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# Build This IP3 Test Set

*A receiver's third order input intercept point is more than just a mouthful.*

*Receivers for shortwave and amateur use need to be able to hear weak signals without creating distortion from adjacent strong ones. In a poorly designed receiver, distortion can completely override and mask out a desired but weak station. One number in a receiver's spec sheet that tells you just how good it is in preventing distortion is the third order input intercept point — IP3. But what does that mean? And how is it measured?*

Any circuit handling more than one signal will create some distortion. If two steady radio frequency signals at, say, 14,060 kHz and 14,080 kHz, enter the antenna terminals of a receiver, then by tuning the receiver we can separate and identify these two signals at two points on the tuning dial. However, due to nonlinearities within the receiver's circuits, there will also be weaker signals found at 14,040 kHz and 14,100 kHz. Where did these come from? The two weaker signals are called third order distortion products. If you are trying to listen to a weak station at 14,040 kHz, you might not be able to hear it because the distortion product generated in the receiver itself could be stronger than the station you are trying to hear. No amount of tuning or IF filtering can separate the distortion product from the desired signal. It sits right on top of what you want to hear.

***Photo A.** Measuring intercept performance of a receiver.*

Nonlinearities in the receiver's RF amplifier and mixer circuits create harmonics. The second harmonic of 14,060 mixes with 14,080 to produce 14,040 kHz. Likewise, the second harmonic of 14,080 mixes with 14,060 to produce 14,100. The mixing can occur in the receiver's mixer circuit or even in the RF amplifier. Remember, nonlinear devices make good mixers.

### Understanding IP3

The top line in the graph of **Fig. 1** shows the output versus input level of a mixer circuit. Mixers have two inputs. In this case, the input on the graph is the signal input. The oscillator

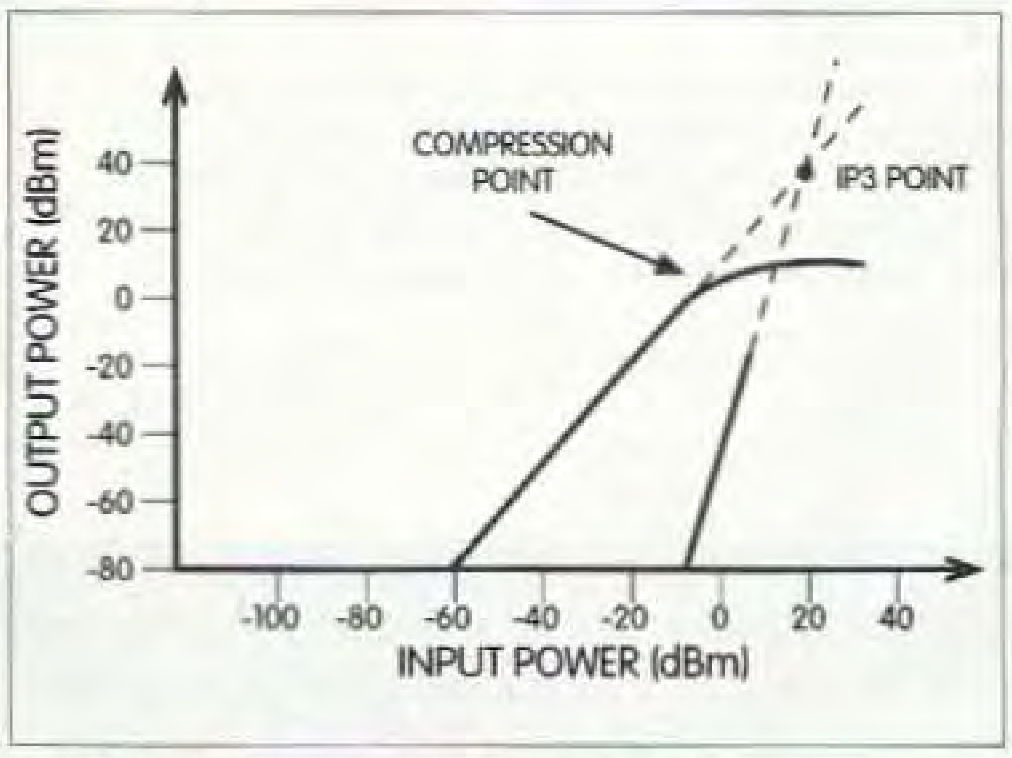

***Fig. 1.** Intermodulation graph.*

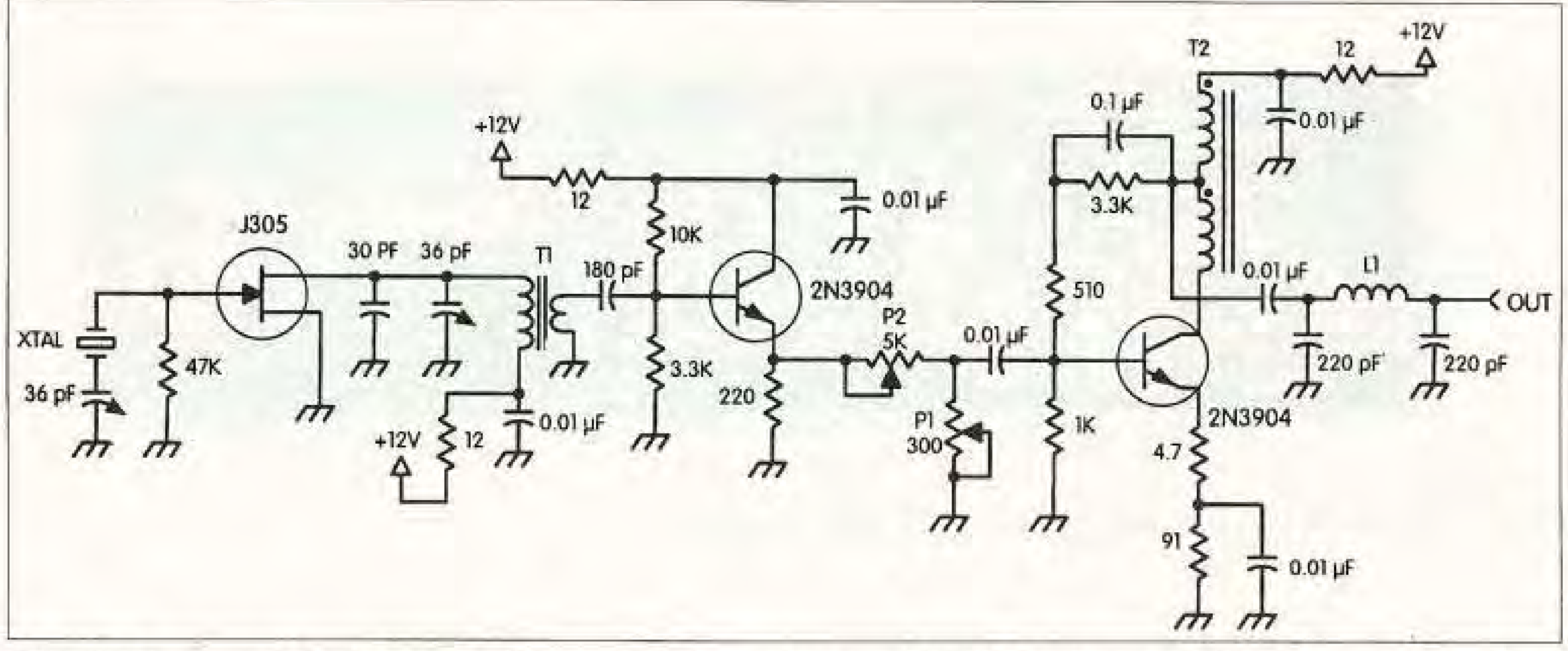


*Fig. 2. Generator schematic diagram. T1 = primary 21T #22 wire on T50-C core; secondary 3T #22. T2 = 7 bifilar turns #26 wire on FT 23-43 core. L1 = 12T #22 wire on T37-6 core.*

input is held at a constant level. Both scales are measured in units of dBm or power in dB above one milliwatt. We see that the mixer has a gain of 10 dB and can handle signals up to about 10 dBm (10 milliwatts) at the input and then flatten out. The line has been artificially extended to higher levels with dots, but note that the mixer does not operate at the dotted points.

Suppose two equal strength signals are fed into the mixer. Each one has the level shown on the horizontal scale. Then there will be two outputs, each one having a level equal to the vertical scale as read using the top line of **Fig. 1**. In addition, there will be the two weaker IP3 distortion product signals. The level of each IP3 signal at the mixer output is shown by the lower line in **Fig. 1**. You immediately notice that the slope of the lower line is three times that of the upper line. This is the way distortion products usually work. Again the lower line has been artificially extended by a dotted line.

The point at which these two dotted lines cross is called the IP3 point. The corresponding level on the horizontal axis is called the input IP3 level and the corresponding vertical axis level is called the output IP3 level. When a spec sheet does not specifically indicate which, it is usually referring to the input IP3 level.

When comparing two mixer circuits, the higher the input IP3, the lower the distortion products will be. A good mixer has a high input IP3 point. Keep in mind, however, that the mixer is not capable of operating at the IP3 point. It's just a way of comparing two mixers. The mixer can only reasonably handle signals up to the point at which the output flattens out, called the compression point.

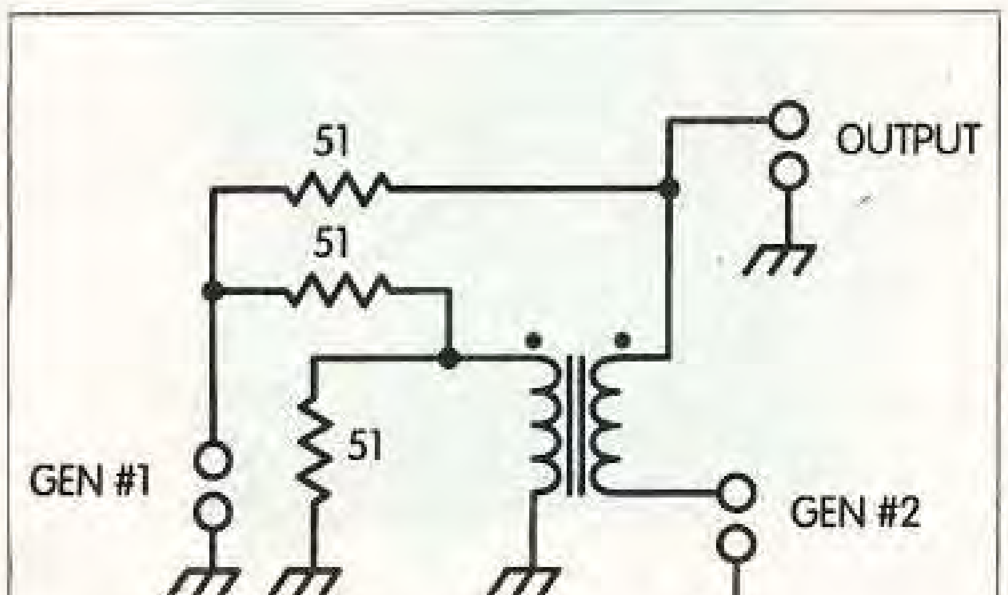


*Fig. 3. Hybrid combiner schematic.*

### How is IP3 measured?

In order to measure the IP3 point of a circuit, you need to inject two fairly strong independent signals into the circuit. They need to be strong enough to create measurable distortion products.

The signals also need to be combined without creating distortion before they get to the circuit under test. One good circuit for producing a signal is shown in **Fig. 2**. A circuit board pattern is shown in **Fig. 4**. Component locations are shown in **Fig. 5** and **Photo B**. A crystal oscillator with a high-Q tank circuit, and low loading on the crystal, generates a clean signal with low phase noise. Inductor L1 has a Q of over 250. See the *Radio Components Handbook* for more information on constructing high-Q inductors. A JFET transistor, J305, is used in the circuit. An MPF102 would be an acceptable substitute.

An emitter follower using a 2N3904 NPN transistor isolates the oscillator

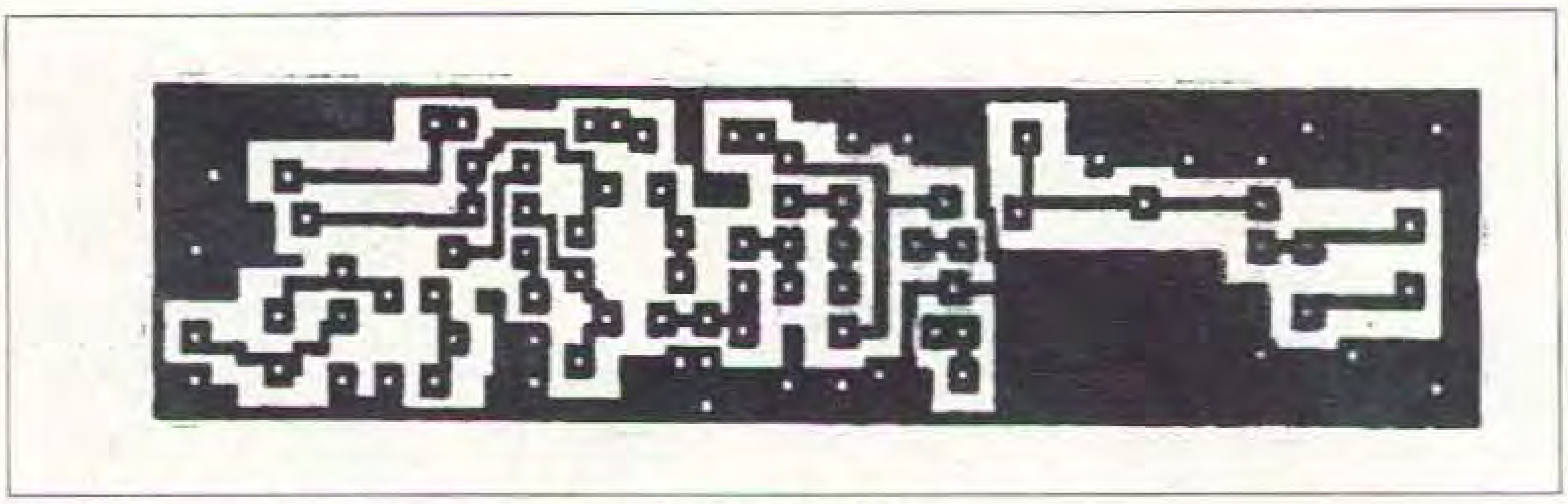

*Fig. 4. Printed circuit pattern for generator (100%).*



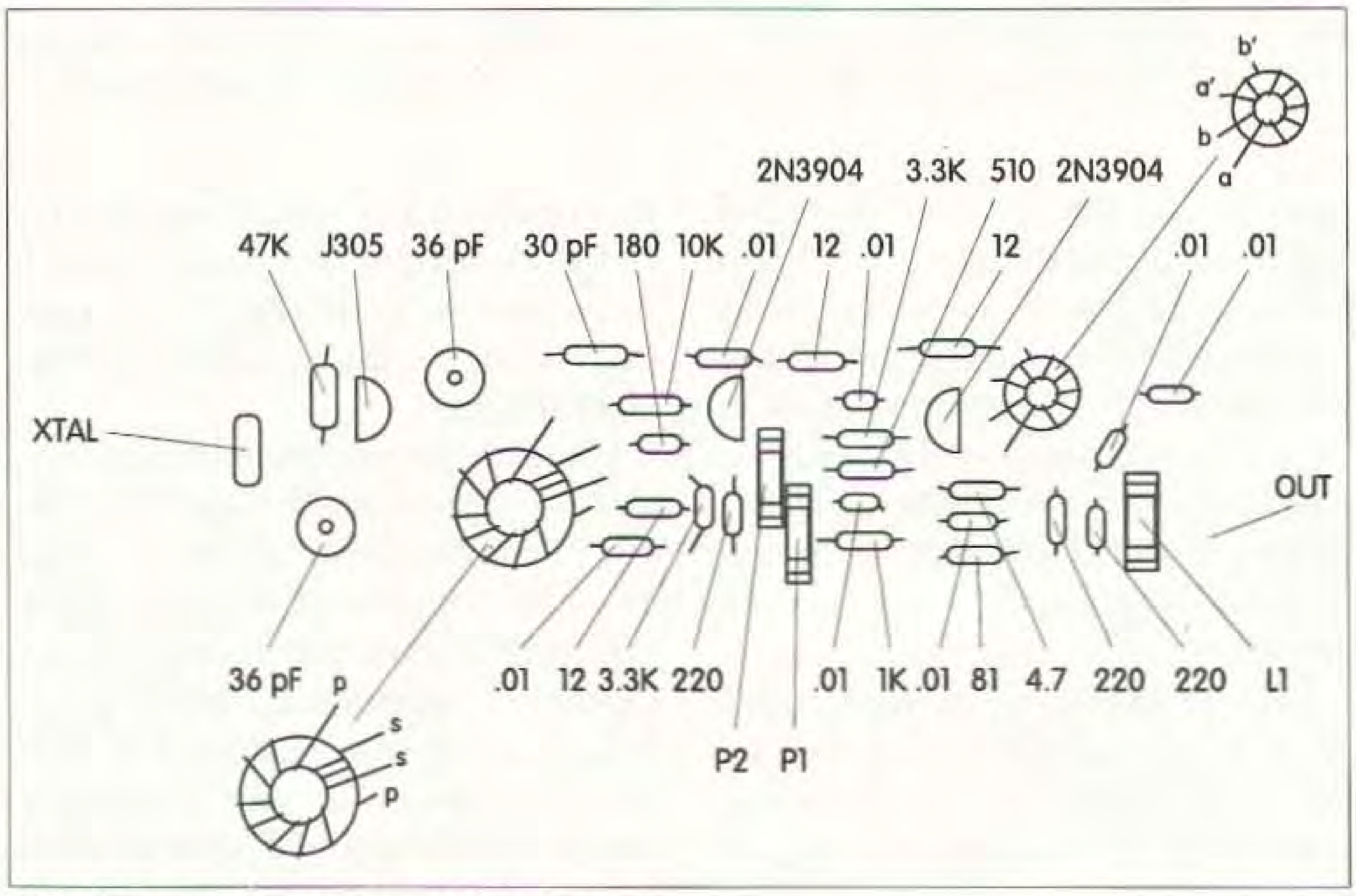


*Fig. 5. Generator component locations.*

circuit from any load variations that might modulate the oscillator and cause distortion.

A final power amplifier circuit is configured using trimpots P1 and P2 to provide an exact 50 ohm output at a level of 6 dBm.

**Set for 50 ohm output**

Negative feedback in the power amplifier circuit provided by the 510 ohm resistor means that the output impedance is dependent on the input impedance. Trimpot P1 is adjusted first for a 50 ohm output. A higher value of P1 produces a lower output impedance. I used the setup shown in **Photo D**. An MFJ-259 SWR analyzer

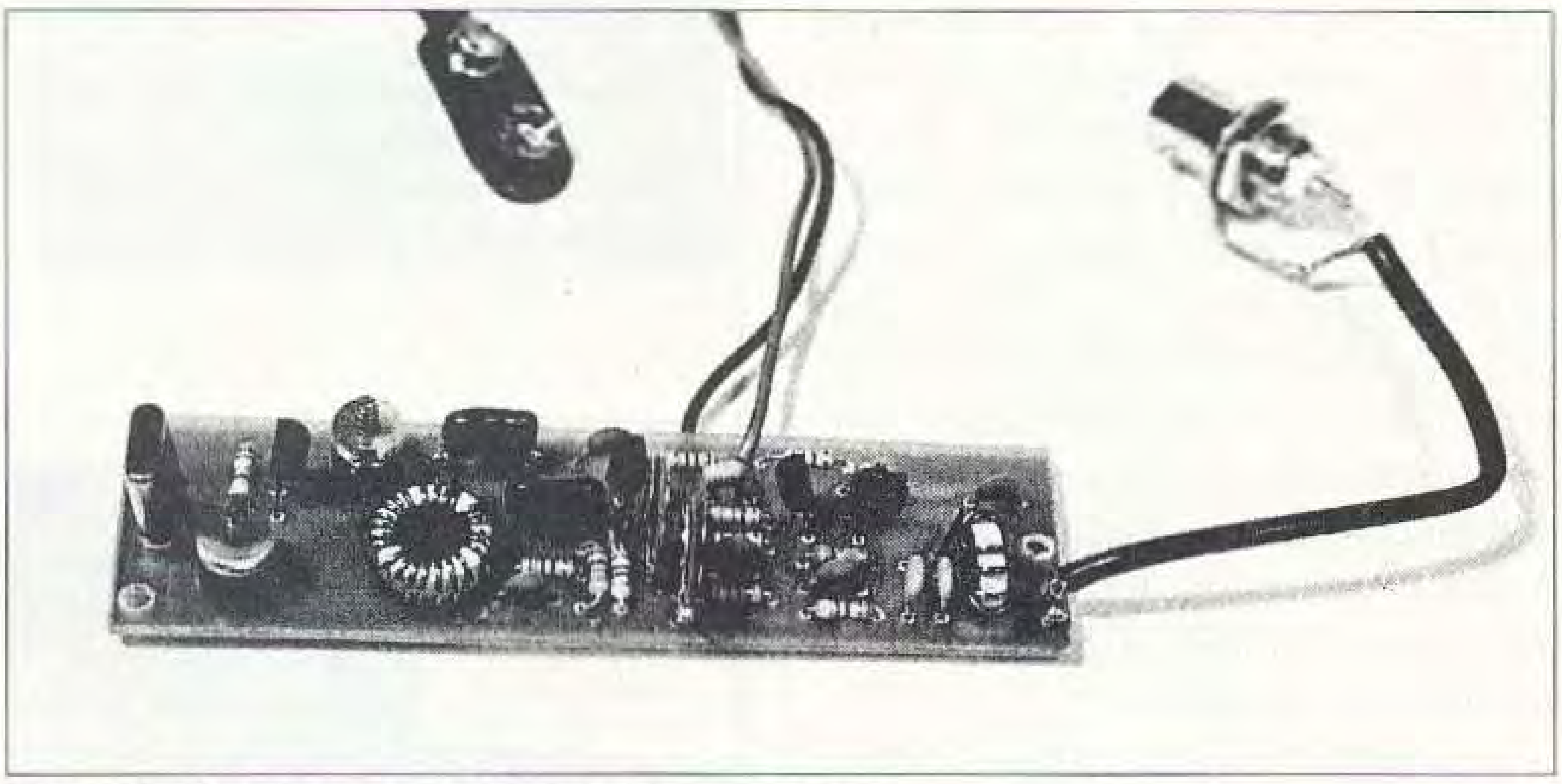

***Photo B.** Signal generator board with components.*

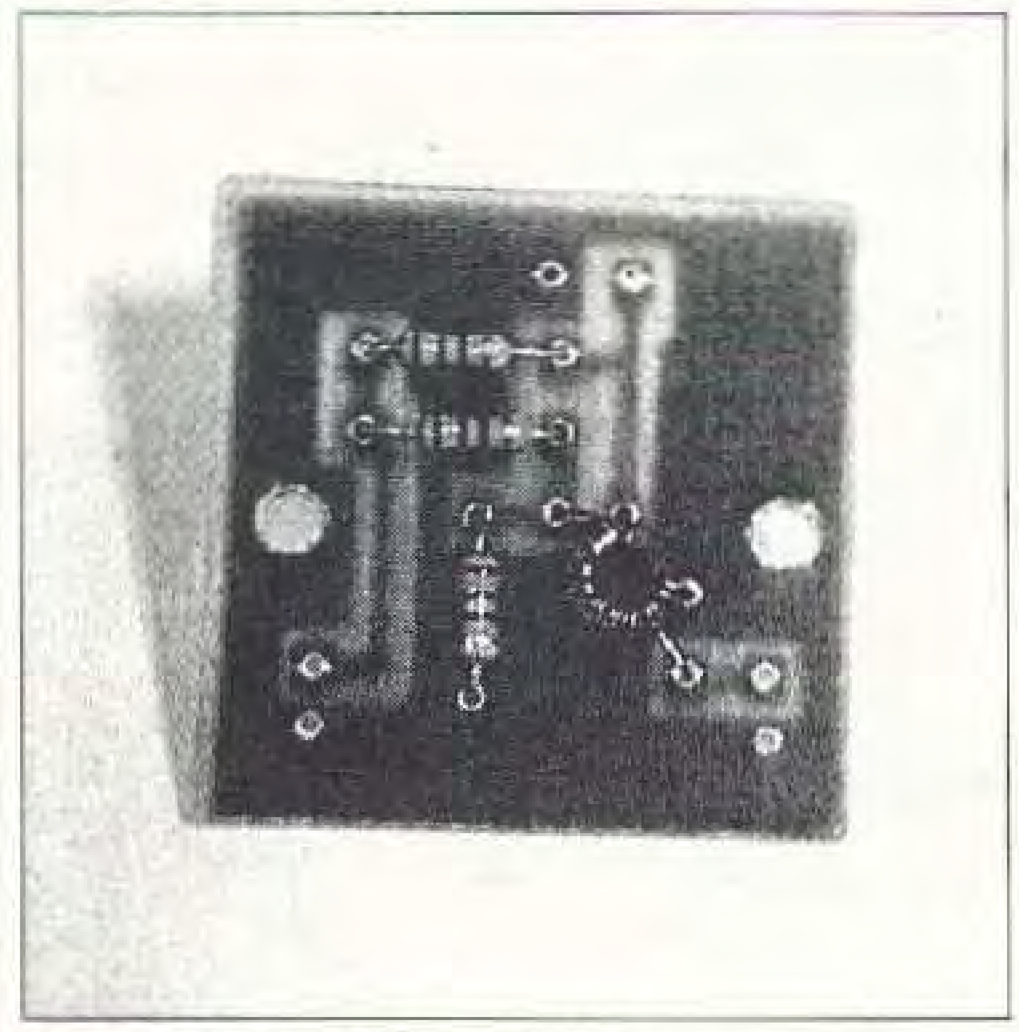

***Photo C.** Hybrid combiner.*

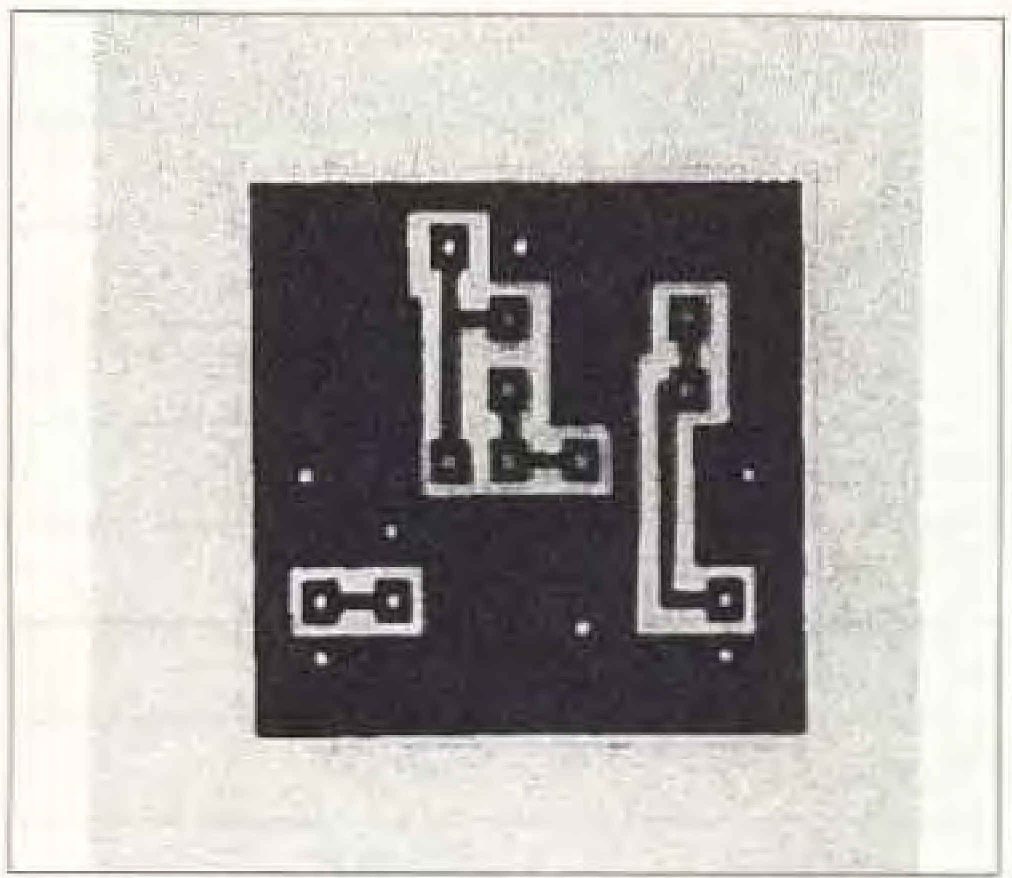

*Fig. 6. Printed circuit pattern for hybrid combiner (100%).*

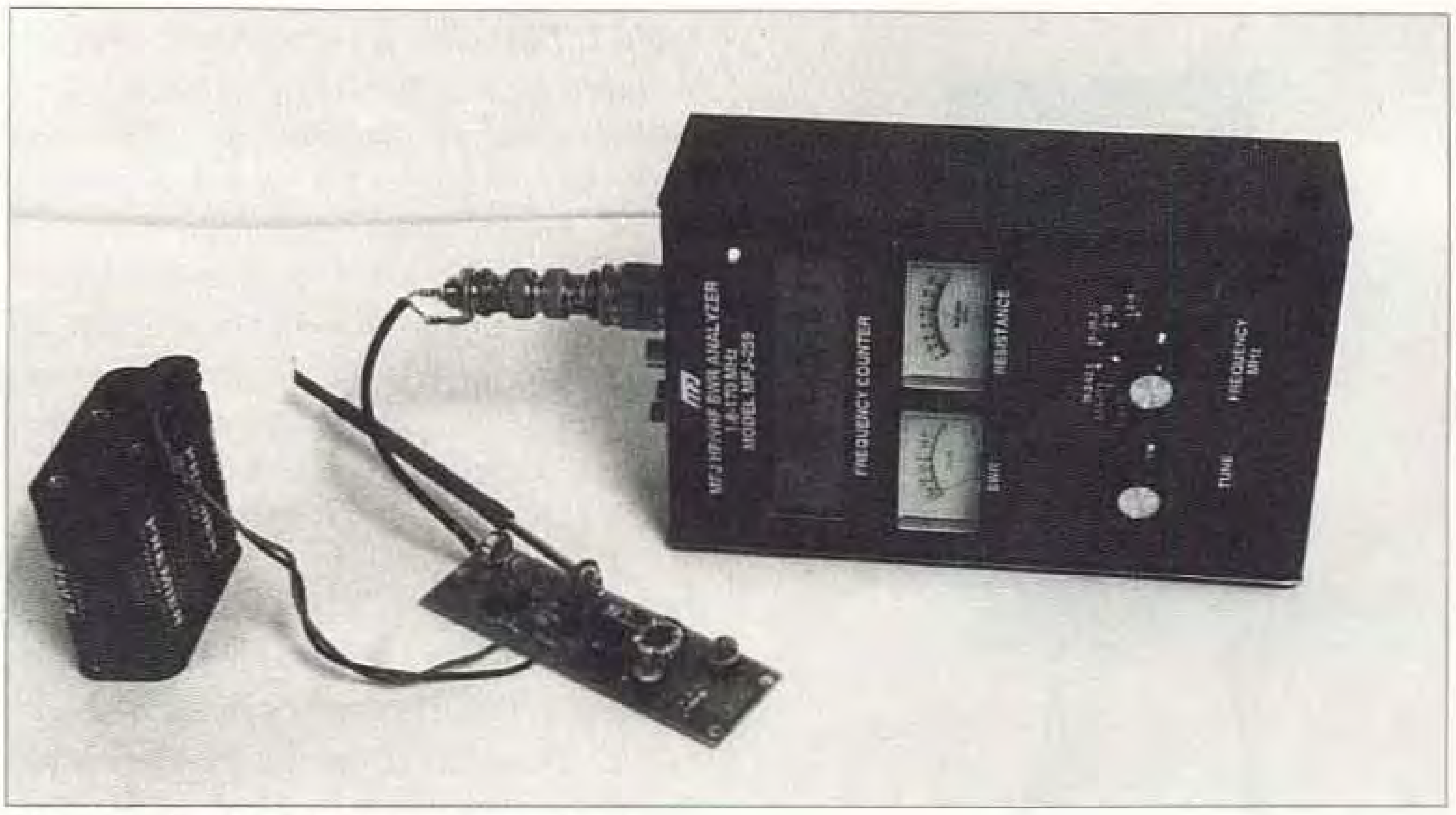

*Photo D. Setting the output impedance.*

set for 14,070 kHz measures the output impedance. Supply voltage must be applied to the power amplifier and emitter follower, but the crystal oscillator

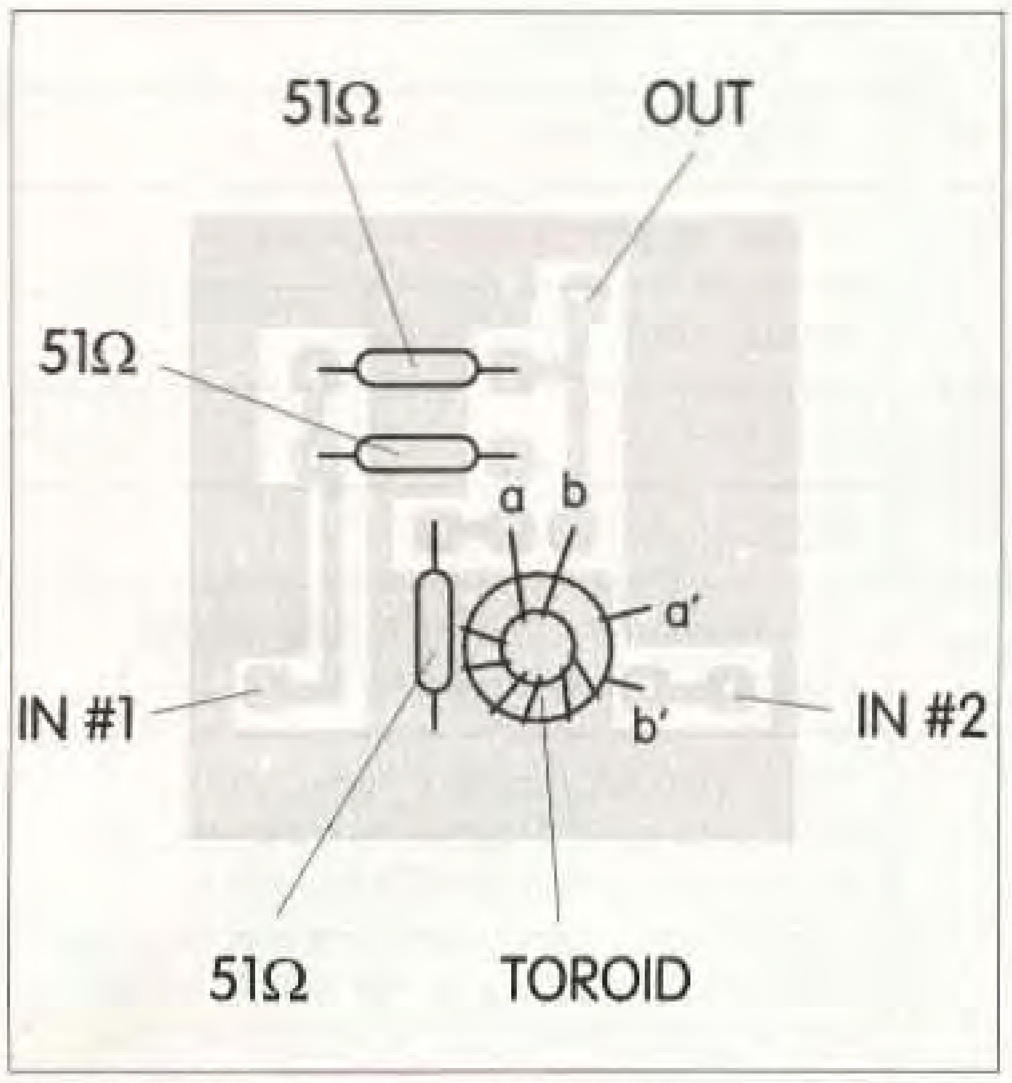


*Fig. 7. Hybrid combiner component locations.*

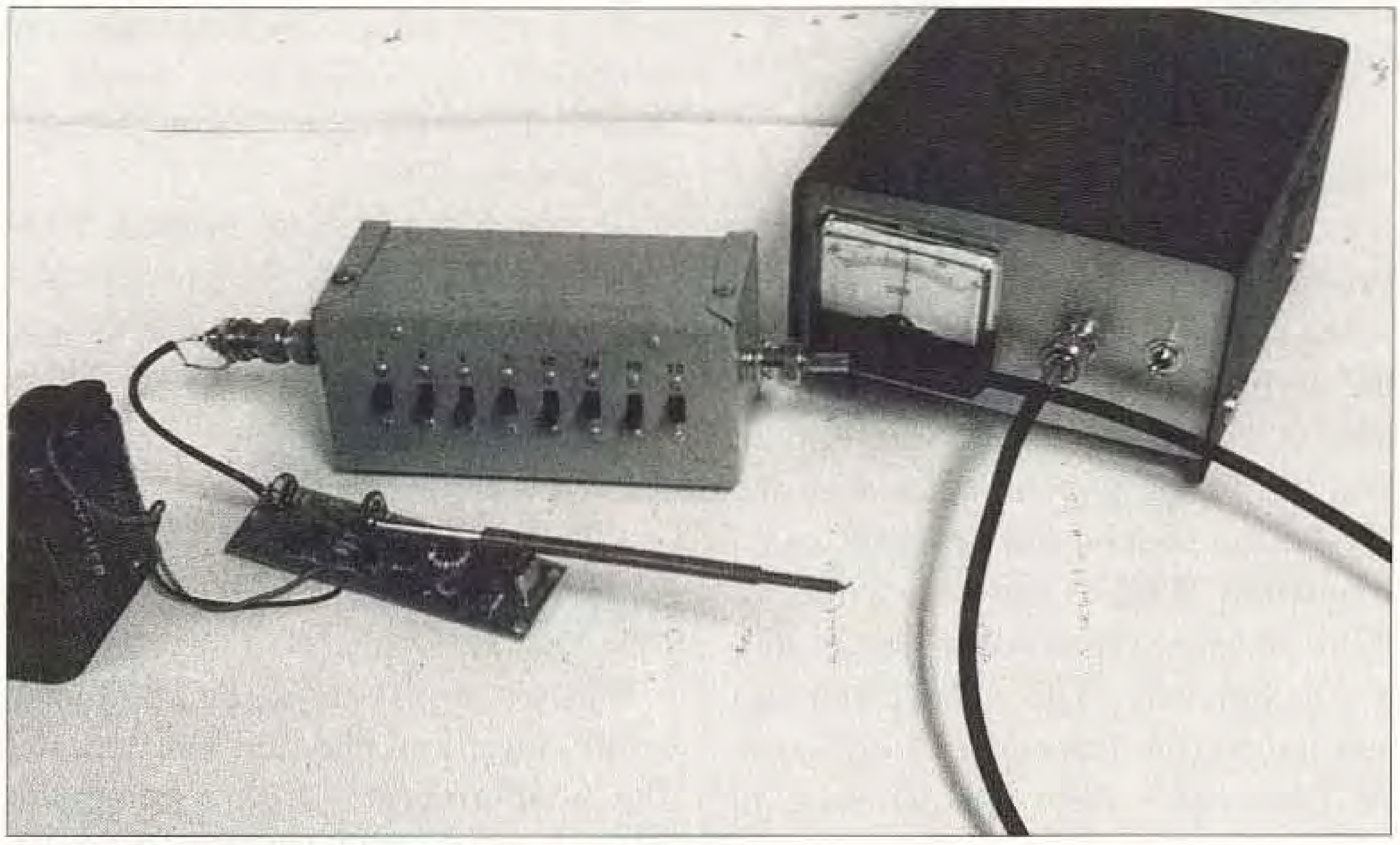

*Photo E. Setting the output level.*

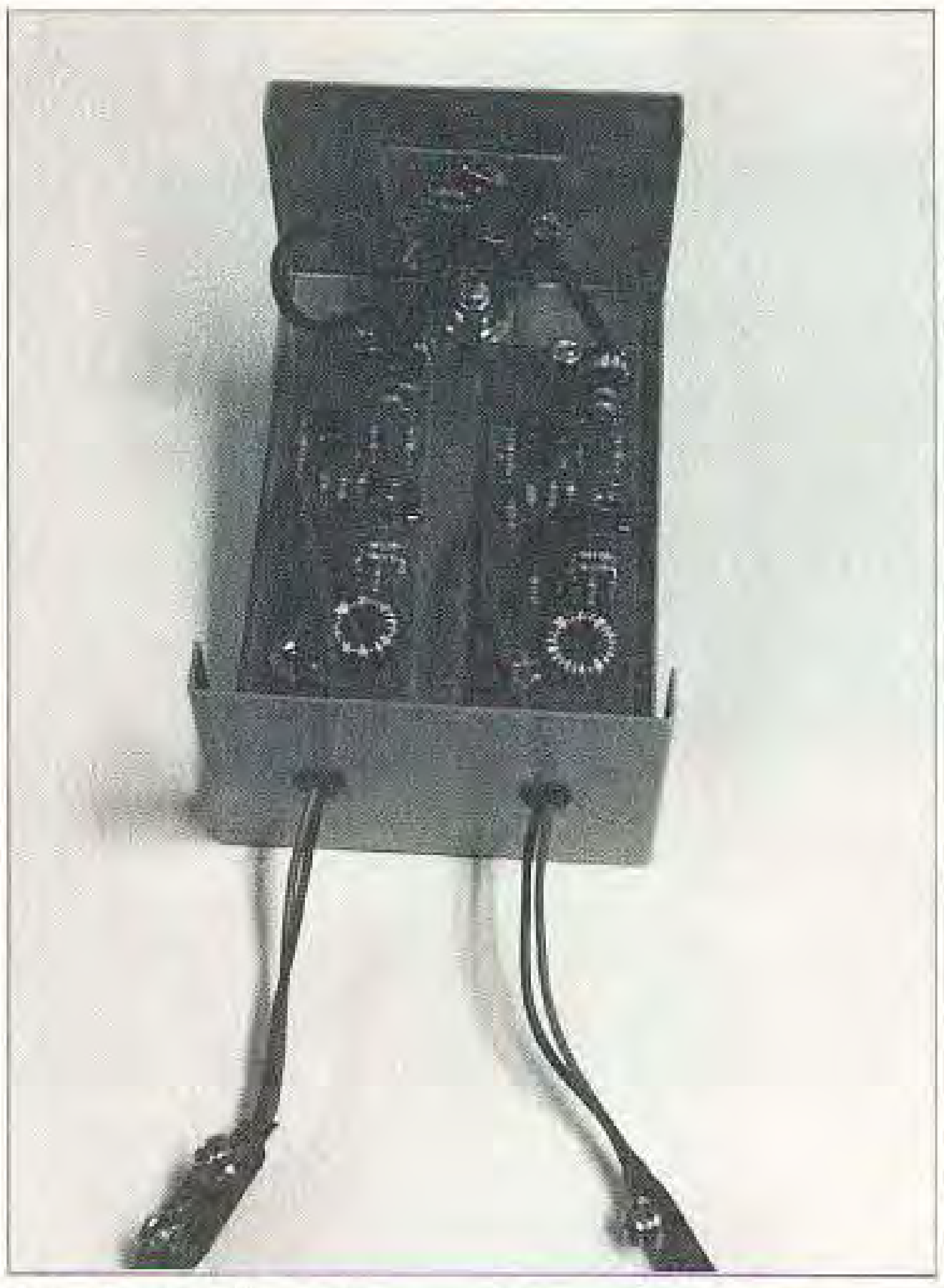

*Photo F. Circuit boards mounted in box.*

must be disabled. You can disable it by removing the crystal or by temporarily shorting the crystal leads together.

Next, insert the crystal and adjust the 36 pF trimmer in parallel with T1 until a signal appears at the output. The 36 pF trimmer in series with the crystal can be adjusted to set the exact frequency. Then, as shown in **Photo E**, P2 is adjusted for a 6 dBm output into a 50 ohm load. The dBm meter described in the November 1995 issue of *Electronics Now* can be used to


*Photo G. Completed test set.*

***Table 1.*** *Parts list. A complete kit of parts, including two generators, combiner, and drilled case, is available for $60 plus $4.50 shipping from Unicorn Electronics, Valley Plaza Drive, Johnson City NY 13790; (800) 221-9454; [www.unicornelex.com]. Kits for the dBm meter and step attenuator are also available from Unicorn. A set (3) of etched and drilled circuit boards for the IP3 test set is available for $10.*

| | |
|---|---|
| **For each signal generator:** | |
| 1 | 4.7 Ω |
| 3 | 12 Ω |
| 1 | 91 Ω |
| 1 | 220 Ω |
| 1 | 510 Ω |
| 1 | 1k |
| 2 | 3.3k |
| 1 | 10k |
| 1 | 47k |
| 1 | 300 Ω trimmer |
| 1 | 5k trimmer |
| 6 | 0.01 µF disc ceramic |
| 1 | 0.1 µF monolythic |
| 2 | 36 pF trimmer cap (purple) |
| 1 | 30 pF silver mica |
| 1 | 180 pF silver mica |
| 2 | 220 pF ceramic |
| 1 | crystal, 14060 or 14080 kHz |
| 1 | J305 FET |
| 2 | 2N3904 NPN transistor |
| 1 | T37-6 powder iron core (small yellow), wind with 12T #22 wire (orange), use 7" |
| 1 | T50-6 powder iron core (large yellow), wind primary 21T #22 wire (orange), use 15"; wind secondary 3T #22, use 3" |
| 1 | FT23-43 ferrite core (small black), wind with 7 bifilar turns #26 wire (green), use two, 5" each |
| 1 | Circuit board |
| **For the hybrid combiner:** | |
| 3 | 51 Ω |
| 1 | FT23-43 ferrite core (small black), wind with 10 bifilar turns #30 wire (small orange), use two, 7" each |
| 1 | Circuit board |
| **For the case:** | |
| 1 | Hammond 1411N utility box, 5 x 3 x 2.2" |
| 1 | BNC chassis mount connector |
| 2 | 1/4" grommets |
| 2 | Battery snaps |
| 8 | 4-40 pan head machine screws 3/8" long |
| 24 | 4-40 hex nuts |

measure the level. You will also need a step attenuator, such as the one described in the April 1999 issue of *Electronics Now*, to drop the 6 dBm level down to where the dBm meter can read it. Note that a 50 ohm low-pass filter L1 and the two 220 pF capacitors in the output reduce any harmonics on the signal. The 6 dBm level should be measured after the signal passes through the low-pass filter.

Two such circuits are needed, with crystals 20 kHz apart. To prevent any interaction between them via the power supply, it is best to power them separately using battery packs. Two packs of eight AA cells each, as shown in the photos, is satisfactory.

## Hybrid combiner

The two signals must be combined before injection into the test circuit. The 6 dB hybrid 50 ohm combiner using a ferrite transformer shown in **Fig. 3** works well. A circuit board is shown in **Fig. 6**. Component locations are shown in **Fig. 7** and **Photo C**. Note that this circuit must be fed with two 50 ohm sources and be terminated with a 50 ohm load. Both generators must be powered on for the levels to be correct. Each signal will be at 0 dBm at the output.

## Building the test set

A complete test set consists of two generators and a hybrid combiner. All three can be included in a single shielded box as shown in **Photo F**. For those who prefer, a complete kit is available. See the parts list, **Table 1**. The completed IP3 Test Set is shown in **Photo G**.

## Making the measurement

**Photo A** shows a typical test setup. A step attenuator is used between the IP3 test set and the receiver to be tested. In the photo, the receiver is my Kenwood TS-830S transceiver. An old

| Input IP3 (dBm) | Rating |
|---|---|
| >10 | Outstanding |
| 0 to 10 | Very good |
| −10 to 0 | Good |
| −20 to −10 | Fair |
| <−20 | Poor |

*Table 2. Rating 1990s-era receivers.*

product review in *QST* lists an average IP3 at 14 MHz as –9 dBm.

Connect up the batteries and locate the two crystal oscillator signals. These signals will be extremely strong and you will need to switch in some attenuation to get a reasonable reading — say S9 levels for the distortion products. The two input signals will be much stronger. Now tune to one of the IP3 distortion product frequencies and note the signal level on the receiver S-meter. Tune back to one of the crystal oscillator frequencies and switch in additional attenuation until the signal level is the same as the distortion product signal was. IP3 is then calculated from:

IP3 = Original Signal Level + 0.5 x Additional Attenuation

The original signal level is 0 dBm minus any attenuation you started with on the step attenuator. Note that this procedure measures input IP3 but not output IP3.

For my measurements of the Kenwood receiver, I used 36 dB attenuation to produce two distortion signals at S7 on the receiver's signal strength meter. Then, tuning to one of the generator frequencies, an additional 52 dB was required to reduce this signal to S7. From the previous equation, then:

$$IP3 = -36 + 0.5 \times 52 = -10 \text{ dBm}$$

which agrees approximately with the ARRL's average of -9 dBm.

From my experience, I would use the chart in **Table 2** to rate 1990s-era receivers. Even very good older receivers will fall further down on the chart.

With this test set, you can make accurate IP3 measurements of your receiver's distortion performance. Good luck with the building and with the measuring!

**Further reading**


"Build a Step Attenuator," *Electronics Now,* April 1999, pp. 34–37; correction, June 1999, p. 7.

"dBm Meter," *Electronics Now,* November 1995, pp. 112–113, 158–159.

*Ladder Crystal Filters,* John Pivnichny N2DCH, MFJ, Starkville MS, 1999.

"Product Review: Kenwood TS-830S," *QST,* May 1981, pp. 38–40.

*Radio Components Handbook,* Guido Silva I2EO, MFJ, Starkville MS, 1998.