White Paper

RF Filter Topologies

Understanding the Performance Aspects of Different Filter Topologies

Author: Sean Adams and Mike Schweyer
Location: Salisbury, MD United States

1. Filtering the choices

Which filter is right for your application?

As humans have pursued ‘faster’, ‘better’ and ‘further’, Radio Frequency (RF) and microwave devices have evolved rapidly to offer higher frequency and power in smaller, lighter packages at a reduced cost.

RF Filters are necessary for filtering out unwanted signals from equipment such as wireless and satellite communications, radar and broadcasting applications and transmit and receive modules. Filter topology can be separated into four filter categories: high pass, low pass, band pass and band reject.

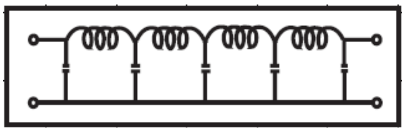


Figure 1: Equivalent circuit for low pass filter

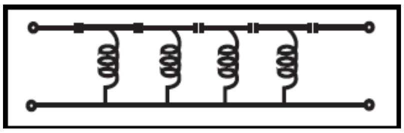


Figure 2: Equivalent circuit for high pass filter

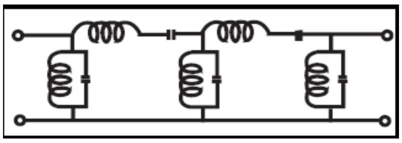


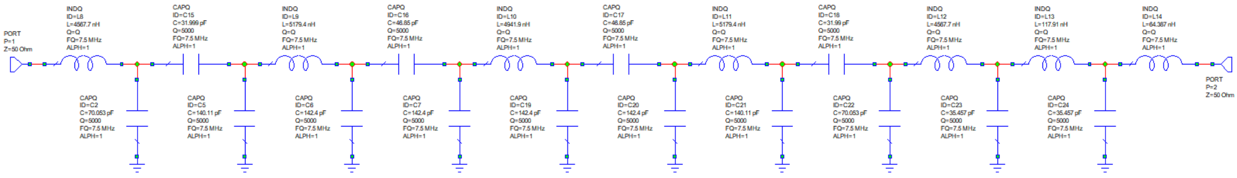
Figure 3: Equivalent circuit for band pass filter

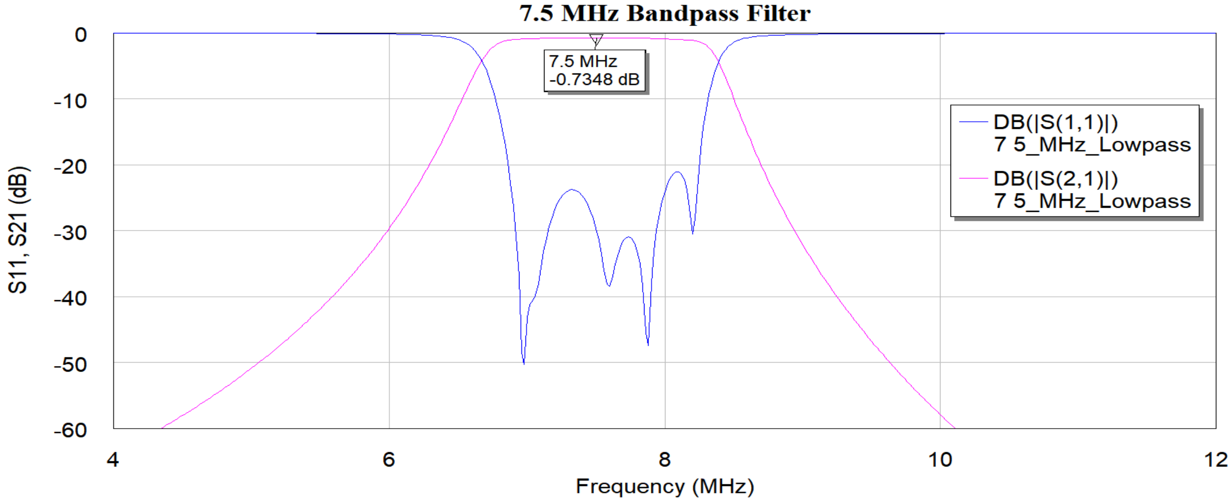
So, which is right for your future application?

Discrete filters

These have been called the ‘Grandad of filters’ because their all-round adaptability and legacy has made them a popular design choice. They can satisfy bandpass, lowpass, high pass or band reject requirements in a wide range of arrangements whilst offering a good balance between throughput (5 MHz to 10 GHz), low power drain and little loss. Accordingly, they can be found across transmit/receive modules, up/down converters, instrumentation, satellite communications, radar and broadcast applications.

Discrete Filter





A particular advantage of discrete filters is the flexibility of fractional bandwidths, as these filters can be very narrow or very wide (<0.5% to >100%). This enables them to sustain a precision performance where small size and reliability is critical. One such application is the Combat Navigation and Identification (CNI) system used in military aircraft, where discrete filters are helping new-generation integrated avionics systems to perform multiple critical functions simultaneously - from identification of friend or foe and precision navigation to various voice and data communications.

Discrete filters, also known as lumped element or chip and wire topologies, incorporate discrete elements to realize the ultimate filter response. These elements are comprised of mostly capacitors and inductors, as these products have reactive elements that can store energy within time varying signals. The filter designs utilize the resonances of capacitor and inductor pairings to create poles and zeros in the frequency domain to simulate the filter response. The values of these components are chosen to place the poles and zeros strategically to provide the desired frequency response of the filter.

A simplified example is shown in Figure 4 for a common pole and zero equivalent circuit that can be configured to form the discrete filter solution. The resonance frequency for these circuits is determined by the values of the inductor and capacitor per Equation 1. Filter designers will place the resonant structures appropriately in their designs to achieve the desired filter response.

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Equation 1: Harmonic frequency of inductor/capacitor resonant structure.

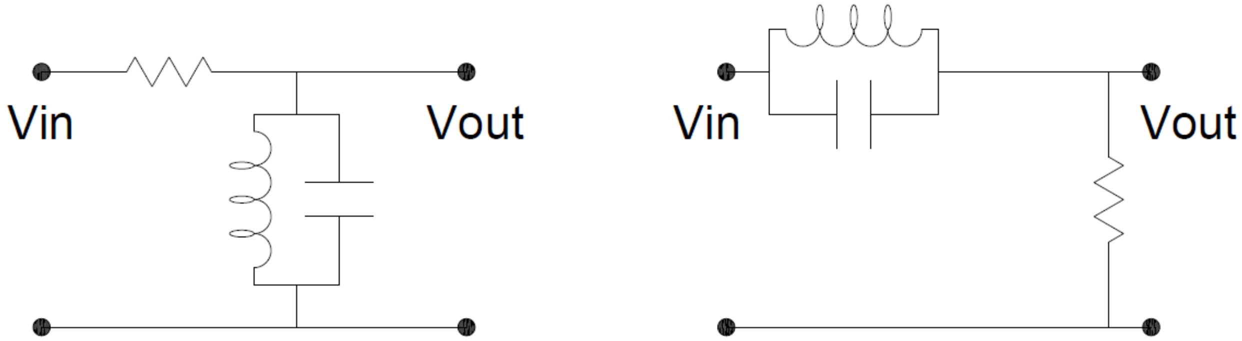


Figure 4: Resonant structure for bandpass (left) and band stop (right) structures

The versatility of utilizing the resonant structures allow for many applications for the discrete filter designs. The resonant frequencies available allow for filters from DC up into the X band. The upper frequency limit is primarily due to the availability and tolerance of components with very small values (pH or fF) that are also efficient (dissipative losses). Therefore, applications that are well suited for discrete filter designs include communications, radar and harmonic filtering for frequency sources or frequency mixing. The designs may be ruggedized for harsh environments such as aerospace applications, with processes available to reduce vibration sensitivity. These filters are suitable for commercial, industrial, defence and space applications.

Cavity filters

When space isn’t a constraint, and extremely low losses, sharp selectivity and high power are priorities, cavity filters may be the right choice.

Cavity designs are almost as versatile as discrete filters: high passes and lowpasses can be realized in suspended stripline topologies for low-PIM and low loss applications, while bandpass and band stop filters can be realized in either dielectric resonator, metal coaxial, or waveguide topologies.

In addition, they offer narrow bandwidths (< 0.5% to > 66%), extremely low loss and excellent stability over temperature. This makes them attractive for a diverse range of applications in the 30 MHz to 80 GHz range, from military and commercial aerospace and Unmanned Aerial Vehicles (UAVs) to wide area networks.

Their capacity for kilowatt-throughput combined with a mass production capability/low cost has seen them recently come to the forefront in the drive to commoditize satellite communications. As a result, they were the filter type of choice for the new ground-based antennae stations designed to provide seamless, superfast and accurate handoffs between Low Earth Orbit (LEO) satellites.

The cavity filters are available as coaxial, where it consists of an inner and outer conductor, hollow metal waveguide, which consists of only an outer conductor and dielectric, where the fields are mostly contained in a high dielectric ceramic material. The theory is similar for each design, where an electrical and magnetic field is generated, supported, and constrained within the conductors. The dimensions of the conductors determine the boundary conditions. The placement of these boundary conditions will promote a resonance, similar in theory to the resonant structure of the discrete filters. The frequency of this resonance is known as the principal mode.

Cavity Filters

Both the electric and magnetic fields can be transverse modes, where the entire field is in the x-y plane and have no z component. When a wave's electric field is transverse, it is called a transverse electric (TE) mode. When the magnetic field is transverse, it is call transverse magnetic (TM) and when both the electric and magnetic fields are transverse, the wave is called transverse electromagnetic, or TEM mode. Coaxial designs can support the TEM wave, but the single conductor is not able to support a TEM mode.

There are multiple integer solutions of modes that can exist within an existing geometry, and these modes are indicated by a subscript of the electric or magnetic field. For example, an important mode for these resonant structures is the TE_{10} mode. This mode has the lowest cut off frequency and allows for lower frequency resonances within the cavity filter.

It is important to note that the conductors used in these filters have very high conductivity, which provide the low loss and the ability to handle high power within these filters. However, since the theory is based on the physical boundaries of the electromagnetic waves within the medium, the dimensions tend to be large.

The typical applications well suited for these types of filters are systems where loss would impact the over performance would be difficult to overcome. Examples include transmitters in communications and radar systems, which are typically high power for improved range. Satellite receivers are another application for these types of filters to improve the range of communication to ground based stations.

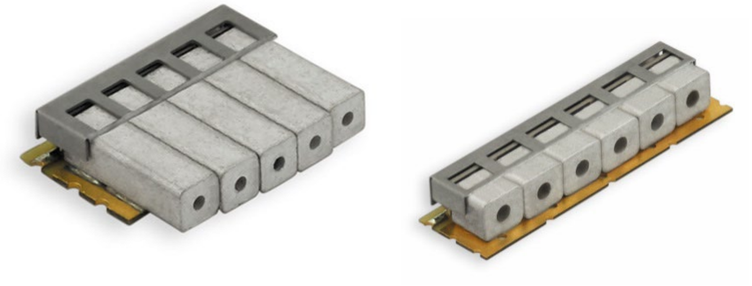
Ceramic Filters

When performance is less critical and price is a deciding factor, ceramic filters may be optimal as they offer good, reliable performance at a lower cost.

They are also typically quick to bring to market, having a short design phase and using readily available ceramic rods which minimize the lead time, making them suitable for commercial communications where fierce competition demands constant 'one-upmanship'. One particular application that has seen them take off is in the UAV (drone) industry.

The ceramic rods, or resonators, are capacitively coupled using a coupling board, typically manufactured with a dual-sided printed wiring board, that controls the response of the filter. The coupling board may utilize different dielectric materials to enhance the filter's performance at the chosen frequency of operation.

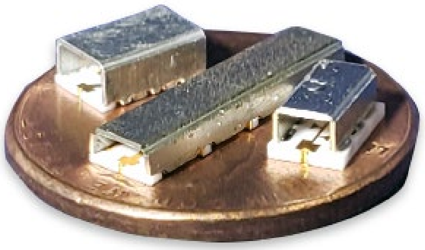
The biggest limitation of this filter type is the power handling capabilities, which is typically less than 1 Watt CW and will likely struggle to keep up with future technological demands. However, for low power applications, such as aeronautical communications for Identify Friend or Foe (IFF), the high Q of the resonators provide a low loss and economical solution for the RF filtering. Additionally, ceramic filters may be hermetically sealed to support hi-reliability applications in the defence and space markets.



Ceramic Filters

Planar Filters

Size is also driving the growth of planar filters. Using thin film processing, these filters can be as small as 0.1″ x 0.1″, whilst offering high rejection (>30 dB) with low insertion loss and power handling of up to 20 Watt.



Planar Filters

The most used planar topology is microstrip, which utilizes a ground plane on the bottom surface of the filter and has metal strips on the top surface which form the transmission lines in coordination with the ground plane. The microstrip designs offer a compact filter with the advantage of enabling the ground plane to also offer a heat sink for the microwave energy. The microstrip transmission lines can also be approximated as equivalent lumped element circuits to determine the filter response.

Along with their suitability for 'pick and place' assembly, this makes them the ideal choice for surface-mount designs where real estate is at a premium such as printed circuit boards. They further boost all performance measurements in switched filter banks through their ability to eliminate transitions between circuits and their internal channelization.

This makes them a popular choice for defence applications such as radar warning receivers, Signal Intelligence and Communication Intelligence (SIGINT and COMINT) receivers, as well as broadcast and satellite communications systems.

Whilst thin film technology doesn't inherently offer as many options as discrete or cavity filters, materials breakthroughs are increasing substrate options which extend the capabilities of planar filters. In addition, optimized designs that would be difficult to achieve in other filter types such as fractal geometries, dual mode and spurline lowpasses are further improving their performance.

These continuing performance gains, combined with their size, low mechanical complexity, and low-cost replicability, will see planar filters play an increasing role in emerging commodity communications markets such as 5G networks and LEO satellite constellations.

Smiths Interconnect

Decades of experience have positioned Smiths Interconnect at the forefront of what's possible in RF and Microwave solutions and we're committed to keep engineering **smarter** filters for the future.

For more detailed, technical information on the filters touched on above, please go to:

- Discrete: https://www.smithsinterconnect.com/products/rf-mw-mmw-components/rf-filters/discrete-filters/

- Cavity: https://www.smithsinterconnect.com/products/rf-mw-mmw-components/rf-filters/cavity-filters/

- Ceramic: https://www.smithsinterconnect.com/products/rf-mw-mmw-components/rf-filters/ceramic-filters/

- Planar X: https://www.smithsinterconnect.com/products/rf-mw-mmw-components/rf-filters/planar-x-filter-series/

Worldwide Support

Connectors

Americas

Sales
connectors.uscsr@smithsinterconnect.com

Technical Support
connectors.ustechsupport@smithsinterconnect.com

Europe

Sales
connectors.emeacsr@smithsinterconnect.com

Technical Support
connectors.emeatechsupport@smithsinterconnect.com

Asia

Sales
asiacsr@smithsinterconnect.com

Technical Support
asiatechsupport@smithsinterconnect.com

Fibre Optics & RF Components

Americas

Sales
focom.uscsr@smithsinterconnect.com

Technical Support
focom.techsupport@smithsinterconnect.com

Europe

Sales
focom.emeacsr@smithsinterconnect.com

Technical Support
focom.techsupport@smithsinterconnect.com

Asia

Sales
focom.asiacsr@smithsinterconnect.com

Technical Support
focom.techsupport@smithsinterconnect.com

Semiconductor Test

Americas

Sales
semi.uscsr@smithsinterconnect.com

Technical Support
semi.techsupport@smithsinterconnect.com

Europe

Sales
semi.emeacsr@smithsinterconnect.com

Technical Support
semi.techsupport@smithsinterconnect.com

Asia

Sales
semi.asiacsr@smithsinterconnect.com

Technical Support
semi.techsupport@smithsinterconnect.com

RF/MW Subsystems

Americas, Europe & Asia

Sales
subsystems.csr@smithsinterconnect.com

Technical Support
subsystems.techsupport@smithsinterconnect.com

Connecting Global Markets

more > **smithsinterconnect.com**