**Heathkit of the Month #76:**
***by Bob Eckweiler, AF6C***

Figure 1: Restyled Heathkit IT-3120
FET / Transistor Tester

**ELECTRONIC TEST EQUIPMENT**

**Heathkit IT-121**
**FET/TRANSISTOR TESTER (Part II)**

**Introduction:**
Last month we looked at the family of Heathkit transistor testers sold over a 28 year period from 1961 through 1989. Our focus fell on the IT-121 model and its restyled replacement, the IT-3120 (Figure 1). We will continue our focus on these two models, which are identical except for paint, knobs and other parts superfluous to the tester's function.

**IT-121 Assembly:**
Assembly of the IT-121 is quite straightforward. In the 1973 Christmas catalog assembly is considered a "two-evening project" (Figure 2). A circuit board holds all of the leaded components except for one disc capacitor, and a resistor that is used for calibration. The heart of the kit is three multiple pushbutton switch assemblies named **RANGE**, **FUNCTION** and **MODE**. These switches have, for each contact, pins for insertion into a circuit board on the bottom, and small lugs for soldering a wire to on the top. The FUNCTION and MODE switches mount to the circuit board as does a trim pot; the single adjustment required for calibration.

**Circuit Board:**
Circuit board assembly consists of installing six jumpers on the single-sided board, then installing one diode, one capacitor, the trim pot, and eleven resistors. Next, eight color-coded wires are prepared and one end of each is connected to the board, with their other ends to be connected later. Finally the FUNCTION and MODE switch assemblies are soldered to the board and the board assembly is set aside momentarily.

**Subpanel:**
A subpanel holds the front panel controls, the RANGE switch assembly and the circuit board. It is assembled and wired next.

No wiring harness is supplied with this kit. Instead five wire clamps are included. These clamps mount on the subpanel and the interconnecting wires are routed through them to keep everything neat and in order.

Once the clamps are carefully installed, the circuit board assembly is mounted to the subpanel using the holes in the switch flanges and #2 hardware. Then the RANGE switch assembly is mounted to the subpanel, followed by the two front panel potentiometer controls (**SET BETA/Gm=0** and **BETA CAL**).

Over the next four assembly pages thirty-eight lengths of wire are prepared and used to wire between the assemblies mounted on the subpanel. Heathkit provided eighteen different varieties of wire to assemble the kit. Four lengths

[1] **Notes from last month are repeated on page 7**


**Figure 2: Heathkit IT-121 from the 1973 Christmas Catalog #800/78**

of stranded wire of different colors and fourteen lengths of solid wire of different colors.

**Front Panel:**
The front panel is really the main chassis for the kit. It has four outside surfaces, a vertical surface that holds the handle, the sloping "front" panel, a top panel that holds the two transistor sockets and four banana jacks for the test leads, and the "rear" panel where the internal battery holders mount.

The two transistor sockets need to be assembled prior to installation. The socket pins come separate from the plastic socket shell, and the pins are inserted and locked in place with a twist (See figure 3). You end up with one 5-pin and one 4-pin socket. In later years Heathkit seemed to often supply components that normally come assembled in pieces, like these sockets.

The transistor sockets, the four banana jacks, the handle and two D-cell battery holders are then mount to the front panel, and the mounted parts are partially wired.

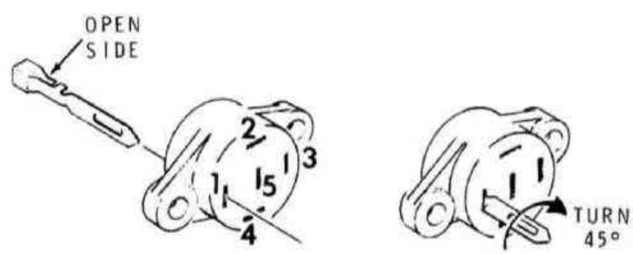


**Figure 3: Transistor/FET Socket Ass'y**

Next the meter is mounted using just one of the four meter mounting studs. The subpanel is then mounted to the front panel. The mounting hardware for the two front panel controls are removed and the subpanel assembly is mated to the front panel and held in place with the hardware for the two controls and the three remaining meter studs using spacers. The final wiring to mate the two assemblies is then completed.

**Final Assembly:**
The four lengths of stranded wire are used to make the four color-coded test leads, the knob inserts are installed in the knobs prior to installing on the controls; 2 "D" cell batteries

(user supplied) are installed and finally the builder is instructed to fasten the Blue and White Label with model and series number to the inside panel. A memorable moment for the serial Heathkit builder!

**IT-121 Circuit Description:**
If you look at the overall schematic[12] of the IT-121 (available online - see notes at end) you will see it is made up mostly of switches. The switching is complex yet mundane, using seven DPDT switches, five 4PDT switches and three 6PDT switches plus a SPST switch on the BETA CAL potentiometer. Thus we'll use abbreviated functioning schematics for each operation.

The IT-121 can be broken down into three major sections: The meter section, the bipolar transistor measurement section and the FET measurement section. Each section may be broken down further.

**Meter Section:**
The IT-121 uses a large 100µA meter with an approximate internal resistance of 1,100 ohms. A diode is located across the meter to protect the meter from excessive voltage. A 750Ω trim pot is wired in series with the meter. During calibration this trimmer is adjusted so that the total meter and trimmer series resistance is accurately 1,500 ohms, effectively making the meter a 100µA 1,500 Ω precision meter.

When testing a transistor the meter is placed in the collector circuit or the base circuit depending upon the function switch selected. To prevent upsetting the circuit when the meter is switched, it is swapped with a precision 1,500 ohm resistor.

| RANGE SW | R Shunt Collector Ckt | R Shunt Base Ckt |
|---|---|---|
| 100 µA | (open) | (n/a) |
| 1 mA | 166 Ω | open |
| 10 mA | 15 Ω | 166 Ω |
| 100 mA | 1.5 Ω | 15 Ω |
| 1 A | 0.15 Ω | 1.5 Ω |

TABLE I: METER SHUNT RESISTORS

The RANGE switch places a shunt across the 1,500 ohm meter resistance (Table I) allowing the meter full-scale reading to be changed.

Notice that when in the collector circuit the meter responds full-scale to the current given in the lefthand column, and when in the base circuit the meter is ten-times more sensitive than the current given in the left hand current. As an example, when the range switch is set to 10 mA the meter will read full-scale at 10 mA when in the collector circuit and 1 mA when in the grid circuit.

The tester operates in both polarities so it can test NPN and PNP transistors and N-Channel and P-Channel FETs. A switch is provided that reverses polarity of the batteries and the meter depending upon polarity being measured. Our discussion will only cover positive polarity.

The meter is also used to test the two 1.5 volt batteries. Figure 4 shows the simplified circuit, which is straight forward. The meter, with its protection diode and calibration pot, has a total resistance of 1,500 ohms. The diode doesn't conduct so it is effectively open. The series 10KΩ resistor causes the meter to read full-scale with a battery voltage of 1.15 volts. Meanwhile the precision 1.5 Ω 2 watt resistor shunting the battery places a load of around 1 am-

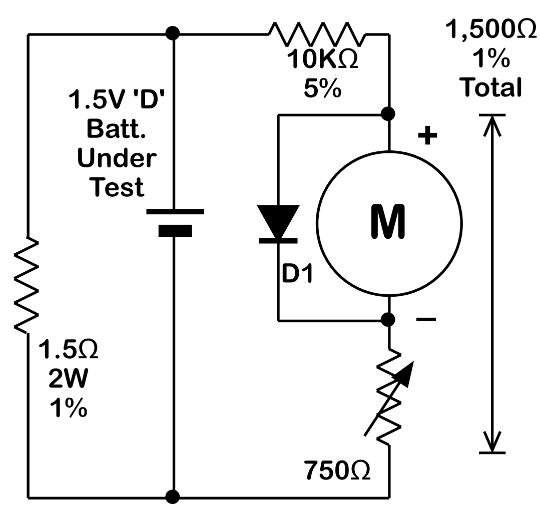


Figure 4: Battery Test Circuit

pere on a fresh battery. The low end of the **BAT. OK** scale on the meter corresponds with 82 µA so a battery that measures 0.94 volts under load will be right at the good - bad mark. The battery test draws heavy current and will drain the batteries if used excessively.

**Bipolar Transistor Measurement**:

The transistor collector load must be compensated for prior to measuring a transistor for beta. This is not a problem with the transistor out of the circuit, but incidental resistance in the collector circuit will affect the reading. To correct this the "Beta Equals Infinity" (**ß = ∞**) calibration is made. This circuit is shown in Figure 5. It is a simple bridge circuit that allows one to adjust R11 to the resistance of R8 in parallel with the external unknown Rx. When the current from B2, flowing through the meter (with shunt Rsh) and R8 in parallel with Rx is equal to the current flowing from B1, through the meter (in the reverse direction) and through R11, the meter reads zero (ß=∞ on the meter), and R11 is equal to the resistance of R8 in parallel with Rx. This is true with the meter switch in any of the range positions that you select for the transistor under test (discussed in Part I).

After ß=∞ is set, the beta calibration is set. Bias current is added to the base of the transistor, - the device under test (DUT), (Figure 6). The current is supplied from B2 through R10, a precision 1,500 ohm resistor in parallel with the selected base shunt resistor (See table I) and the 250KΩ **Beta Cal** potentiometer control. The current through the base of the tran-

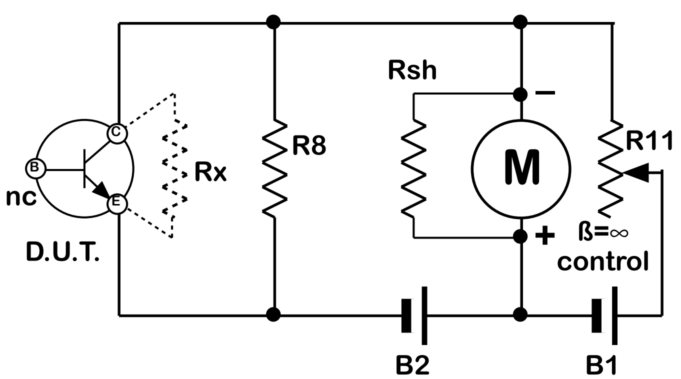


Figure 5: ß = ∞ Circuit

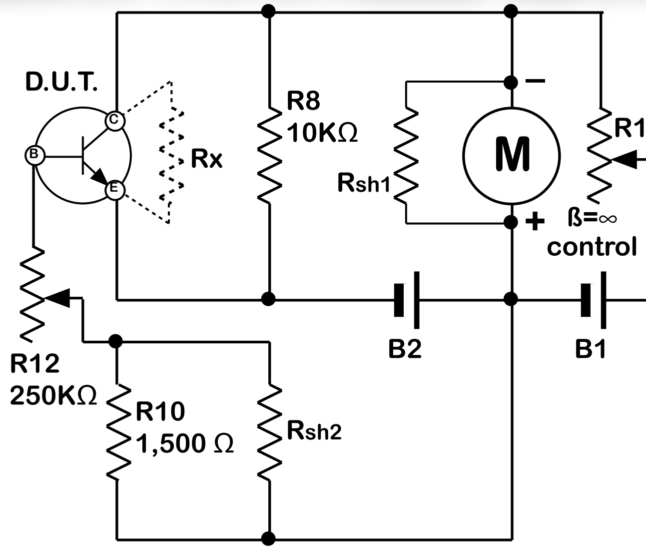


Figure 6: Beta Cal. Circuit

sistor causes current to flow between the collector and the emitter. The Beta Cal potentiometer sets the collector current read on the meter. It may be set under one of three marks on the Beta scale - either X10 (at 10% of full scale,) X5 at 50% of full scale) or X1 (at 100% of meter scale).

To measure Beta, the FUNCTION switch is then placed in the BETA position. In this position the 1,500 Ω precision resistor and the meter with 1,500 ohms resistance are swapped (Figure 7). Since the resistances haven't changed there is no change in the circuit, and

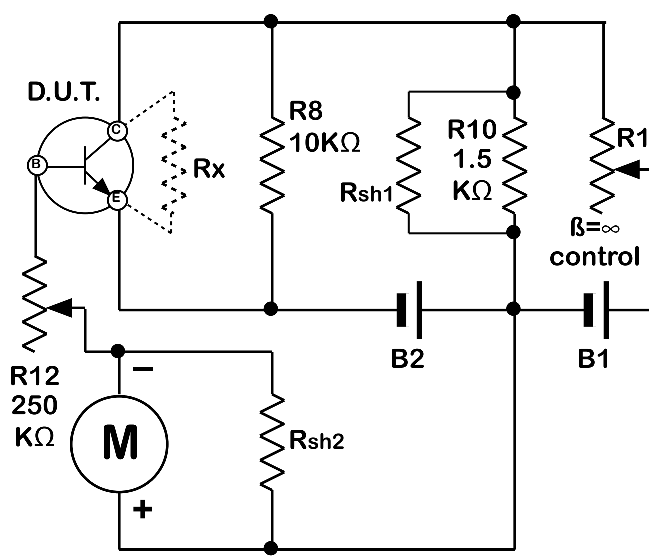


Figure 7: Beta Measurement Circuit

the collector current remains as set. With the meter now in the base circuit, the meter shunt has changed from Rsh1 to Rsh2 making the meter 10 times more sensitive and the meter now reads the transistor's Beta on the Beta scale. The reading must be multiplied by the Beta Cal setting selected by the meter marking used in the previous step.

What is happening is that when you calibrate you adjust R12 - BETA CAL. which causes the transistor to draw collector current. Say the RANGE switch is in the 10 mA position. As you adjust the BETA CAL. pot the meter will move. If you stop at the **CAL X1** mark the collector current is 1 mA, if you stop at **CAL X5** the collector current is 5 mA and if you stop at **CAL X10** the collector current is 10 mA.

Once calibrated, the BETA switch is pressed. This moves the meter into the base circuit and increases its sensitivity by a factor of ten. Beta is read on the meter scale. Let's say the meter reads a beta of 5. This corresponds to a base current of 200 µA with the range switch set to 10 mA. Depending upon which **CAL** mark you used, this represents a beta of 5, 25 or 50. If you used the **CAL X10** mark the collector current is 10 mA and the base current is 0.2 mA and:

$$\beta_{DC} = \frac{I_c}{I_b} = \frac{10}{0.2} = 50$$

**Transistor Leakage Measurements:**

It should be obvious that leakage measurements must be done out-of-circuit, as any circuit resistance would otherwise be taken as leakage. The IT-121 measures the three common transistor leakage parameters, Icbo, Ices and Iceo, As discussed last month, Icbo is the leakage current between the collector and base with the emitter open, Ices is the leakage current between the collector and emitter with the base connected to the emitter, and Iceo is the leakage current between the collector and the emitter with the base open. The circuits for measuring these three parameters are shown in Figure 8. Rsh is the meter shunt set by the Range switch. The leakage current is read on the 0 - 100 leakage scale with the range switch setting the full-scale value. These measurements are generally very small for silicon transistors, but can be significant for germanium transistors. Values for germanium devices that seem excessive should be checked with the device's data sheet. The leakage will also change with temperature.

**Field Effect Transistor (FET) Measurement:**

The IT-121, unlike the previous Transistor Testers, can also test FETs. It performs a test to measure the transconductance Gm0. This is the value of the transconductance with the gate and source at the same potential. Transconductance is the reciprocal of resistance (1/R) and is

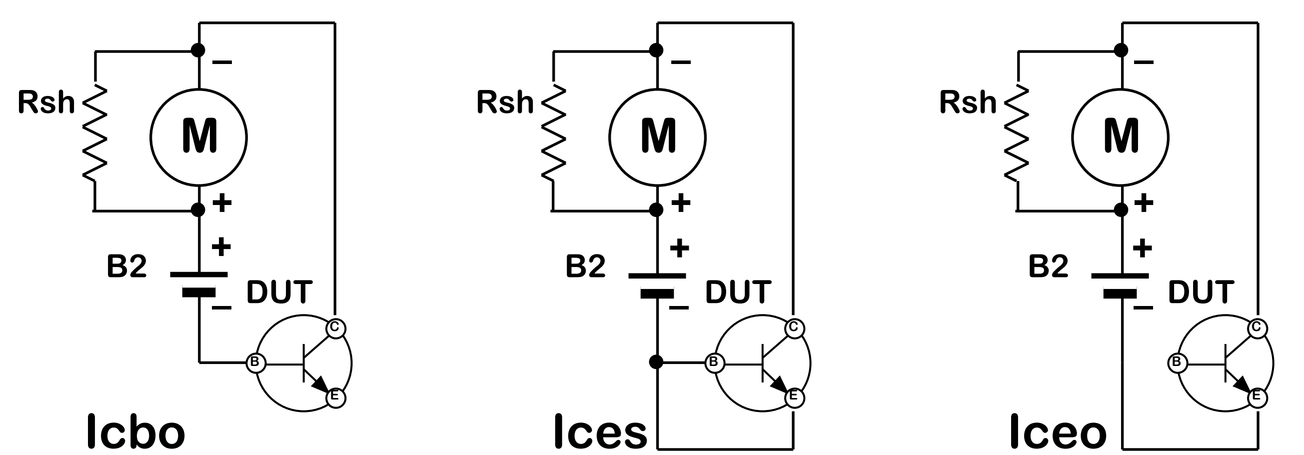


**Figure 8: Simplified Circuits for Measuring Icbo, Ices and Iceo**

measured in µmhos (µ℧). In more modern terms the µmho has been changed to the micro-siemens (µS). Since transconductance is related to resistance, it can be measured by a ohmmeter-like circuit. If you've ever used a VTVM you remember setting the meter to full-scale with the leads open prior to making your measurement. The **Gm=0** FET FUNCTION does exactly that. With the **SET Gm=0** control, the meter is set to full-scale. This basic circuit is shown in figure 9.

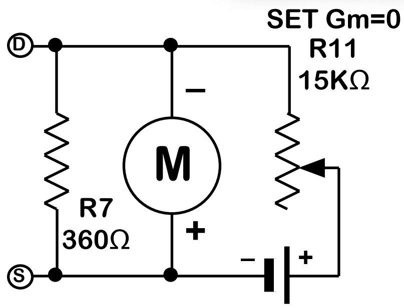


**Fig. 9: SET Gm=0 Circuit**

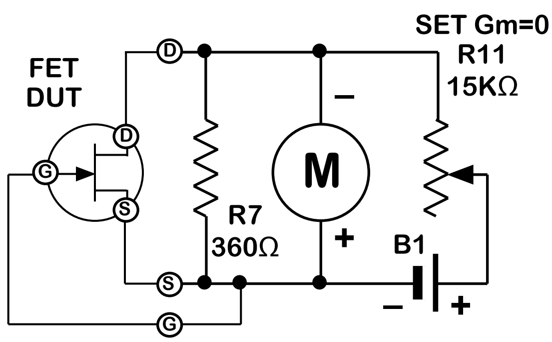


**Figure 10: Gm0 Measurement Circuit**

Once set, the FUNCTION is changed to **Gm** which connects the FET as shown in figure 10 with the gate and source shorted. The lower the effective resistance of the drain to source channel, the lower the meter reads, indicating a higher transconductance.

## GATE 1 and GATE 2 TESTING:

To be sure the FET is working properly another test is performed. It is rather a simple test. Pressing the **GATE 1 MODE** switch applies a negative voltage on the gate of the FET under test (Figure 11). This should result in a decrease in the value of Gm (Meter moving towards full-scale).

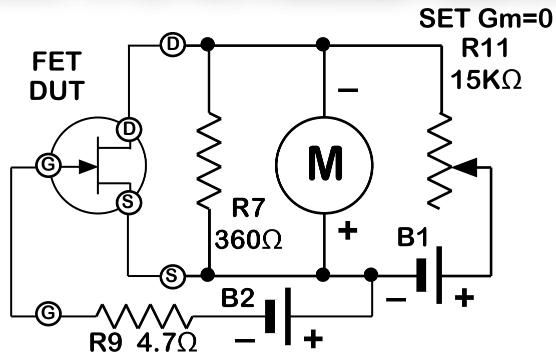


**Figure 11: Gate Testing Circuit**

Some FETs have dual gates and you can test the second gate in the same manner using the **GATE 2 MODE** switch. R9 protects the IT-121 in case the FET gate is shorted.

## FET Leakage Test - Igss:

Igss checks the leakage between the gate and the drain - source channel when the junction is reverse biased. The circuit is shown in Figure 12a. Not shown in the schematic is a small resistor for protection in case the junction is shorted. This is a real leakage test and no leakage should be noticeable. If needed, all the RANGE meter shunts function.

## FET Leakage Test - Idss:

Idss is not a leakage test even though the IT-121 manual treats it as such. Idss is the current that passes from the drain to the source at

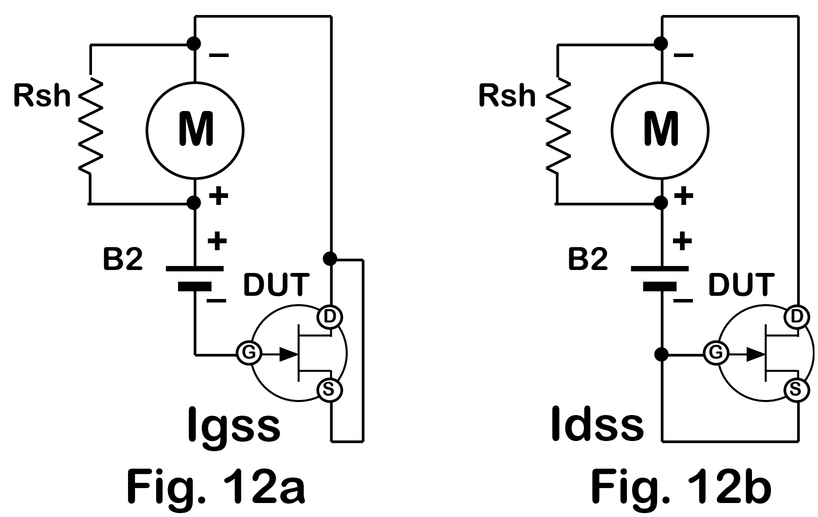


**Figure 12: Igss and Idss Circuits**

a given drain to source voltage with the gate connected to the source. In a JFET (Junction FET) this is the maximum current the channel can carry since it is dependent on gate voltage and the gate voltage must be zero or negative with respect to the source to keep the gate - source junction reverse biased. The circuit is shown in figure 12b. Since the current can be significant, it is best to start with the shunt set to one of the higher current ranges.

**Diode Testing:**
Signal and rectifier diodes are tested using the Iceo leakage circuit (Figure 8c). The diode is connected with the anode to the emitter jack and the cathode to the collector jack. Leakage current is read on the meter. To measure forward conductance set the RANGE to a measure current and press set the mode to PNP to forward bias the diode.

**General Comments:**
An IT-121 was obtained at a sale a few years ago. Upon opening the unit up, it was obvious that at sometime in its life the two 'D' batteries had leaked. Damage was confined to the aluminum battery holders. Replacements that fit the existing mounting holes were purchased and installed. The first thing that was noted was that those ganged pushbutton switches were dirty and acting intermittent. Use seemed to ease the problem, but after not being used for a few months the problem is right back. A way to clean the switch banks needs to be found. Also the soldering has not yet been examined closely (alas, too many projects). The IT-121 was used to mach two complementary transistors used in a project here. It did a good job and the transistors balance well in the circuit.

***73, from AF6C***

**LAST MONTH's NOTES ARE REPUBLISHED FOR REFERENCE:**

Notes:

1. **Iceo** is the current that flows between the collector and emitter with the base is open.
2. **Icbo** is the current that flows between the collector and base with the emitter is open.
3. **DC Beta** ($\beta$) is the ratio of the collector current to an applied base current. It is the DC current gain.
3. **DC Alpha** ($\alpha$) is the collector current divided by the emitter current. It is always less than one and is related to the DC beta by $\alpha = \beta/(\beta+1)$.
5. **Ices** is the current that flows between the collector and emitter with the base is shorted to the emitter.
6. **Gm** (transconductance )is a measurement of how a change in FET gate voltage affects drain current. It is usually expressed in µmhos.
7. **Igss** is the FET current that flows between the gate and the source with the source shorted to the drain.
8. **Idss** is the FET current that flows between the drain and the source with the gate shorted to the source.
9. **Ieb$_2$s** is the leakage current between the emitter and base 2 with base 1 shorted to base 2. of a UJT.
10. **Ib$_2$b$_1$s** is the forward current through base 2 and base 1 with the emitter shorted to base 1 of a UJT.
11. **Ib$_2$es** is the emitter current that flows between base 2 and the emitter with base 1 shorted to the emitter of a UJT
12. A schematic of the IT-3120 (IT-121)may be found at: http://www.w6ze.org/Heathkit/Sch/IT3120_Sch.jpg

*Remember if you come across any old Heathkit Manuals or Catalogs that you do not need, please pass them along to for my research.*

*Thanks - AF6C*

*This article originally appeared in the July 2017 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.*