Low Cost Lowpass Filter Design Using Image Parameters

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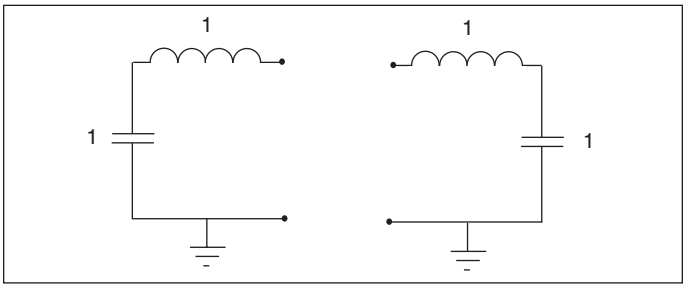
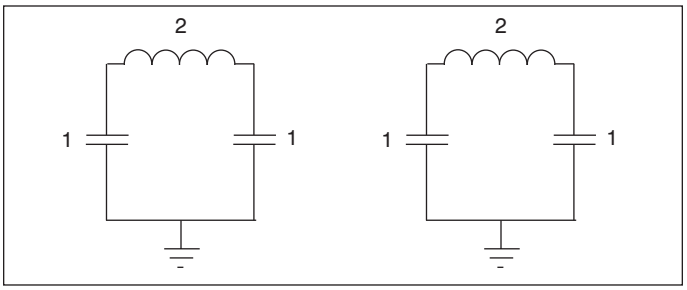
Although modern network synthesis has taken over most L-C filter design tasks, the classic method of image parameters still provides useful filter performance with definite time and cost advantages. Determination of filter circuit elements can be performed readily using simple computations on a pocket calculator. Filter realization with a minimum number of different circuit element values results in reduced costs for both parts procurement and unit manufacture.



▲ **Figure 1a. Two constant-k half sections.**



▲ **Figure 1b. Two constant-k full sections (double pi).**

Image parameter lowpass filter design

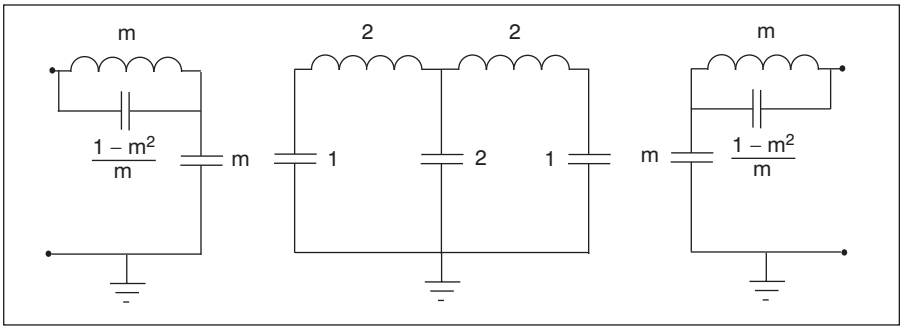
The starting point for image parameter design, per Figure 1a, is the constant-k half section, which has normalized series inductance and shunt capacitance equal to unity. Composite filter design, as shown in Figures 1b and 1c, entails constant-k and/or m-derived interior full sections with m-derived half sections for impedance matching to source and load [1,2]. As a convenient example, the double pi constant-k configuration has been selected as the filter interior. Impedance matching is achieved using mid-shunt m-derived half sections. A schematic of the composite lowpass filter is shown in Figure 2; normalized circuit element values are in Table 1.

The composite filter was usually designed with m = 0.6. This resulted in near-optimum impedance matching. With m = 0.6 design, there are two different values of inductance and three different values of capacitance. If we use m = 0.5, it can be seen that there are two different values of inductance and only two different values of capacitance.

Filter design proceeds from normalized prototypes, which are de-normalized for actual cutoff frequency and impedance. Normalized circuit elements are multiplied by reference inductor L and reference capacitor C, as shown in Table 2 for f = 10 MHz cutoff frequency and source and load impedance Z = 50 ohms. For m = 0.5 and m = 0.6, actual circuit element values are shown in Table 3. The m-derived half sections provide peak rejection as shown in Table 4.

Filter performance

The composite filter networks are ladder networks that can easily be analyzed using ABCD matrix multiplications. Unloaded Qs of fifty are assumed for all filter inductances. With normalized circuit elements, the amplitude and passband VSWR responses are obtained for the composite filter with m = 0.5 and m = 0.6. The normalized frequency variable x is unity at the design cutoff frequency so that the passband is for x less than unity and the stopband is for x greater than unity. These responses are shown in Table 5. It can be seen that using m = 0.6 gives a flatter passband VSWR response than with m = 0.5.



▲ **Figure 1c. Composite lowpass filter development.**

Circuit Elements	General	With m = 0.5	With m = 0.6
L1, L7	m	0.5	0.6
C1, C7	$(1-m^2)/m$	1.5	1.0667
C2,C6	1+m	1.5	1.6
L3, L5	2	2	2
C4	2	2	2

▲ **Table 1. Lowpass filter normalized circuit elements.**

$L = Z/(2\pi f) = 50/(2\pi 10)$	$L = 0.796\ \mu H$
$C = 1\times10^6/(2\pi fZ) = 1\times10^6/(2\pi 10\cdot 50)$	$C = 318.3$ pF

▲ **Table 2. Computation of Reference Inductance and Reference Capacitance.**

Circuit Elements	Values for m = 0.5	Values for m = 0.6
L1, L7	0.398 μH	0.4776 μH
C1, C7	477.5 pF	339.5 pF
C2, C6	477.5 pF	509.3 pF
L3, L5	1.592 μH	1.592 μH
C4	636.6 pF	636.6 pF

▲ **Table 3. Lowpass filter circuit element values.**

m	Normalized peak rejection	Actual peak rejection
0.5	x = 1.1547	11.547 MHz
0.6	x = 1.25	12.5 MHz

▲ **Table 4. Peak rejection frequencies.**

Realization of ultimate selectivity can become impaired as the stopband frequency increases. Inductors [3] and capacitors [4] behave quite differently when the contributions of parasitic circuit elements are taken into account. Inductors will become self-resonant with stray shunt capacitances, and capacitors will become self-resonant with stray series lead inductances. Other anomalies can occur when lumped element electrical lengths exceed one-tenth of a wavelength. Then, lumped circuit elements become distributed circuit elements.

Conclusions

Composite lowpass filters with m-derived terminating half sections can provide can provide filter responses that are quite acceptable. Cost savings are achieved by using only four or five different circuit elements. These filters are symmetrical ladder networks that can be quickly designed. Performance prediction via computer takes into account the inductor unloaded Qs.

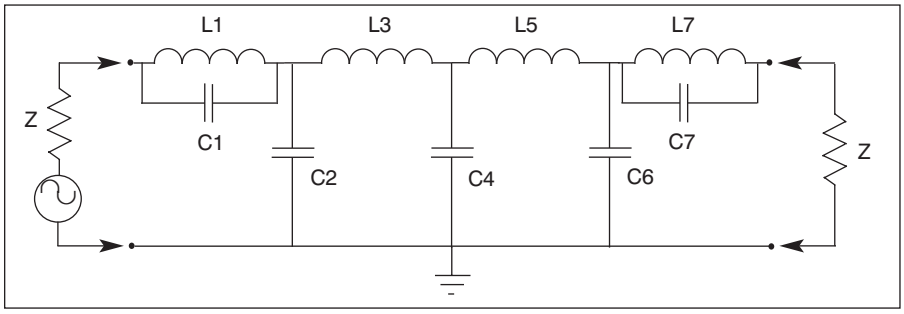
The filter example uses two interior constant-k full sections. Additional interior constant-k full sections can be added without introducing any new circuit element values. The techniques presented for lowpass filters can be readily applied to high pass filters [5]. ■

x	m = 0.5 Loss (dB)	m = 0.5 VSWR	m = 0.6 Loss (dB)	m = 0.6 VSWR
0	0.42	1.100	0.44	1.104
0.1	0.43	1.096	0.44	1.099
0.2	0.44	1.085	0.45	1.084
0.3	0.45	1.075	0.46	1.062
0.4	0.47	1.088	0.48	1.055
0.5	0.49	1.109	0.51	1.073
0.6	0.52	1.078	0.54	1.081
0.7	0.60	1.123	0.62	1.137
0.8	0.90	1.471	0.82	1.300
0.9	1.42	1.731	1.32	1.528
1.0	6.04	8.019	6.39	8.388
1.1	25.39		19.74	
1.2	35.96		37.57	
1.3	33.08		44.57	
1.4	34.73		41.13	
1.5	37.22		42.13	
1.7	42.66		46.42	
2	50.42		53.63	
3	70.84		73.66	
4	85.63		88.39	

▲ **Table 5. Computed amplitude and VSWR responses.**

References

1. *Reference Data for Radio Engineers,* Fifth Edition, ITT/Howard W. Sams, 1968, Ch. 7.
2. G. L. Matthei, L. Young and E. M. T. Jones, *Microwave Filters, Impedance Matching Networks, and Coupling Structures*, McGraw-Hill, 1964, pp. 60-68.
3. G. A. Breed, "Inductor Behavior at Radio Frequencies," *RF Design*, Feb. 1996, pp. 67-68.
4. G. A. Breed, "Capacitor Behavior at Radio Frequencies," *RF Design*, Jan. 1996, pp. 58, 61.
5. R. Rhea, *HF Filter Design and Computer Simulation*, Noble Publishing, 1994, pp. 145-146.



▲ **Figure 2. Composite lowpass filter schematic.**

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