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A Review of Key Filter Specifications and What They Mean

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Here is a tutorial review of filter specifications, which must be understood before designing a filter or purchasing a commercial unit

Whether designing or buying a filter, the key specifications must be understood in order to make the right design decisions or unit selections. This tutorial article offers a review of filter technical specifications, what they mean, and some of the applications that are most affected by particular specifications. In commercial electronics, technical specifications are often subordinate to unit cost and adequate performance is acceptable without optimization. In government electronics, reliability considerations can be paramount and high unit costs will occur. Reliability is crucial in the commercial field of medical electronics

A filter provides selectivity in signal processing. Filters reject unwanted spurious outputs from transmitters and partially determine the sensitivity of receivers for applications in communications, radar, and electronic countermeasures. Filters also suppress noise and reduce ripple in DC power supplies. Digital filters usually are part of integrated systems and subsystems and are rarely available as stand alone components. They will not be considered herein.

Analog filters are available as both passive and active units where specifications can be in either the frequency domain or the time domain. Passive filters are characterized by their frequency responses between matched source and matched load. Active filters are characterized by Bode plots applicable to voltage transfer responses through frequency selective amplifiers. This article will primarily discuss analog passive filter specifications in the frequency domain.

Passive Filter Realization

Passive filters often use lumped and/or distributed circuit elements providing one or more passbands and one or more stopbands. In the passband, signal transmission is desired while in the stopbands, signal rejection is desired. Individual passive filters are normally operated between a matched source (generator) and matched termination (load). To achieve desired passband fidelity and stopband selectivity, filters are designed for various transmission response shapes using the classic method of image parameters or the more current method of modern network theory. Both design methods can provide good results when applicable computer programs are used to predict filter performance and

Response Shape	Design Method	Characteristic	Remarks
Constant-k	Image Parameters		Design Simplicity
m-derived	Image Parameters	Sharp Cutoff	Design Simplicity
Butterworth	Modern Network	Compromise Design	Math Simplicity
Chebychev	Modern Network	Most Common	
Gaussian	Modern Network	Reduced Cutoff	Good Transient Resp.
Elliptic Function	Modern Network	Superior Design	Expensive

Table 1 · Typical filter response shapes and notes on their implementation.

determine necessary circuit element values. This must be accompanied by accurate modeling of all circuit elements. Electromagnetic simulation can be used for current microwave filter design as an alternative to developmental techniques.

Some typical filter response shapes are compared in Table 1.

Filters can have low pass, high pass, band pass, or band reject behavior. A popular starting point is a normalized low pass prototype with unity source and load impedances. A low pass prototype (circuit g or q and k values) is used for most LC and some microwave filters. Actual filter circuit elements are obtained by denormalization of pass band, cutoff frequency(s), and actual source/load impedance levels. The normalized schematic (three dB normalization) of a seven pole lossless Chebyshev lowpass filter with 0.1 dB passband ripple is shown in Figure 1.

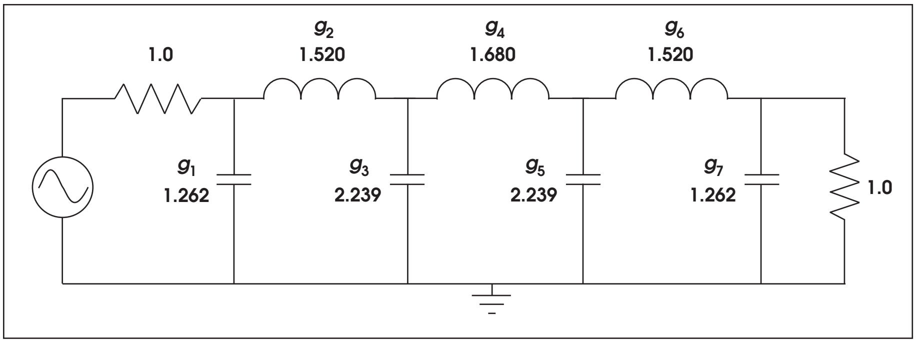

Figure 1 · Normalized (3 dB) Chebyshev lowpass filter prototype; n = 7 poles, ripple = 0.1 dB.

		Lossless		$Q_{ul} = 50$		$Q_{ul} = 10$	
x	f (MHz)	L (dB)	RL (dB)	L (dB)	RL (dB)	L (dB)	RL (dB)
0	0	0	>40	1.02	33.8	5.05	23.1
0.05	0.5	0.01	25.1	1.03	25.4	5.06	22.3
0.1	1	0.05	19.7	1.06	20.5	5.08	20.9
0.15	1.5	0.08	17.3	1.09	18.2	5.11	19.7
0.2	2	0.1	16.4	1.11	17.4	5.16	19.2
0.25	2.5	0.09	16.9	1.11	17.8	5.20	19.4
0.3	3	0.06	18.8	1.10	19.7	5.26	20.3
0.35	3.5	0.02	23.4	1.09	23.9	5.33	21.6
0.4	4	0	>40	1.09	32.6	5.42	22.4
0.45	4.5	0.01	25.2	1.13	25.5	5.54	21.8
0.5	5	0.05	19.3	1.18	20.1	5.69	20.3
0.55	5.5	0.09	16.9	1.24	17.9	5.86	19.2
0.6	6	0.1	16.5	1.29	17.6	6.06	18.9
0.65	6.5	0.06	18.4	1.32	19.4	6.31	19.3
0.7	7	0.01	25.1	1.35	25.0	6.61	19.9
0.75	7.5	0.01	29.6	1.43	27.4	7.01	19.6
0.8	8	0.06	18.6	1.58	19.6	7.53	18.1
0.85	8.5	0.1	16.5	1.77	17.6	8.25	16.5
0.9	9	0.01	24.8	2.04	21.4	9.28	14.6
0.95	9.5	0.032	11.5	2.89	12.9	10.81	11.8
1.0	10	3.01	3.0	5.47	5.2	13.01	8.6
1.1	11	13.3		14.4		19.1	
1.2	12	22.3		22.9		25.7	
1.4	14	35.9		36.2		37.6	
1.6	16	46.3		46.5		47.4	
1.8	18	54.9		55.1		55.7	
2.0	20	62.3		62.4		62.9	

Table 2 · Calculated insertion loss and return loss responses for the 7 pole, 0.1 dB ripple lowpass filter of Figure 1, using inductor and capacitor unloaded Qs of 1×10^6 (lossless), 50, and 10.

Filter Frequency Responses

Filters have two different types of responses: transmission and reflection. Transmission responses are specified as insertion loss in dB, phase nonlinearity in degrees, and differential group delay in milliseconds, microseconds or nanoseconds. Reflection responses are usually specified as return loss in dB. Both transmission and reflection responses are usually specified as some lessor portion of the three dB or design reference bandwidth. A normalized frequency variable x is customarily used for analysis and design purposes. Ideal dissipationless filters have lossless reactive circuit elements with unloaded Qs in excess of 1×10^6. Practical dissipative filters using miniaturized surface mount components can have unloaded Qs of only 10 for both capacitors and inductors. This significantly degrades the filter performance. Unloaded Q is a figure of merit for the quality of reactive components. For the seven pole Chebyshev filter of Figure 1 with a 3 dB cutoff frequency of 10 MHz, predicted filter insertion loss and return loss performance is shown in Table 2.

Discussion of Typical Filter Specifications—

1. Transmission and Reflection Responses:

Usable Passband (s) Transmission Responses—Maximum insertion loss in dB over specified frequency range(s), maximum phase nonlinearity in degrees over specified frequency range(s), maximum differential group delay in unit of time over specified frequency range.

L-C
Quartz Crystal
Mechanical
Active Using Op-Amps
SAW
MEMS
Coaxial Line
Ferromagnetic (YIG)
Waveguide
Strip Transmission Line
Dielectric Resonator
Superconducting

Table 3 · Various filter structures.

Usable Passband Reflection Responses—Minimum Return Loss in dB over specified frequency range(s).

Usable Stopband Rejection—Minimum Insertion Loss in dB over specified frequency range(s)

Source and Load Impedance in ohms—50 and 75 ohm impedances are typical above audio frequencies.

2. Filter Interfaces:

Specify filter input/output interfaces such as coaxial connectors, standard waveguide size, solder lugs, surface mount tabs, etc.

3. Mechanical:

Location of interfaces and any adjustable circuit elements. A mechanical outline drawing showing mounting information is necessary.

4. Environmental:

Specify both operating and storage temperature, humidity, altitude, shock and vibration, salt spray, etc. This can affect acceptable unit surface finishes. When applicable, include Government specifications.

5. Reliability:

This can be specified as availability. Government specifications should be included when applicable.

Unit cost is directly related to the number of specifications imposed and their stringency. Imposition of source inspection and workmanship standards can also affect the cost. Unit costs will go down as production volume goes up.

Miscellaneous Considerations

Filters are not always obtained as single unit. Filter subsystems can entail multiplexing of individual units and require different impedance levels at some interfaces.

Transmission line filters with distributed circuit element can have spurious passbands that are nominal harmonics of usable passbands. Other spurious passband can be excited by higher mode propagation in anticipated filter stopbands.

Many of the possible filter structures are listed in Table 3.

Each filter structure has its own set of problem areas relating to materials and manufacturing processes. Also, special attention is required when working at high signal levels. High average power levels can result in overheating while high peak power levels can result in voltage breakdown. Some filter structures are sensitive to shock and vibration. YIG filters are sensitive to adjacent magnetic fields. Superconducting filters require control of temperature. In some applications, intermodulation distortion in passive filters can be a problem area. Switched filters can vary from simple mechanical switching to local/remote computer controls.

Acknowledgement

Filter design and development can entail a wide of technology. The contributions of many other engineers and technicians are gratefully acknowledged. References have been omitted for purposes of brevity—there are many useful publications that cover this subject.

Author Information

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