

The EMI Finder

Easily locate sources of electromagnetic interference with this sensitive, low cost, UHF receiving system.

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This article describes a UHF receiving system used to easily locate a very wide variety of sources of electromagnetic interference (EMI). The system consists of a sensitive narrow-bandwidth 318 MHz receiver, a directional handheld Yagi antenna and a headset (see Figs 1-3). Some of the typical broadband emitters of radio frequency interference (RFI) that you can pinpoint are power-line insulators, computers and industrial equipment.

The following are the principle technical features of the receiving system, which contribute to its effectiveness:

- High gain, directional five-element hand-held Yagi antenna for precise

position location of noise emitters (see Fig 2).

- Simple construction.
- Surface acoustic wave RF filter (SAWF) for good front-end selectivity.
- High-gain, low-noise figure RF preamplifier (LNA) for high sensitivity.
- Regenerative detector stabilized with a surface acoustic wave resonator (SAWR) produces a very narrow detection bandwidth hence a low noise floor.
- High detection sensitivity, -136 dBm minimum discernable signal.
- Low-loss direct coupling technique between the LNA and regenerative detector.
- Low-voltage, low-current operation for long battery life.
- With only two active RF components, the circuit is simple and the cost low.

- All surface-mount devices and components for best RF performance, easy construction and low cost.
- Receiver design technique useful at other frequencies including the 70-cm amateur band.

Find Broadband Sources of EMI

You can locate sources of electromagnetic interference by listening in the VHF/UHF range for their broad emission spectrum, which typically extends to 300 MHz and sometimes well beyond. Such spurious noise is usually amplitude modulated or contains both AM and FM.

For example, power lines, which are often a source of amplitude-modulated EMI put out noise into the UHF range from corona and sparking. These problems can be caused by defective hardware such as insulators and ungrounded transformers, which can act

like spark gap transmitters radiating electromagnetic energy with a very broad spectral content. This broad spectrum usually contains enough energy at 318 MHz to be detected by a sensitive AM receiver such as the one described here. It is common practice in the power industry to search for defective power-line equipment by listening in the 300 MHz range with sensitive receivers and directional antennas. Commercial gear used to search for such EMI is available from companies like Radar Engineers (www.radarengineers.com) or Trilithic Incorporated (www.trilithic.com). Prices for commercial equipment range from several hundred to several thousand dollars.

Most digital electronic devices such as personal computers, games, DSL lines, VCRs and electronic instruments can also radiate a spectrum with components extending to above 300 MHz. Even if such equipment is compliant with the FCC Part 15 class B regulations for residential use, this receiver will usually find them if you are within 3 to 15 feet. Such equipment often have internal microprocessor and DSP clocks running in the 10 MHz to 100 MHz range, which create harmonics to beyond 300 MHz. Digital bus speeds are usually in this range as well and may vary in frequency and amplitude as software performs operations on peripherals and memory chips. All of this can produce a very rich spectrum at 200-300 MHz and above.

At my particular location, I can "hear" computers, displays, printers, a digital scope, a microwave oven controller, power lines, power substations, automobile ignition systems and garage-door opener superregenerative receivers. Around town, I can walk into

most any building, sniff around and find most active electronic devices. All of these sources of RFI are broadband in nature. That is, their emissions extend over many megahertz and to very high frequencies. This receiving system, though, is a very narrow-band device, which listens to only a small slice of the total spectral output of any RFI emitter. The bandwidth of the five-element Yagi antenna is only a few percent of 318 MHz, and the receiver passband is only a few kilohertz wide.

A receiving frequency of 318 MHz is chosen for three main reasons. First, at this frequency the antenna is small and easily transported. It also has high gain and sharp directivity with only five elements. In addition, 318 MHz is a generally interference-free frequency in the USA. Although garage-door openers and automotive keyless entry systems operate at 315 MHz, no other radio services use 318 MHz. The harmonics of the lower frequency TV stations and communications radios are elsewhere.



Fig 1—The author searching for power-line noise.

Thirdly, there are off-the-shelf SAW filters and SAW resonators readily available for 318 MHz.

A High Sensitivity Receiver

To detect a very low-level slice of a broad-spectrum emitter you need a sensitive narrow-bandwidth receiver. The receiver described here uses a unique, but simple, RF circuit design to achieve sufficient sensitivity to locate noise sources. It has a minimum discernable signal sensitivity of about -136 dBm when using headphones, corresponding to a bandwidth of a few kilohertz.

Consider the following: The five-element Yagi antenna has a source impedance of 50 Ω at 318 MHz. So, as a noise generator its equivalent circuit is a voltage source in series with a 50 Ω resistor. If we measure the output noise of the antenna with a high-impedance measuring device that has a known 3-dB bandwidth, we will measure the following RMS voltage.

$$e_n = \sqrt{4k_BTR} \quad (\text{Eq 1})$$

Where

e_n = The open circuit RMS noise output of the antenna.

k = Boltzmann's constant.

B = Bandwidth of the receiving or measuring device in hertz.

T = Temperature of the antenna noise resistor in kelvins.

R = Antenna resistance in series with the voltage source.

This equation determines the lowest possible noise floor, hence sensitivity, of the receiver assuming perfect noise figure of 0 dB (the noise figure of the receiver preamplifier is actually about 2 dB). If we substitute a signal generator with a 50-Ω output

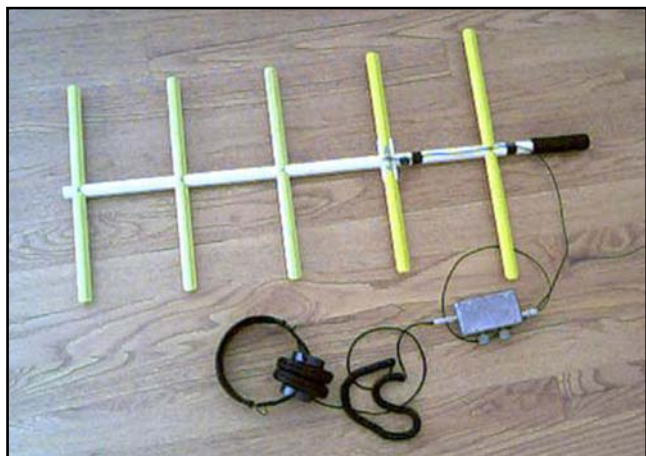


Fig 2—The complete receiving system: 318 MHz Yagi, receiver and headset.



Fig 3—The 318 MHz receiver. The controls are for regeneration and volume.

impedance for the antenna, we can determine the approximate bandwidth of the receiver. If we insert a signal level that is equal to the noise level then the receiver bandwidth can be calculated from:

$$e_n = \sqrt{4 \times 1.38 \times 10^{-23} \times B \times 293 \times 50} \quad (\text{Eq 2})$$

Where

e_n = the generator RMS voltage.
 B = equivalent bandwidth of the receiver.

For this receiver a 100% AM modulated generator at -133 dBm (50.2 nV) produces a signal that is about equal to the noise. So, the 3 dB bandwidth of the receiver is about 3.1 kHz, and the minimum discernable to the human ear signal level is about 3 dB lower at -136 dBm. Not too bad for a circuit with only two active RF parts!

Receiver Circuit Description

The receiver circuit works as follows. Refer to the schematic diagram in Fig 8. A signal or noise in a narrow band at 318 MHz is picked up by the Yagi antenna, which has a source impedance of 50Ω . The antenna output voltage is applied to the input of a SAW bandpass filter centered at 318 MHz. The filter rejects adjacent-channel interfering signals, which could overload the preamplifier causing spurious responses—not the noise you are looking for. Such interfering signals could be TV transmitters below 300 MHz, transmitters in the 70-cm Amateur Radio band (420-450 MHz) or other communications radios. L1, L2, C28 and C27 provide impedance matching for the input and output of the SAW filter. L5 is an RF choke for front-end ESD protection. The output of the SAW is then amplified by a Motorola preamplifier chip, the MBC13916. This is a cascade preamplifier with 22 dB of gain and a noise figure of 2 dB. It is a silicon-germanium part that contains a temperature-compensated internal bias circuit.

The high-impedance output of the preamplifier is summed by superposition in the collector of the regenerative detector, Q1. This is a very straightforward current-source summing technique that eliminates a coupling capacitor or other parts that might load the collector of the regenerative detector. The circuit of Q1 is the regenerative detector, which is a common-base oscillator stabilized by a 318 MHz SAW resonator (SAWR). The SAWR acts like a 318 MHz fundamental-mode crystal, with a similar equivalent circuit. It serves to provide excellent short-term oscillator

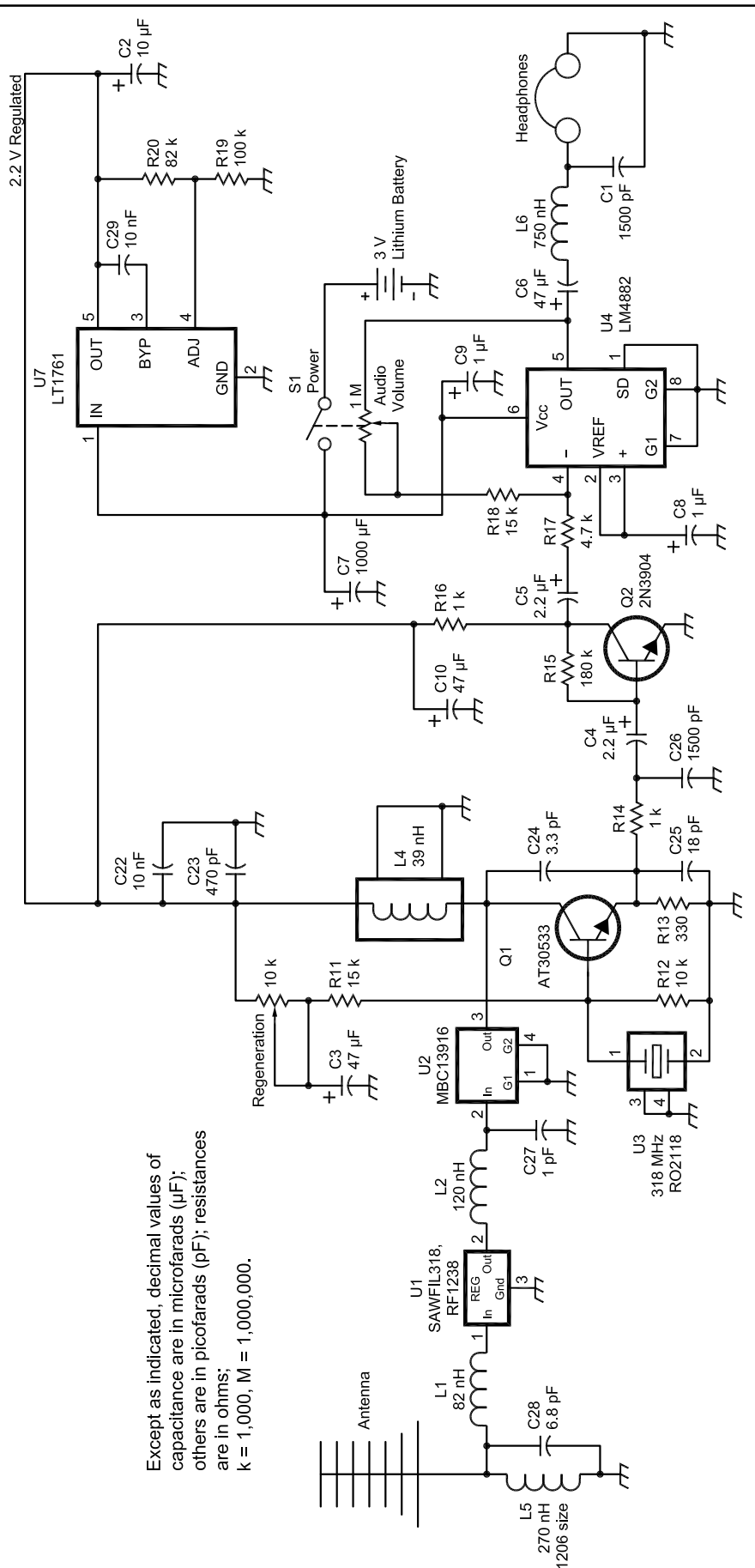


Fig 4—The schematic diagram of the EMI Sniffer.

stability because of its high Q. The unloaded Q of the SAWR is specified at 16,900 by the manufacturer, RF Monolithics. This is good although not as high as a crystal, which is typically greater than 20,000. The circuit loaded Q of the SAWR will be less than 16,900 but still high enough to produce a very narrow receive bandwidth when used as the frequency determining element of a regenerative detector.

The frequency tolerance of the SAWR is ± 100 kHz, and the long-term and temperature stability is on the order of several tens of kilohertz. Here, only the short-term stability of the SAWR, and hence the regenerative detector, is important. For this application we can listen to any frequency near 318 MHz as long as the short-term stability is good enough to produce a low noise floor. This assumes that the noise we listen to is uniformly distributed over a 200 kHz bandwidth centered on 318 MHz, a pretty good assumption for most EMI emitters. The short-term stability of the detector is determined by its loaded Q, which is something less than 16,900 multiplied by the regenerative effect of the detector circuit. If the effective bandwidth of the receiver is 3.1 kHz, as discussed above, this corresponds to an effective Q at 318 MHz of 102,600.

The 18 k Ω potentiometer fixes the onset of oscillations of the regenerative detector, hence the most sensitive detection point, and is adjusted by the operator with a knob (see Fig 4). The output of the regenerative detector is taken at the emitter, low-pass filtered and preamplified by the audio stage, Q2. The output of the preamplifier is then passed to the National Semiconductor power amplifier chip, the LM4992 and boosted to a level sufficient to drive a headset or small speaker. The audio volume is adjusted with the 1 M Ω potentiometer. The whole circuit is powered by a 3 V CR123A lithium battery. This battery is typically used in film cameras, and it is readily available. The 3 V output of the battery is regulated down to 2.2 V by the Linear Technology LT174 low-dropout regulator. The receiver circuit is designed to operate from 2.2 V because this is about the end of life for the battery.

The Five-Element Tape-Measure Yagi

The ability to precisely locate sources of EMI is enhanced by the five-element hand-held Yagi antenna used with the receiver. The antenna improves the sensitivity and utility of the system because of its high gain and

directionality. The beamwidth is quite narrow as you can see from the computer simulation of the pattern in Fig 6. A narrow pattern makes it easy to peak up the noise from an emitter as you swing the antenna back and forth, up and down.

Changing the polarity from horizontal to vertical also sometimes improves the strength of the noise. Usually you can pinpoint a source of noise

within inches if you are five feet away. From ground level, you can locate defective insulators on power poles.

The Yagi is computer optimized for the best pattern and impedance match using the computer program Yagi Optimizer (YO). The front-to-back ratio of 25.2 dB is adequate for good direction finding. [Fig 6 was generated with YW, a similar program packaged with *The ARRL Antenna Book*. The

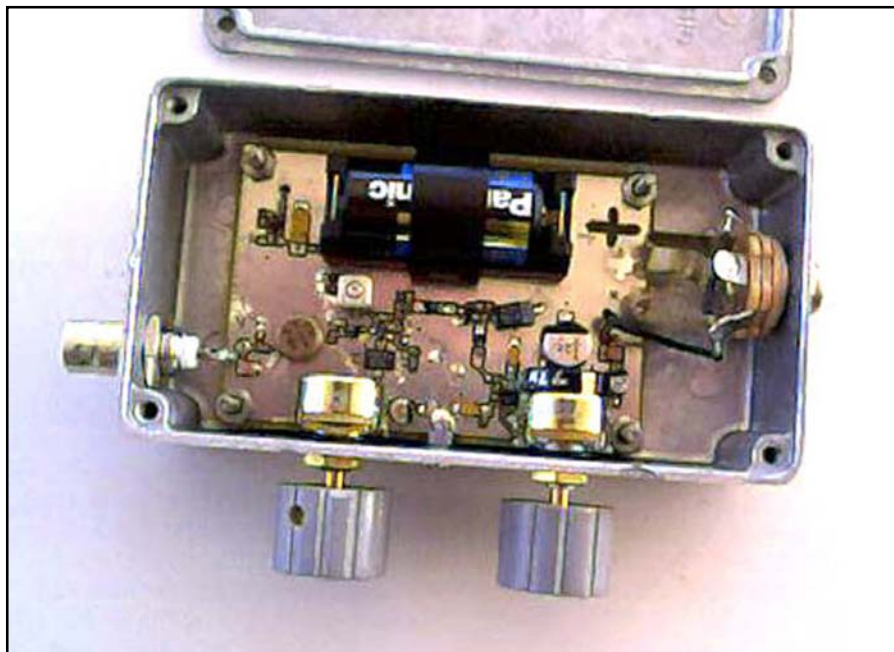


Fig 5—The receiver printed-circuit board showing the regeneration and volume controls.

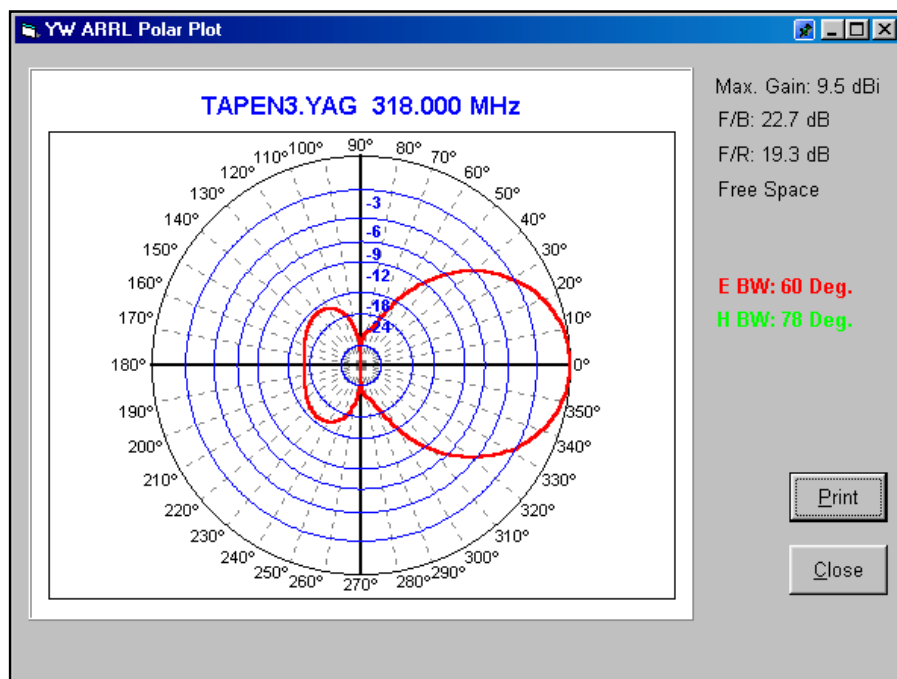


Fig 6—Computer modeled pattern for the antenna.

performance varies slightly from that calculated by *YO*.—*Ed*] The 42 Ω feed-point impedance (see Fig 7) presents a pretty good match to 50 Ω coaxial cable, such that the mismatch loss is very low. No matching network is used, just a single bead balun. The one-inch-wide spring-steel tape measure material is simulated in *YO* with a 0.15 inch diameter round aluminum element. This equivalent element diameter is determined by measuring the resonant frequency of a dipole made from the one-inch-wide tape-measure material. Then the actual length and resonant frequency are used as fixed parameters in the antenna modeling program *EZNEC* to find the equivalent diameter of a round aluminum element. In other words, the 1-inch-wide tape-measure material acts electrically like 0.15-inch diameter aluminum tubing at 318 MHz. So the elements modeled in *YO* are 0.15 inches in diameter and the lengths and spacings of the elements as calculated by *YO* are as shown in Table 1.

The boom of the antenna is made of CPVC, the hot-water version of PVC. It is stiffer than regular PVC and machines very easily. The elements are very rugged because of their flexibility, being made from steel tape-measure material. The driven-element mount is

machined from Delrin using a 45° dovetail cutter as shown in Fig 8A. The cuts in the boom that hold the elements are also made with a 45° dovetail cutter. The elements are each fastened to the boom with a #8-32×1½ bolt and locking nut. If an element breaks, it is easily replaced in the field. The same

antenna construction can be used for fox hunting on the 2 meter or 70 centimeter bands. Because of the flexible elements you can easily travel in close quarters and through bushes without difficulty. The antenna is very lightweight and can be carried for extended periods without fatigue. A foam bicycle

Table 1

Yagi Antenna Dimensions in Inches

Element	Length	Boom Position
Reflector	19.0	0
Driven Element	17.2	7.5
Director #1	15.6	15.0
Director #2	15.4	22.0
Director #3	15.4	29.0

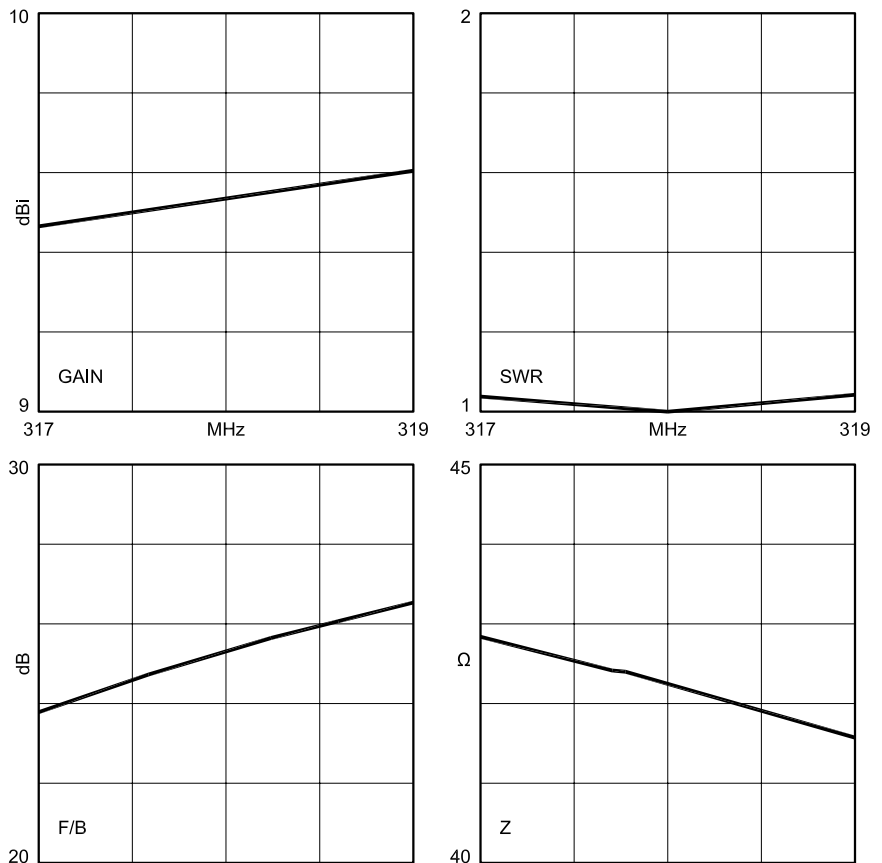
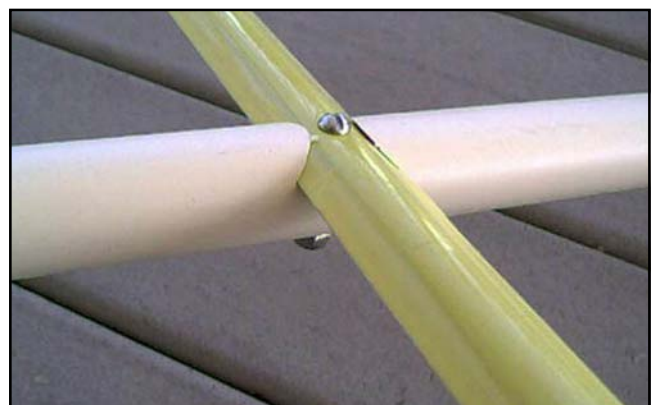


Fig 7—Computer modeled Yagi performance.



(A)



(B)

Fig 8—At A, the feedpoint details. The mount is made from a 1¼×3×¼-inch-thick piece of Delrin plastic. It is machined with a 45° dovetail bit to accept the halves of the driven element, then drilled and tapped for three #8-32 bolts. The bolt positions are not critical. The two outer bolts secure the element halves to the Delrin mount, and the center bolt (fed through a hole in the boom) secures the mount within a notch cut into the CPVC boom. At B, milled dovetail cuts in the boom secure the tape-measure elements.

handlebar grip is used for the handle and it is quite comfortable.

Other Applications

The UHF regenerative receiver technique described here may be used in other applications as well. For example, you could build a simple AM or FM system to communicate voice or data over short distances in the 70 cm band. The receiver could be just as described, but use a commonly available SAWR at 433.92 MHz. The same resonator would also be used to control the transmit frequency. Since SAW resonators can be pulled about ± 50 kHz in frequency, both the transmitter and receiver can be tuned to the same frequency. The circuits also operate at very low current levels for long battery life. It might also be possible to implement a microprocessor to automatically adjust the level of regeneration at the detector to maintain best sensitivity.

SAW devices are commonly used by the millions in automotive keyless-entry and garage-door opener products. A typical automotive keyless-entry system would use a SAWR stabilized transmitter in the key fob and an LC stabilized superregenerative receiver inside the instrument panel of the car. The transmitters are usually amplitude keyed with digital data at about 1 kbps. At least one keyless entry system that I know of is frequency modulated with a deviation of about ± 30 kHz. You can pull a SAWR this far with a Varactor diode. You can also use other types of antennas to

sniff for EMI on printed-circuit boards and enclosures. These could be loops, shielded loops and simple capacitively coupled tips. Or, you can make a direct connection to a circuit with a piece of coax. When attaching antennas and coax, observe static-protection procedures to not "static zap" or otherwise destroy the input SAWF. An input inductor to ground is provided, but this component will fail open if you apply more than a few hundred milliamperes to the antenna connector.

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