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INTRODUCTION TO FILTER STRUCTURES FOR RADIO SIGNALS

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INTRODUCTION TO FILTER STRUCTURES FOR RADIO SIGNALS

Introduction

This paper is an introduction to filter structures used in the transmission and reception of radio signals. It will begin with an explanation of a resonant cavity and goes on to show how the filter is used in duplexers, pre-selectors, multicouplers and combiners.

Resonant Cavities

Cavities are the basic building block in filters. Typical construction consists of a cylindrical cavity, a central tuning rod assembly and one or two loops which one connects to using the connectors on top of the cavity. The cylindrical cavity is often referred to as a "can", but it is really much more. A typical cavity cross section is shown if figure 1.

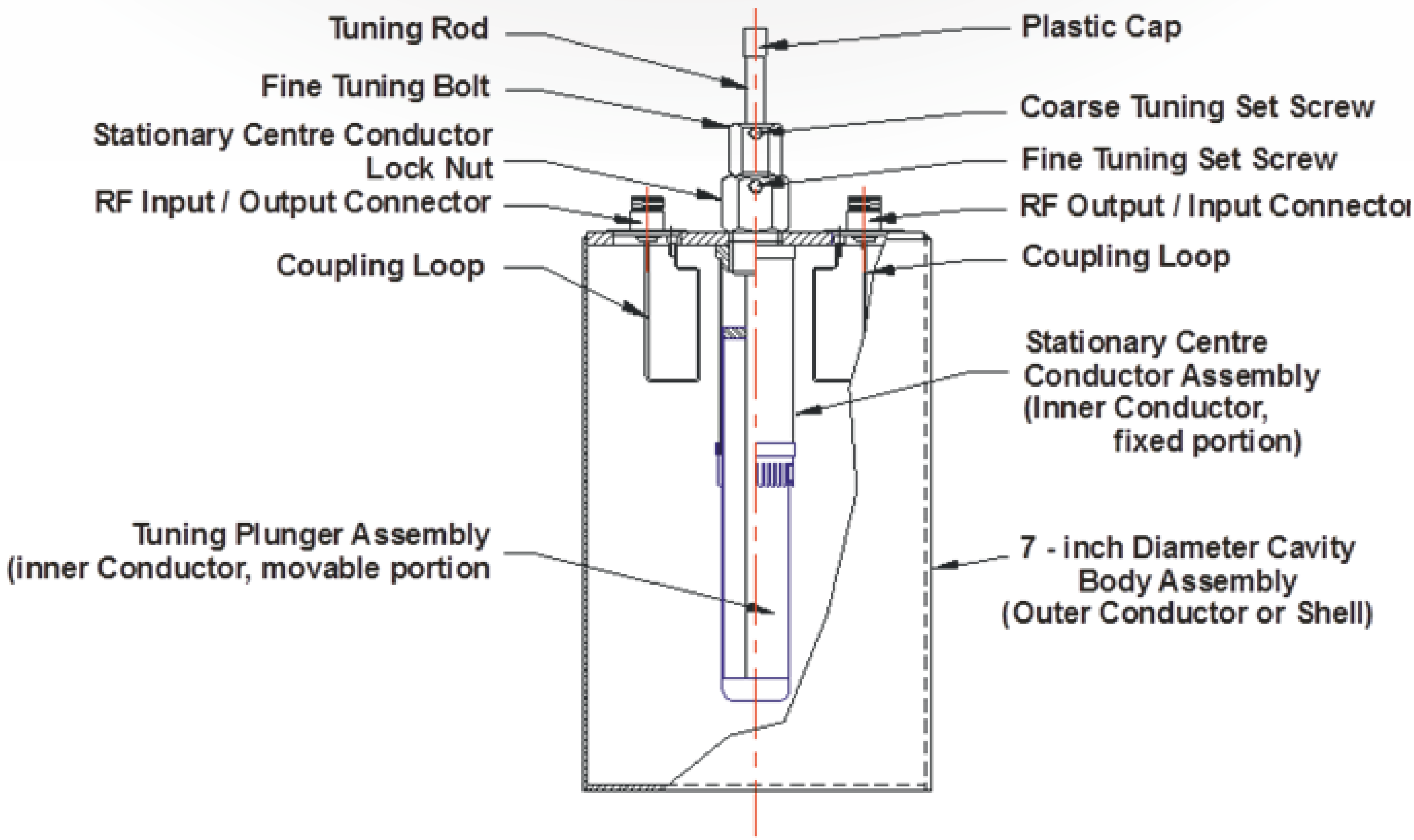

Figure 1, Cavity filter cross section is illustrated

The operating frequency is determined by the length of the stationary center conductor probe plus the exposed length of the moveable plunger tuning probe. Frequency adjustments can be performed on site by moving the tuning rod in a specific manner. The amount of signal loss when a signal passes through the cavity, called insertion loss, is determined by the angular position of the loops with respect to the tuning rod. These loops are rotated together to set the desired insertion loss of the cavity. One might expect that the minimum insertion loss setting would be most desirable.

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Certain system requirements, such as separation between desirable and undesirable frequencies, may make the minimum setting impossible. Sinclair Technologies cavities have an insertion loss setting that varies between 0.4 and 3dB.

A cavity filter only does one of two things. One is to allow a given range of frequencies to pass through and the second is to stop a specific range of frequencies from passing through. By connecting multiple cavities together the pass or reject frequency range can be made quite narrow, effectively passing or rejecting only one signal.

Filters are characterized by their attenuation versus frequency. A typical curve for a band pass type is shown in figure 2. Similarly, a typical curve for a band reject type is shown in figure 3. On these curves, minimum attenuation, which is the lowest loss is shown at the top of the curve. The bandpass filter passes the tuned frequency with the least amount of attenuation. The band reject filter attenuates the tuned frequency but leaves other signals relatively unaffected.

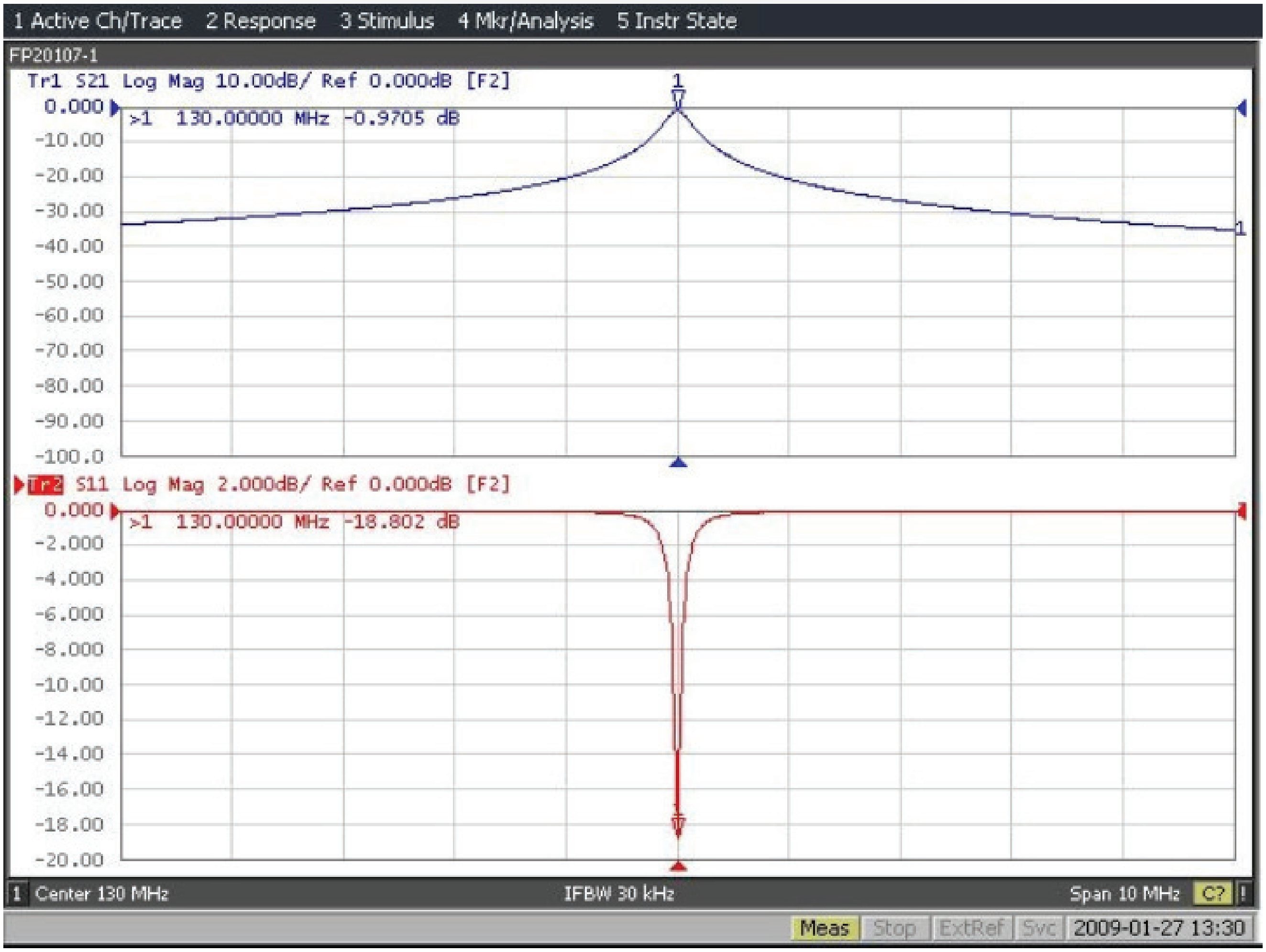

Figure 2, Typical band pass cavity filter curve

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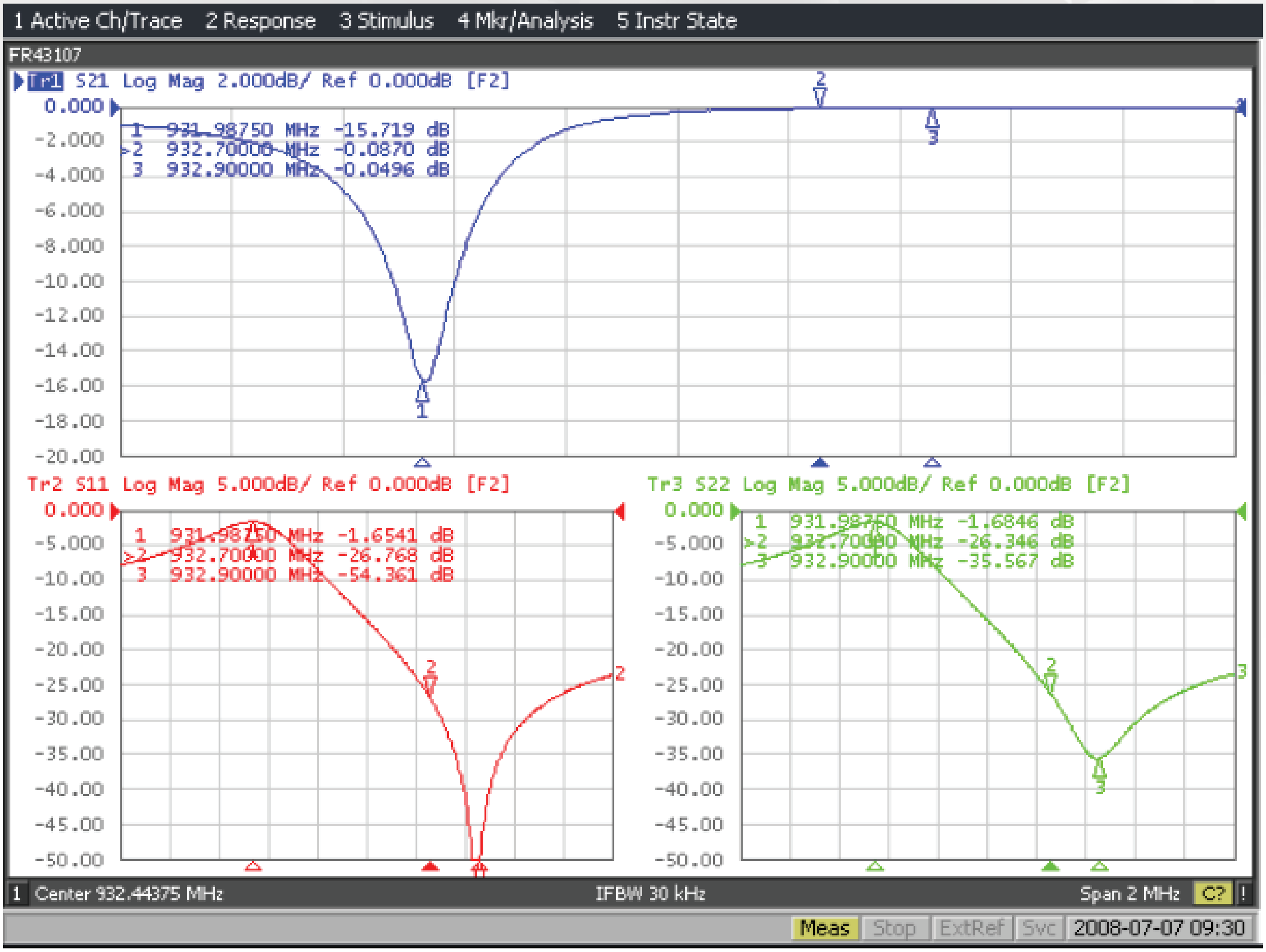

Figure 3, Typical band reject cavity filter curve

Connections for the two types of filters are shown in figure 4. The pass connection is straight forward as the signal passes through the cavity. The reject type filter appears different from what may be expected.

The reject cavity is tuned to a short circuit at the frequency to be rejected. A critical length quarter wave line section transforms this short circuit into an open circuit at the junction. As a result, the reject frequency is reflected but all other signals at different frequencies pass through unaffected.

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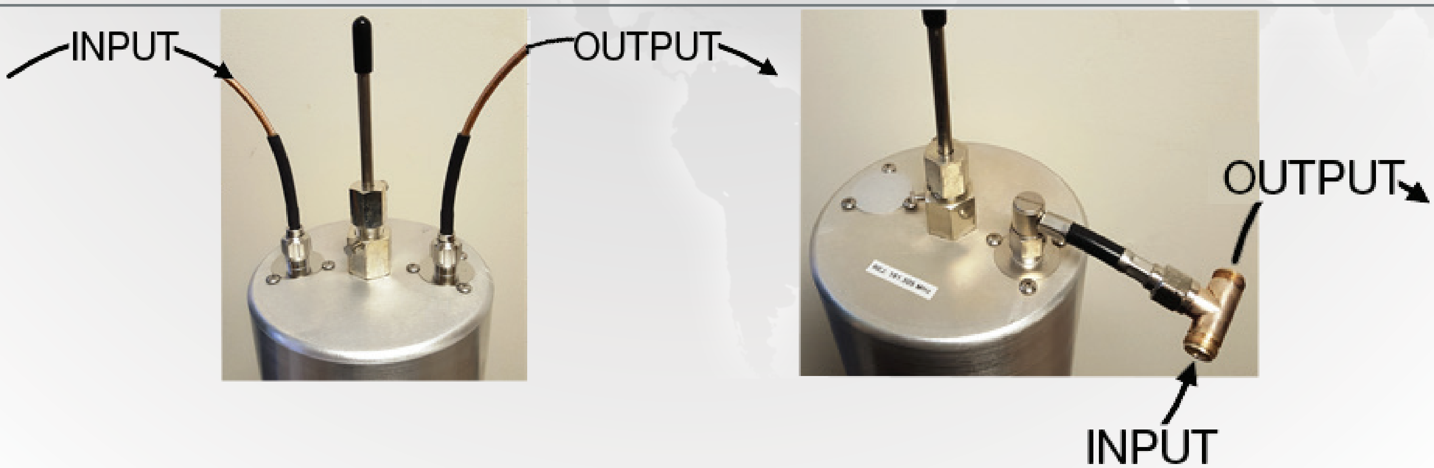

Figure 4, Connections for a bandpass cavity (left) and a band reject cavity (right)

If a very selective pass or reject response is required, pass or reject cavities are cascaded to produce a steeper slope in the filter response curve. Filter selectivity requirements are determined by other radios in use at the site. If a transmitter and a receiver are close together in frequency, precise filtering is important in order to prevent their interaction with each other. Increasing the isolation at adjacent frequencies can be done in three ways. One method is to increase the attenuation on an individual cavity as shown on the left side of figure 5. A second method is to combine two or more cavities in series. Cascading cavities changes the slope of the response curve while increasing the insertion loss. The third method is to use a larger diameter cavity such as shown on the right side of figure 5. Cascading the cavities or increasing the size of the cavity both result in better filter selectivity, but at a higher cost. The single 7 inch diameter cavity has higher losses and less selectivity. In figure 5 below the amount of filtering in dB that is provided at a certain distance in KHz or MHz from the tuned pass frequency is shown like "-10dB @ 900 KHz".

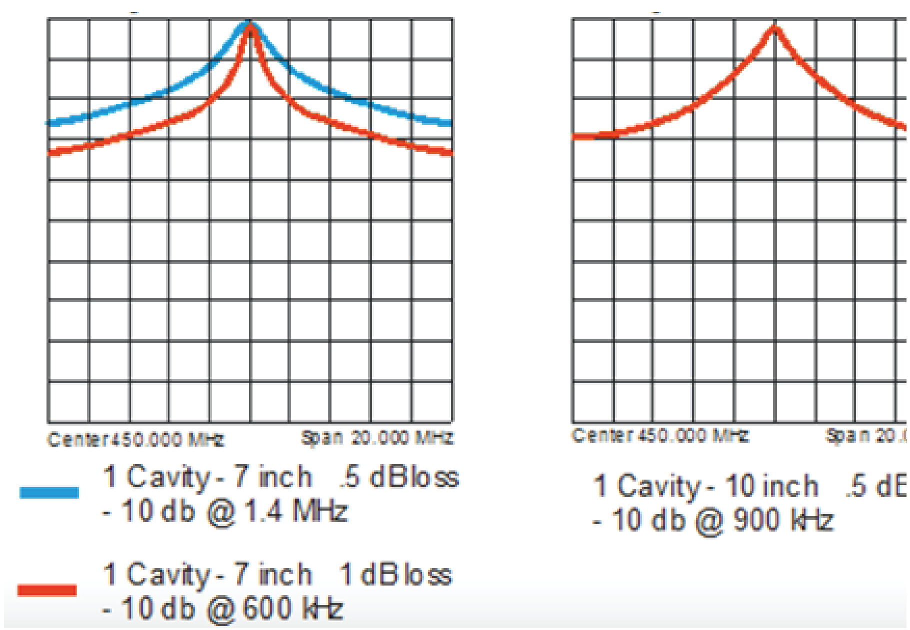

Figure 5, Increased insertion loss (left) and larger cavities (right)

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A modification on the reject cavity is called a Q-Circuit cavity. This cavity looks like a reject cavity but has a small capacitator in the loop. This loop produces a characteristic that combines both pass and reject characteristics. The reject notch can be positioned on either side of the pass band. A typical curve is shown in figure 6.

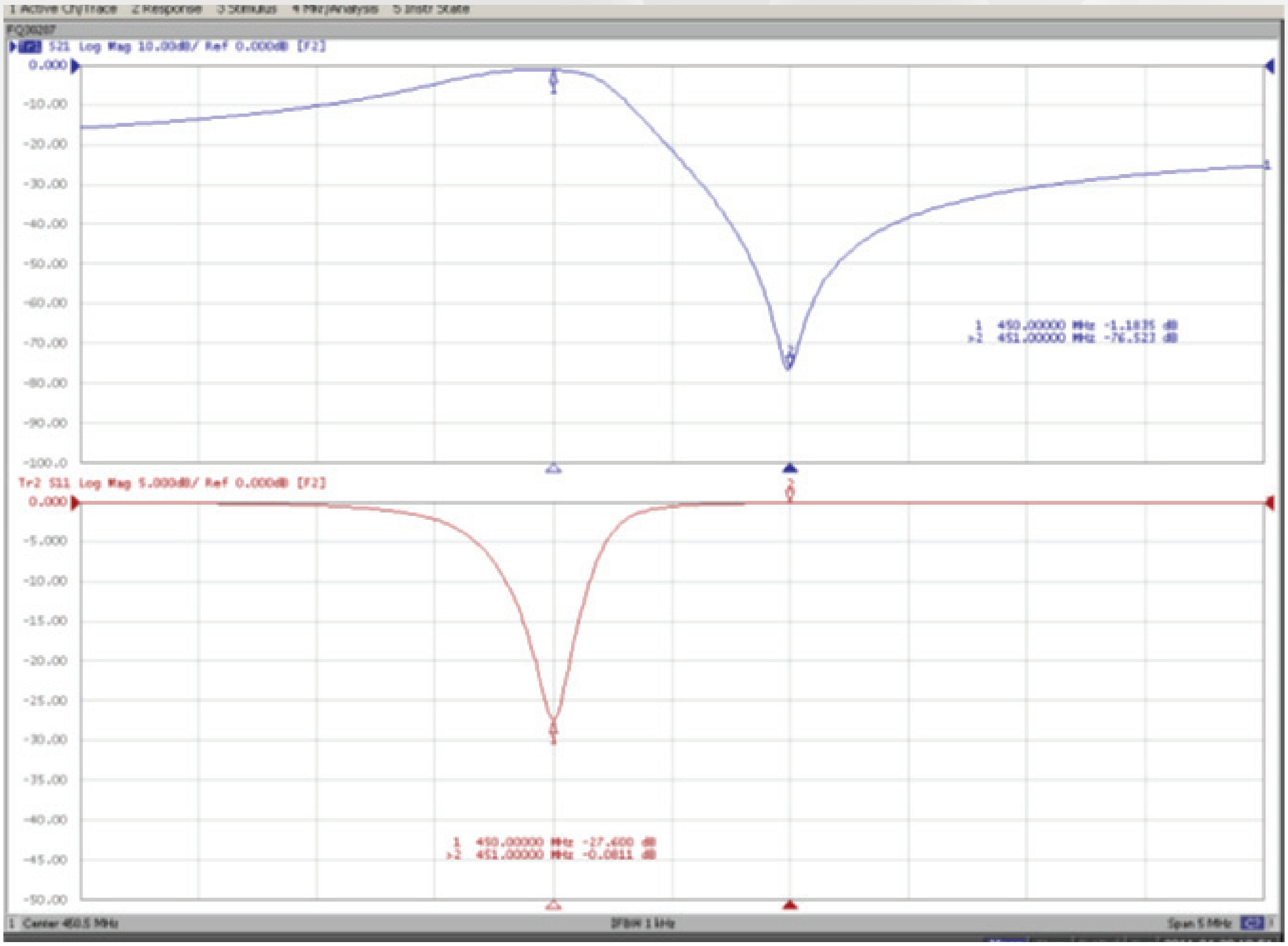

Figure 6, Attenuation versus frequency curve for a Q-Circuit filter with the pass frequency at marker 1 and the reject frequency at marker 2

This type of cavity finds use when it is necessary to provide bandpass filtering in a signal, yet still attenuates one nearby signal. A reject cavity alone normally attenuates signals at a further distance than the Q-Circuit cavity. For example, a VHF reject cavity will show 5 dB of attenuation at 250 KHz off of the 25dB notch frequency. A Q –Circuit cavity will attenuate one signal by only 0.6dB while producing a notch at 25dB only 250 KHz away.

To answer the question why one would ever use a reject cavity when the Q-Circuit cavity seems to offer better performance, remember that the Q-Circuit can pass only one signal. If it is necessary to reject one signal while passing many others a reject cavity is the only option.

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One filter unit which uses pass or reject cavities is a duplexer. A duplexer allows the simultaneous transmission and reception of two signals on a common antenna. Duplexers exist in two basic types: band pass and band reject. Combinations of pass and reject types also exist.

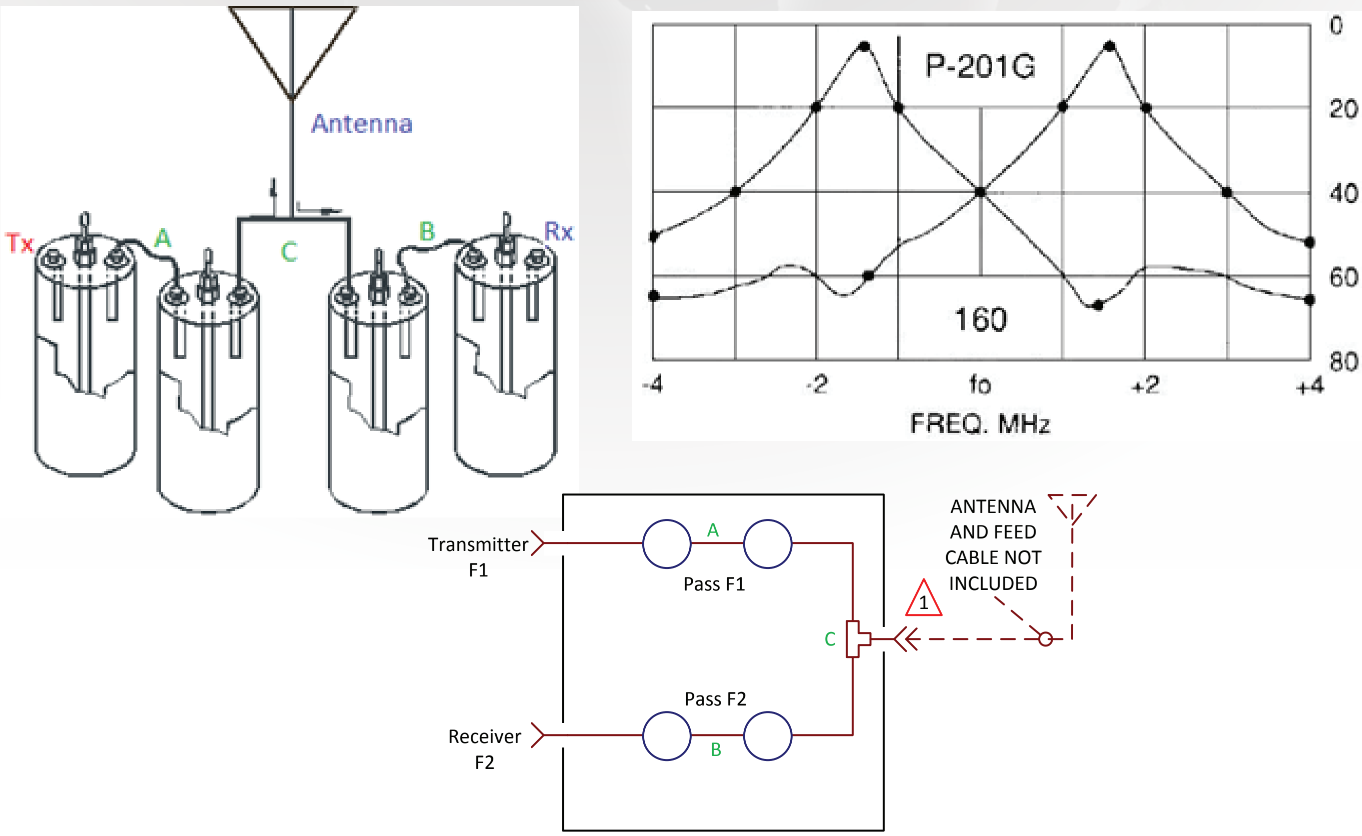

Figure 7, Band pass filtering as applied to a duplexer

To illustrate a band pass filter, a P201 type band pass duplexer will be used. This duplexer operates in the VHF frequency range and allows for a minimum separation of 3 MHz between transmit and receive frequencies.

The P201 duplexer is composed of four cavities; both pictorial and schematic diagrams of this duplexer are shown in figure 7. Filter set A is composed of two bandpass filters as is set B. The cable length from the antenna junction, point C to the first cavity in set A is chosen so that the path to filter set A looks like an open circuit to frequency F2 but allows F1 to pass.

Filter set B performs the same function but it allows F2 to pass but looks like an open circuit to F1. Therefore if a receiver is tuned to F2 and a transmitter to F1, filter set A will permit only the transmit frequency to pass and set B will only allow the receive signal to pass. Therefore, the transmit signal does not interfere with the receiver and a received signal is not split at junction C which would result in extra losses.

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If frequencies F1 and F2 are closer together than 3 MHz in spacing there is not sufficient isolation for this bandpass duplexer to work.

Figure 8 illustrates what happens when a bandpass filter is used with two closely spaced signals. Using a bandpass duplexer in this situation would result in a splitting of the signals and subsequently, poor performance in the system. To remedy this situation, a band reject type of duplexer is required.

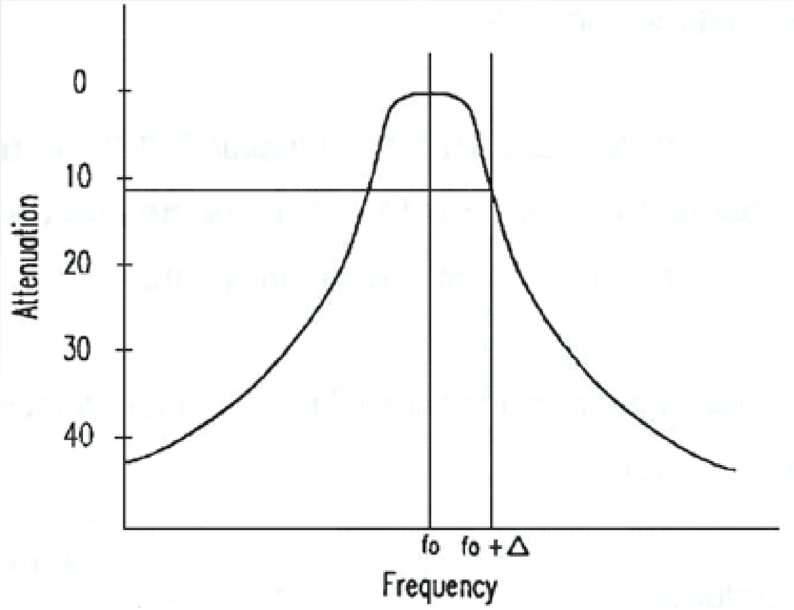
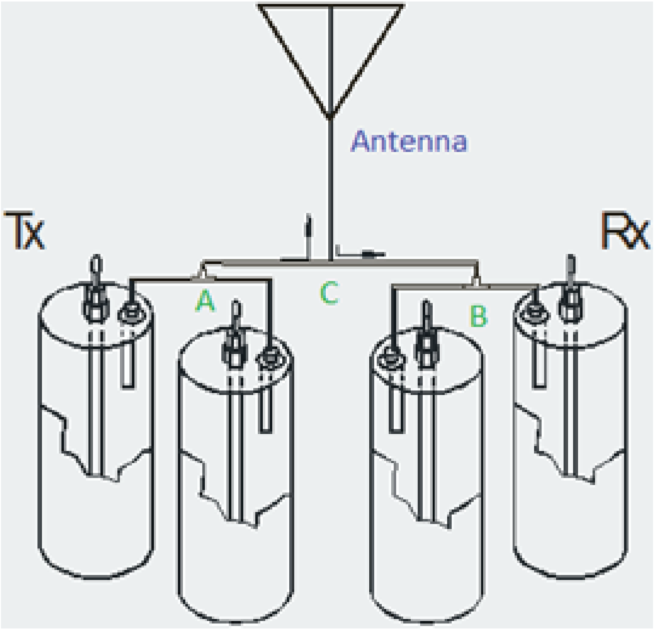
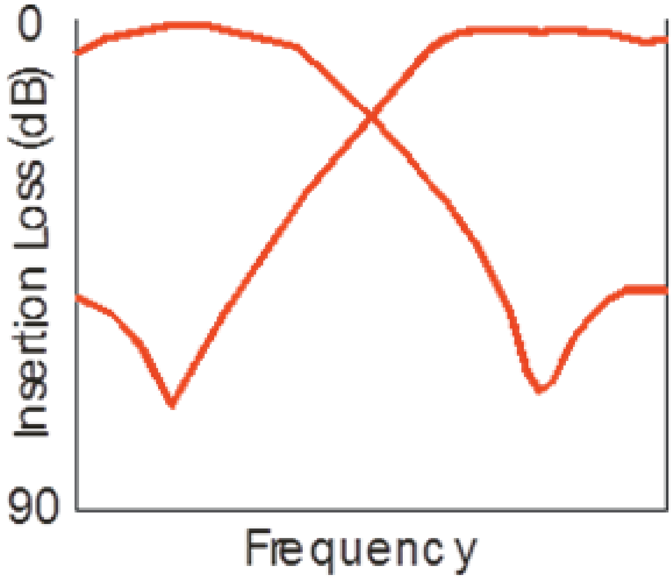


Figure 8, Band pass duplexer using closely spaced frequencies

A typical reject duplexer using four cavities all connected in a reject configuration is shown in Figure 9. Using this unit allows simultaneous transmission of signals only 500 KHz apart, in the VHF band.





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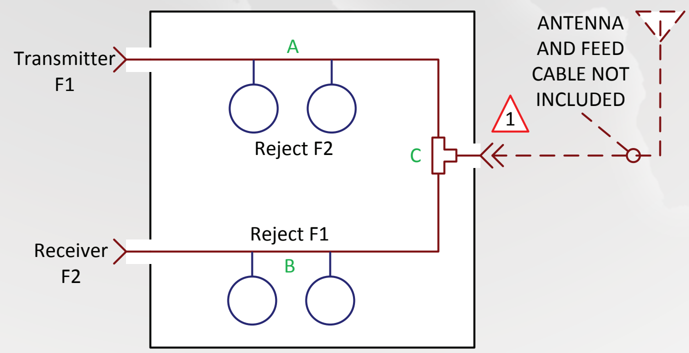

Figure 9, Reject filtering as applied to a duplexer

Cable lengths are very critical in this unit for proper operation of the reject cables. For this reason, field adjustment of this unit can be quite difficult if retuning over a wide range is required. Small adjustments can be made with the proper equipment.

Filter set A is tuned for a notch at F2 while filter set B has a notch at F1. If a received signal is of frequency F2 it will see an open circuit in the direction of the transmitter but a 50 ohm impedance path in the direction of the receiver. Similarly a transmit signal on F1 will travel to the antenna since it sees an open circuit in the direction of the receiver. An illustration of attenuation versus frequency for this duplexer is shown in figure 10. Note how each half shows low attenuation at all frequencies except the corresponding tuned system frequencies.

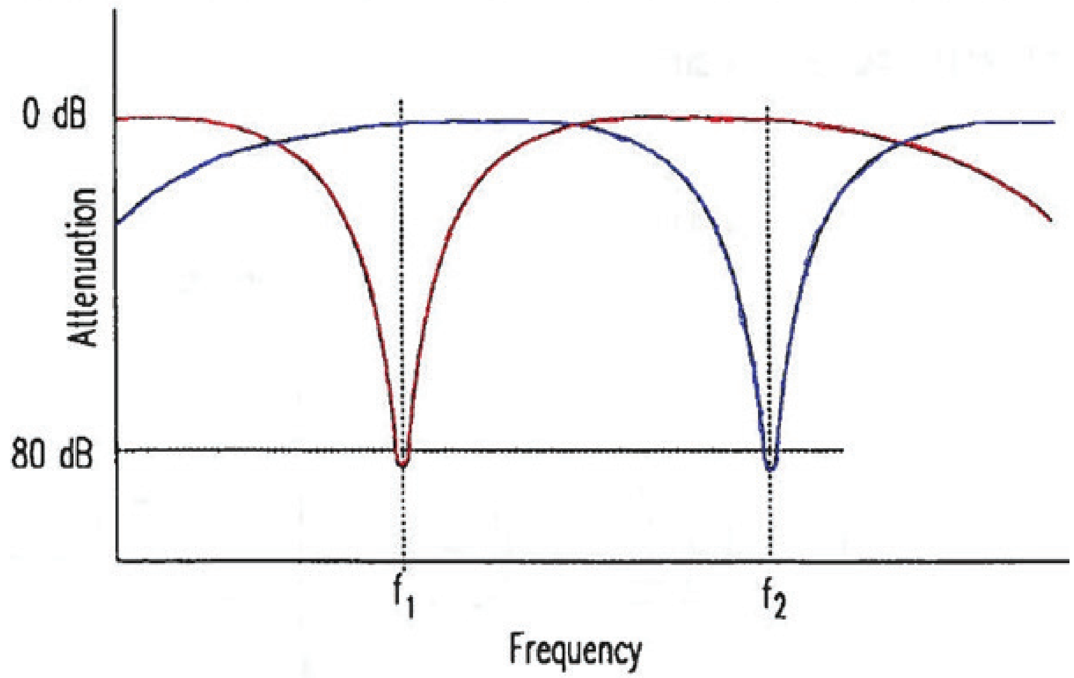

Figure 10, Response of a band reject duplexer

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Note that while using notch cavities, the signal does not pass directly through the cavity so lower losses can be obtained. This advantage is gained at the expense of no off-band filtering which is obtained in a band pass configuration. Figure 11 shows the band pass and band reject curves and what happens if a signal F3 is received. Note that the band pass case, the signal is attenuated by 40 dB, but the reject case allows only an attenuation of 10 dB. If F3 is a strong signal, only the pass type will avert potential problems. It is not uncommon to add pass filtering to reject duplexers. Sinclair Q-Circuit duplexers all combine pass and reject characteristics.

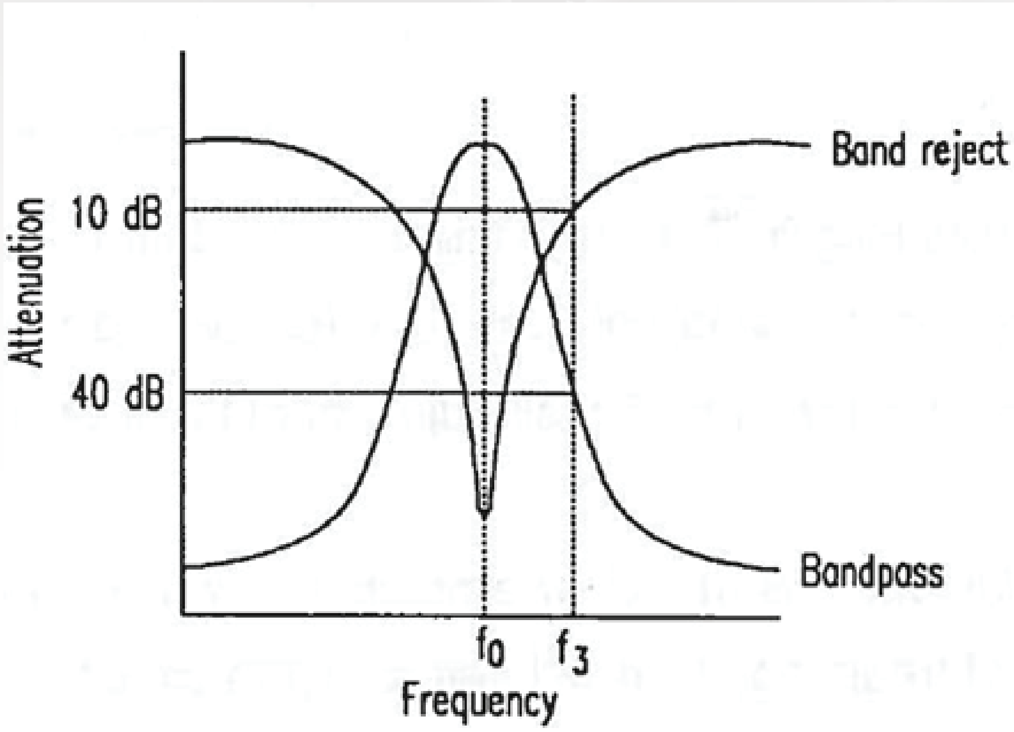

Figure 11, Illustrates higher attenuation for distant signals which is available through bandpass filtering

Transmitter combiners can also employ bandpass filtering. A four channel combiner is illustrated in Figure 12.

Each cavity permits only its tuned frequency to pass while blocking all others. This blocking is not perfect so these units are often equipped with isolators as Figure 12 shows. Isolators will be covered as a separate topic in another white paper. However, as long as frequency spacing is far enough apart, this type of combining works quite well. If frequency spacing gets too close a different type of combiner is necessary since the bandpass cavities no longer offer sufficient isolation. This type of problem is identical to that which occurs when attempting to use bandpass duplexers with close frequency spacing.

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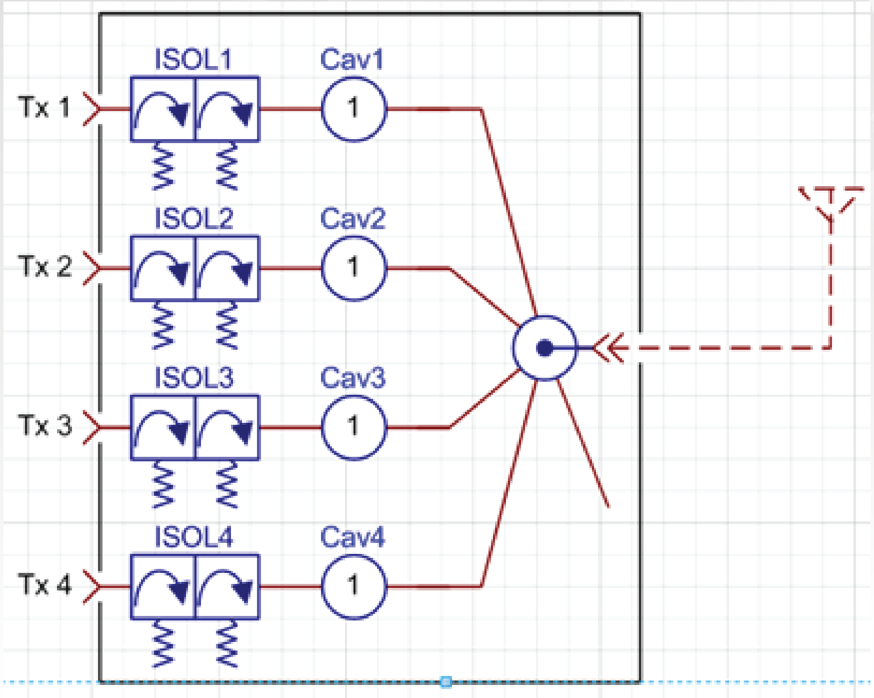

Figure 12, Illustration of a Four Channel Bandpass Type Transmitter Combiner

Consider what would happens if a bandpass combiner were used with two transmitters with frequency spacing of only 100 KHz in the UHF frequency band. The situation illustrated in Figure 13. Signal f0 will pass through its bandpass cavity as expected. However, when the signal reached the antenna port it will see 50 ohms in the direction of the antenna and also a bandpass cavity in the direction of the other transmitter. This cavity presents a low loss to this signal since its passband center frequency is only 100 KHz away. Therefore the signal will split, half going to the antenna and half going to the other transmitter. In reality, the impedance as point A is only 25 ohms which will present other problems but that is beyond this white paper's scope.

For close spacing of transmitters bandpass combining techniques do not work due to the loss of isolation. To solve this problem directional couplers are used. This type of combining is not discussed here as it does not use filtering.

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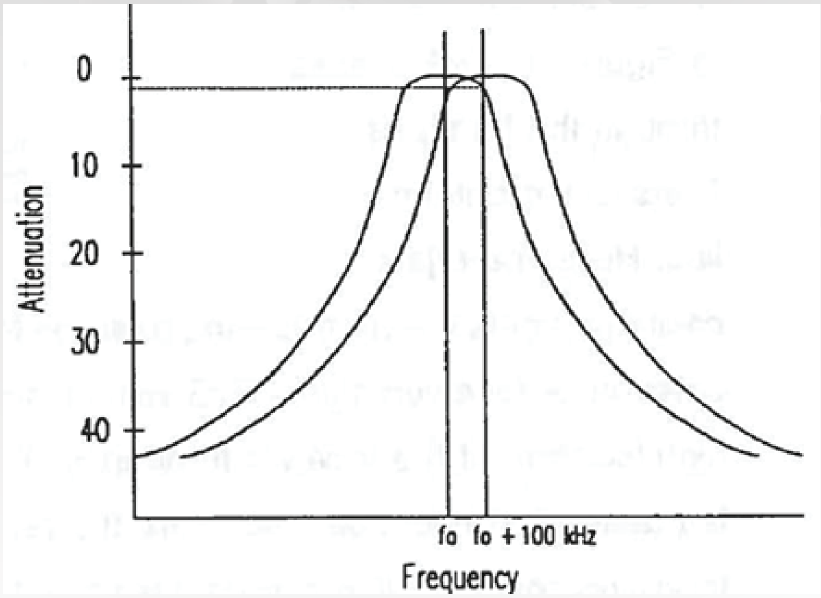

Figure 13, Problem caused by using two closely spaced transmit frequencies in a transmit combiner

Preselectors are another type of filter structure. These filters are used for helping receivers discriminate in a very noisy environment. Typically they have a wide, flat passband with very sharp sides. An illustration comparing the passband of a preselector filter to a bandpass cavity filter is shown in Figure 14.

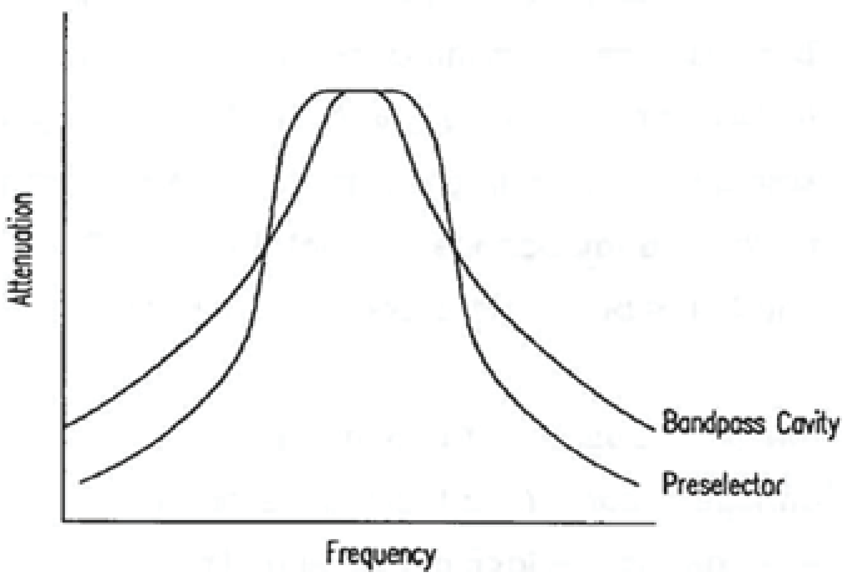

Figure 14, Illustration comparing a bandpass filter curve with a preselector filter curve on the left, Photo of a typical preselector made up of four cavity filter sections is on the right

Preselectors find use in receiver multicouplers. A receiver multicoupler is used when combining several receivers onto one antenna, with all the receivers in a certain band. A schematic of a receiver multicoupler is shown if Figure 15.

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The preselector inhibits any signals but the desired ones from the amplifier. The isolation means that the amplifier is not amplifying out of band noise or signals which may desensitize the receivers. The splitter shown in Figure 15 equally divides the signal to various receivers. The four output splitter can easily be substituted with one that has a different number of outputs. The splitter may also be referred to as a power divider.

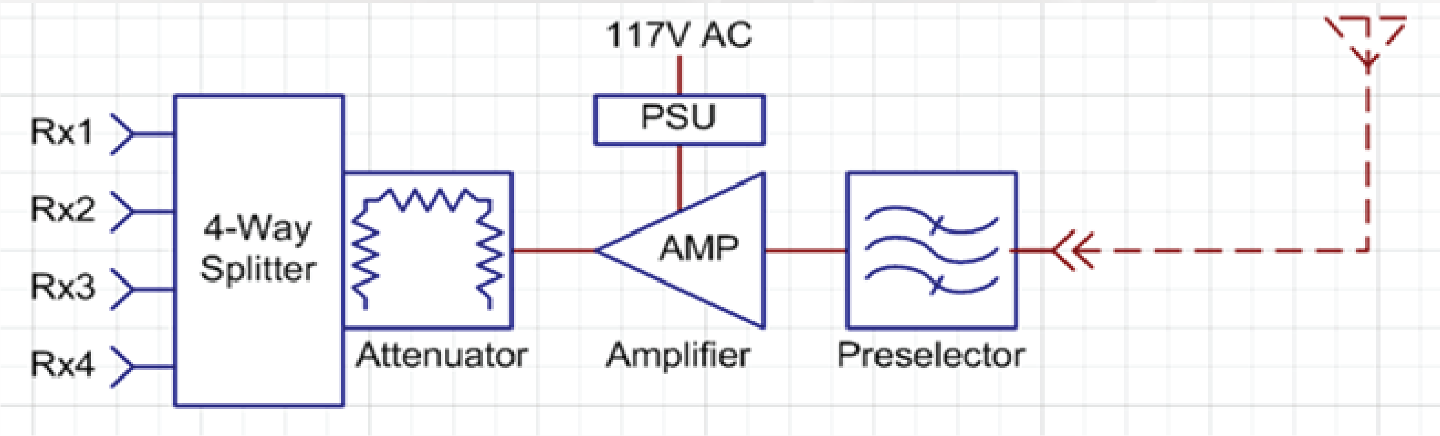

Figure 15, A four output receive multicoupler is shown

Another type of combining possible is in Sinclair's C-Series multicouplers. Provided frequency separation is adequate, this series is easy to use and expand. A schematic of a C-Series system is shown in Figure 16. Tx1 passes through the bandpass cavity filters to the antenna line. Here the reject cavity prevents it from travelling down toward the termination so instead it travels to the antenna. A received signal Rx1 will pass right by the transmitter cavities due to their high isolation at the receiver frequency. Thus the received signal reaches the receiver bandpass and the reject cavitie. Here the reject cavity stops the receive signal from travelling down the line and so it is routed to the receiver. This type of system is readily expandable; the only limitation is the frequency separation between the channels.

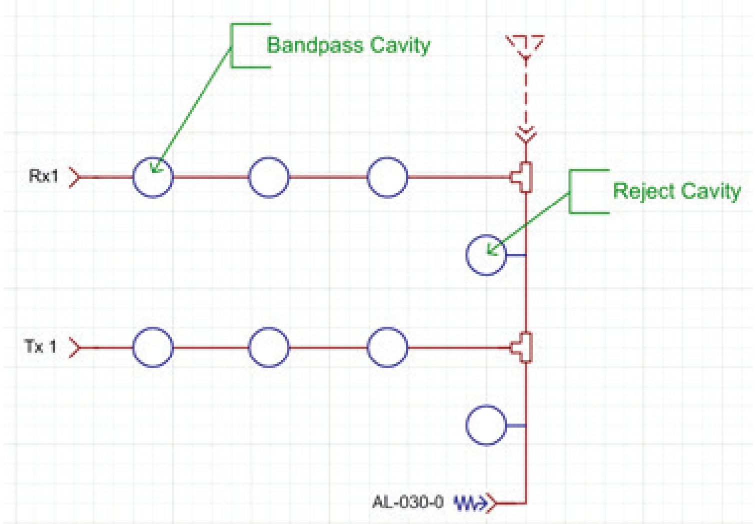

Figure 16, A C-Series transmitter and receiver combiner example

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Figure 17 will provide you with a basic filter selection guide. Its purpose is to assist you to determine what type of filter you may need for your particular application. Sinclair engineers are available to assist you with this task.

Filter Selection Guide			
Filter Technology	**Filter Category**	**Filter Series**	**Filter Use**
Cavity	Band Pass	FP	This is used to pass one or several close frequencies while simultaneously rejecting all others. It is also used for combiners
Cavity	Band Reject	FR	Use this filter when you want to Reject one undesirable frequency out of a wide passband
Cavity	Q-Circuit	FQ	Used when you need to pass a narrow band of frequencies and reject a nearby frequency either above or below the desired signal(s)
Cavity	Pass Through	FS	This filter is a variant of band pass filter used exclusively for transmit or receive combining systems
Cavity	Preselector	FPx0401,PHx040	Use when you need to passsignals within a bandwidth of one to five MHz.
Cavity	Combline	FP40615CL	Use when you need to pass very wide bandwidth, typically used at higher frequencies
Lumped Sum	Second Harmonic	AF	Use in conjunction with an isolator or hybrid to attenuate second harmonic signals produced by magnetic devices
Lumped Sum	High Pass/Low Pass	FP161R & FP220R	Use to reduce potential interference from other frequency bands like the FM broadcast band

Figure 17, A Filter selection guide

This completes an overview of basic discussion of radio filter structures. Additional white papers shall become available soon to address all the mentioned topics. Sinclair can offer all the components described in this paper and the professional services to complete an RF system design that meets a customer's specific needs.

Please refer to the Sinclair Technologies website **www.sinctech.com** for more information related to duplexer, preselector, combiner and cavity filter products.