Principles for Division and Analyses of Microwave and Radio Frequency Signal Filters

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Abstract: This paper describes division and analyses of Microwave (MW) and Radio Frequency (RF) filters. These filters are devices that pass or reject signals by frequency. The filter design determines the amount of insertion loss and phase shift for signals that pass through the certain filter. Over the past decades are developed several basic types of MW and RF filters as one of the main requirements in designing the telecommunication transmitters and other devices. In general, all filters can be systemized as active and passive, while in particular can be ceramic, crystal, SAW (Surface Acoustic Wave) and adjustable filters. The main types of MW and RF filters, such as bandpass, bandstop, highpass and lowpass, and their characteristics are discussed.

Keywords: Microwave (MW), Radio Frequency (RF), Signal Filters, Surface Acoustic Wavev(SAW), Resistor, Inductor, Capacitor

1. Introduction

A MW & RF band-pass filters are special devices that passes frequencies within a certain range and rejects or attenuates frequencies outside that range. An example of an analogue electronic band-pass filter is an RLC circuit (Resistor/Inductor/Capacitor) or RC Circuit. These filters can also be created by combining a low-pass filter with a high-pass filter. Bandpass is an adjective that describes a type of filter or filtering process, which it is to be distinguished from passband and that refers to the actual portion of affected spectrum. Hence, one might say "A dual bandpass filter has two passband." A bandpass signal is a signal containing a band of frequencies not adjacent to zero frequency, such as a signal that comes out of a bandpass filter.

An ideal bandpass filter would have a completely flat passband (e.g. with no gain/attenuation throughout) and would completely attenuate all frequencies outside the passband. Additionally, the transition out of the passband would be instantaneous in frequency. In practice, no band-pass filter is ideal, but if a signal with a combination of several different frequencies is passed through the filter, it should deal with unwanted frequencies and give us the desired frequency response. The filter does not attenuate all frequencies outside the desired frequency range completely; in particular, there is a region just outside the intended passband where frequencies are attenuated, but not rejected. This is known as the filter roll-off, and it is usually expressed in dB of attenuation per octave or decade of frequency. Generally, the design of a filter seeks to make the roll-off as narrow as possible, thus allowing the filter to perform as close as possible to its intended design. Often, this is achieved at the expense of pass-band or stop-band ripple.

In general, all filters have the property of removing unwanted frequencies from same signal, which can be divided in two classes: passive (made of capacitors, resistors, inductors) and active (involving an amplifier). Then filters can be systematized in four types: Low-Pass (remove high frequencies), High-Pass (remove low frequencies or DC), Band-Pass (remove a range of frequencies on two sides) and Notch, Reject or Bandstop (removes frequencies in the middle), which diagram is illustrated in **Figure 1.**

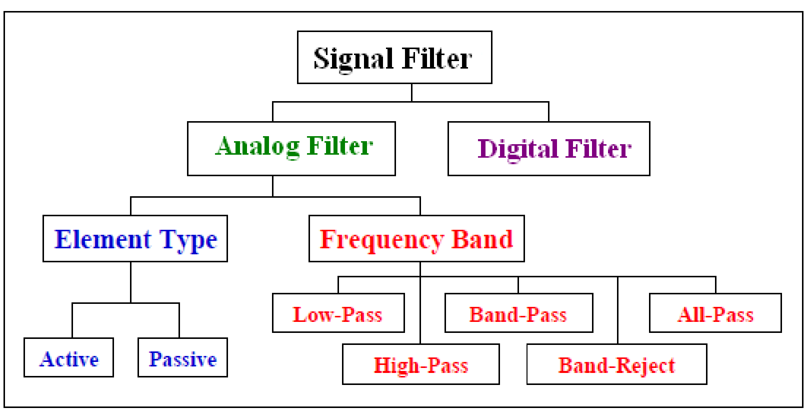

Figure 1. Classification of MW and RF Filters

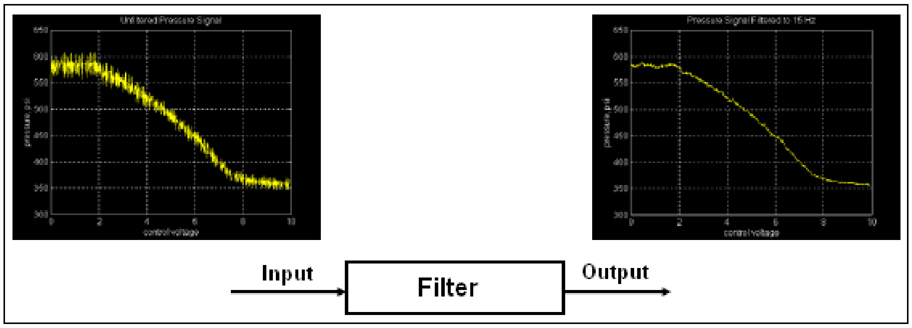

Figure 2. Outlines of Filter Design

The bandwidth of the filter is simply the difference between the upper and lower cutoff frequencies. The shape factor is the ratio of bandwidths measured using two different attenuation values to determine the cutoff frequency, e.g., a shape factor of 2:1 at 30/3 dB means the bandwidth measured between frequencies at 30 dB attenuation is twice that measured between frequencies at 3 dB attenuation. Optical bandpass filters are common in photography and theatre lighting work, which take the form of a transparent colored film or sheet. Terminology parameters of MW/RF filter design are Signal-to-Noise Ratio (S/N); bandwidth is range of frequencies as G (jw) > 0.707; cutoff frequency is and of passband frequency; and break point of a filter is a point of – 3 dB. The signal-to-noise ratio (or signal-to-interference) ratio, S/N (or SNR) is defined as relation:

$$S/N = 20\log_{10}\ (E_{th}/V_{SM}) = 10\log_{10}(W_S/W_N)\ \text{ in [dB]} \quad (1)$$

Where W_S and W_N is the signal and noise power, respectively, while Eth and V_{SM} are the root mean square **(**r.m.s.) values of the voltages. Thus, G (jw) is a complex number for any angular frequency, w, so the plot is a plot of complex numbers. In **Figure 2** are illustrated outlines of filter design with input and output signal after filtration. Thus, filtering is providing that certain desirable features are retained and other undesirable features are suppressed.

2. Bandpass Filters

Microwave and RF bandpass filters are active or passive circuits that pass signals from a specific frequency band and reject signals from out-of-band frequencies. One simple use for these types of passive filters is in audio amplifier applications or circuits such as in loudspeaker crossover filters or pre-amplifier tone controls, which circuit is shown in **Figure 3 (A).** This is example of an analogue electronic bandpass filter is an RLC circuit (Resistor–Inductor–Capacitor). These filters can also be created by combining a low-pass filter with a high-pass filter, which will be separately introduced in the following context. Sometimes it is necessary to only pass a certain range of frequencies that do not begin at 0Hz, (DC) or end at some high frequency point but are within a certain frequency band, either narrow or wide.
However, the active bandpass filter is slightly different in that it is a frequency selective filter circuit used in electronic systems to separate a signal at one particular frequency, or a range of signals that lie within a certain "band" of frequencies from signals at all other frequencies, shown in **Figure 3 (B).** An active filter is a type of analog electronic filter that also uses active components such as an amplifier. Amplifiers included in a filter design can be used to improve the performance and predictability of a filter, while avoiding the need for inductors, which are typically expensive compared to other components.

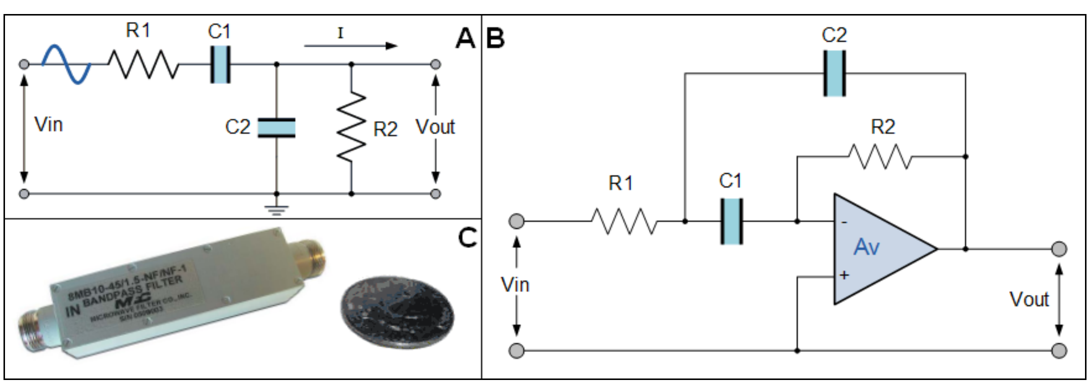

Figure 3. Circuits and Product of Passive and Active Bandpass

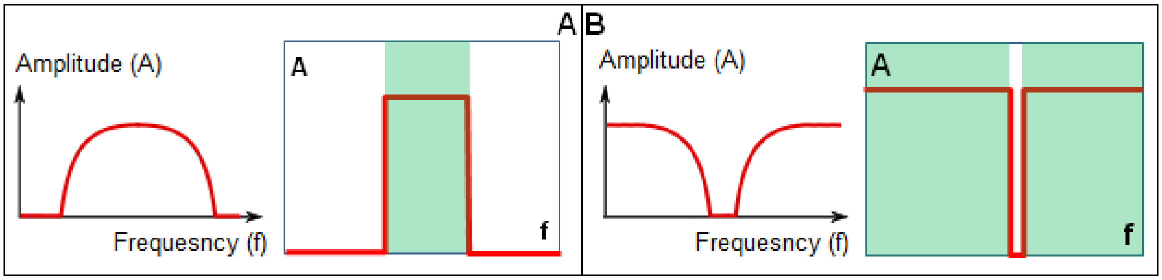

Figure 4. Amplitude Spectrum of Bandpass and Bandstop Filters

In **Figure 3 (C)** is illustrated Miniature Bandpass Filters product 8 MB10 100/10- PN/PN-1 of Microwave Filter Company's MB series of miniature bandpass filters utilize high quality components for narrow and wide band filter applications available frequency range from 0.5 to 500 MHz.

In **Figure 4 (A Left)**is shown amplitude spectrum of bandpass filter introducing terms and filter parameters. The bandpass filter is by far the commonest filter used in MW and RF technique. Therefore, bandpass filter is a filter that passes a certain range of frequency and blocks both lower and higher region than the specificied range, illustrated in **Figure (A Right).** The frequency range that passes the bandpass filter is determined by the specification for calculation of "Resonant" or "Centre Frequency" (f_r) point of the band pass filter were the output gain is at its maximum or peak value:

$$f_r = \sqrt{f_L} \text{ x } f_H \quad (2)$$

where f_L is the lower -3dB cut-off frequency point; and fH is the upper -3db cut-off frequency point. In fact, this peak value is not the arithmetic average of the upper and lower -3dB cut-off points as might expect but is in fact the "geometric" or mean value.

Therefore, bandpass is an adjective that describes a type of filter or filtering process, and thus it is to be distinguished from passband, which refers to the actual portion of affected spectrum. Hence, one might say "A dual bandpass filter has two passbands." A bandpass signal is a signal containing a band of frequencies not adjacent to zero frequency, such as a signal that comes out of a bandpass filter.

3. Bandstop or Bandreject Filters

Bandstop, Bandreject or Bandelemination (Notch) filters are tuned circuits that prevent the passage of signals within a specified band of frequencies. The specified frequency is the center frequency, which performance specifications for these filters include specified frequency, bandwidth, ripple, insertion loss and voltage standing wave ratio. Bandwidth is the range of frequencies that RF band reject filters pass with maximum attenuation. Ripple is the peak-to-peak variation of the passband response. Insertion loss is the total RF power transmission loss resulting from the insertion of a device in a transmission line.

In **Figure 4 (B Left)** is shown amplitude spectrum of bandstop filter introducing terms and filter parameters.

The bandstop filter is a filter that passes most of the frequency except a very narrow range of the frequency. The purpose of the other types of the filter is to pass signals with a certain range, but the purpose of the bandstop filter is to block a selected frequency of the signal, illustrated in **Figure (B Right).**

Therefore, in signal processing bandstop filters passes most frequencies unaltered, but attenuate those in a specific range to very low levels, which circuit is shown in **Figure 5 (Left).** It is the opposite of a bandpass filter, however in particular it is a filter with a narrow bandstop with high Q-factor). This kind of filter passes all frequencies above and below a particular range set by the component values.

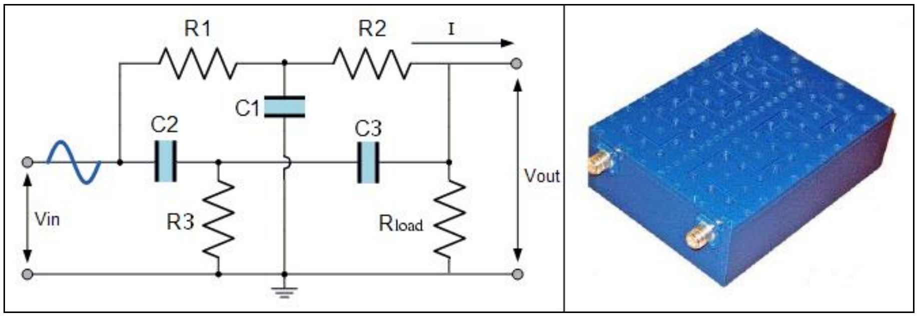

Figure 5. Circuits and Product of Bandstop Filter

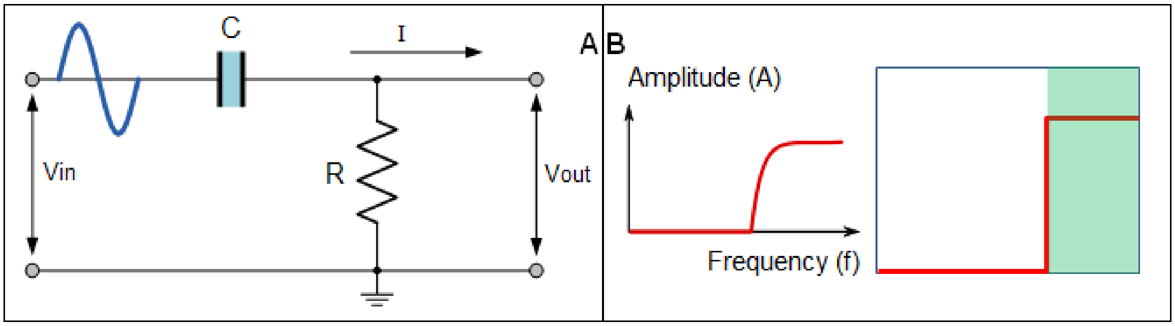

Figure 6. Circuits and Amplitude Spectrum of Highpass Filters

In fact, it can be made out of highpass and lowpass filters, just like the bandpass design, except that this time it can connect the two filter sections in parallel with each other instead of in series. In **Figure 5 (Right)** is shown VHF-band bandstop filter of Reactel producer that rejects all frequencies between 240 to 270 MHz by 60 dB in small package size. The bandstop filter is containing the lowpass filter section comprised of R_1, R_2, and C_1 in a "T" configuration, while the highpass filter section is comprised of C_2, C_3, and R_3 in a "T" configuration as well. Together, this arrangement is commonly known as a "Twin-T" filter, giving sharp response when the component values are chosen in the following ratios:

$R_1 = R_2 = 2(R_3)$ and $C_2 = C3\ (0.5)\ C_1$

Given these component ratios, the frequency of maximum rejection known as "Notch Frequency" (NF) can be calculated as follows:

$f_{NF} = 1/4\pi R_3C_3$

There are several mounting styles for RF bandstop filters, which use several types of connectors. Bandstop filters are used as telephone line noise reducers, DSL Internet technology, digital image processing, and many power amplification technologies. They are also very useful in communications electronics for eliminating desired harmonics of signals and are very common in electric guitar amplifiers. However, they can help to reduce static in radio, interference in cell phones and can be employed to eliminate residual harmonics.

4. Highpass Filters

Highpass filters is the exact opposite to that of a low pass filter, which pass signals from high frequencies and reject signals from low frequencies, which circuit diagram is shown in **Figure 6 (Left).** Thus, in this circuit arrangement, the reactance of the capacitor is very high at low frequencies so the capacitor acts like an open circuit and blocks any input signals at (Vin) until the cut-off frequency point (f_C) is reached. Thus, above this cut-off frequency point the reactance of the capacitor has reduced sufficiently as to now act more like a short circuit allowing the entire input signal to pass directly to the output. The cut-off frequency point (f_C) for a first order highpass filter can be found using the same equation as that of the low pass filter, while the equation for the gain (A_V) and phase shift (φ) is modified slightly to account for the positive phase angle as shown below:

$A_V = Vout/Vin$; $f_C = 1/4\pi RC$; & $\varphi = \arctan 1/4\pi fRC$

In such a way, here the signal is attenuated or damped at low frequencies with the increasing output, where as the low pass filter only allowed signals to pass below its cut-off frequency point (f_C), the passive high pass filter circuit as its name implies, only passes signals above the selected cut-off point, eliminating any low frequency signals from the waveform. There are several mounting styles and connectors for highpass filters.
Therefore, a highpass filter is an electronic filter that passes high-frequency signals but attenuates (reduces the amplitude of) signals with frequencies lower than the cutoff frequency. The actual amount of attenuation for each frequency varies from filter to filter. A highpass filter is usually modeled as a linear time-invariant system. It is sometimes called a low-cut filter or bass-cut filter. Highpass filters have many uses, such as blocking DC from circuitry sensitive to non-zero average voltages or RF devices. They can also be used in conjunction with a lowpass filter to make a bandpass filter. In **Figure 6 (B Left)** is shown amplitude spectrum of highpass filter introducing terms and filter parameters. A highpass filter is often used to suppress acquisition noise and this filter passes the signal with high frequency and blocks low frequency signal, shown in **Figure 6 (B Right).** How high the frequency should be is dependent on the specification of the filter.

Figure 7. Products of Highpass and Lowpass Filters

In **Figure 7 (Left)** is illustrated wideband highpass filter produced by Reactel manufacturer, which has a passband of 18 to 40 GHz. This tiny unit is perfect for portable or "hi-rel" applications.

5. Lowpass Filters

Lowpass filters are the opposite of highpass filters, which passes low-frequency signals and attenuates or reduces the amplitude of signals with radio frequencies higher than the cutoff frequency. The actual amount of attenuation for each frequency varies depending on specific filter design. Therefore, it is sometimes called a high-cut filter or treble cut filter in audio transmission applications. There are also several mounting styles and connectors for lowpass filter.

A simple passive RC lowpass filter can be easily made by connecting together in series a single resistor with a single capacitor as illustrated in **Figure 8 (A).** In this type of filter arrangement the input signal (Vin) is applied to the series combination (both the resistor and capacitor together) but the output signal (Vout) is taken across the capacitor only. This type of filter is known generally as a "first-order filter" or "one-pole filter", because it has only "one" reactive component, the capacitor, in the circuit.

While the circuit above is that of an RC Low Pass Filter circuit, it can also be classed as a frequency variable potential divider circuit, which provides the following calculation of the total resistance of the circuit (R_T) and the output voltage for two single resistors connected in series.

$Vout = Vin \times R_2/R1 + R_2$, where $R_1 + R_2 = R_T$

Lowpass filters exist in many different forms, including electronic circuits, such as a hiss filter used in audio, anti-aliasing filters for conditioning signals prior to analog-to-digital conversion, digital filters for smoothing sets of data, acoustic barriers, blurring of images, and so on. The moving average operation used in fields such as finance is a particular kind of lowpass filter, and can be analyzed with the same signal processing techniques as are used for other low-pass filters. Thus, lowpass filters provide a smoother form of a signal, removing the short-term fluctuations, and leaving the longer-term trend.

In **Figure 8 (B Left)** is shown amplitude spectrum of lowpass filter introducing terms and filter parameters. A highpass filter is often used to suppress acquisition noise and this filter passes the signal with high frequency and blocks low frequency signal, illustrated in **Figure 8 (B Right).** How high the frequency should be is dependent on the specification of the filter.

In **Figure 7 (Right)** is shown high power lowpass filter produced by Reactel manufacturer, which passes the HF band with rejections out to 500 MHz all while withstanding power levels of 1250 W CW. The RF low ass filters use several t mounting styles and types of connectors.

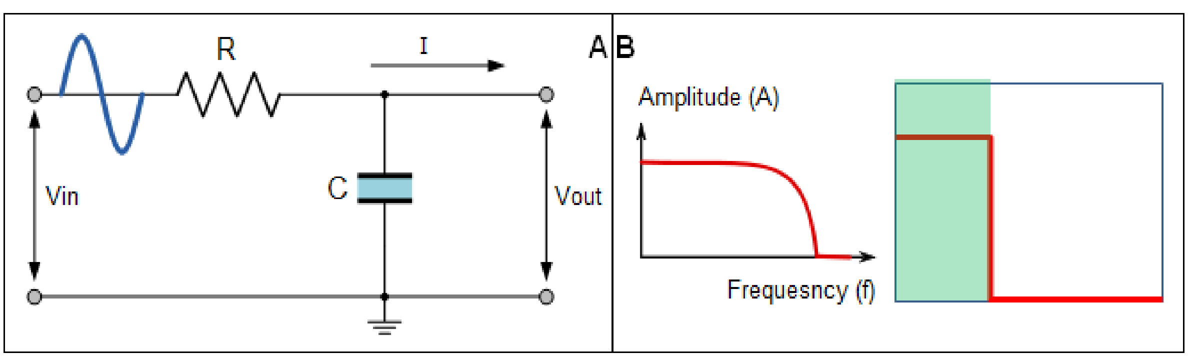

Figure 8. Circuits and Amplitude Spectrum of Lowpass Filters

6. Conclusion

In the maritime, aeronautical, military industries, telecommunications, satellite, radio and radar applications are using transmission systems to transmit and receive MW and RF signals to perform specific tasks for all users. This information may consist of travel path information from commercial transporation assests, or it could consist of military equipment detecting enemy radar systems or jamming their transmitted frequencies. Depending on the specific requirements of the equipment, a high-poweréddiplexer with different types of MW and RF filters will be needed to sort the different transmitted and received signals through a common antenna based on the frequency allocation. By understanding the characteristics of a diplexer, people can select the right filter and components for the application.

In transmission systems, analog filters provide different factual shapes, bandwidths, and frequency responses appropriate to their application. Solid electronics could include piezoelectric filters, while hybrid Microwave Integrated Circuit (MIC) elements in test instruments would use filters with grouped and distributed elements. Although much larger, waveguide and cavity filters are necessary for duplexers where they can be tuned for ultimate selectivity in radio communications, and waveguide filters can withstand the high power required for radar and other devices. In order to choose the ideal filter, it may be important to understand the construction and electrical characteristics in order to properly integrate a particular filter into the architecture.

8. References

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Prof. Dimov Stojce Ilcev is a research leader and founder of the Space Science Centre (SSC) for research and postgraduate studies at Durban University of Technology (DUT). He has three BSc degrees in Radio, Nautical Science and Maritime Electronics and Communications. He got MSc and PhD in Mobile Satellite Communications and Navigation as well. Prof. Ilcev also holds the certificates for Radio operator 1st class (Morse), for GMDSS 1st class Radio Electronic Operator and Maintainer and for Master Mariner without Limitations. He is the author of several books in mobile Radio and Satellite CNS, DVB-RCS, Satellite Asset Tracking (SAT), Stratospheric Platform Systems (SCP) for maritime, land (road and railways), and aeronautical applications.