electrolytic, which does a good job of filtering the low frequency components.

So, if you ever are attempting to get high frequency noise off a power supply line, use a small by-pass, not an electrolytic.

ELECTRONIC COUNTERS—Input Protection

5303A 500 MHz Counter
5327 Series Timer - Counter-DVM

Accidental overloads are blowing the 50Ω inputs on the 5303A, and also the 550 mHz high frequency inputs on the 5327. We could plead with you to be more careful, but to be on the safe side, we're offering instead an input protection circuit—for free. If you own a **5303A**, you will receive the same fused input protection that is now standard on the 5303B. If you own a **5327(A, B, or C)**, you will receive a board containing a fused input protection circuit with instructions on how to install it. To insure these instruments against repair downtime, contact your nearest HP Sales & Service Office and tell them you want to take advantage of this bargain.

FREQUENCY DIVIDERS—Rebuilt Motors

115BR Frequency Divider and Digital Clock

If the 1-kHz synchronous motor in your frequency divider has gone bad, it can be rebuilt for less than half the cost of a new motor. That is, having HP rebuild it costs from $100 to $200, and a new replacement costs $400.

The motor should be removed but not disassembled—once the motor is opened it must be specially remagnetized. Deliver the motor to your local HP office. They can obtain a quote if you wish and will forward the motor to our Customer Service Center in Mountain View, Calif. for repair. For customers outside the U.S., talk to your HP representative.

SIGNAL GENERATORS

8660B Synthesized Signal Generator

Some customers have reported a flashing sixth digit (100 kHz) in the readout at low line voltage. We have found this problem to occur in Serial Numbers 1240A00180 and below. The solution is to increase the +4V power supply decoupling; change A20C7 from a 1200 μf to a 1900 μf capacitor, HP 0180-2154. You can order Service Note 8660B-1 for full instructions on this change (see back cover).

8660A Synthesized Signal Generator

A misprint in the Operating and Service Manual printed March 72 makes it difficult to locate the main block diagram. It is really on Service Sheet 1, page 8-15, so please cross out the wrong title "Reference Loop" and re-label this page "Block Diagram."

COMPUTING COUNTERS—Rapid Repair Program

5360A Computing Counter

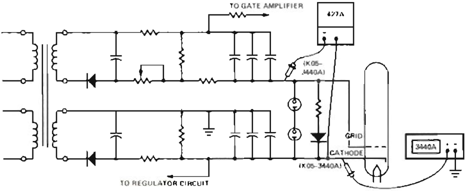
A rapid-repair procedure and a streamlined service kit are now available for troubleshooting this complex counter. The new 5360A Rapid Repair Program consists of diagnostic shortcuts and a service kit containing a complete set of circuit boards, a test adaptor, and carrying case. You can order these through your nearest HP Sales and Service Office, HP Stock No. 10636A for the service kit and HP 05360-90022 for the diagnostic procedures. There is no charge for the diagnostic procedures—check appropriate box on the back page if you want a copy sent to you.

OSCILLOSCOPE HIGH VOLTAGE MEASUREMENTS

Consideration must be given to power supply loading when making high voltage power supply measurements. Most CRT cathode supplies can supply at least 1 mA of current without being loaded to the point of non-regulation, while grid supplies can usually have only 1 μA of current drawn before significant voltage changes occur. For these reasons, a 1000:1 high voltage probe with at least 1000 megohms impedance is recommended for oscilloscope high voltage measurements.

The cathode supplies in most oscilloscopes are regulated supplies and can be measured by connecting between the cathode supply and ground. If a 1000-megohm probe is used on a 3000-volt supply, only 3 μA is drawn from the cathode supply and there is no problem in holding the supply.

Don't forget to adjust for probe accuracy error when measuring the cathode supply, as stated in most Operating and Service Manuals. Since even a 1000-megohm probe will cause loading on most CRT grid supplies, a different technique is recommended for grid supply measurements. The 1000:1 probe and an isolated voltmeter (HP 427A) should be connected between the cathode and grid supply (see figure below). The grid voltage will be the sum of the grid-to-cathode voltage.



NOTE: If you use one of the new, inexpensive digital multimeters in place of the HP 3440A shown above, check the manual to see if the DMM input resistance is of the correct magnitude for the 1000:1 probe and is constant from range to range. If in doubt, check the probe/DMM calibration using a known power supply, with the DMM set to the range you're going to use.

SOLDER FLUX REMOVAL

Our scope division at Colorado Springs, Colorado, discovered recently that the chemicals or solvents used to remove excess rosin flux from hand-soldered connections caused failures later, particularly when the instrument was operated in a high humidity environment. It was determined that leakage paths were being created from the residue combination of flux, chemicals, and solder activators.

As a result, our repair technicians at this division stopped cleaning off the flux after re-soldering connections. This cured the failures but customers kidded us about our sloppy looking work. So now this division is using a non-conductive, non-corrosive, non-chloride solder called Gardiner X400® (HP 8090-0509). This solder has its flux located externally, reducing the amount of residue to 0.5% as opposed to 3.5% average.

If you have experienced leakage problems after re-soldering with a high-residue solder, this solder is recommended for clean and neat re-soldering jobs. This solder is intended for gold-plated PC boards; for tin-nickel boards, a fully activated solder such as Kester 44® is recommended. (If any of you have found better solutions to this problem, we'll publish your ideas if you'll forward them to us, c/o *BENCH BRIEFS.*)

OSCILLOSCOPES— 180 Series

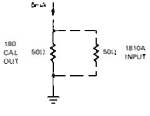
1810A 1 GHz Plug-in

Setting Vertical Gain

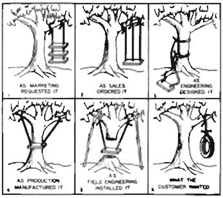
CAUTION: Maximum input to 1810A is 5 Volts! When using the 250 mV CALIBRATOR output of a 180-series mainframe to calibrate the vertical sensitivity of the 1810A, you will get exactly one-half of the available voltage to the 1810A.

There is a logical reason for this; the output resistance of the 250 mV CALIBRATOR on the 180 is 50 ohms to ground. When the 50-ohm input of the 1810A is connected across this there is an effective resistance of 25 ohms. Since the current from the 180 CALIBRATOR is now divided in half, the voltage available to the 1810A is 125 mV instead of 250 mV.

The result of this is 6.25 divisions on the screen at 20 mV/div. To avoid calibrating the 1810A to an odd number of divisions an alternate method is available. A 200:1 divider (HP 01802-63201) is available which, when connected to the 10V output, will give you 5 divisions on the 10 mV/div range of the 1810A.



The following cartoon may or may not be new to you. We like it because it pokes a finger at everyone except us, that is, service.



COULD YOUR INSTRUMENTS USE A SCRUBBING?

by Margaret Nagao, technician assistant at the HP Customer Service Center in Mountain View, California.

The HP Customer Service Center has found that dirt is a major factor in instrument failures. Would you believe this dirt can often be removed by washing the instrument with soap and water? Of course, common sense must be used to keep water out of motors, transformers, and other components where water can get trapped. Basically the instruments undergo a 4-step process as follows:

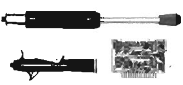
1. Remove surface dirt with a long-bristled brush.
2. Spray inside and out with mixture of detergent and water.
3. Rinse thoroughly with water only.
4. Blow away excess water with air hose.
5. Bake in oven to remove all moisture.

Use the following procedure to wash an instrument that you are certain cannot be damaged with soap and water. If you are not sure, contact your nearest HP Sales and Service office for advice. Always bear in mind that nothing should be washed that cannot stand water and heat. Also remember that high impedance areas (10 megohms and above) should be cleaned with pressurized Freon rather than soap and water.

1. Remove instrument covers and blow loose dirt away with air hose and paint brush.
2. Wash the instrument with a detergent/water mixture using a compressed-air siphoning spray nozzle. AVOID SPRAYING MOTORS, TRANSFORMERS, AND AREAS WHERE WATER CAN GET TRAPPED. A detergent we have found to be effective is KELITE *Spray White.*®
3. Rinse away all traces of detergent with water, preferably lukewarm. A pistol-type spray nozzle works well.
4. Drain excess water from instrument; an air gun complements this process.
5. Bake out all traces of moisture by placing instrument in circulating-type oven at 60° to 68° C (140° F max). Leave in from 8 to 24 hours, depending on component density.
6. Re-lubricate all mechanical assemblies. Replace covers.

NEW DESOLDERING TOOL

The manufacturer of the familiar and popular "Solda pullt" (HP P/N 8690-0060) has developed a smaller version called the "Solda vac."



This all-plastic device is available under HP P/N 8690-0143 for $4.50. Replacement tips are HP P/N 8690-0126, priced at $2.50 each.

The "Solda pullt," which is priced at $24, is shown in the top of the photo. The new "Solda vac" is the lower item.

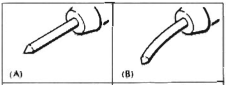
TIP TIP

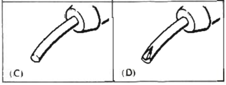
Mr. G. Scott Lindsay of Port Perry, Ontario sends us the following tip on soldering iron tips:

"After battling for years trying to remove components from printed circuit boards with the regular pointed miniature soldering iron tips, I found the following trick:

First, bend the regular pointed conical tip from shape (A) to shape (B) as shown at right. Then, file off the conical point to get shape (C). Finally, cut a V-groove with a sharp triangular file into the nose of the bent tip to get shape (D). Now, you can get excellent heat transfer to the leads on resistors and capacitors by merely placing the V-groove around their leads where they pass through printed circuit boards.

Better heat transfer means you can get components out (and put them back, too) much faster than with the regular tips. You'll also reduce the risk of burning up the board."





We appreciate this "tip tip" from Mr. Lindsay—sometimes the easiest modifications save the most time—let us know yours and we'll publish them with your name in BENCH BRIEFS, c/o Hewlett-Packard Co., 1501 Page Mill Road, Palo Alto, California 94304.

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