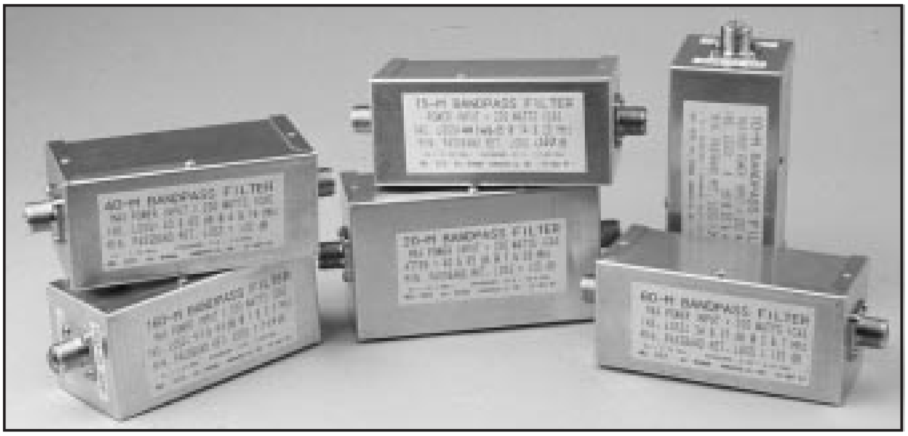
By Ed Wetherhold, W3NQN

Clean Up Your Signals with Band-Pass Filters

Part 2—You're now much closer to saying goodbye to your unwanted signal problems!

Last month,[13] I described the design of band-pass filters that provide a level of selectivity and reliability heretofore unavailable. In this installment, I'll delve into filter assembly, tuning and performance.



Filter Assembly and Tuning

For the prototypes shown here, $2\frac{1}{4}\times 2\frac{1}{4}\times 5$-inch (HWD) aluminum boxes are used. While tuning the 20 meter filters, I discovered that the passband return loss was adversely affected when the enclosure cover was installed. That effect was traced to the close proximity between the inductors and the sides of the smaller box. Using a box with a 3-inch width eliminates the problem. Now, except for the 10 meter filter, all the other filters are housed in $2\frac{1}{8}\times 3\times 5\frac{1}{4}$-inch (HWD) boxes such as the LMB 880.

The detector I used to tune the resonators has a sensitivity of –12 dBm, and is described in Wes (W7ZOI) Hayward's article, "Beyond the Dipper."[14] Instead of the two hot-carrier diodes specified by Hayward, I use 1N4148 diodes as they are more conveniently available and are adequate for use up to 10 meters.

Before installing C1 and C3, use a digital capacitance meter to ensure they're the same value, preferably within a picofarad. As shown in Figure 1 (see part 1), the 50 Ω taps on the L1 and L3 inductors are connected to the SO-239 UHF connectors; capacitors C1 and C3 are connected between ground lugs and the ends of the inductor windings. The components for the other BPFs are installed similarly. The L2 inductors are secured by tying them to a strip of cardboard that is attached to the box bottom with RTV silicone sealant.

Using the tuning procedure described in the notes of Table 1A, tune resonators 1 and 3 to the design center frequency. When tuning these two circuits, use a digital frequency counter to ensure they resonate as closely as possible to the same frequency. If these circuits are not tuned to the same frequency, it may be impossible to obtain an acceptable return-loss response. Micrometals specifies a 5% core-permeability tolerance. The resulting L1 and L3 inductance variation is compensated for by squeezing or spreading the turns on the cores until both resonators tune to the same frequency.

To resonate L1 and L3 to within 0.2% of the *design center frequency*, a small amount of capacitance (3 to 10 pF) must usually be added in parallel with C1 and C3. The amount of additional capacitance required is determined by noting the exact values of C1 and C3, and measuring the initial resonant frequency. The required additional capacitance is equal to

$$\{[(F1/Fc)^2] \times C1\} - C1 \qquad \text{(Eq 1)}$$

For example, assume C1 and C3 of the 40-meter BPF design both measure 123 pF, and C1 and L1 and C3 and L3 each resonate initially at 7.30 and 7.35 MHz. Squeeze and spread the turns on L1 and L3 until the circuits resonate at the same frequency, say, 7.33 MHz. Because C1 and C3 were previously matched to exactly the same value, L1 and L3 now must also be of equal value because the 1 and 3 resonators are both tuned to 7.33 MHz. Eq 1 is used to find the required additional capacitance to add to C1 and C3:

$$Ca = (7.33/7.15)^2 \times 123 - 123 = 6.3 \text{ pF} \qquad \text{(Eq 2)}$$

A close approximation of this value can be obtained by connecting in series two 12 pF, 1 kVDC Ceramite capacitors. Any final resonator adjustments are made by squeezing and spreading the L1 and L3 inductor turns until both resonators are tuned to the same frequency with 0.2% of the design value.

After resonators 1 and 3 are tuned, note the resonant frequency and preliminarily tune resonator 2 to this frequency to find the proper number of turns on L2A and L2B. Do this by grounding the center pins of both SO-239 connectors to short resonators 1 and 3 to ground. Then, couple a test signal and detector to L2A and L2B using single-turn loops. Add or remove turns on L2 until peak output is obtained at the design center frequency. Final tuning of L2 is done by squeezing and spreading turns on L2A and L2B while using an oscilloscope to observe the passband return-loss response. (See the Appendix for details of the return-loss measurement procedure.)

Tuning is complete when a three-peak passband return-loss response—typical of a third-order band-pass filter—is obtained.

[13]Notes appear on page 41.

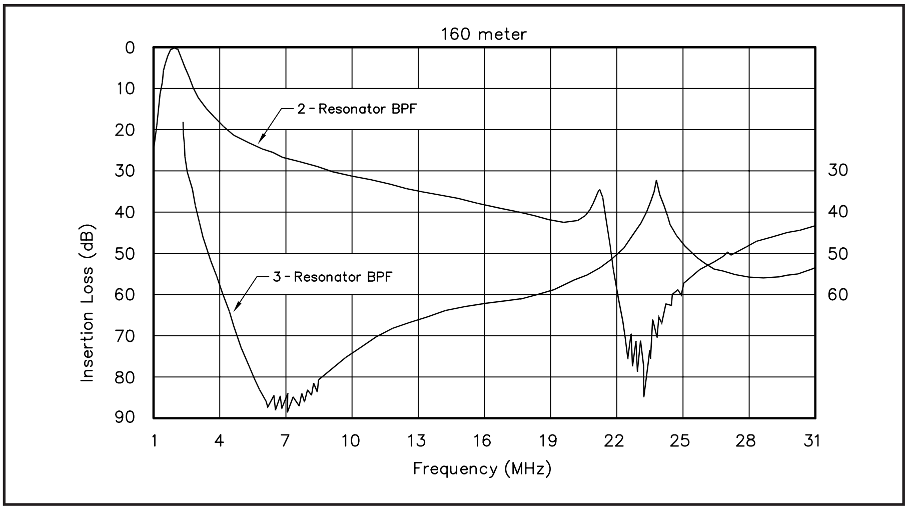


Figure 2— Insertion-loss responses of a commercial 160 meter, two-resonator BPF, and the 160 meter, three-resonator BPF described here. Note how the three-resonator BPF exhibits substantially more loss than the two-resonator BPF between 4 and 10 MHz.

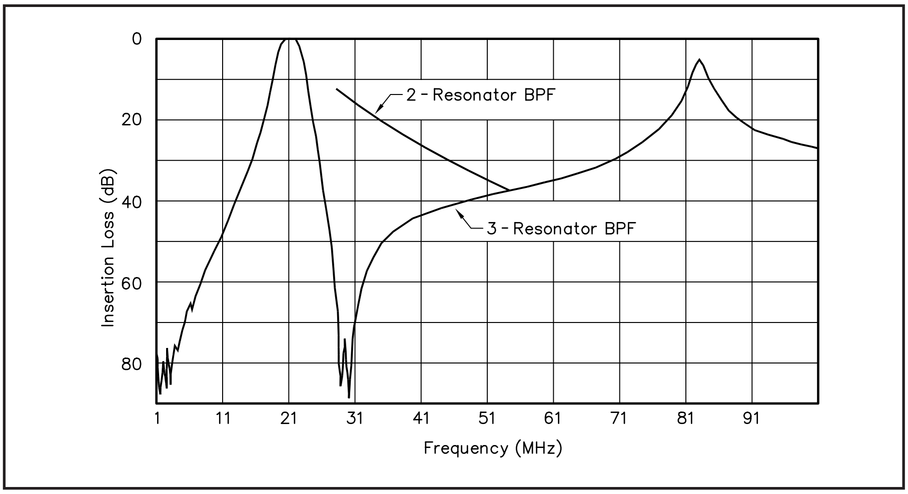


Figure 3— Insertion-loss responses of a commercial 15 meter, two-resonator BPF and the three-resonator BPF. The three-resonator BPF has more than 60 dB loss in the 10 meter band compared to less than 15 dB for the two-resonator BPF, and the three-resonator BPF loss is greater than the two-resonator BPF up to about 52 MHz.

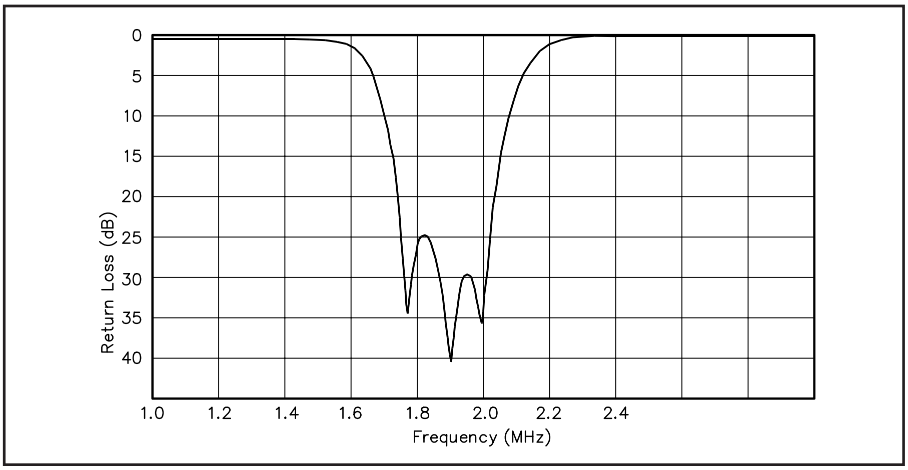


Figure 4— Passband return-loss response of the 160-meter, three-resonator BPF. The three sharp peaks in the passband are typical of the three-resonator BPF. Return-loss minimums of a perfectly tuned BPF are at the same level; however, the minimum return loss of 25 dB indicates that the tuning is quite satisfactory.

The two valleys of minimum return loss should theoretically be equal to the calculated return-loss value listed in Table 1; however, any passband minimum return loss greater than 22 dB is quite acceptable. For the 160 meter BPF, the calculated minimum return loss is 30 dB.

BPF Passband and Stopband Performance

The stopband insertion-loss responses of the 160 and 15 meter three-resonator BPFs are shown in Figures 2 and 3. The stopband insertion-loss response of the commercial two-resonator BPF is included for comparison to illustrate the superior performance of the three-resonator BPF. The superior performance of the three-resonator BPF is mainly due to the series-coupling circuit between resonators 1 and 3 having an inductor in addition to a capacitor, whereas the two-resonator BPF has only a capacitor. Consequently, at frequencies above the upper passband cut-off frequency, the two-resonator BPF looks like a high-pass filter and provides little attenuation to the higher frequencies, whereas the series inductor in the three-resonator BPF provides increasingly greater attenuation as the frequency increases. The stopband responses of the other three-resonator BPFs are similar to the 160 meter and 15 meter BPFs.

Comparing the 160 meter BPF measured insertion-loss response with that of the computer-calculated response in Figure A1 (see the Appendix), you can see that the increase in the measured response is more abrupt than the calculated response. This abrupt attenuation rise is typical of all six BPFs and is attributed to the effect of imperfect coupling between the L1 and L3 50 Ω tap and the rest of the windings.[15] As the tap approaches the top of the coil, the effect of imperfect coupling becomes less and less, so when the tap reaches the top of the coil, the calculated and measured responses are virtually identical. Of course, the component values and impedance level will then be impractical.

In Figure 3, the undesired abrupt drop in stopband attenuation of the 15 meter BPF above 30 MHz is also attributed to the less-than-perfect coupling between the tapped windings of L1 and L3 (see Note 15). However, the use of the quadrifilar winding in L1 and L3 minimizes the effect of the imperfect interwinding coupling and produces an acceptable loss response of more than 40 dB between 35 and 50 MHz. Compare this 40 dB level of attenuation with the substantially lower 14 to 16 dB attenuation of the 15 meter BPF shown in Figure 5, page 36 of the June 1994 *QST* article (see Note 4).

As the frequency decreases below the lower BPF cut-off frequency, the increasing attenuation is caused primarily by the increasing reactance of the series capacitor, and the series inductor of the three-resonator BPF becomes increasingly ineffective. Consequently, the low-frequency attenuation responses of the two and three-resonator BPFs are similar.

Depending on the band, the measured

passband insertion loss of the three-resonator BPF ranges from 0.25 to 0.50 dB. The corresponding power dissipated in the BPF, relative to a 200 W input, is about 11 and 22 W, respectively. The major portion of the power loss occurs in the inductor cores, but there is sufficient surface area in the 1.30-inch powdered-iron cores to dissipate this amount of power without an excessive rise in temperature.

Figure 4 shows a network analyzer plot, provided by WØUN, of the passband return-loss response of the 160 meter, three-resonator BPF. Because being able to observe the return-loss response is crucial in making the final adjustment to L2, it soon became obvious that this particular test had to be performed at the time of assembly. Consequently, I developed a return-loss test procedure using circuits similar to those described by Randy Henderson, WI5W,[16] for testing all the BPFs. Details of the return-loss test procedure and the associated circuits are described in the Appendix. An example of the performance of these filters used during the 1997 ARRL International CW DX Contest is indicated by the comment of N6RO: "The combination of double stubs (tnx K2KW) and W3NQN band-pass filters (tnx K3LR) provided interference-free operation for the first time ever."[17]

Summary

The new BPF design, construction and testing techniques discussed in this article advance the current state of the Amateur Radio art. These new techniques should serve as a useful guide until they are superseded by future improvements.

Assembled and tested band-pass filters are available from me. Send me a business-size, self-addressed, stamped envelope for details.

Acknowledgments

A project of this size and length could not have been completed without the assistance of many others. I am grateful to Tim Duffy, K3LR, for proposing this project and providing recommendations based on his unique experience in running one of the top multi-multi contest operations. His network analyzer plots and heating tests assured that the final BPF designs would meet the special requirements of the multi-multi contester. Tim's contacts with the multi-multi contest-operator fraternity was crucial in distributing a number of BPF sets to those needing a more reliable BPF than currently available. During the later development and testing phase, John Brosnahan, WØUN, provided additional test data with his network analyzer plots and heat run tests.

My thanks to Frank Glatz, Regional Sales Manager of Tusonix, for providing samples of Tusonix capacitors. The samples permitted testing of prototype designs to confirm that the capacitor types and values selected were satisfactory before quantity orders were placed. Harry Roseberry, W1HRZ, of Tusonix Customer Engineering assisted in selecting the proper capacitor types.

Dale Nicol of Micrometals, Inc, discussed with me the temperature limitations of powdered-iron cores, and Micrometals provided the many samples I needed to find the most suitable cores for each BPF design.

Notes

[13]Ed Wetherhold, W3NQN, "Clean Up Your Signals with Band-Pass Filters," QST, May 1998, pp 44-48.

[14]Wes Hayward, W7ZOI, "Beyond the Dipper," *QST*, May 1986, p 17, Figure 6.

[15]Philip Geffe, *Simplified Modern Filter Design,* p 32, Figure 4-4, "Tapped Coil Hazards"; John F. Rider Publisher, Inc, New York, 1963.

[16]Randy Henderson, WI5W, "A Swept-Frequency Generator for Crystal-Filter Evaluation," *QEX*, Mar 1994, pp 3-8. See page 6, Figure 6, for the deflection and sweep circuit.

[17]1997 ARRL International DX Contest CW Results, *QST*, Sep 1997, p 112, third column (under photo).

Appendix

Return-Loss Measurement Equipment and Procedures

Figures A2 and A3 show the deflection and sweep circuit and a block diagram of the equipment used in the return-loss testing of the BPFs. For return-loss testing of the 160, 80, 40, 20 and 15-meter BPFs, I used a B&K Precision 4040 sweep generator. Because that sweep generator has an upper-frequency limit of 26 MHz, I used a Mini-Circuits POS-50 VCO driven by the deflection and sweep circuit shown in Figure A2 when testing the 10 meter BPFs.

Except for revising the deflection and sweep output circuit with the addition of an **AUTO/MAN** switch and using smaller capacitors to increase the sweep rate and ramp

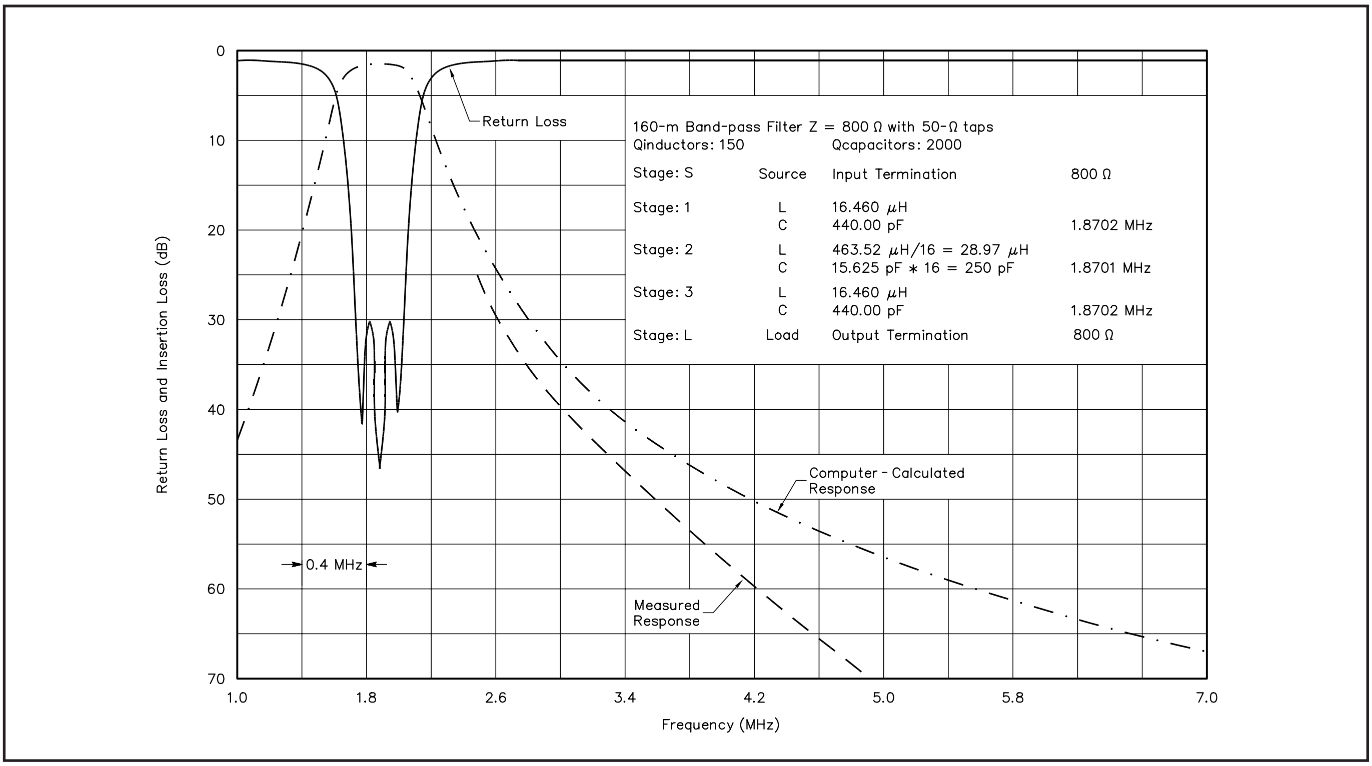


Figure A1—Computer-calculated and plotted return loss and insertion loss responses of a 160 meter band-pass filter selected for assembly.

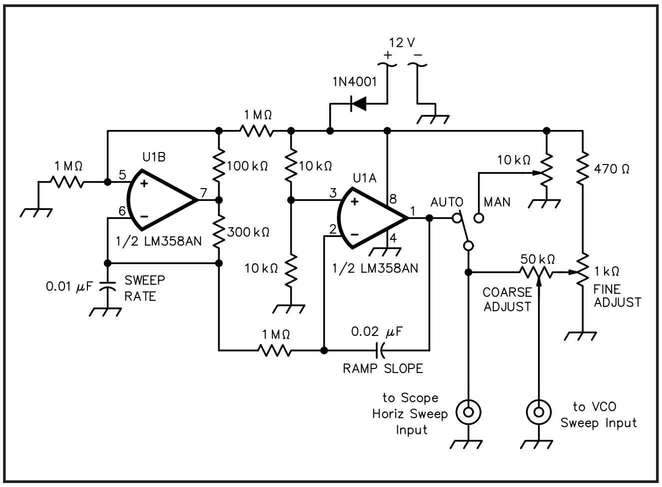


Figure A2—Deflection and sweep circuit used with the Mini-Circuits POS-50 VCO for return-loss testing of the 10 meter BPF.

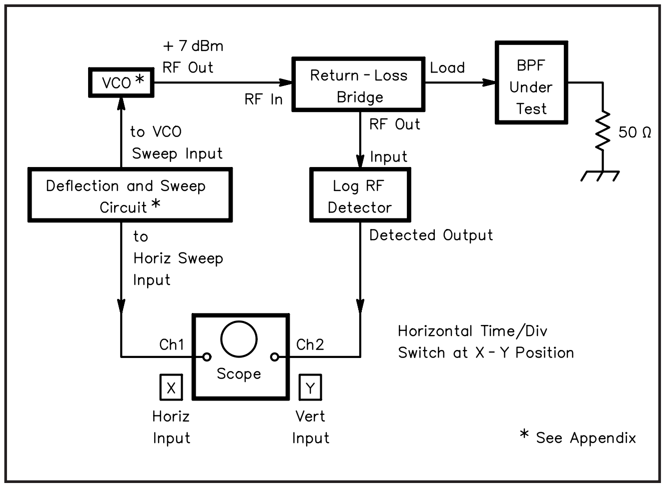


Figure A3—Block diagram showing the equipment arrangement used for measuring the return-loss testing of the BPFs. A B&K Precision Model 4040 sweep generator was used as the VCO on the 160, 80, 40, 20 and 15-meter bands. On 10 meters, a Mini-Circuits POS-50 replaced the B&K Precision unit. The oscilloscope is a TENMA Model 72-3055, with a 20 MHz bandwidth.

slope, it's the same as that used by Randy Henderson, WI5W, in his March 1994 *QEX* article.* It was from Randy's article that I got the idea of using a VCO with a deflection and sweep circuit, a return-loss bridge, a log RF detector and an oscilloscope to observe the return-loss responses of the BPFs. I used commercially available swept oscillators and Zack Lau's RF log detector circuit[†] instead of the four-stage amplifier and detector shown in Henderson's article. A similar article in *Popular Electronics*,[‡] features a sweep oscillator and an RF detector for filter testing.

For the 10 meter BPF tests, I connected the +7 dBm output of the VCO to the input of an RF return-loss bridge (RLB) described on pages 26.41 and 26.42 of *The 1997 ARRL Handbook*. The **UNKNOWN Z** port of the RLB attaches to the input of a 50-W-terminated BPF and the **RF OUTPUT** port connects to the log RF detector.

After some trial and error, a combination of sweep rates and 'scope adjustments produced a swept-frequency return-loss response that related to adjustments made to the windings on the center resonator inductor. Using this equipment and return-loss test procedure, it was possible to adjust all the BPFs to obtain either a three-peak passband return-loss response, or a minimum passband return loss greater than 23 dB indicating that optimum BPF tuning was achieved.

By replacing the BPF with a 60 Ω resistor in the return-loss test setup, I obtained a 20 dB return-loss reference curve against which the BPFs' return loss could be compared. Whenever the minimum return-loss response of a BPF is below the 20-dB reference curve, it indicates that the BPF is not properly tuned and further adjustment of the L2A and L2B windings is necessary.

*Randy Henderson, WI5W, "A Swept-Frequency Generator for Crystal-Filter Evaluation," *QEX*, Mar 1994, pp 3-8. See page 6, Figure 6, for the deflection and sweep circuit.

[†]Zack Lau, W1VT, "A Logarithmic RF Detector for Filter Tuning," *QEX*, Oct 1988, pp 10-11. (Note: In Figure 1, p 10, the ground connection of pin 1 is missing.)

[‡]John J. Yacono's column *Think Tank* in *Popular Electronics,* Feb 1997, pp 77-78; letter from Douglas Ripka, Rebersburg, Pennsylvania: "RF Signal-Strength Circuit." Figure 4 shows a circuit featuring the Motorola MC3356P RSSI IC (received signal-strength indicator) used as an RF log detector to drive the vertical input of an oscilloscope.

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