CORRY MICRONICS, INC

Stuck In the Middle:

How To Choose Your Next Band Pass Filter

Authored by **James Price**

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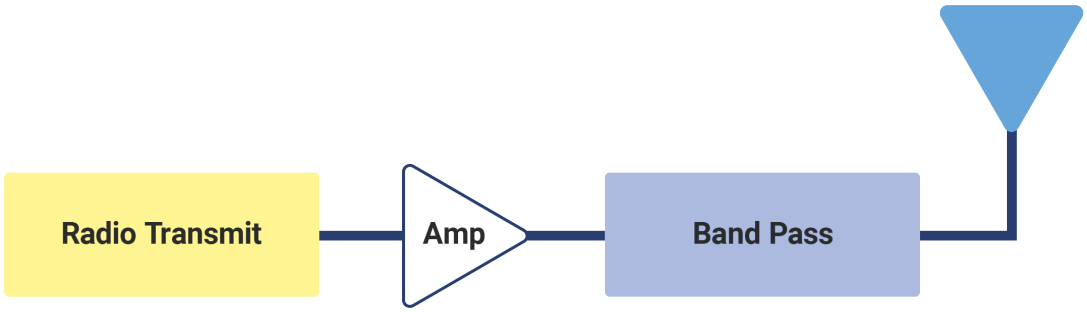
How to Choose Your Next Band Pass Filter

Band pass filters ideally allow signals between a lower frequency and an upper frequency to pass with very little loss, rejecting signals outside the two frequencies' range. The allowed range of frequencies is called the pass band.

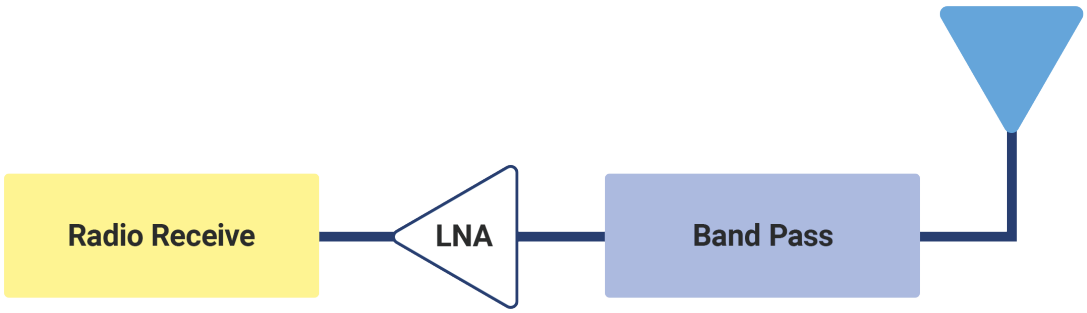
How Band Pass Filters Are Used

Band pass filters are used in both wired and wireless communications systems, sensor applications, instrumentation, medical applications, and many other applications. When it comes to these types of applications, the goal is to pass signals of interest from point A to point B, while reducing noise and unwanted radiation from the signal source, other equipment, and the environment.

Band pass filters are used to transmit as well as receive in applications. For example, in a wireless transmit application, the filter is placed between the power amplifier and the antenna, ensuring that amplifier harmonics and out-of-band artifacts are significantly attenuated so that the transmitter does not cause interference with other wireless channels.



In a wireless receiver application, the filter is placed between the antenna and a low noise amplifier to reject any nearby interfering transmitters and out-of-band noise, passing only the desired channel to the receiver.



Band Pass Filter Performance

Filters are often designed with published tables of numbers that are converted into inductors and capacitors to achieve responses, including Chebyshev, Butterworth, Gaussian and others. Filters can also be synthesized, a process that begins with an equation and results in a network of physical elements. The object of these exercises is always to determine inductance and capacitance values that achieve the pass band and rejection criteria desired. Once the inductance and capacitance elements have been calculated, the theoretical performance of the filter is determined.

Band Pass Filter Construction

Translating equations and specs to reality is of course, often a challenge. A band pass filter must be built so that it can:

1. ***handle the required power,***
2. ***fit within the alloted space,***
3. ***meet any other special criteria for its ultimate end use, and***
4. ***remain on budget***

There are many different technologies available for building the filter, and any given set of specifications can dictate a variety of ways of construction. Different filter elements and physical structures all have advantages and disadvantages that can be compared against the specific design criteria for your application.

Choosing The Best Band Pass Filter For Your Application

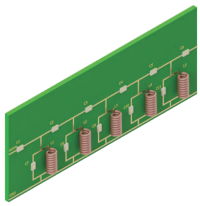
As with everything in this world, there are advantages, disadvantages and trade-offs that need to be considered and accounted for with each approach. So, how do you choose the proper technology for the job? Here is a great example.

Suppose you need a 50 MHz bandwidth band pass filter centered around 1 GHz and rejection of 50 dB at 200 MHz bandwidth (50 dB rejection at 900 MHz and below and at 1100 MHz and above). After consultation with readily available filter attenuation tables, you decide that a 5-pole filter design will do the job. This filter could be constructed with a variety of distributed or combination approaches, including:

- ***LC***
- ***Cavity***
- ***Comb***
- ***Stripline, Microstrip or Suspended Stripline***
- ***Ceramic Coaxial***
- ***Helical***

All of these filters will achieve the desired passband-rejection response specified. They are all 5-pole filters, and any one of them will work. Ultimately, the choice of which filter type to choose will come down to system requirements and priorities. These priorities could include trade-offs among insertion loss, power handling, size, weight, temperature stability, ease of construction, cost, and other project parameters. Let's examine the differences between these options.

Understanding The Different Types of Band Pass Filters

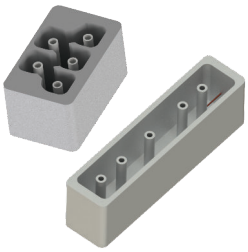


Lumped element, or LC filters

Lumped element, or LC filters, provide the desired frequency response using inductors and capacitors (L's and C's). LC filters are perhaps the most familiar filter type to most engineers. There are many alternatives available for creating LC filters. These are broadly characterized as distributed element filters, and there are many different ways to make and use them. Distributed filters use transmission lines, short circuits, open circuits, air gaps, and dielectric materials in place of lumped inductors or capacitors. To add even more possibilities for their use, inductors and capacitors can be used in combination with distributed elements to craft specific performance characteristics. Many filter tables and synthesis tools start out assuming lumped elements are to be used. Inductors and capacitors are readily available and are an attractive choice for any application already using printed circuit boards.

Insertion Loss: *Worst* **Filter Size:** *Small* **Power Handling:** *< 10 watts*

Typical Q: *50 - 200* **Cost:** *Low*

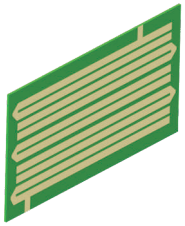


Cavity and comb filters

Cavity and comb filters both make use of distributed elements. They each use 5 rods that can be modeled as parallel resonant LC circuits. Each filter is carefully constructed so that the electromagnetic field from one rod couples energy to the next rod to achieve the desired filter bandwidth. For the comb filter, the wider the bandwidth, the closer the rods must be spaced. For the cavity filter, the wider the bandwidth, the larger the openings must be between the rods.

Insertion Loss: *Best* **Filter Size:** *Large* **Power Handling:** *100's of watts +*

Typical Q: *1000 - 5000* **Cost:** *High*

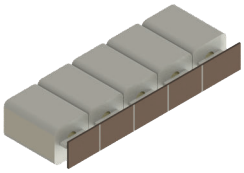


Microstrip filter

Another distributed approach is the microstrip filter. The one shown here is a hairpin design consisting of 5 u-shaped traces of precise spacing and length.

Insertion Loss: *Worst* **Filter Size:** *Medium-small* **Power Handling:** *< 10 watts*

Typical Q: *100 - 200* **Cost:** *Low / Very Low*

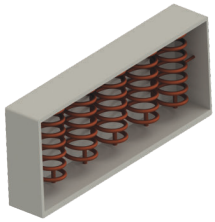


Ceramic coaxial filter

The ceramic coaxial filter may seem perplexing at first. There are 5 ceramic resonators, each functioning as a miniature coaxial cable shorted on one end and open on the other. Each shorted resonator acts as a parallel resonant LC circuit just like the cavity and comb filters. Energy is coupled from one to the other using a silver plated ceramic plate printed with capacitors. The size of each printed capacitor determines the energy coupled from one resonator to the next. This sets the filter bandwidth. The ceramic coaxial approach shown here is a combination distributed lumped approach as it uses both transmission lines and capacitors.

Insertion Loss: *3rd Place* **Filter Size:** *Small* **Power Handling:** *up to 50 watts*

Typical Q: *300 - 600* **Cost:** *Low / Mid*



Helical filter

The helical filter is also a combination of lumped and distributed elements as it makes use of shorted inductors and electromagnetic coupling from inductor to inductor through air gaps.

Insertion Loss: *2nd Place* **Filter Size:** *Medium-large* **Power Handling:** *up to 100 watts*

Typical Q: *600 - 1000* **Cost:** *High*

Insertion Loss

If insertion loss is an important system parameter, you should consider the possibilities of each filter. Each of these filter types can be analyzed for loss by looking at the quality factor, or "Q" of the elements that make up each filter. The higher the quality factor of the filter elements, the better the insertion loss of the filter.

LC filters are made up of inductors and capacitors, so those are the two Q factors you should consider. Inductor Q is typically much lower than capacitor Q and tends to drive the losses in LC filters. When glancing at data sheets for inductors, you will notice that Q is typically below 200. Ranges of 50 to 100 are actually very common.

Using these numbers as a basis for comparison and knowing the Q values of the other filter technologies, you can infer the relative insertion loss performance.

Note that RC or RL Resistor-Capacitor or Resistor-Inductor based filters are not shown as they are rarely used due to their increased insertion loss characteristics.

Technology	Typical Q	Insertion Loss
LC	*50 - 200*	*Worst*
Cavity	*1000 - 5000*	*Best*
Comb	*1000 - 5000*	*Best*
Microstrip	*100 - 200*	*Worst*
Ceramic Coaxial	*300 - 600*	*3rd Place*
Helical	*600 - 1000*	*2nd Place*

Filter Size

Ultimately, if insertion loss is the overriding concern, cavity or comb would be the best filters for you. But, there is a trade-off between Q and size, which is the same as a trade-off between insertion loss and size. Distributed filters get smaller as the frequency increases. So, it is important to be aware of the relative sizes of the 1 GHz filter our example is considering.

Filter Type	Filter Size
LC	*Small*
Cavity	*Large*
Comb	*Large*
Microstrip	*Medium-small*
Ceramic Coaxial	*Small*
Helical	*Medium-large*

Power Handling

Any of these filters will work just fine if the power levels going through the filter are relatively low (think just a few watts). If the power level will be on the higher side, you will definitely need to take that into consideration when selecting your band pass filter.

The best technology for power transfer among these filter candidates are the cavity and comb filters due to their grounded metal enclosures. It is hard to beat a grounded metal enclosure for power handling and heat dissipation. In addition, both cavity and comb filters have the lowest insertion loss. Filter types with higher insertion loss will dissipate more of the signal passing through the filter as heat. Lower Q components have higher resistive losses. Lower insertion loss will improve the power handling ability of the filter.

Technology	Filter Size
LC	*< 10 watts*
Cavity	*100's of watts plus*
Comb	*100's of watts plus*
Microstrip	*< 10 watts*
Ceramic Coaxial	*up to 50 watts*
Helical	*up to 100 watts*

Cost

If economy is the driving factor in selection, microstrip and LC filters are the best choices. LC filters use low cost inductors and capacitors. Microstrip filters use no components at all, but may price slightly more due to their controlled dielectric laminate. These laminates are generally more expensive than standard FR-4 pcbs. Next would be ceramic coaxial filters followed by helical, comb, and cavity filters, the most expensive options.

VSWR

All of these filters can achieve any desired VSWR, but because VSWR is affected by stray capacitance, inductance and other physical nuances, the best VSWRs are achieved when individual filter characteristics can be adjusted. This is somewhat difficult with LC filters and near impossible with microstrip filters. In the case of LC filters, coils can be knifed, but variable capacitors are impractical most of the time. Similarly, ceramic coaxial resonators have a limited adjustment range.

The candidates for best VSWR performance are the larger filters – the cavity, comb, and helical. These all have built-in tuning adjustments and can achieve excellent VSWR performance by means of "tweaking" these adjustments.

Top Quality Band Pass Filters and Real World Engineering Advice

By now it should be clear that there are many ways to meet a set of filter requirements. At Corry Micronics, we get it. We've been advising our engineering clients and producing electronic components since 1970. We design custom filters for a variety of clients and applications, and can work with your specifications to develop the best filtering solution for your application or system.

Author Bio

James Price received a BS degree in Electrical Engineering from West Virginia University in Morgantown, WV in 1983. From 1985 to 1995, he was an engineer specializing in communications with RCA which eventually became Lockheed-Martin in Camden NJ. From 1995 through 2004 he designed CATV products for Tollgrade Communications, Cheswick, PA.

He is currently VP of Engineering for Corry Micronics, Warrendale, PA. His areas of focus include RF and microwave filters, multiplexers, switches and antennas.