Garbage In—*No* Garbage Out

Turn hardware store purchases into a cavity filter for satellite and 2m reception.

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Do you capture pictures from Automatic Picture Transmission (APT) weather satellites on 137 MHz? If so, you probably are plagued by aircraft interference. The APT satellite frequencies are uncomfortably close to the aviation band used by every airplane and airport in the world. I live right under the glide path of San Francisco International Airport and, to make matters worse, I run a high-gain receiver and a wideband GaAsFET preamp so that I can copy the satellites down near the horizon. I was a prime target for the endless flow of planes that passed over my house, resulting in innumerable glitched and noisy weather satellite images.

The bandpass cavity shown here was like pennies from heaven. Aircraft interference is gone, and I get noise-free pictures. But let me offer you some advice: Don't test the cavity like I did – in the middle of my home office where my computer and WX receiver are. The QRM from the XYL was far worse than that from the aircraft.

There is something fascinating about building an RF device from hardware store parts, especially a 20-gallon garbage can. Getting good results from such "garden" variety materials is very satisfying. By the way, you 2 meter types can effectively modify this cavity for use at 144-148 MHz by merely taking an inch off the center pipe.

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Why you need a cavity

Many hams do not know that modern superhet receivers develop selectivity late in their circuitry. **Fig. 1** shows a simple block diagram of a typical modern receiver. The front end, including the RF amplifier, must be extremely broad. Its job is to span a broad range of frequencies. The 2 meter band, for example, is 4 MHz wide. The receiver's front end, by design, cannot exhibit high selectivity. Even receivers with helical resonator front ends are several MHz wide. Many of the commercially available receivers used by hams for the weather satellite band, like my Hamtronics R-138, are even broader.

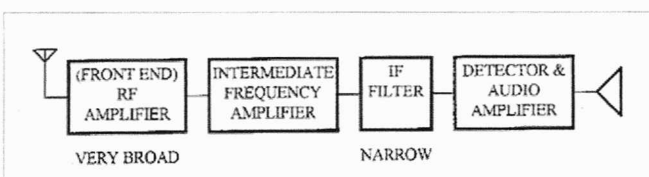

Fig. 1. Block diagram of a typical superheterodyne receiver. Selectivity is developed late in the circuit, in the IF filter. The earlier stages, especially the RF front end, are wide open to overload by strong adjacent signals and other noise.

A broad, unprotected front end like this can easily be overloaded (desensed) by signals several MHz off frequency. True, the IF filter in your receiver may stop you from hearing these signals, but such signals destroy the working sensitivity of your receiver whether you hear them or not. Even the normal noise in the passband of the front end of your receiver degrades the sensitivity. A receiver may show spectacular sensitivity when connected to a signal generator, but when it's connected to an antenna in a noisy environment, the working sensitivity of the receiver may be terrible. This is something many ham repeater owners often fail to consider.

By adding a passive filter ahead of your receiver and preamp, you will eliminate the aircraft interference the correct way and the effective sensitivity of your receiver will be greatly increased. I not only eliminated the interference from planes and the airport's tower, but I can now copy the WX satellites several degrees lower in the sky. Amazing, all of this from a garbage can, a piece of stovepipe, two connectors, and some 14 AWG wire!

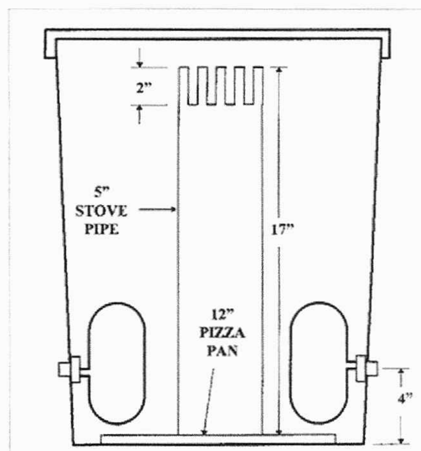

Fig. 2. Cross section of cavity, showing dimensions of inner conductor and placement of coupling loops.

Cavity basics

Like most of the cavities used in duplexers, this one is a 1/4-wavelength section of large diameter coaxial transmission line. It is open at one end and shorted at the other. The lid, as long as it is not too close to the open end, acts mostly as an RF-tight cover (see **Fig. 2**).

In designing any resonant cavity, theory specifies three things required for achieving efficiency: large volume, a 3.6:1 outer-to-inner conductor ratio, and low resistivity. Let's examine each briefly.

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Volume

Quite simply, the bigger the cavity, the better. Anything up to roughly 1/3 wavelength in diameter (21 inches at 137 MHz) will work. Above 1/3 wavelength, a cavity breaks into alternate modes of oscillation which have too much loss for filter service. Selectivity, the cavity's Q factor, improves in direct proportion to diameter. Since I was already constrained to make my cavity roughly 20 inches tall (1/4 wavelength on 137 MHz), when I visited my local hardware store in search of cylindrical metal containers with lids, metal garbage cans immediately caught my eye. They commonly come in two sizes: 20-gallon and 33-gallon. The smaller size is 17 inches in diameter and 22 inches tall. It was just what I needed, though the larger size would have worked well too.

Outer-to-inner ratio

A little-known fact about coaxial transmission line is that loss is minimum at a characteristic impedance of roughly 77 ohms. This is why we use 75-ohm cable where minimum signal loss is important, such as for TV receiver cables. We use 50-ohm cable for power applications because at 50 ohms impedance the cable will carry maximum power without breakdown.

The characteristic impedance of air line is determined mostly by the ratio of the diameter of the outer conductor to the inner conductor. For those of you who like mathematics, the formula for air-insulated coaxial line is:

$Z_0 = 138 \log(D_O/D_I)$

D_O = Diameter of outer conductor (the garbage can)

D_I = Diameter of inner conductor (both in the same units)

Since we want Z_0 to be 77Ω, we simply substitute in the above equation and find that D_O/D_I must equal 3.6.

In other words, the ratio between the garbage can diameter and the inner conductor needs to be 3.6:1 for low loss. Using a tape measure while still in the hardware store, I discovered that ordinary 5-inch galvanized sheet metal stove pipe is very close to the ideal size needed when used with a 17-inch diameter garbage can. Modest variations in this ratio are not critical, however.

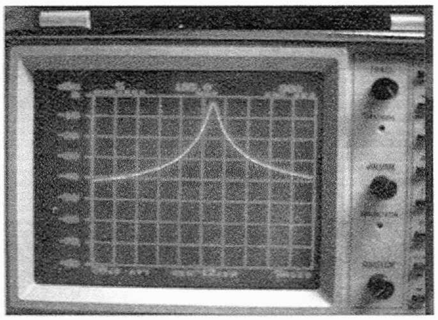

Photo A. Spectrum analyzer display of the filter's frequency response.

Low resistivity

The biggest source of loss in cavities is ohmic loss in the metal. It might not seem that something this large could have much resistance, but don't forget skin effect. RF current, even at low frequencies, flows in a thin film on the inner surface of a conductor, so even a large cavity can have significant ohmic losses. The galvanized surface of the garbage can is not a particularly good conductor. Aluminum or copper would be much better, but at this size and at 137 MHz the losses are modest. This is, after all, a receiving application where a few dBs are not critical. For transmitting purposes or duplexer use, you should go to the trouble of lining the inner surfaces of the cavity with copper or aluminum foil, particularly at the bottom and on the inner conductor.

The loops

Hams tend to consider cavity design a "black art," but it's not. Coupling loops seem especially mysterious, but are actually fairly straightforward. They simply need to be equal in size and shape, oriented perpendicular to the magnetic field, and placed near the shorted end of the cavity. The exact location, wire size and loop shape have very little effect on performance once they are optimized.

I simply kept changing the area of both loops, by altering the amount of wire or by bending the loops, until I obtained critical coupling. Critical coupling is the condition in which, as the loops get larger in area, losses have just begun to reach a minimum and selectivity is just beginning to fall off. This point is easy to find using a spectrum analyzer with a tracking signal generator (see **Photo A**). For this project, merely duplicate my dimensions and you'll be very close.

Construction

Dimensions and parts placement are shown in **Fig. 2**. Construct the center conductor by cutting a length of 5" stove pipe 18" in length (17" for 2 meters). At the bottom end, make axial cuts, 1" long and 1" apart, around the end to form bend tabs. Do the same at the top end, but make the tabs 2" long and 1/2" apart (see **Photo B**). At the bottom end, bend the tabs outward perpendicularly. At the top, break off every other tab, leaving the remaining ones straight. You will later bend these slightly to tune the cavity.

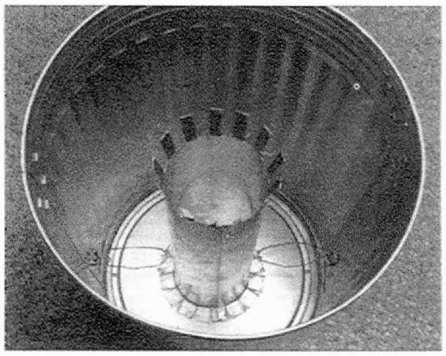

Photo B. Interior of completed filter showing center conductor soldered to pizza pan (in place) and coupling loops.

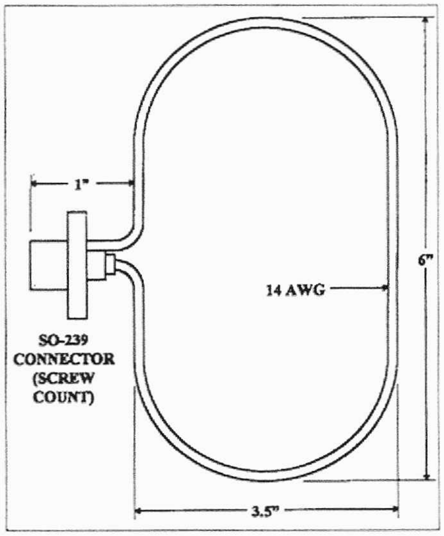

Fig. 3. Detail of coupling loops. Mount in the position shown.

Solder the bottom of the center conductor to the center of an inverted 12" common pizza pan (use a large, high wattage soldering iron). Use a pan that is not plastic-coated, or scrape off the plastic and tin the surface before soldering. Do not use excessive solder; it's required only for mechanical support. Capacity and skin effect make the necessary RF connection. Finally, secure the center conductor, on its pizza pan, into the bottom of the garbage can with a couple of screws.

Make the loops as shown in **Fig. 3** and **Photo C.** Attach the loop to its connector prior to installation. Install the connector and loop from the inside, rather than the outside. This makes the loops easier to remove. Use the kind of SO-239 connector that installs with four 4-40 screws, as opposed to the type that uses a large locking nut. Once the loops are installed, carefully bend the wire until both loops are the same shape and in the same position. The loops should be extended sideways so that they come within about 1/2" of the center conductor. Install them so that the end of the loop connected to the center pin is downward toward the bottom of the cavity. If you intend to install the cavity out of doors, be sure to seal the connectors from the weather. The lid need not be secured, but some wide plastic tape to hold it on would be a good idea.

Tuning the cavity

Be sure that the lid is on whenever you measure the resonant frequency. Without the lid, the resonant frequency will be quite a lot higher. The ideal test equipment to tune the filter is a spectrum analyzer with a tracking signal generator. With it you can display the shape of the bandpass curve, and set the coupling of the loops and the resonant frequency.

A less elegant way to tune the filter is with a dip oscillator. To do this, solder a small test loop of wire, roughly one inch in diameter, onto a PL-259 connector. Connect it to one connector on the cavity and connect a non-inductive 50-ohm terminating resistor on the other. You will then be able to "dip" the cavity at the small test loop.

Another possible method is to use an RF signal generator to inject a signal into one side and an oscilloscope on the other side of the cavity as a detector. Again, be sure that the cavity has a 50-ohm terminator installed on the output. The oscilloscope will have to be able to display a signal at 137 MHz.

If you lack the above equipment, you can also tune the cavity with just a signal generator and a receiver. Reduce the generator output until the received signal is near the quieting point of the receiver, and adjust the loops for best quieting. If you can't get your hands on a signal generator you can loosely couple some signal from a distant transmitter (yours or the satellite's) into the input of the cavity. Use a step attenuator on the output, and connect it to your receiver. Once again, adjust the attenuator to get the received signal down near the quieting point of the receiver, and make your adjustments.

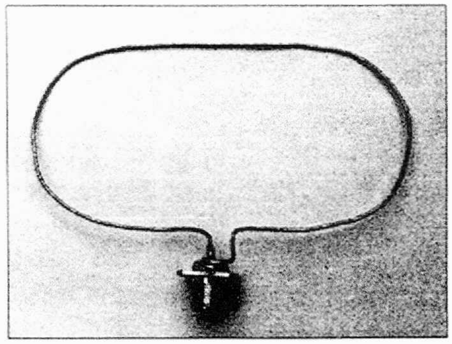

Photo C. Detail of a coupling loop.

Tuning is a simple matter. As you bend the tabs outward at the top end of the center conductor, the resonant frequency of the cavity will decrease. Effectively, you are adding capacitance. Such a cavity is electrically a parallel tuned circuit. Altering the capacitance in this way will not decrease the Q of the cavity to any degree. Q is determined almost entirely by cavity volume and metal resistivity. Tune the cavity for the center of the WX satellite band, or about 137.6 MHz. Changing the length of the inner conductor will also change the frequency. For 2 meters, for example, the center conductor will need to be roughly one inch shorter.

After building this cavity, I have to admit that it qualifies for an honored place in the long-standing ham practice of making do with very little. It also fits nicely into the grand ham tradition of tuna fish can, filing cabinet and lunch box radios. So if you are being plagued by pesky aviators or mountain-top intermod, give this project a try. You'll find it a winner, if you can get it by the XYL. 73

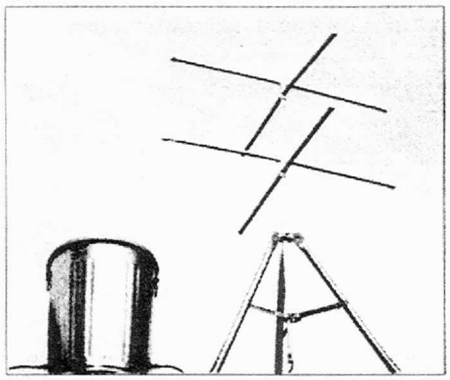

Photo D. Author's turnstile weather satellite antenna and cavity filter on the roof of his house.