

Joe Carr's Radio Tech-Notes

Filter, Attenuator, Preamplifier, Preselector

--- or Barefoot?

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Radio enthusiasts just love to hang accessories on their equipment. For shortwave receivers and VHF/UHF scanners, the list of popular accessories on the antenna end includes *filters, wavetraps, attenuators, preamplifiers, and preselectors*. If you read all the hype for these products, then you might be tempted to think of the story about the "gas saving" devices sold for cars. If you put all of those things that will improve the mileage on any one car, then you would have to stop every fifty miles to bail the excess gas out of your tank. And if all those weight loss products worked as advertised, then an overweight person ought to be come absolutely anorexic in two-weeks time by taking all of them at once. But that's not how the real world works. All of the radio accessories mentioned above have their legitimate uses, but not all of them are suited to any one situation. Indeed, for many situations none of them are needed. Let's take a look at each of these classes and see when, where and if they are needed. But first, let's take a look at the basic function of a radio receiver.

Radio Receiver Function

A radio receiver is an electronic device that is designed to *pick up and demodulate a desired radio frequency and reject all others*. Both functions are important to the success of the receiver.

The *front-end* of the receiver is responsible for selecting the particular frequency that is tuned in, and also for rejecting all other signals. The front-end consists of a local oscillator and mixer to convert the RF signal to an intermediate frequency (IF), and some sort of input filtering to limit the range of frequencies that can be applied to the mixer. Some receivers also have a RF amplifier between the input filtering and the mixer to improve sensitivity.

The reason that input filtering is needed is that the RF amplifier and the mixer have a limited *dynamic range*. The dynamic range is a measure of how much RF energy the circuit can handle before going into overload. If the circuit overloads, then the performance of the receiver is severely reduced. On crowded bands, or where there are one or more

strong local stations, the dynamic range of the receiver can quickly be used up.

The filtering limits the frequencies that can be applied to the receiver, thereby freeing more of the overall dynamic range for productive use on signals that are within the desired band. Two types of input filtering are used: 1) single-tuned variable frequency tuners and 2) bandpass filters. The first category typically requires a special front panel control marked *Antenna* or *RF*, or something similar to resonate the input tuning circuit. The bandpass method uses a special bandpass filter, several of which may be selected when changing bands.

Accessory Filters

Filters are frequency selective devices that reject some frequencies and pass others. Typical configurations are:

1) *Low-pass filters*: pass all frequencies below a cut-off frequency (F_c) and reject all frequencies above F_c .

2) *High-pass filters*: Pass all frequencies above F_c and reject all frequencies below F_c .

Note: *Low-pass and high-pass filters are inverse of each other.*

3) *Bandpass filters*: These filters pass all frequencies that are above a lower cut-off frequency, and below an upper cut-off frequency.

4) *Bandstop filters*: A bandstop filter is the inverse of a bandpass filter. It will stop all frequencies above the lower cut-off frequency and below the upper cut-off frequency. The notch filter is a narrowband bandstop filter, and is usually called a wavetrap. That filter will be examined separately.

Discussion. The reason for using an accessory filter ahead of the receiver antenna input is to limit the range of frequencies that can be applied to the receiver. This action is used to prevent overload of the front-end circuits.

Pro: An accessory filter can solve some tremendous problems, especially if there are strong local stations or the front-end of a particular receiver is lacking in

capability (as are many low cost receiver designs). No filter is perfect at attenuating out-of-band signals (some will always get through), but the degree of attenuation can be very large and is usually quite significant.

Con: All filters have an insertion loss, so will also reduce the strength of in-band signals. This effect may not be a problem, however, if the ratio of the desired signal to the undesired signal is increased significantly by using the accessory filter.

Con: The use of a filter limits band changing unless all desired bands are within the passband of the filter. This problem can be mitigated by using a switchable filter, or by using a coaxial switch to select from several different filters.

Con: Most filter designs are sensitive to input and output impedances. Filter circuits tend to be designed for impedances of 50-ohms, 75-ohms or 300-ohms, depending on use. By far, the 50-ohm version is of use to general radio enthusiasts, and 75-ohm is used in television receivers (older sets used 300-ohm). If you mismatch the input or output impedances, then you might produce unpredictable results and also cause problems with the input filtering inside the receiver.

Recommendations: Use an accessory filter if there is any form of receiver problem caused by overloading. The overloading could be due to crowded band conditions or by a single (or several) strong local stations. Problems to look for include: desensitization, intermodulation distortion, generation of spurious harmonics (hearing a station on its harmonics when its transmitter is clean), and splattering or broadening of signals.

Select a filter that best matches the application. For example, if you find AM BCB interference on your shortwave receiver, then select a high-pass filter with a cut-off frequency between 1700 and 2500 Khz. For FM BCB interference to VHF/UHF scanner receivers, select the filter that matches the band of interest:

a) If all desired frequencies are above 108 Mhz, then select a high-pass FM BCB filter with a cut-off frequency at or above 108 Mhz;

b) If all desired frequencies are below 88 Mhz, then select a low-pass FM BCB filter with a cut-off frequency at or below 88 Mhz;

c) If the desired frequencies are both above and below the 88 to 108 Mhz FM BCB, then select a bandstop filter tuned to the FM BCB (also see Wavetraps discussion below).

d) If you are only interested in a narrow range of frequencies, then use a bandpass filter. Examples include operation on single ham bands, Jupiter reception (18 to 25 Mhz), monitoring the weather satellite bands between 120 and 144 Mhz, and so forth.

Wavetraps

A *wavetraps* is a special case of a bandstop filter. It notches out one frequency, and passes all others. Series tuned wavetraps are placed across the transmission line, so that it's low impedance at the resonant frequency short circuits the undesired frequencies, while passing all others. The parallel resonant variety is placed in series with the transmission line, and uses its high impedance at resonance to block further transmission of the undesired signal.

Some wavetraps circuits use both series and parallel forms. If the two wavetraps are tuned to the same frequency, then the attenuation at that frequency is increased. If the two wavetraps are tuned to two different frequencies, then the two traps will work independently of each other with minimum mutual interference.

Pro: The wavetraps has the same advantages as other filters (see discussion above). It also has the added advantage of taking out a single strong signal that is causing most of the problem. For example, if you live close to an AM or FM broadcast station, or a commercial landmobile radio station, then you might experience various forms of interference due solely to that signal. A wavetraps to notch out the offending signal will work wonders for your reception on other frequencies.

Con: The wavetraps also has most of the disadvantages of the other forms of filter. In addition, they must be tuned to the frequency of the undesired signal.

Recommendations: Use a wavetraps when there is only one or two strong local signals that need to be reduced.

[**Note:** *Half wavelength shorted transmission line stubs are often used as wavetraps.*]

Attenuators

Attenuators are resistor circuits, or sometimes resistor-capacitor circuits, that uniformly reduce all frequencies a specified amount (usually stated in decibels - dB). A typical attenuator will work from frequencies near DC to well into the VHF or UHF regions. Fixed attenuators offer one attenuation ratio such as 1 dB, 6 dB, 12 dB, 20 dB and so forth. Variable attenuators are smoothly adjustable to any attenuation ratio within its range. A switch selectable attenuator allows you to select one or more fixed attenuation ratios. If more than one ratio is selected, the overall ratio is the sum of the individual ratios.

Discussion. It seems counterintuitive to place a device in series with the antenna that reduces signal levels, i.e. reduces sensitivity. Normally that would be the case. However, the purpose of the attenuator is to reduce overall sensitivity when a strong local signal, or very high amplitude signals in a busy band, overloads the front end. If the front-end is overloaded, then desensitization may occur. Alternatively, severe intermodulation distortion might be noted. An attenuator reduces all signals equally, and if used correctly, will reduce the overall RF energy applied to the receiver front-end enough to back it out of the distortion region of its output-Vs-input power curve.

Pro: An attenuator can remove the effects of strong local signals across the band, not at just one frequency. The attenuator can significantly improve the performance of a receiver in cases where such strong overload is causing problems. Many modern receiver designs include a built-in attenuator exactly for this reason.

Con: The attenuator reduces all signals equally. It is possible that it will reduce weak signal capability of the receiver too much. However, if the receiver is driven severely into the distortion region of its curve, then the attenuator may mitigate the problem rather than add to it.

Con: The attenuator produces noise of its own. This noise is due to thermal agitation of the atoms inside the resistors. In some cases, especially where very weak signals (near the noise level) are being sought, the added noise could deteriorate performance. This is rarely a problem, however.

Recommendation: Use a switchable or variable step attenuator that can be switched in and out of the circuit. When strong local stations are present, connect the attenuator in the line. Otherwise, leave it out. Always use the minimum attenuation ratio that accomplishes the job.

Preamplifiers and Preselectors

These devices are different, but serve overlapping functions so are considered together. A *preamplifier* is a wideband RF amplifier that is positioned between the receiver and the antenna. In some cases, the preamplifier is mounted at the antenna and is used to overcome transmission line losses. In other cases, it is positioned right at the receiver antenna input.

A *preselector* is a tuned circuit that passes the desired frequencies. As the name implies, a preselector pre-selects the RF signals that will be applied to the receiver input.

The preselector may or may not be amplified: an *active preselector* is amplified, and a *passive preselector* is not amplified. Some preselectors offer both active and passive modes depending on switch settings. Typical installation of a preselector is right at the antenna terminals of the receiver, or through a short piece of coaxial cable to permit operator access.

Discussion. Preamplifiers and amplified preselectors have an inherent attraction because they appear to make the receiver more sensitive. However, there are some problems that can cause performance of the receiver to deteriorate when amplifiers are used ahead of the receiver antenna input.

One such problem is that the amplified signal may push the receiver into the distortion region of its operating curve, i.e. above its normal maximum allowable signal level. When this happens, desensitization or intermodulation may

occur. Receiver performance is severely impaired when this problem occurs.

An example of intermodulation from overload was reported in the amateur radio press not long ago. An amateur operator working in the 2-meter ham band was told that he had a transmitter problem because his signal appeared at multiple spots in the band. The problem was traced not to a "dirty" transmitter, but rather to the fact that the receiver operator who reported the problem was using two cascaded 30-dB preamplifiers ahead of a very sensitive VHF receiver. The transmitter was essentially "local" so produced enough signal to drive the amplifiers or the receiver into saturation (giving rise to intermods).

Another potential problem is that the amplifier increases the level of both the noise and the signal equally. If there is no improvement of *signal-to-noise ratio* (SNR) when the preamplifier or amplified preselector is inserted, then there is also nothing gained by using the device. All you do in that case is hear the same trash at a lower volume control setting!

Related to the SNR problem above is the fact that all amplifiers produce noise of their own. This noise is seen by later stages (or the receiver) as a valid signal and amplified right along with the regular signals. If the noise level of the external amplifier is excessive, then the overall SNR of the receiver is deteriorated. System noise figures are dominated by the first stage in a cascade chain. If the additional amplifier has a noise figure that is significantly less than the noise figure of the receiver, then some improvement might occur. Otherwise, there will be either no change or a deterioration of the noise situation.

Preselectors, both active and passive, pre-tune the signals desired. Some preselectors are single-frequency devices and have a tuning knob. Others are essentially bandpass filters that limit the incoming signals to a specified band. In either case, some of the problems attributed to wideband preamplifiers are somewhat mitigated by the preselection that takes place. By limiting the input frequencies allowed to enter the receiver both the natural noise and unwanted signals are removed, so the receiver can concentrate its resources on the desired signals.

Recommendations: If the weak signal performance of a receiver is bad on all or a major portion of the available frequencies, and there are no strong local signal sources contending for attention, then use a wideband preamplifier ahead of the receiver. The preamplifier selected should have a noise figure lower than that of the receiver. Further, the preamplifier gain should be as low as is needed to accomplish the job. Using gains larger than the minimum needed accomplishes nothing and may deteriorate receiver performance.

Preselectors are useful where you need help on only a few frequencies, or a specific band. They require tuning, which is a problem for some people, but they also provide improved weak signal performance in crowded bands, or where there is a strong local out-of-band signal source preventing reception of the weaker signals.

[Note: Some preamplifiers or preselectors will oscillate under certain conditions. Battery operated models sometimes oscillate when the battery voltage is low. When this occurs, the oscillating signal may be radiated from the antenna attached to the amplifier, causing illegal (and at least impolite) interference to nearby receivers. Many a case of television interference (TVI) has been traced to faulty TV master antenna amplifiers!]

[Note: High quality shortwave and VHF/UHF communications receivers rarely require either a preselector or preamplifier. They tend to have sufficient sensitivity for even most weak signal situations. If such receivers are being used, then it will probably work best when running "barefoot" (i.e. no accessory amplifiers ahead of the antenna terminal). A preamplifier or preselector tends to help these receivers only when very weak signals are being sought, or where there is a large amount of in-band and adjacent band interference. 888Even then, the performance improvement is conditional on the SNR being improved by the addition of the amplifier.]

[Note: Some small portable shortwave receivers have very good sensitivity but poor dynamic

range. Most of those receivers will not accept a preamplifier or amplified preselector without creating overload problems. So avoid the temptation to use these accessories, even if the receiver has an external antenna connection in addition to its internal loopstick or telescoping whip antenna.]