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For the Above and Beyond Crowd

Here's a neat RF modulator/detector for use with surplus microwave SWR meters.

Microwave test equipment has never been plentiful or inexpensive. This fact becomes readily apparent as soon as you want to make a measurement of power, gain, frequency, and so forth. Here's something you can build for yourself.

The earliest microwave experimenters found value in modulating their sources with a 1 kHz tone and using a simple crystal detector followed by a tuned audio amplifier and voltmeter as a measurement tool. The technique was quickly adapted for use with slotted lines for making impedance and SWR measurements.

Even today, the technique is used for amateur radio VHF/UHF/Microwave antenna gain measurement contests. A tone-modulated oscillator or signal generator with a broad beamwidth antenna is used as a source, and a crystal or video detector followed by an HP 415 or similar SWR meter is used to make power measurements relative to an antenna with known gain.

This idea works well if your source can be easily amplitude-modulated (AM). However, most microwave brick oscillators, klystrons, and Gunn diodes do not lend themselves to direct AM modulation. Most can easily be frequency modulated (FM), but AM must be done with an external modulator such as a PIN-diode. The only PIN-diode switches I own exhibit a large reflected impedance difference between their on and off states which can upset the stability of some sources.

I wanted to be able to test with a variety of microwave sources without having to build a unique dedicated modulator for each source, so I decided to modulate the receiver instead of the transmitter. This idea is not that much different than what is done with a Dicke radiometer or even the earliest automotive radar detectors. The idea is to chop the input line to the detector. With no RF present, there is no output. When RF is present, the output is an AC signal at the chopping frequency, proportional to the amplitude of the incoming RF. The only difference between the two approaches is that with this system, the meter will respond to all RF present, whereas with the modulated source, the meter only responds to the modulated RF. While a simple RF bandpass filter should cure any interference problems if they occur, I have yet to need one.

Years past, at a hamfest, I had purchased several Hewlett-Packard (HP) PIN-diode SPDT switch modules as an investment that now seemed ideal for the task. All I would have to do would

Photo A. *Front view of modulator/detector.*

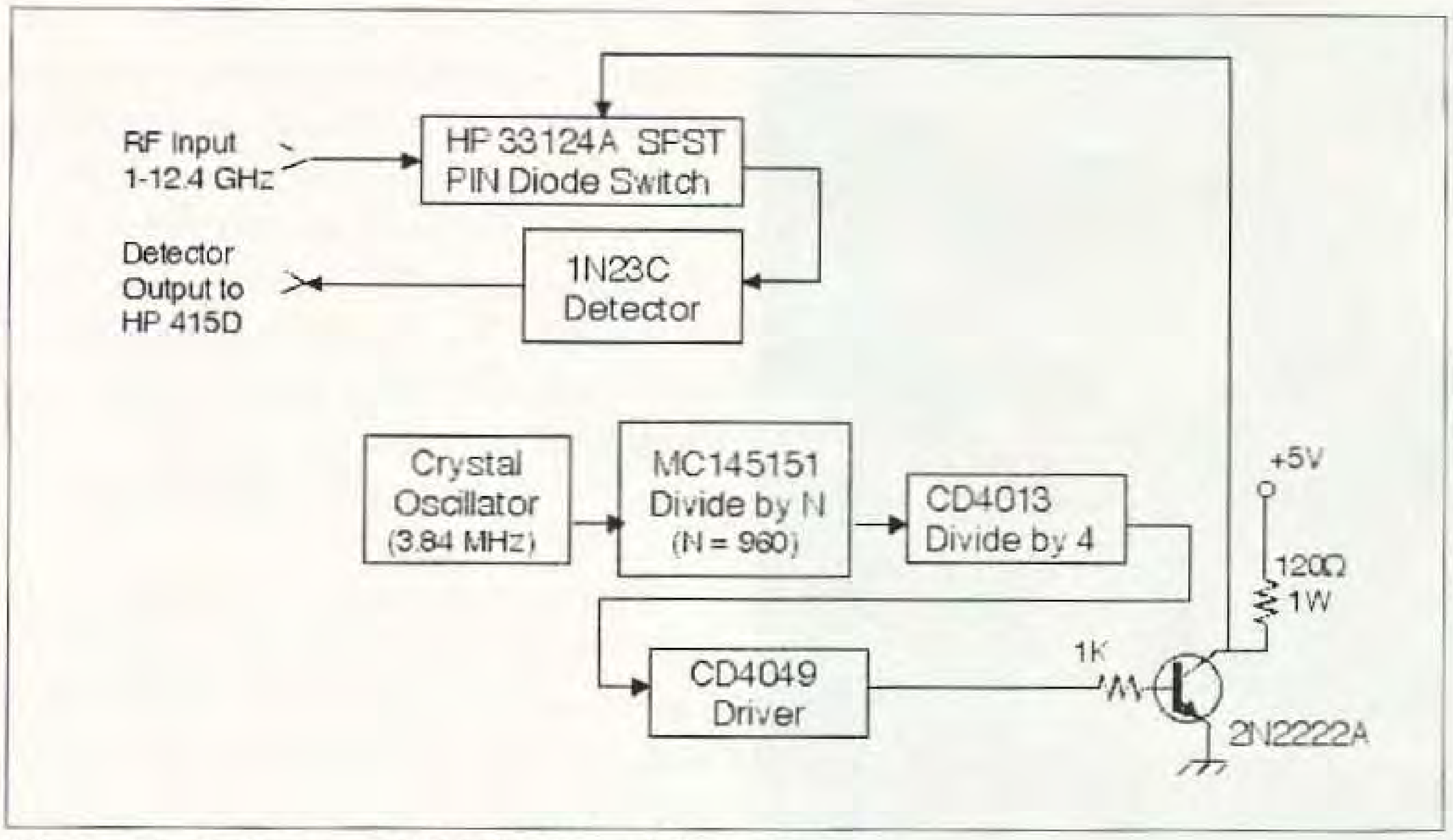

Fig. 1. Block diagram of HP 415D modulator/detector.

be to feed the received RF to one of the switches, turn the switch on and off at a 1 kHz rate, and follow the switch with a broadband RF detector. The result would be a universal adapter to allow me to use my HP 415D SWR meter with any source within the frequency range of the PIN-diode switch and detector. The PIN-diode switch I used, a Hewlett-Packard model 33124A, has a bandwidth of 0.1 to 12.4 GHz, and the detector I used, a Sage 1021H, has a bandwidth of 1 to 12.4 GHz. The net result is a system bandwidth of 1 to 12.4 GHz.

A block diagram of the system is shown in **Fig. 1**. A complete schematic diagram of the PIN-diode switch driver is presented as **Fig. 2**. I have several HP PIN-diode switches, but the 33124A was the only one I could use in a negative ground system.

I could have used a simple, free-running, NE555 1 kHz oscillator to drive the PIN-diode switch, but decided instead to use a crystal-controlled driver for several reasons. First, the cost of a crystal oscillator and divider chain is not that much more than a free-running oscillator. Second, a very stable source would be needed to take full advantage of the fact that the HP 415 bandwidth can be narrowed down from 100 to 15 Hertz. And, third, I like the idea of no

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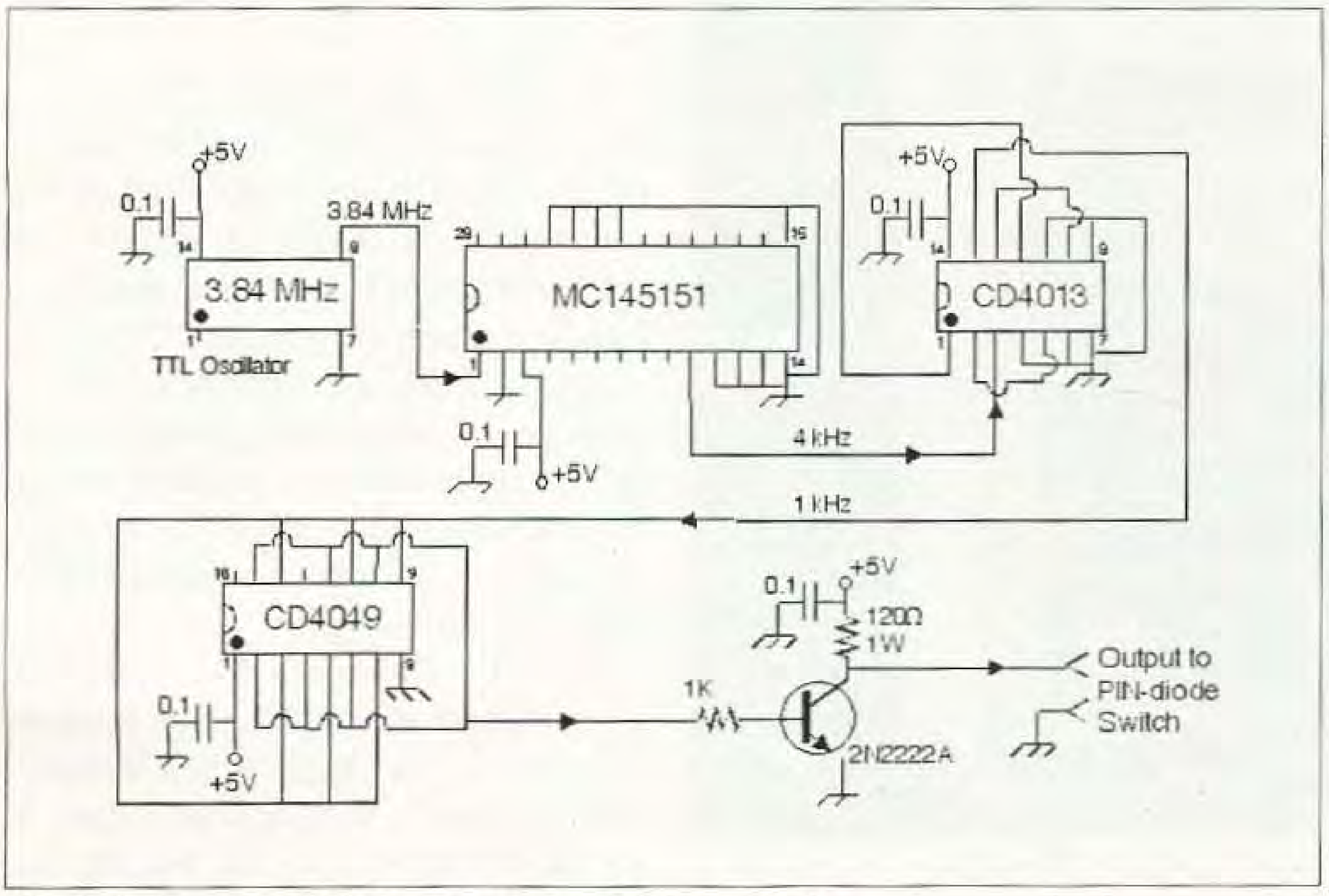
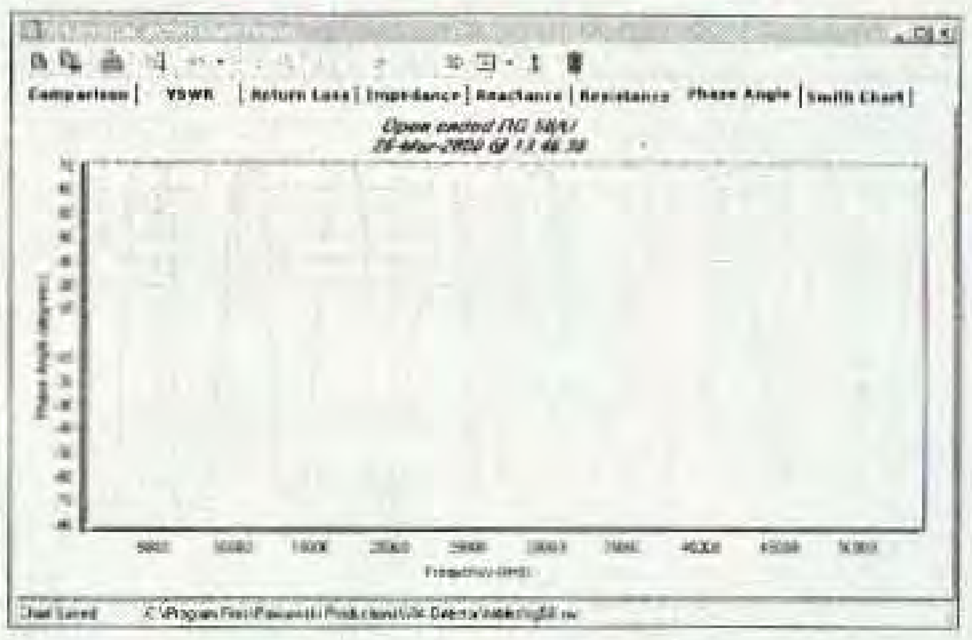


Fig. 2. Schematic of 1 kHz generator and driver circuit.



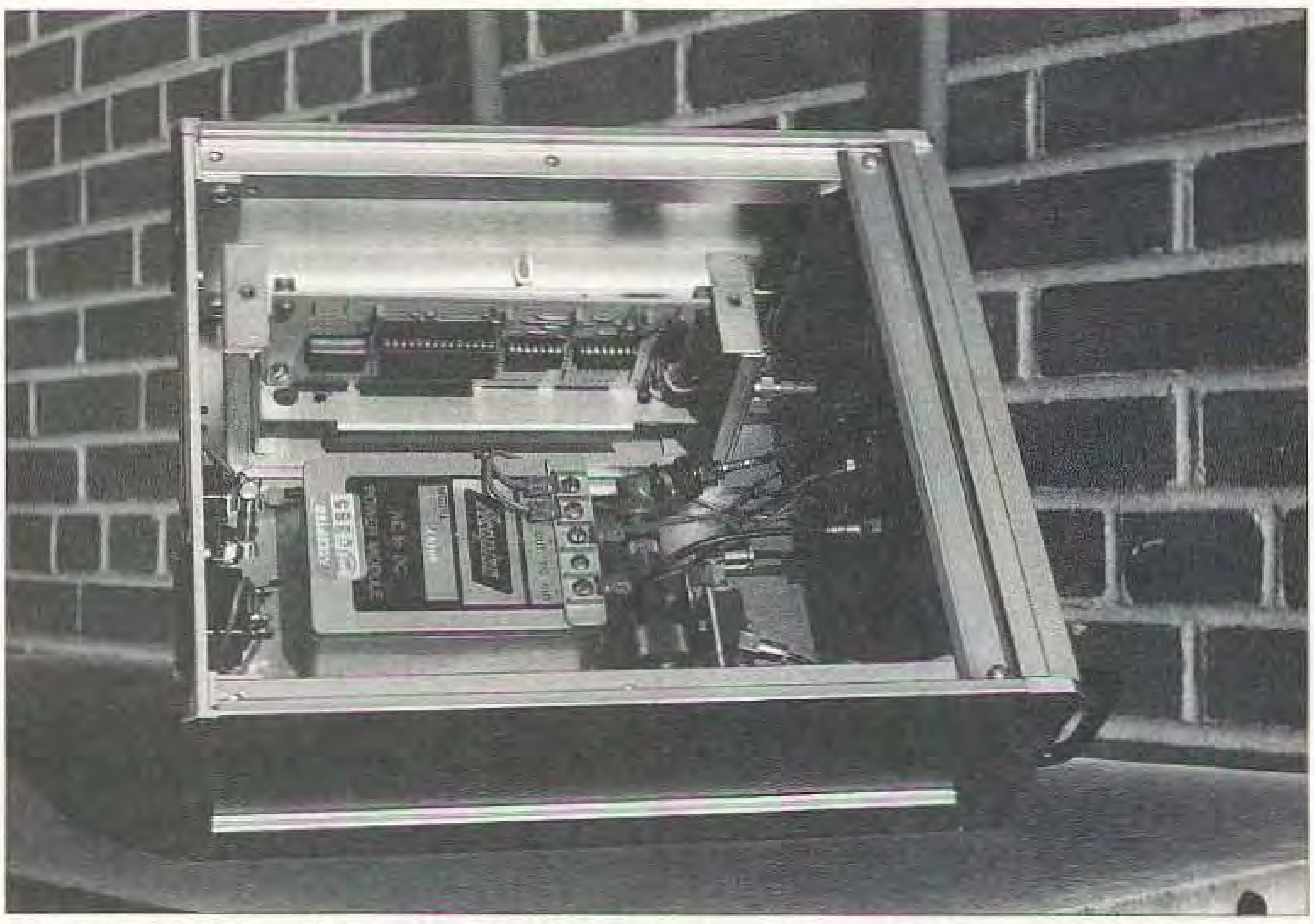


Photo B. *Modulator/detector with cabinet cover and driver shield removed.*

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adjustments or calibration required — too many knobs spoil the measurement.

Having decided to start with a crystal oscillator, why didn't I use a common 1 MHz TTL oscillator? Well, a quick check of my junk box revealed several TTL unit oscillators. I hated to use one of my 1.000 MHz units when I had some other units with seemingly odd-ball frequencies. I selected a 3.84 MHz unit because it will probably otherwise never be used. Use whatever oscillator you have, as long as the output frequency is an even integer multiple of 1 kHz.

Following the oscillator, I used an MC145151 integrated circuit to divide the 3.84 MHz by 960 to get 4 kHz. The MC145151 was designed to be part of a phase locked loop and has many internal functions which are not needed for this application. However, the divide-by-N portion can be used independently of the other functions. The MC145151, when operated from a 5 volt supply, has an upper frequency limit of 15 MHz and is hardwire-programmable to divide by any integer from 3 to 16,383. To divide by 960, the N = 9, 8, 7 and 6 pins (512 + 256 + 128 + 64 = 960) are left floating (internal pull-ups) and all other divisor pins are grounded. Use whatever divisor will divide your particular oscillator down to 4 kHz.

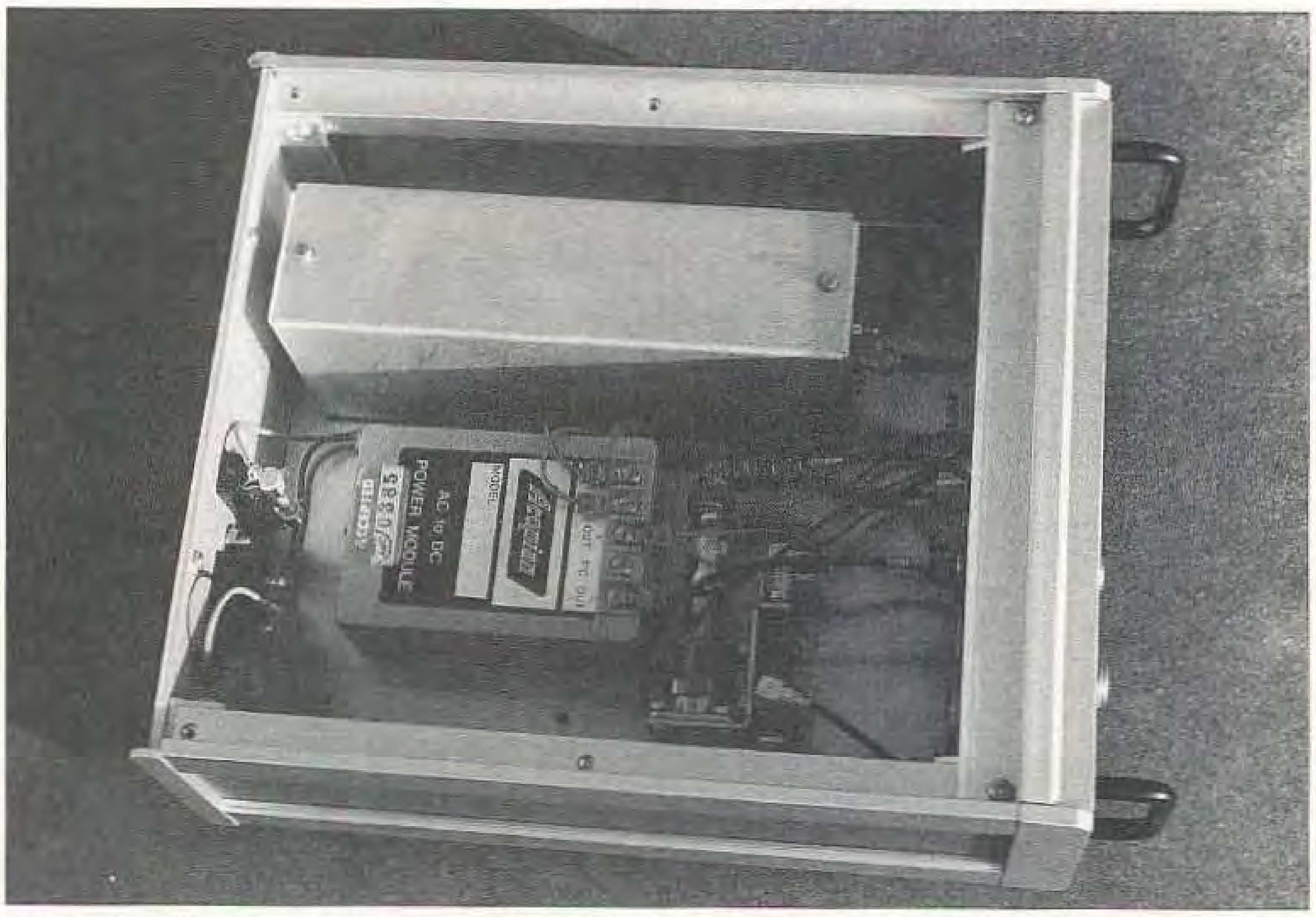

Photo C. *Modulator/detector with cabinet cover removed. PIN-diode driver at top, power supply in the middle, and PIN-diode switch with detector in lower right.*

Why did I go for 4 kHz instead of 1 kHz? Well, I wanted to drive the PIN-diode switch with a 50% duty ratio square wave. The output pulses from the MC145151 are not a 50% duty ratio square wave, but have a pulse duration equal to the period of one cycle of the input signal, 0.26 microseconds in this case. Therefore, I knew I would need to add at least one binary flip-flop following the MC145151 to achieve the 50% duty ratio. Since most integrated circuit flip-flops have at least two stages per package, the output of the MC145151 could be either 2 or 4 kHz. I chose 4 kHz. The divider I selected to follow the MC145151 is a CD4013, a common two-stage type D flip-flop. A type D flip-flop will toggle or divide by two if the set and reset pins are grounded and the not-Q (complementary) output is connected to the D input. The flip-flop input is the C or clock pin, and output is taken from the Q pin. As I mentioned, I used both stages to divide by four and achieve a 50% duty ratio 1 kHz square wave output.

Of course, the CD4013 CMOS integrated circuit does not have the capacity to directly drive the PIN-diode switch. I paralleled the six inverters in a CD4049 to act as a drive amplifier followed with a simple 2N2222A switching transistor. Of course, all six inverters are not needed, but the inputs to the unused inverters would have had to have been tied to ground or the supply anyway, so why not just parallel them and not worry.

The PIN-diode switch is supplied current through a 120 ohm resistor from the 5 volt supply line. I initially tried a lower value resistor to get a higher PIN-diode current, but the increase in signal output was marginal, and the power consumption and radiated noise level were much higher. The difference in detected output between using a switch that switches from 0 to 10 dB versus one that switches from 0 to 100 dB is less than 10%.

The 2N2222A transistor, when switched off, has no influence on the PIN-diode current. When switched on, the 2N2222A shunts all the current through the 120 ohm resistor to ground, thereby reducing the PIN-diode current to zero. The PIN-diode switch is on when the transistor is on and vice versa. By using a shunt switching configuration, the current through the 120 ohm resistor is relatively constant. This way, no large switching currents are generated that can radiate and be picked up by the HP 415D SWR meter. After all, the HP 415D has a useful sensitivity approaching 0.1 microvolt, and the final system noise floor will determine the ultimate sensitivity of the complete instrument.

The voltage across the PIN-diode switch is 0.1 V when the transistor is on and 0.9 V when the transistor is off and all of the current is passing through the PIN-diode. The 120 ohm current limiting resistor is dissipating 0.2 W when the transistor is on and 0.14 W when the transistor is off. The average power dissipated by the resistor is 0.17 W. For reliability, I used a resistor with a 1 W rating. The current drain on the 5 V regulated power supply, not including the LED power indicator, is approximately 60 mA. The LED power indicator draws an additional 12 mA.

To further reduce radiated noise, the driver circuit board is mounted inside a shielded enclosure and the TTL oscillator module and each integrated circuit is bypassed with a 0.1 µF capacitor. The circuit board, mounted in its shielded enclosure, is shown in the photographs both with the shield removed and in place.

The shielded driver is mounted in a larger aluminum cabinet along with the regulated 5 volt power supply, PIN-diode switch, and crystal detector. The cabinet volume is less than the HP 415D and is easily stacked under or over the HP 415D as seen in the photographs. Coax cables are used internal to the cabinet between the front panel feedthrough connectors and the PIN-diode switch input and the detector output. A short SMA jumper cable connects the PIN-diode switch and the detector as seen in the photographs. An SMA to SMC cable is used to route the 1 kHz drive to the PIN-diode switch. I mounted the PIN-diode switch and the detector on a common bracket for ease of assembly and to minimize the length of the interconnect cable. The usual paint trim, handles, and label decals were applied to the front panel.

In operation, the HP 415D "INPUT SELECTOR" switch is set to "XTAL," either 200 ohm or 200k depending on which position gives the strongest reading with your detector. I usually use the 200k position. Do not use the "BOLO" or bolometer position, as it is designed to supply a current bias to the detector and can destroy the crystal diode. If you use a Hewlett-Packard detector with its own, matched, square-law optimized load resistor, use the 200k setting.

Because a diode detector, when used with low level signals, is a square-law device, the dB scales are reasonably accurate relative power indicators. For example, a change in meter reading, up or down, of 3 dB, represents a factor of two power change. The unit can be used for antenna gain measurements, relative to a known antenna, attenuation measurements, and small signal amplifier gain measurements, as well as slotted line impedance measurements as explained in the HP 415D manual. While the unit was designed and built with the HP 415D in mind, it should work equally well with other 1 kHz tuned SWR meters having a crystal detector input.

How well does it work? I continue to be pleased with the performance and use it regularly. Using a mid-value gain setting on the HP 415D, the noise floor is mid-scale on the 50 switch position. At 1 GHz, a signal of –42 dBm is 3 dB (full scale deflection) above the noise floor. At 2 GHz, a signal of –47 dBm is also 3 dB above the noise floor. The only regret I have is that I did not build it sooner.