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Introduction to the Fundamentals of Telewave's Cavity Filters

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This paper covers the core concepts of cavity filters and what should be known prior to system design or purchase.

Introduction

Cavity filters are a type of resonant filter used for either passing desired RF signals within a specified frequency range or rejecting RF signals within a range of frequencies. The resonant cavity within these filters can be constructed from durable materials, such as highly conductive and dimensionally stable metals, to reliably perform for years in harsh environments. Along with the ability to provide high quality filtering for high powered signals, these filters are ideally suited for telecommunications applications from tens of megahertz to a gigahertz. Most common matching impedances are 50 ohm, followed by 75 ohm.

Cavities augment the filters built into a radio, and function to:

- Prevent interaction between transmitters in combining systems,
- Reduce off channel sideband noise, harmonic or spurious outputs from transmitters,
- Protect receiver front end and automatic gain control (AGC) circuits from off channel energy.

Almost all cavities are built to internally be ¼ or ¾ of the wavelength of the center frequency of interest. There are some compact cavity designs that are internally shorter than ¼ wavelength; but will have reduced performance. The internal wavelength is created by a combination of:

- Length and width of the inner conductor (the length is adjustable by turning the center rod)
- Length, width, shape, and angle of the loop(s)
  (wider loops allow windows of wider bandwidth)
- Internal components such as capacitors
- External components such as cables

Cables that connect two cavities together in a system should be cut to x/4 of the wavelength of the center frequency of interest so that the entire cavity system maintains a wavelength of x/4.

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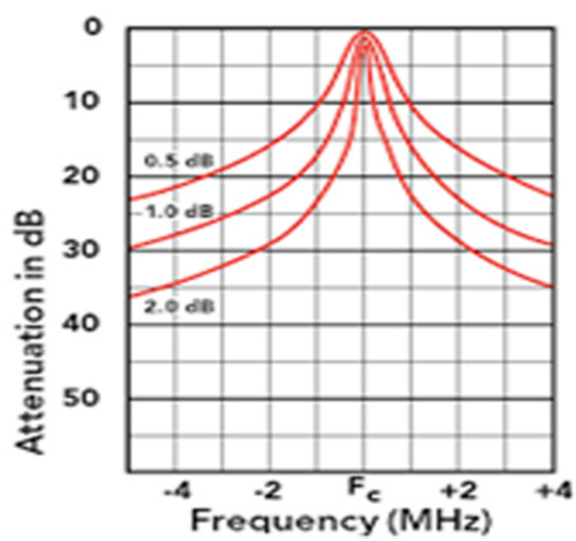
Because of the x/4 wavelength "rule" there is a practical minimum and maximum frequency at which a particular design can operate due to the size of the cavities, and length of the cables between the cavities:

- At lower frequencies the cavities will be larger and the interconnecting cables longer
- At higher frequencies the cavities will be smaller and the interconnecting cables shorter

The base "Q" (quality) or sharpness between the frequencies that are passed, and the frequencies that are attenuated, is generally determined by the distance between the loop(s) and the inner conductor, and the angle of the loop(s) in relation to the inner conductor.

- The farther away the loop(s) are located from the inner conductor, the higher the "Q"
- The higher the frequency the higher the "Q" will be for a given distance between the inner conductor and the loop(s).

Telewave cavities do not support dynamically adjusting the distance between the loop(s) and the inner conductor - the distance is fixed.



Telewave cavities do support the dynamic change of the "Q" of a cavity by adjusting the angle of the loop(s) in relation to the inner conductor. Turning the loop(s) to add insertion loss increases the "Q", decreasing the insertion loss decreases "Q". The pass or reject band symmetry can also be changed by adjusting the loop angles, which may add more insertion loss.

"Insertion Loss" is the attenuation of desired pass frequencies.

It is recommended to keep the total insertion loss of any one cavity to 2 dB or less. Above 2 dB, the cavity's bandwidth becomes too narrow for practical use in many applications.

Above 1 dB, the power handling capacity of the cavity is reduced due to internal voltages. Cavity filter effects are additive; to achieve high "Q" values, it is usually best to string two or three cavities together, enabling lower system insertion loss.

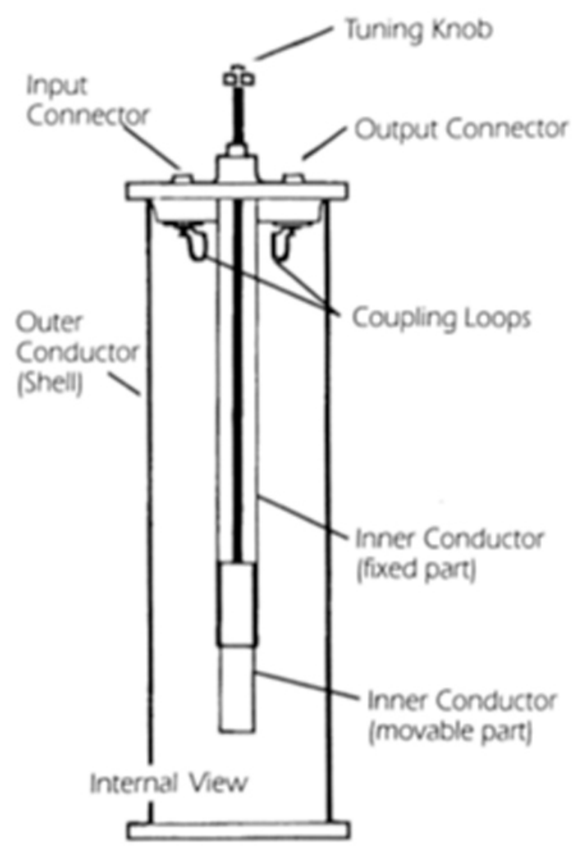
The loops are attached directly to the backside of the cavity's coaxial connector; creating the loop assembly. The default connector at Telewave is the "N" type. Universal High Frequency (UHF) connectors are available (the UHF connector is not recommended for frequencies above 300 MHz.)

None of the cavities alone have an "input" or "output". The passband and/or reject band (symmetry) as well as the return loss seen at any port will be identical. When multiple cavities and cables are configured as a system, such as a duplexer; this system may exhibit different return loss seen at different ports.

Pass Cavities

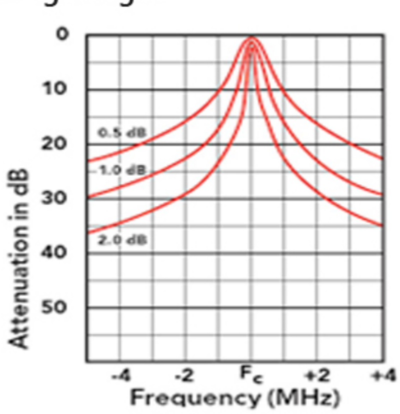
Pass cavities allow one frequency or a "window" of frequencies to pass, while attenuating or "blocking" all other frequencies above and below the window.

The Pass Cavity has two loops and is placed in series (in line) between the radio (transmitter and/or receiver) and the antenna.



This cavity will have an insertion loss indicator. Most of the time the "dot" indicator should be set to indicate the same thing on both sides... i.e. both set to 1 would indicate that the cavity has 1 dB of insertion loss.

As the inner conductor is adjusted to change the center frequency, the loop angle must change to keep the "Q" constant. The insertion loss indication is most accurate in the center of the cavity's tuning range.



Increasing the insertion loss increases the "Q" of the cavity (the pass bandwidth will be more narrow and the undesired frequencies will have greater attenuation.)

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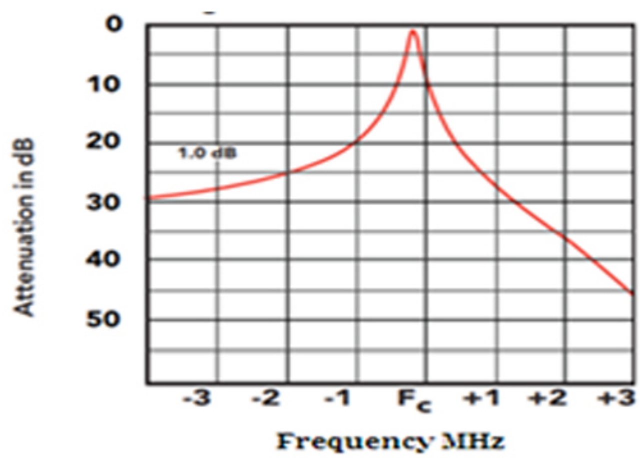
Increasing the insertion loss beyond 2 dB per cavity is not recommended. As the insertion loss (Q) is increased, the bandwidth of acceptable return loss is decreased. There may be a high return loss at the center of the pass bandwidth, but at the edges of the occupied bandwidth (of the modulation), the return loss may be too low. In this situation too much of the sideband energy will be reflected back to the signal source. When this happens: the transmitter may shut down, analog fidelity (audio volume or frequency range) may be reduced, and digital data may suffer bit errors. When additional attenuation outside the pass frequency, or additional "Q" is required, place two or more pass cavities in series and spread the insertion loss evenly among them (not to exceed 2 dB insertion loss for any one cavity.)

This cavity type allows the most manipulation of the pass band symmetry, by adjusting the two loops to have different angles relative to the inner rod. This provides more attenuation to frequencies either above or below the pass frequency of the filter when required. It is recommended to keep the input and output insertion loss as even as is practical.



Placing multiple Pass Cavities in series allows:

- Deeper overall attenuation of the frequencies outside the pass band

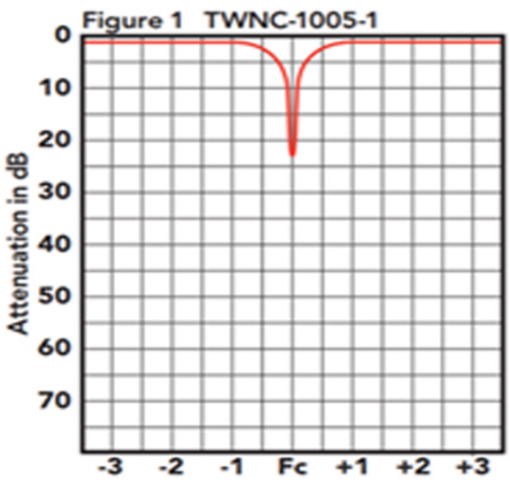
- Sharper slopes above and below the passband (i.e. narrower skirt selectivity)

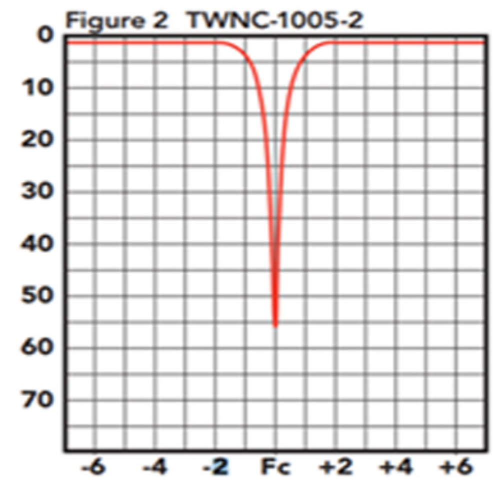
- A wider passband at the desired frequency. (Example: Multi-Cavity Preselector)

Note: A problem with pass cavities is that they will also resonate near odd harmonics of the primary frequency. Thus, a single cavity tuned to pass 150 MHz will also pass 450 MHz, and 750 MHz, etc. If all frequencies above the primary frequency need to be attenuated, use two or more pass cavities in series.

Notch Cavities

Notch cavities reject one frequency or a "window" of frequencies, while allowing all other frequencies to pass. Note that a Notch Cavity has a finite pass window above and below the rejected frequency.





Frequency (MHz)

The Notch Cavity has one loop and is placed in "parallel" (via a Tee Connector) with the cable that connects the radio (transmitter and/or receiver) to the antenna.

Some lower frequency Notch Cavities may have a short piece of cable between the TEE and the connector on the top of the cavity (the lower the frequency band, the longer the cable.) The short cable helps to match the internal loop to frequencies above and below the notch frequency up to the minimum and maximum tuning range of the cavity. Without the matching cable, the cavity will have an unpredictable, narrowband pass/reject response that will vary as the tuning rod is adjusted.

The symmetry of the notch window can be manipulated some.

Placing multiple Notch Cavities in "series" (one after another via the TEE connectors) allow:

- Deeper attenuation of the frequencies within the notch
- Widening of the notch bandwidth but with slopes that are not as sharp.

Placing multiple Notch Cavities in "series" will add some attenuation to the signals outside of the notch.

Notch cavities are sometimes used in compact or mobile duplexers; the frequency of the opposing side of the duplexer is notched out, but all other frequencies within the cavity BW are allowed to pass through.

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Pass/Reject Cavities

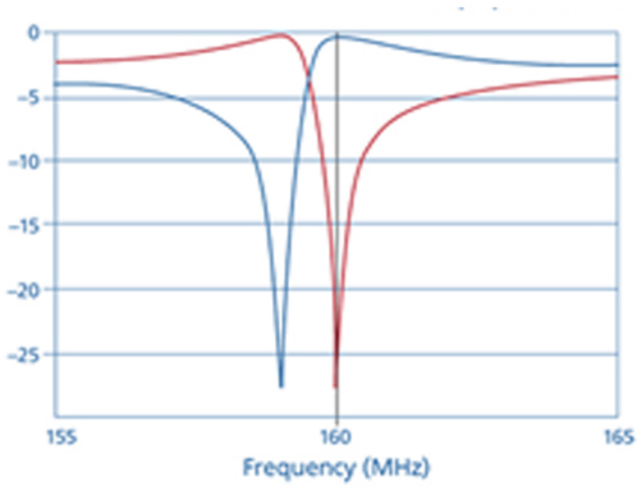

Pass(H)/Reject(L)


Pass(L)/Reject(H)

Pass / Reject (P/R) Cavities have attributes of both a pass and a notch cavity in one package. Compared to the pass frequency, the notch will generally be as deep as a notch on a notch only cavity; however the attenuation of all other frequencies outside the pass and notch frequencies will not be as deep as is seen with a typical pass cavity. This type of cavity is typically used in pairs to create repeater duplexers.

The P/R Cavity has one loop and is placed in "parallel" (via a Tee Connector) with the cable that connects the radio (transmitter and/or receiver) to the antenna.

The pass frequency is configured by adjusting the tuning rod. The notch is set a certain "distance" from the pass frequency by adjusting a capacitor (slot located to the side of the coax connector.) The Notch will tend to "follow" the pass frequency as the cavity is tuned.



Some cavities configured to be pass low and reject high, will have an additional fixed capacitor in parallel with the tunable capacitor. The extra capacitor allows setting the notch frequency to be close to the pass frequency. The pass high and reject low type P/R cavity does not require or have the extra capacitor.

The symmetry of the pass or notch window cannot be manipulated. Clockwise or counterclockwise adjustment of the loop will change the depth of the notch, and the "Q" of the passband.

Placing multiple Pass/Reject Cavities in "series" (one after another via the TEE connectors) will add some insertion loss to the signals within the pass band, however it will allow:

- Deeper attenuation of the frequencies within the notch
- Widening of the notch bandwidth though slopes are not as sharp.
- Deeper attenuation of the frequencies beyond the pass and notch frequencies

For additional information about specific Telewave cavity filters and solutions that employ the filters, please visit our web site at www.telewave.com.