PASSIVE ELLIPTIC FILTERS USING STANDARD-VALUE CAPACITORS

Introduction

In a previous issue of ITEM (see References 1-14), it was demonstrated how the Chebyshev passive LC filter could be used for many signal line filtering applications, including the attenuation of undesired harmonics from a signal generator or for receiver preselection. The design and construction of the Chebyshev equally-terminated filter was greatly simplified with computer-calculated design tables covering one decade of frequency in which only standard-value capacitors were needed. The user scanned the table to find a cutoff frequency suitable for the intended application, and then constructed the filter in accordance with the tabulated values and the schematic diagram given in the table. Because only standard-value capacitors were required, the filter was easier to construct than if non-standard value capacitors had been required. Also, the computer calculation of all component values eliminated the chance of computational errors that very likely would have occurred if the customary design procedures had been used.

These precalculated design tables are of special interest to the EMI/RFI test engineer, for they allow one relatively inexperienced in the design and construction of filters to quickly, accurately and conveniently select and fabricate a suitable filter.

Chebyshev Filter Has Limited Selectivity and Versatility

Although the Chebyshev filter is very easy to construct because of its simple ladder configuration (alternating capacitors and inductors), this filter type has limited selectivity and versatility, making it unsuitable for the more stringent filtering applications. For example, the 5-element Chebyshev filter has about 31 dB of attenuation at one octave from the cutoff frequency; however, some applications require that a higher attenuation level be reached at a frequency less than one octave from the cutoff frequency. Another disadvantage of the Chebyshev filter is its lack of versatility in allowing one to control the stopband attenuation response. This is illustrated by its continually increasing attenuation that theoretically approaches infinity as the frequency proceeds into the stopband. In actual applications, a filter attenuation in excess of 80 dB is seldom needed; consequently, it is not feasible to utilize the theoretical attenuation of the Chebyshev response much beyond the first or second octave from the cutoff frequency. A more versatile filter response would allow the user to design for some minimum acceptable stopband attenuation (for example, 50 dB), where the stopband attenuation would never fall below this level. Also, by trading lower or higher levels of minimum stopband attenuation, the abruptness of attenuation rise could be changed.

Of course, if more selectivity is needed, a Chebyshev filter with more elements could be used, but this has the disadvantage of added complexity, bulk and cost. Also, the disadvantage of being unable to control the minimum stopband attenuation level remains.

Use the Elliptic Function Filter for Increased Selectivity

In order to obtain a more abrupt increase in attenuation than is possible with the Chebyshev, a different and more versatile type of filter called the *elliptic function* (also known as the *Cauer-parameter*) must be used. The elliptic filter configuration is distinguished from the Chebyshev by resonant sections tuned to frequencies in the filter stopband near the cutoff frequency. These resonant sections cause a more abrupt rise in the elliptic filter attenuation as compared to the Chebyshev filter, which lacks resonant sections. The resonant frequencies of the elliptic filter can be placed in the filter stopband to provide any desired level of minimum stopband attenuation. The passband of the elliptic filter is similar to that of the Chebyshev in that attenuation ripples are present and have a maximum amplitude

$$\text{(1)} \quad R.C._{(\%)} = 100*SQR[1 - (0.1\uparrow x)] \quad \text{where } 100*SQR = 100 \text{ times the square root of...}$$

$x = 0.1 * (A_p)$

$\uparrow$ = symbol for exponentiation

$*$ = symbol for multiplication

$$\text{(2)} \quad A_{p(dB)} = -4.3429*LOG[1 - (.01*RC)\uparrow 2]$$

$$\text{(3)} \quad VSWR = [1 + (.01*RC)] / [1 - (.01*RC)]$$

Equations (1-3) are presented in a format suitable for computer programming. The LOG function in Eq. (2) is based on the natural log.

A_p = Maximum passband ripple amplitude in dB

RC = Reflection coefficient in percent

VSWR = Voltage standing wave ratio

Figure 1. Equations Relating R.C., A_p and VSWR for all designs in Tables 1, 2 and 3.

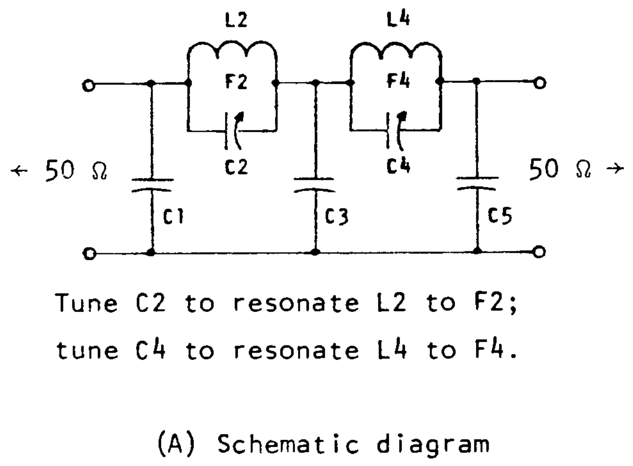
related to the reflection coefficient and VSWR of the filter. The relationship of these three parameters to each other are shown in Figure 1 and Table 1.

For a particular level of passband ripple, the abruptness of the attenuation rise in the stopband can be increased or decreased by decreasing or increasing the minimum stopband attenuation level. The versatility of the elliptic filter makes it much more useful than the Chebyshev with its relatively inflexible stopband attenuation response.

This article will discuss the 5th-degree elliptic filter which is related to the 5th-degree (5-element) Chebyshev filter. This particular degree of elliptic filter was selected because its attenuation response is adequate for most of the more stringent filtering requirements encountered by the EMI/RFI engineer, and because it is possible to define many unique designs in which all of the *non-resonating* capacitors can be standard values. The fact that the *resonating* capacitors are not standard values is not important because these capacitors will be varied anyway to tune the inductors precisely to the specified frequencies.

REFLECTION COEFFICIENT (%)	MAX. RIPPLE AMPLITUDE (DB)	MAX. VSWR	REFLECTION COEFFICIENT (%)	MAX. RIPPLE AMPLITUDE (DB)	MAX. VSWR
1.0000	0.000434	1.020	16.000	0.1126	1.381
1.5173	0.001000	1.031	18.000	0.1430	1.439
2.0000	0.001738	1.041	20.000	0.1773	1.500
3.0000	0.003910	1.062	22.000	0.2155	1.564
4.0000	0.006954	1.083	23.652	0.2500	1.620
4.7958	0.010000	1.101	24.000	0.2576	1.632
5.0000	0.010871	1.105	25.000	0.2803	1.667
6.0000	0.015663	1.128	26.000	0.3040	1.703
7.0000	0.021333	1.151	28.000	0.3546	1.778
8.0000	0.027884	1.174	30.000	0.4096	1.857
9.0000	0.035321	1.198	32.977	0.5000	1.984
10.0000	0.043648	1.222	34.000	0.5335	2.030
11.0000	0.052870	1.247	36.000	0.6028	2.125
12.0000	0.062992	1.273	38.000	0.6773	2.226
13.0000	0.074022	1.299	40.000	0.7572	2.333
14.0000	0.085966	1.326	42.000	0.8428	2.448
15.0000	0.098831	1.353	44.000	0.9345	2.571
15.0874	0.100000	1.355	45.351	1.0000	2.660

Table 1. Filter Reflection Coefficients with Corresponding Values of Passband Ripple Amplitude and VSWR (for all designs in Tables 1, 2 and 3.



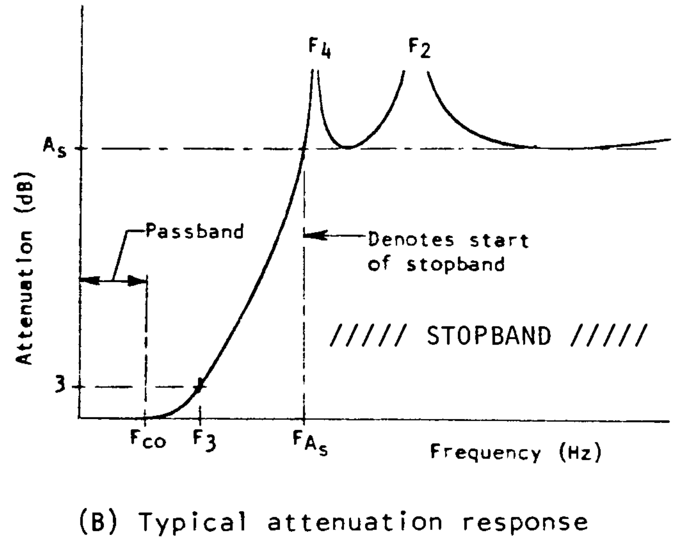
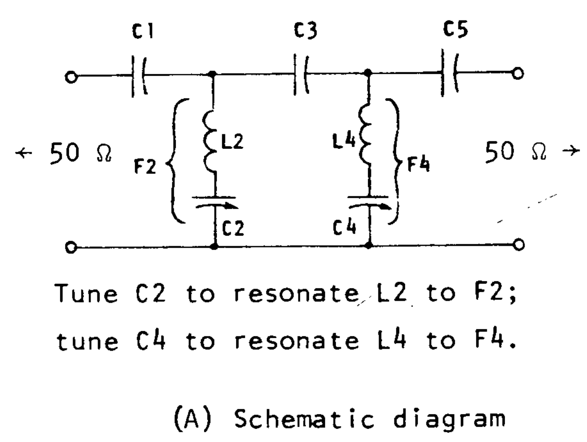


Figure 2. 50-ohm 5th-Degree Elliptic Lowpass Filter.

Figures 2 and 3 show the low-pass and high-pass schematic diagrams and attenuation responses, respectively, of 5th-degree elliptic designs. The configurations are similar to the corresponding 5th-degree low-pass and high-pass Chebyshev designs, except the inductors are resonated with parallel capacitors in the low-pass designs, and series capacitors in the high-pass designs. You will recall that one of the conveniences of the Chebyshev design was that for the 5-element filter, the inductor values were identical, and the input and output capacitor values were also identical. Of course, this characteristic greatly simplified construction. Unfortunately, the elliptic filter component values do not share this characteristic—there are no common values; that is, all capacitor values are different from one another and so are the two inductor values. This characteristic of the elliptic filter is a continual inconvenience to those attempting to design and construct this filter when using the standard text book design procedure. However, this problem has been solved by finding and tabulating all those elliptic designs that can use standard-value capacitors for C1, C3 and C5.



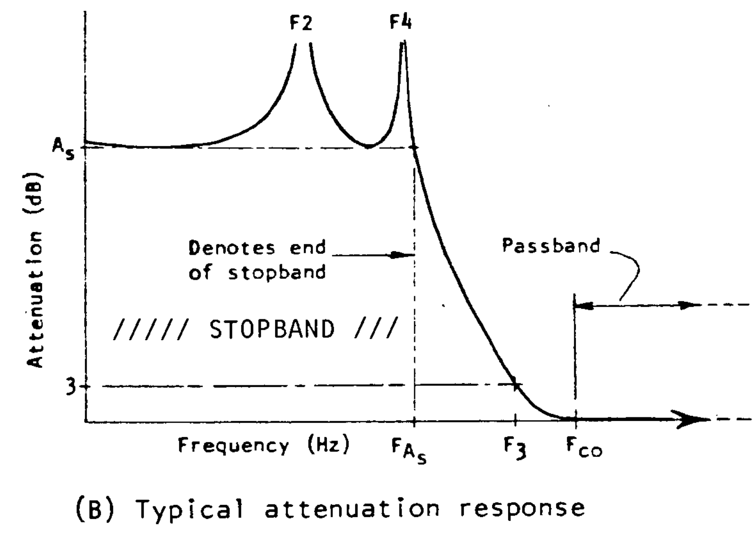


Figure 3. 50-ohm 5th-Degree Elliptic Highpass Filter.

Precalculated Tables Simplify Elliptic Filter Design and Selection

Tables 2 and 3 list the low-pass and high-pass designs, respectively, in which C1, C3 and C5 are standard values. The table headings correspond to similarly labelled parameters in Figures 2 and 3. Similar tables have been previously published (15, 16), but this is the first publication of designs using all the standard capacitor values in the 5% tolerance group. There are 144 designs in each table approximately extending over one frequency decade, and the increments in cutoff frequency from one design to the next are usually small enough so that virtually any cutoff frequency

Table 2. 50-ohm 5th-Degree Elliptic Lowpass Filter Designs Using Standard-Value Capacitors for C1, C3 and C5.

FLT NO.	F-CO (MHZ)	F-3DB (MHZ)	F-AS (MHZ)	AS (DB)	R.C. (%)	C1 (PF)	C3 (PF)	C5 (PF)	C2 (PF)	C4 (PF)	L2 (UH)	L4 (UH)	F2 (MHZ)	F4 (MHZ)
1	0.80	0.99	1.57	47.4	4.40	2700	5600	2200	324	937	12.1	10.1	2.54	1.64
2	0.93	1.09	1.67	46.7	7.16	2700	5100	2200	333	960	10.6	8.74	2.67	1.74
3	1.06	1.20	1.77	46.2	10.5	2700	4700	2200	341	982	9.36	7.56	2.82	1.85
4	1.23	1.35	1.92	45.8	15.3	2700	4300	2200	352	1010	7.92	6.27	3.02	2.00
5	1.47	1.57	2.15	45.4	22.7	2700	3900	2200	365	1045	6.32	4.88	3.32	2.23
6	2.15	2.21	2.85	45.5	42.7	2700	3300	2200	392	1121	3.55	2.61	4.27	2.94
7	1.00	1.20	1.93	49.1	6.04	2400	4700	2000	262	748	9.91	8.36	3.12	2.01
8	1.16	1.33	2.06	48.6	9.37	2400	4300	2000	269	765	8.67	7.19	3.30	2.15
9	1.39	1.60	3.10	61.5	10.8	2200	3900	2000	130	355	7.53	6.79	5.08	3.24
10	1.37	1.51	2.25	48.1	14.5	2400	3900	2000	277	786	7.25	5.90	3.55	2.34
11	1.96	2.11	3.78	61.3	23.9	2200	3300	2000	134	365	5.03	4.45	6.13	3.95
12	1.89	1.99	2.76	47.7	28.6	2400	3300	2000	293	829	4.74	3.72	4.27	2.87
13	0.93	1.18	1.91	48.0	3.71	2200	4700	1800	257	743	10.2	8.59	3.11	1.99
14	1.08	1.30	2.02	47.3	6.05	2200	4300	1800	264	759	9.09	7.55	3.25	2.10
15	1.27	1.45	2.17	46.7	9.69	2200	3900	1800	271	779	7.85	6.39	3.45	2.26
16	1.45	1.61	2.32	46.3	13.8	2200	3600	1800	278	798	6.80	5.44	3.66	2.42
17	1.69	1.82	2.54	45.9	19.7	2200	3300	1800	287	821	5.64	4.42	3.96	2.64
18	2.63	2.71	3.51	45.9	42.5	2200	2700	1800	312	889	2.91	2.16	5.29	3.63
19	1.18	1.41	2.12	45.4	6.07	2000	3900	1600	265	771	8.27	6.73	3.40	2.21
20	1.34	1.54	2.24	44.8	8.89	2000	3600	1600	272	790	7.36	5.89	3.56	2.33
21	1.56	1.82	3.32	57.3	8.91	1800	3300	1600	131	360	6.61	5.85	5.42	3.47
22	1.86	2.08	3.62	57.0	14.1	1800	3000	1600	133	366	5.52	4.83	5.87	3.78
23	2.31	2.48	4.12	56.8	22.7	1800	2700	1600	136	374	4.25	3.66	6.61	4.30
24	3.11	3.24	5.11	57.2	38.1	1800	2400	1600	141	384	2.75	2.33	8.09	5.32
25	1.12	1.44	2.41	49.8	3.42	1800	3900	1500	192	549	8.45	7.25	3.95	2.52
26	1.49	1.73	2.70	48.7	8.40	1800	3300	1500	200	570	6.75	5.62	4.33	2.81
27	1.75	1.95	2.92	48.2	13.0	1800	3000	1500	206	585	5.72	4.68	4.64	3.04
28	2.11	2.27	3.27	47.8	20.2	1800	2700	1500	213	604	4.55	3.64	5.12	3.40
29	2.70	2.82	3.88	47.7	32.3	1800	2400	1500	222	629	3.20	2.49	5.96	4.02
30	3.41	3.50	4.66	48.1	45.3	1800	2200	1500	230	651	2.20	1.67	7.07	4.82
31	1.35	1.68	2.64	47.1	4.54	1600	3300	1300	195	564	7.10	5.92	4.28	2.75
32	1.89	2.19	3.68	53.3	9.50	1500	2700	1300	132	369	5.39	4.64	5.96	3.84
33	1.88	2.11	3.05	45.8	12.0	1600	2700	1300	207	596	5.26	4.21	4.82	3.18
34	2.35	2.58	4.12	52.9	16.3	1500	2400	1300	136	379	4.28	3.62	6.59	4.30
35	2.80	2.99	4.60	52.8	23.8	1500	2200	1300	140	387	3.42	2.85	7.28	4.79
36	2.73	2.87	3.85	45.0	27.3	1600	2200	1300	224	642	3.27	2.49	5.88	3.98
37	1.28	1.66	2.63	46.3	3.11	1500	3300	1200	192	561	7.20	6.00	4.28	2.74
38	1.79	2.05	2.99	44.8	8.89	1500	2700	1200	204	592	5.52	4.42	4.74	3.11
39	2.61	2.94	5.99	65.0	14.0	1300	2200	1200	65.0	176	4.01	3.66	9.86	6.27
40	2.52	2.70	3.63	43.8	20.8	1500	2200	1200	220	636	3.71	2.82	5.58	3.76
41	4.23	4.44	8.22	65.5	36.0	1300	1800	1200	67.3	181	2.12	1.90	13.3	8.58
42	3.89	3.99	5.01	43.6	43.7	1500	1800	1200	241	697	1.90	1.36	7.43	5.17
43	1.68	2.10	3.56	51.2	4.41	1300	2700	1100	129	365	5.79	4.99	5.83	3.73
44	2.05	2.40	3.87	50.5	8.22	1300	2400	1100	133	375	4.90	4.15	6.24	4.04
45	2.40	2.82	5.76	63.4	9.23	1200	2200	1100	64.5	175	4.35	3.97	9.50	6.03
46	2.39	2.68	4.16	50.0	12.3	1300	2200	1100	136	383	4.22	3.52	6.65	4.34
47	3.64	3.92	7.29	63.2	24.4	1200	1800	1100	66.7	180	2.71	2.42	11.8	7.61
48	3.53	3.71	5.31	49.5	28.7	1300	1800	1100	145	406	2.57	2.05	8.26	5.51
49	1.56	2.08	3.55	50.1	2.69	1200	2700	1000	127	363	5.88	5.07	5.83	3.71
50	2.23	2.59	4.04	48.7	8.40	1200	2200	1000	133	380	4.50	3.75	6.50	4.22
51	2.22	2.48	3.36	41.5	11.3	1300	2200	1000	211	625	4.37	3.32	5.24	3.49
52	3.24	3.60	6.73	61.3	16.0	1100	1800	1000	66.0	180	3.18	2.85	11.0	7.04
53	3.17	3.41	4.90	47.8	20.2	1200	1800	1000	142	402	3.03	2.42	7.67	5.10
54	4.79	4.94	6.62	47.9	41.5	1200	1500	1000	152	430	1.64	1.25	10.1	6.85
55	2.09	2.55	4.07	48.5	5.39	1100	2200	910	124	356	4.68	3.94	6.60	4.25
56	2.97	3.44	6.75	61.7	10.1	1000	1800	910	58.4	159	3.52	3.18	11.1	7.07
57	2.93	3.25	4.77	47.4	13.9	1100	1800	910	131	375	3.38	2.74	7.55	4.97
58	2.88	3.09	3.97	39.8	17.9	1200	1800	910	216	645	3.23	2.33	6.03	4.11
59	4.32	4.64	8.37	61.5	24.0	1000	1500	910	60.3	164	2.28	2.02	13.6	8.74
60	3.99	4.13	4.99	39.0	34.0	1200	1500	910	237	711	1.99	1.35	7.32	5.14
61	1.94	2.52	4.15	48.4	3.11	1000	2200	820	115	331	4.79	4.06	6.78	4.34
62	2.73	3.14	4.73	47.0	9.05	1000	1800	820	121	348	3.66	2.99	7.56	4.93
63	3.82	4.26	7.72	59.5	15.2	910	1500	820	59.6	163	2.70	2.39	12.6	8.06
64	3.73	4.02	5.63	46.1	19.7	1000	1500	820	129	369	2.56	2.01	8.76	5.85
65	6.61	6.86	11.3	60.1	41.7	910	1200	820	62.6	170	1.26	1.08	17.9	11.7
66	6.22	6.37	8.23	46.3	46.5	1000	1200	820	141	403	1.18	0.87	12.3	8.50
67	2.57	3.11	4.92	48.1	5.71	910	1800	750	105	301	3.82	3.19	7.95	5.13
68	3.52	4.13	8.34	62.9	9.31	820	1500	750	45.2	123	2.96	2.70	13.8	8.73
69	3.49	3.87	5.68	47.0	13.4	910	1500	750	111	316	2.84	2.30	8.97	5.91
70	5.64	6.02	11.0	62.8	27.2	820	1200	750	47.0	127	1.71	1.52	17.8	11.4
71	5.38	5.61	7.54	46.5	32.9	910	1200	750	120	342	1.59	1.21	11.5	7.81
72	7.25	7.53	13.2	63.4	40.5	820	1100	750	47.8	129	1.18	1.04	21.2	13.8

requirement can be satisfied: The low-pass table covers the 1 - 10 MHz decade, and the high-pass table covers the 0.1 - 1 MHz decade. Designs for other frequency decades may be obtained from the tables by inspection after shifting the decimal points of the frequency values to the right or left while shifting the component value decimal points the same number of places *in the opposite direction.* For example, the frequency heading of "MHz" in Table 2 can be changed to "kHz" if the capacitance and inductance headings are changed to "Nanofarads" and "Millihenries."

Table 2. (Con't.)

FLT	F-CO	F-3DB	F-AS	AS	R.C.	C1	C3	C5	C2	C4	L2	L4	F2	F4
NO.	(MHZ)			(DB)	(%)	(PF)					(UH)		(MHZ)	
73	2.39	3.11	5.20	49.4	3.15	820	1800	680	89.3	256	3.91	3.35	8.51	5.43
74	3.24	4.00	8.13	61.4	5.68	750	1500	680	44.7	123	3.13	2.85	13.4	8.51
75	3.26	3.79	5.85	48.2	8.46	820	1500	680	93.6	267	3.07	2.54	9.39	6.10
76	4.96	5.46	10.0	60.7	17.7	750	1200	680	46.5	127	2.06	1.83	16.3	10.5
77	4.83	5.17	7.30	47.2	22.1	820	1200	680	101	286	1.95	1.54	11.4	7.58
78	7.88	8.19	13.8	61.3	40.5	750	1000	680	48.3	131	1.08	0.94	22.1	14.4
79	3.07	3.73	5.96	48.5	5.39	750	1500	620	84.9	243	3.19	2.68	9.67	6.23
80	4.54	5.21	10.2	62.1	11.1	680	1200	620	39.0	106	2.30	2.08	16.8	10.7
81	4.47	4.91	7.15	47.2	15.3	750	1200	620	90.7	258	2.21	1.77	11.3	7.43
82	6.68	7.14	12.9	62.0	26.3	680	1000	620	40.3	109	1.45	1.29	20.8	13.4
83	6.40	6.68	9.07	46.8	31.7	750	1000	620	96.9	275	1.35	1.04	13.9	9.40
84	8.19	8.41	11.0	47.2	45.6	750	910	620	101	286	0.91	0.68	16.6	11.4
85	2.85	3.71	6.15	48.8	3.06	680	1500	560	76.6	220	3.26	2.78	10.1	6.43
86	4.15	5.01	9.89	60.5	6.80	620	1200	560	38.6	106	2.47	2.23	16.3	10.4
87	4.16	4.74	7.14	47.3	9.94	680	1200	560	81.3	233	2.40	1.97	11.4	7.44
88	5.88	6.49	11.8	59.9	16.9	620	1000	560	39.8	109	1.74	1.54	19.1	12.3
89	5.72	6.13	8.58	46.5	21.5	680	1000	560	86.3	246	1.65	1.30	13.3	8.90
90	9.12	9.35	12.2	46.8	46.2	680	820	560	93.7	266	0.81	0.60	18.3	12.6
91	3.91	4.67	7.29	47.8	6.38	620	1200	510	72.6	208	2.53	2.10	11.8	7.61
92	5.38	6.22	12.2	61.9	10.5	560	1000	510	32.5	88.5	1.94	1.76	20.0	12.8
93	5.31	5.85	8.47	46.8	14.7	620	1000	510	76.7	219	1.86	1.49	13.3	8.81
94	8.18	8.73	15.6	61.8	26.8	560	820	510	33.7	91.3	1.18	1.04	25.3	16.3
95	7.81	8.15	10.9	46.3	32.4	620	820	510	82.6	235	1.10	0.84	16.7	11.3
96	9.87	10.1	13.2	46.6	45.5	620	750	510	85.9	244	0.75	0.56	19.8	13.6
97	3.67	4.69	7.95	50.5	3.66	560	1200	470	57.7	164	2.59	2.23	13.0	8.31
98	5.02	5.77	9.01	49.4	9.57	560	1000	470	60.3	171	2.01	1.68	14.5	9.40
99	4.96	5.45	7.16	40.2	13.6	620	1000	470	108	323	1.92	1.42	11.0	7.43
100	7.39	8.15	16.1	64.5	17.8	510	820	470	26.3	71.0	1.39	1.26	26.3	16.8
101	7.18	7.68	11.1	48.6	22.5	560	820	470	64.1	181	1.32	1.06	17.3	11.5
102	11.4	11.7	15.7	49.1	47.5	560	680	470	68.9	194	0.64	0.49	23.9	16.3
103	4.71	5.69	9.34	50.4	6.04	510	1000	430	52.3	148	2.11	1.79	15.2	9.76
104	6.74	7.70	15.2	62.8	11.8	470	820	430	26.0	70.7	1.55	1.41	25.0	15.9
105	6.64	7.32	11.0	49.4	15.4	510	820	430	55.2	156	1.50	1.23	17.5	11.5
106	6.49	6.93	8.92	40.5	19.9	560	820	430	97.3	289	1.42	1.03	13.5	9.23
107	10.1	10.8	19.5	62.9	28.6	470	680	430	26.9	72.8	0.94	0.84	31.6	20.4
108	9.30	9.57	11.6	40.0	38.4	560	680	430	107	319	0.82	0.56	17.0	11.9
109	4.40	5.60	9.24	49.3	3.81	470	1000	390	51.4	147	2.16	1.84	15.1	9.66
110	6.17	7.39	14.7	61.2	7.40	430	820	390	25.7	70.4	1.67	1.52	24.3	15.4
111	6.17	7.01	10.6	48.0	10.5	470	820	390	54.2	155	1.63	1.34	17.0	11.1
112	6.10	6.69	8.86	40.7	13.9	510	820	390	86.4	257	1.57	1.17	13.7	9.19
113	8.63	9.20	12.9	47.3	23.2	470	680	390	57.6	164	1.09	0.86	20.1	13.4
114	14.9	15.4	25.8	61.7	45.2	430	560	390	27.7	75.1	0.54	0.47	41.1	26.9
115	5.73	7.35	16.6	65.7	4.25	390	820	360	18.9	51.5	1.74	1.61	27.7	17.5
116	5.84	6.93	11.1	49.5	6.94	430	820	360	46.1	131	1.71	1.44	17.9	11.6
117	5.84	6.60	9.01	41.4	9.93	470	820	360	76.6	227	1.66	1.27	14.1	9.37
118	8.21	9.38	19.4	65.0	12.1	390	680	360	19.4	52.6	1.28	1.17	31.9	20.3
119	7.87	8.38	10.7	40.3	20.7	470	680	360	82.9	246	1.16	0.84	16.2	11.1
120	12.7	13.5	25.4	65.2	30.4	390	560	360	20.1	54.0	0.74	0.67	41.2	26.5
121	5.47	6.91	11.8	51.3	4.11	390	820	330	38.5	109	1.76	1.52	19.3	12.3
122	7.55	8.59	13.5	50.2	10.8	390	680	330	40.4	114	1.34	1.12	21.7	14.1
123	7.45	8.13	10.7	40.9	14.8	430	680	330	72.4	215	1.28	0.95	16.5	11.1
124	11.2	12.2	23.0	63.2	20.6	360	560	330	19.9	53.8	0.91	0.81	37.5	24.0
125	10.9	11.5	16.7	49.5	24.8	390	560	330	42.8	120	0.86	0.70	26.2	17.4
126	17.3	17.7	24.0	50.3	50.1	390	470	330	45.7	128	0.41	0.32	36.6	24.9
127	6.97	8.79	18.3	62.1	4.77	330	680	300	19.1	52.2	1.44	1.31	30.4	19.2
128	7.06	7.98	10.9	41.7	9.99	390	680	300	62.6	185	1.38	1.06	17.1	11.4
129	10.1	11.3	21.6	61.3	13.4	330	560	300	19.7	53.6	1.03	0.93	35.3	22.5
130	9.65	10.3	13.1	40.5	21.4	390	560	300	67.9	201	0.94	0.68	19.9	13.6
131	14.8	15.7	27.6	61.4	30.2	330	470	300	20.4	55.2	0.63	0.56	44.4	28.8
132	13.6	14.0	17.0	40.1	39.5	390	470	300	74.4	221	0.55	0.38	24.8	17.5
133	6.59	8.17	13.0	47.7	4.57	330	680	270	39.0	112	1.46	1.22	21.1	13.6
134	9.10	10.2	15.0	46.5	11.8	330	560	270	41.2	118	1.09	0.88	23.7	15.6
135	12.8	14.0	24.7	59.2	19.2	300	470	270	20.1	54.9	0.79	0.69	40.0	25.8
136	12.4	13.2	18.1	45.8	24.1	330	470	270	43.9	125	0.74	0.57	27.9	18.8
137	21.0	21.7	35.2	60.0	44.3	300	390	270	21.0	57.0	0.39	0.33	56.0	36.7
138	19.7	20.1	25.7	46.2	49.0	330	390	270	47.6	136	0.36	0.26	38.5	26.6
139	8.44	9.86	14.5	45.1	7.51	300	560	240	40.3	117	1.17	0.94	23.2	15.2
140	11.4	13.0	23.1	57.1	11.5	270	470	240	19.8	54.5	0.90	0.79	37.7	24.2
141	11.2	12.2	16.9	44.0	16.1	300	470	240	42.8	124	0.86	0.66	26.2	17.5
142	16.8	17.8	29.1	56.9	26.8	270	390	240	20.6	56.6	0.57	0.49	46.5	30.4
143	16.0	16.6	21.4	43.5	32.7	300	390	240	46.3	134	0.52	0.38	32.3	22.2
144	20.7	21.6	34.1	57.2	38.1	270	360	240	21.1	57.7	0.41	0.35	53.9	35.4

All designs are based on equal terminations of 50 ohms, but designs for other equally terminated impedance levels differing from 50 ohms by an integral power of ten (for example, impedance levels of 5, 500 or 5k ohms) can be obtained by inspection. In these cases, it is obvious that the values of C1, C3 and C5 will remain standard because the only change is that of the position of the decimal points in the component values. For example, to shift the table to an impedance level ten times greater than 50 ohms (500 ohms), multiply all inductance values by ten and divide all capacitance values by ten. The listed frequencies remain unchanged. Do the opposite to shift the table to a 5-ohm impedance level. For the case where a desired impedance level differs from the 50-ohm impedance level by a *non-integral power of ten* (such as 75 or 600 ohms), it is still possible to use the tables, but a simple scaling procedure is required if C1, C3 and C5 are to be standard values. This means that Tables 2 and 3 provide *universal 5th-degree elliptic designs* in the sense that they may be used to satisfy filter requirements for *any cutoff frequency and any impedance level* while maintaining the convenience of standard-value capacitors for C1, C3 and C5.

Table 3. 50-ohm 5th-Degree Elliptic Highpass Filter Designs Using Standard-Value Capacitors for C1, C3 and C5.

FLT	F-CO	F-3DB	F-AS	AS	R.C.	C1	C3	C5	C2	C4	L2	L4	F2	F4
NO.	------(KHZ)-----			(DB)	(%)	----------(NF)----------					---(UH)--		--(KHZ)---	
1	75.4	72.5	45.9	57.2	38.1	24	18	27	307	112	98.0	116	29.0	44.1
2	88.6	82.3	47.6	59.2	23.4	27	18	30	400	146	72.7	83.1	29.5	45.6
3	101	93.6	67.0	45.9	19.7	27	18	33	207	72.4	65.8	84.0	43.1	64.6
4	98.2	87.8	46.5	61.3	14.7	30	18	33	502	184	62.2	69.4	28.5	44.5
5	114	103	76.3	41.4	12.1	30	18	39	184	62.0	57.3	75.7	49.1	73.5
6	114	97.6	60.8	50.4	8.50	33	18	39	323	114	55.3	65.4	37.7	58.2
7	105	99.8	74.3	45.3	27.4	22	16	27	160	55.8	67.5	88.5	48.5	71.7
8	102	94.4	56.9	56.8	22.7	24	16	27	317	115	63.6	73.8	35.5	54.5
9	116	108	79.7	43.8	19.1	24	16	30	165	57.1	57.6	75.3	51.6	76.8
10	124	111	75.6	46.5	12.1	27	16	33	216	75.2	51.5	63.9	47.7	72.6
11	137	118	83.4	42.2	7.22	30	16	39	192	64.7	47.6	60.9	52.7	80.1
12	139	112	66.0	51.1	4.59	33	16	39	332	117	46.7	54.3	40.4	63.1
13	85.1	81.9	48.1	61.9	40.9	20	15	22	320	118	88.0	101	30.0	46.1
14	99.7	93.4	50.8	63.3	27.0	22	15	24	394	146	65.7	73.6	31.3	48.6
15	119	111	81.0	45.4	21.3	22	15	27	164	57.1	56.5	72.8	52.3	78.0
16	116	106	61.8	56.9	17.0	24	15	27	322	117	53.7	61.7	38.3	59.2
17	138	120	79.7	46.8	9.03	27	15	33	220	76.6	46.1	56.5	49.9	76.5
18	156	119	68.5	51.6	3.11	33	15	39	337	119	43.2	49.7	41.7	65.5
19	129	123	90.6	45.7	26.9	18	13	22	134	46.8	54.3	70.8	59.0	87.4
20	125	115	63.2	61.3	21.3	20	13	22	330	121	50.7	57.1	38.9	60.5
21	137	121	61.6	63.2	13.8	22	13	24	405	149	44.4	49.0	37.6	58.9
22	153	137	93.9	46.1	11.9	22	13	27	172	60.0	41.7	51.9	59.4	90.2
23	152	130	71.1	57.3	8.60	24	13	27	332	120	40.4	45.6	43.5	68.0
24	175	140	87.9	47.8	4.37	27	13	33	229	79.5	37.7	45.0	54.1	84.2
25	113	109	68.9	57.2	38.1	16	12	18	205	74.9	65.3	77.2	43.5	66.2
26	133	123	71.4	59.2	23.4	18	12	20	266	97.7	48.5	55.4	44.3	68.4
27	151	140	101	45.9	19.7	18	12	22	138	48.2	43.9	56.0	64.6	96.8
28	161	144	96.3	48.2	13.0	20	12	24	175	61.6	39.3	48.1	60.7	92.5
29	175	151	100	46.6	8.27	22	12	27	177	61.4	36.5	44.7	62.7	96.1
30	187	154	101	45.6	5.33	24	12	30	182	62.7	35.1	42.9	62.9	97.1
31	146	139	100	47.7	29.5	15	11	18	123	43.3	48.8	62.3	65.1	96.9
32	142	133	81.4	56.9	26.0	16	11	18	210	76.5	46.6	54.3	50.9	78.1
33	160	144	79.9	59.2	15.7	18	11	20	271	99.2	38.6	43.6	49.2	76.5
34	176	159	110	46.3	13.8	18	11	22	142	49.6	36.4	45.5	69.9	106
35	187	161	104	48.7	8.74	20	11	24	179	63.0	33.8	40.6	64.6	99.5
36	202	166	106	47.1	5.36	22	11	27	181	62.8	32.2	38.8	65.8	102
37	138	133	90.8	53.1	39.4	13	10	15	135	48.7	55.5	68.2	58.2	87.4
38	178	165	115	47.8	20.2	15	10	18	127	44.7	37.1	46.4	73.3	110
39	174	159	92.7	56.9	17.0	16	10	18	215	78.0	35.8	41.1	57.4	88.9
40	192	165	88.0	59.5	9.91	18	10	20	276	101	31.8	35.5	53.7	84.1
41	207	180	120	46.8	9.03	18	10	22	147	51.1	30.7	37.7	74.9	115
42	219	180	111	49.3	5.41	20	10	24	184	64.5	29.4	34.8	68.4	106
43	181	174	134	43.5	31.0	12	9.1	15	78.2	27.0	40.9	55.6	88.9	130
44	175	165	109	52.8	26.6	13	9.1	15	139	50.0	38.6	46.5	68.8	104
45	193	181	134	45.1	23.5	13	9.1	16	94.5	32.9	35.6	46.4	86.7	129
46	211	190	127	48.2	13.6	15	9.1	18	131	46.0	30.2	36.9	80.1	122
47	227	200	139	44.7	9.88	16	9.1	20	117	40.2	28.2	35.5	87.7	133
48	242	200	128	47.4	5.69	18	9.1	22	151	52.4	26.8	32.2	79.2	123
49	154	148	83.8	63.9	40.8	11	8.2	12	194	71.8	48.3	54.7	52.1	80.3
50	179	168	88.5	65.1	27.8	12	8.2	13	234	86.9	36.6	40.6	54.4	84.7
51	222	208	155	43.7	21.0	12	8.2	15	81.9	28.3	30.5	40.2	101	149
52	217	198	125	52.9	17.0	13	8.2	15	143	51.3	29.1	34.4	78.1	120
53	252	217	139	48.7	8.49	15	8.2	18	135	47.3	25.1	30.1	86.5	133
54	269	225	150	45.4	6.05	16	8.2	20	121	41.5	24.2	29.7	93.2	143
55	208	199	145	47.7	32.3	10	7.5	12	81.0	28.6	35.1	45.2	94.4	140
56	199	187	102	63.3	27.0	11	7.5	12	197	72.9	32.8	36.8	62.6	97.2
57	260	237	170	44.2	14.7	12	7.5	15	84.8	29.2	25.1	32.2	109	164
58	256	226	137	53.2	11.4	13	7.5	15	146	52.4	24.2	28.2	84.7	131
59	270	239	163	46.0	10.7	13	7.5	16	101	35.2	23.6	29.3	103	157
60	293	240	148	49.3	5.41	15	7.5	18	138	48.4	22.1	26.1	91.2	142
61	189	181	106	62.1	40.3	9.1	6.8	10	147	54.4	39.4	45.1	66.1	102
62	224	210	118	61.3	26.2	10	6.8	11	163	60.2	29.1	33.0	73.0	113
63	256	240	168	47.8	21.9	10	6.8	12	84.0	29.6	26.0	32.7	108	162
64	249	226	117	63.2	17.1	11	6.8	12	201	74.0	24.6	27.3	71.6	112
65	305	268	185	44.7	9.72	12	6.8	15	87.7	30.2	21.0	26.4	117	178
66	317	268	176	46.6	6.74	13	6.8	16	104	36.2	20.2	24.7	109	169

Table 3. (Con't.)

FLT NO.	F-CO	F-3DB (KHZ)	F-AS	AS (DB)	R.C. (%)	C1	C3	C5 (NF)	C2	C4	L2 (UH)	L4	F2 (KHZ)	F4
67	256	246	184	45.9	32.2	8.2	6.2	10	60.5	21.2	28.8	37.9	121	178
68	245	229	128	61.6	26.5	9.1	6.2	10	150	55.4	26.7	30.2	79.4	123
69	311	291	229	39.6	19.4	9.1	6.2	12	50.0	16.8	22.2	30.9	151	221
70	304	276	187	48.1	14.9	10	6.2	12	86.6	30.5	21.0	25.8	118	179
71	322	281	177	50.2	9.94	11	6.2	13	107	37.8	19.4	23.1	110	170
72	354	297	198	45.3	6.30	12	6.2	15	90.3	31.1	18.3	22.5	124	190
73	226	218	124	63.4	40.8	7.5	5.6	8.2	129	47.6	32.9	37.4	77.4	119
74	275	258	150	59.5	26.1	8.2	5.6	9.1	122	44.8	23.9	27.3	93.2	144
75	317	296	213	46.1	21.7	8.2	5.6	10	63.1	22.1	21.3	27.2	137	205
76	307	277	148	61.5	16.5	9.1	5.6	10	153	56.3	20.0	22.4	90.9	142
77	366	333	252	40.2	13.2	9.1	5.6	12	52.4	17.6	18.1	24.4	164	243
78	362	316	205	48.6	9.51	10	5.6	12	89.3	31.4	17.4	21.0	128	196
79	309	296	217	47.2	31.9	6.8	5.1	8.2	53.5	18.9	23.7	30.6	141	209
80	296	277	152	62.7	26.6	7.5	5.1	8.2	131	48.4	22.1	24.8	93.5	145
81	338	306	171	59.4	17.1	8.2	5.1	9.1	125	45.6	18.3	20.7	105	164
82	375	340	236	46.4	14.9	8.2	5.1	10	65.2	22.8	17.2	21.5	150	227
83	422	371	272	40.9	8.97	9.1	5.1	12	54.4	18.2	15.5	20.3	173	261
84	424	352	219	49.2	6.00	10	5.1	12	91.6	32.1	15.1	17.9	135	210
85	262	253	148	62.8	43.3	6.2	4.7	6.8	102	37.8	29.3	33.4	92.1	142
86	318	299	171	60.8	28.0	6.8	4.7	7.5	108	39.6	20.9	23.7	106	164
87	368	345	245	47.2	23.2	6.8	4.7	8.2	55.3	19.5	18.4	23.3	158	236
88	356	324	171	62.6	18.2	7.5	4.7	8.2	133	49.0	17.3	19.3	105	164
89	397	347	187	59.6	11.6	8.2	4.7	9.1	127	46.2	15.4	17.2	114	178
90	430	379	255	46.9	10.4	8.2	4.7	10	66.9	23.3	14.8	18.2	160	245
91	359	346	258	46.4	34.4	5.6	4.3	6.8	42.0	14.8	21.0	27.5	170	250
92	342	322	181	62.1	28.8	6.2	4.3	6.8	104	38.4	19.5	22.0	112	173
93	390	356	196	60.7	18.7	6.8	4.3	7.5	110	40.2	15.9	17.9	120	187
94	434	397	272	47.5	16.1	6.8	4.3	8.2	57.0	20.0	14.8	18.4	173	262
95	498	442	330	40.0	9.83	7.5	4.3	10	42.8	14.3	13.2	17.6	212	318
96	498	421	273	47.4	6.86	8.2	4.3	10	68.7	23.9	12.8	15.5	169	261
97	399	384	287	46.3	33.8	5.1	3.9	6.2	38.1	13.4	18.8	24.7	188	277
98	444	417	301	46.5	23.6	5.6	3.9	6.8	43.7	15.3	15.4	19.7	194	290
99	430	391	210	61.9	18.4	6.2	3.9	6.8	106	39.1	14.4	16.1	129	201
100	520	476	365	39.9	14.4	6.2	3.9	8.2	35.0	11.7	12.8	17.5	238	352
101	514	452	299	48.0	10.6	6.8	3.9	8.2	58.8	20.6	12.3	15.0	187	287
102	551	463	296	47.9	6.60	7.5	3.9	9.1	64.6	22.5	11.6	14.0	184	284
103	415	399	290	48.6	35.6	4.7	3.6	5.6	39.4	14.0	18.1	23.2	188	279
104	398	377	214	61.9	31.1	5.1	3.6	5.6	84.3	31.1	17.1	19.4	133	205
105	460	422	237	59.9	20.0	5.6	3.6	6.2	86.5	31.7	13.7	15.5	146	227
106	516	474	331	46.7	17.1	5.6	3.6	6.8	45.0	15.8	12.6	15.8	211	318
107	588	524	390	40.4	10.4	6.2	3.6	8.2	36.2	12.1	11.1	14.8	251	376
108	588	498	318	48.4	7.24	6.8	3.6	8.2	60.1	21.0	10.8	13.0	197	305
109	525	504	407	40.0	30.1	4.3	3.3	5.6	23.4	7.87	14.4	20.7	274	395
110	507	477	335	48.5	25.2	4.7	3.3	5.6	40.7	14.4	13.5	16.9	215	322
111	492	453	247	61.7	20.9	5.1	3.3	5.6	85.8	31.6	12.8	14.4	152	236
112	609	562	438	39.2	15.9	5.1	3.3	6.8	27.6	9.20	11.1	15.4	287	423
113	599	534	360	47.1	11.8	5.6	3.3	6.8	46.3	16.2	10.6	13.1	227	346
114	672	576	415	41.1	7.11	6.2	3.3	8.2	37.4	12.5	9.78	12.7	263	399
115	506	487	360	47.3	35.3	3.9	3.0	4.7	30.5	10.8	14.9	19.4	236	348
116	483	455	252	62.9	29.9	4.3	3.0	4.7	75.0	27.7	13.9	15.7	156	241
117	625	588	461	40.4	21.5	4.3	3.0	5.6	24.5	8.26	11.2	15.5	305	445
118	610	559	377	48.8	17.1	4.7	3.0	5.6	42.0	14.8	10.6	13.0	239	363
119	600	531	277	61.7	13.4	5.1	3.0	5.6	87.3	32.1	10.1	11.3	169	265
120	703	600	389	47.7	7.64	5.6	3.0	6.8	47.6	16.6	9.06	10.9	242	373
121	451	435	239	65.9	43.1	3.6	2.7	3.9	69.0	25.7	16.8	18.9	148	229
122	658	629	505	39.9	27.7	3.6	2.7	4.7	19.6	6.59	11.2	16.0	339	489
123	638	599	426	47.3	23.4	3.9	2.7	4.7	31.8	11.2	10.6	13.4	274	410
124	619	563	297	62.7	18.4	4.3	2.7	4.7	76.5	28.2	10.0	11.1	182	284
125	743	680	513	41.0	14.4	4.3	2.7	5.6	25.7	8.66	8.91	12.0	333	495
126	734	647	418	49.2	10.8	4.7	2.7	5.6	43.3	15.3	8.56	10.3	261	401
127	659	627	440	49.5	29.5	3.3	2.4	3.9	29.6	10.6	10.7	13.4	283	423
128	636	592	308	65.0	24.8	3.6	2.4	3.9	70.6	26.2	10.1	11.2	189	294
129	808	752	581	40.4	18.1	3.6	2.4	4.7	20.7	6.99	8.41	11.5	381	561
130	794	718	487	47.7	14.4	3.9	2.4	4.7	33.1	11.6	8.05	9.93	308	468
131	893	782	565	41.7	8.86	4.3	2.4	5.6	26.9	9.07	7.29	9.46	359	543
132	897	744	458	49.9	6.07	4.7	2.4	5.6	44.7	15.7	7.12	8.39	282	438
133	609	583	339	61.7	36.8	3.0	2.2	3.3	48.2	17.8	11.8	13.5	211	325
134	819	779	619	40.3	25.8	3.0	2.2	3.9	16.8	5.67	8.84	12.4	413	599
135	792	736	498	49.6	20.7	3.3	2.2	3.9	30.5	10.8	8.28	10.2	317	479
136	928	841	630	41.0	12.9	3.6	2.2	4.7	21.5	7.26	7.09	9.46	407	608
137	921	805	527	48.1	9.80	3.9	2.2	4.7	34.0	11.9	6.86	8.32	330	506
138	975	809	493	50.4	6.14	4.3	2.2	5.1	41.9	14.8	6.54	7.68	304	472
139	818	781	581	45.7	29.6	2.7	2.0	3.3	19.9	6.95	8.82	11.6	380	561
140	784	729	406	61.3	23.9	3.0	2.0	3.3	49.2	18.1	8.20	9.26	251	389
141	966	898	691	40.8	18.2	3.0	2.0	3.9	17.6	5.93	7.03	9.58	453	667
142	946	851	554	49.9	13.8	3.3	2.0	3.9	31.4	11.1	6.67	8.04	348	532
143	1076	940	680	41.6	8.67	3.6	2.0	4.7	22.4	7.53	6.06	7.87	433	654
144	1080	900	566	48.7	6.17	3.9	2.0	4.7	34.9	12.2	5.93	7.07	350	542

How to Use the Elliptic Filter Design Tables

In order to select a filter to meet a specific application, the user must know the impedance level, the cutoff frequency and also must have some idea of where the stopband is to start and what the stopband attenuation level must be. All these data are available in the tables, and the filter selection is based on finding a design that meets all or most of the required performance specifications.

The cutoff frequency (F-CO column) specifies the end of the passband and the start of the stopband. The F-3dB data is included for reference—it indicates the frequency where the attenuation of the filter starts to become significant. The F-A_s frequency specifies the start of the stopband at the minimum stopband attenuation level, A_s. Designs having minimum A_s values between 39 and 65 dB were selected as having the greatest usefulness, with most designs having A_s values between 45 and 55 dB within one octave of the cutoff frequency.

The R.C. (%) column gives the reflection coefficient of each filter, and this parameter should be considered when selecting a design. For RF filtering applications, the designs having reflection coefficients of less than 10% are recommended to keep the VSWR below 1.22. For audio filtering applications, where VSWR is of little concern but maximum selectivity is important, the high R.C. designs are recommended. Almost all designs have R.C. values less than 45%, which means maximum passband ripple amplitudes of less than 1.0 dB. This maximum level of passband ripple generally will not be noticed in audio filtering applications.

Sometimes the ease of filter construction will be important, and in these instances, the values of C1, C3 and C5 should be carefully noted. For audio frequency applications, the design values of C1, C3 and C5 should not be in the 5% tolerance group, because this tolerance in the capacity range normally used in audio filtering (.068 - 2.2 μF) generally is not stocked by electronic parts distributors. For example, low-pass designs #1, 3, 5 and 6 are satisfactory for audio filtering applications (after scaling to an audio frequency decade) because all values of C1, C3 and C5 are in the 10% tolerance group that is available from distributors. For RF filtering, the required capacitance will be in the 10 pF - 10k pF range, and any design with low R.C. can be considered because all the tabulated values of C1, C3 and C5 are available in the polystyrene capacitor type that is stocked by many distributors.

As previously explained, the values of capacitors C2 and C4 will invariably be non-standard, but since these capacitors must be varied anyway to correctly resonate L2 and L4, the fact that the values are non-standard is not important. For audio filtering applications, it is recommended that two capacitors be paralleled to get the required design capacity within a few percent. Final adjustments can be made with the inductors by removing or adding turns until the design resonant frequency is obtained with less than 1% error. In the case of RF filters, C2 and C4 can be variable trimmer capacitors in parallel with a larger capacitor (if necessary) that closely approximates the design value. Correct resonance in audio filters can be determined with a signal generator, a frequency counter and an AC VTVM. Proper resonance in RF filters can be checked with a calibrated grid-dip meter or a spectrum analyzer and tracking generator. If all component values and resistive terminations are within 5% of the design values and the resonant circuits are properly tuned, the expected attenuation response will be obtained. (For a discussion of suitable construction techniques, see Reference 17.)

A Design Example is Constructed and Tested

A 1.2 k Hz, 50-ohm low-pass filter design was selected from Table 2 as an example to demonstrate the design procedure. The filter was then constructed on a breadboard (see Figure 4), and its attenuation response was measured and plotted (see Figure 5). Before the designs in Table 2 were examined, the headings were changed to "kHz," "nF" and "mH" to get the tabulated data in the appropriate frequency decade. The impedance level was then changed from 50 to 500 ohms by dividing all capacitor values by ten and multiplying the two inductance values by ten. For example, the C1 and L2 capacitance and inductance values in design #1 change from 2700 nF and 12.1 mH to 0.27 μF and 121 mH. The other component values change in a similar manner.

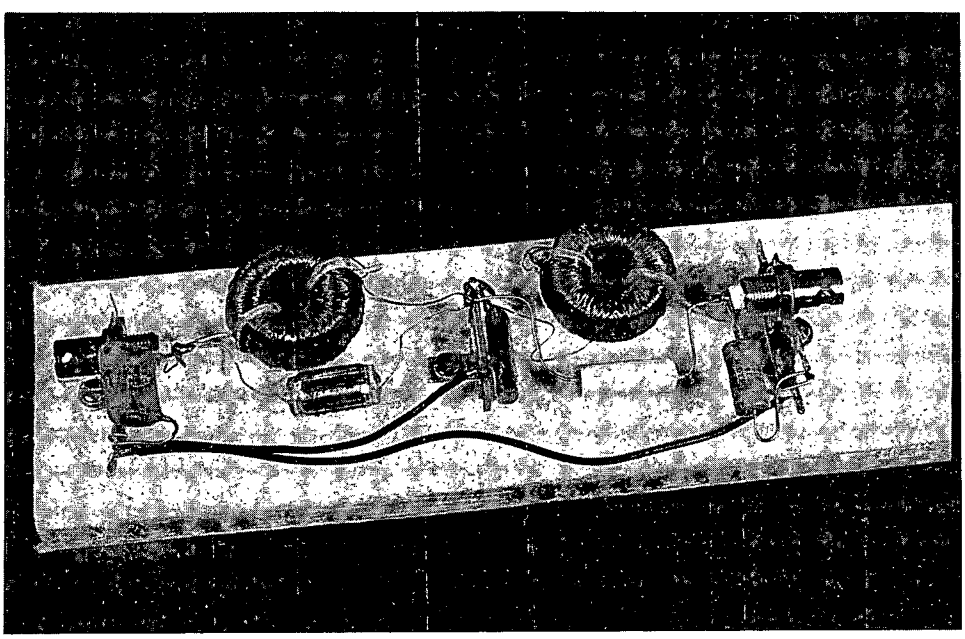


Figure 4. Lowpass filter design no. 15 assembled on a breadboard to demonstrate ease of construction. From left to right are: C1, L2, C2, C3, L4, C4 and C5.

The F-CO column was then examined for values near the desired cutoff frequency of 1.2 kHz. Designs #4, 8, 15 and 19 were reasonably close to 1.2k Hz, but design #15 was selected because its C1, C3 and C5 values could all be realized with 10% polyester capacitors. The A_s level of 46.7 dB was adequate, and the 9.69% reflection coefficient was satisfactory. In this particular example, the F-A_s value was not important. By a fortunate coincidence, the C2 value was .0271 μF which can be realized with a standard-value polystyrene capacitor as shown in Figure 4. By another coincidence, C4 was realized with a single .082 μF 10% polyester capacitor that measured 5% on the low side of the nominal 10% value. Of course, C1, C3 and C5 were realized with single 10% capacitors selected to be within ±5% of the design value.

Final tuning of the filter was accomplished by removing turns from the unpotted toroidal inductors. As indicated in Figure 5, the measured F2 was slightly different from the design value of 3.45 kHz, but the measured F4 was exact. Because the resonant circuits were properly tuned, and because the inductor Q was adequate (in excess of 70), the measured attenuation response agreed very closely with the expected response. The insertion loss of the filter at 1 kHz was less than 0.4 dB.

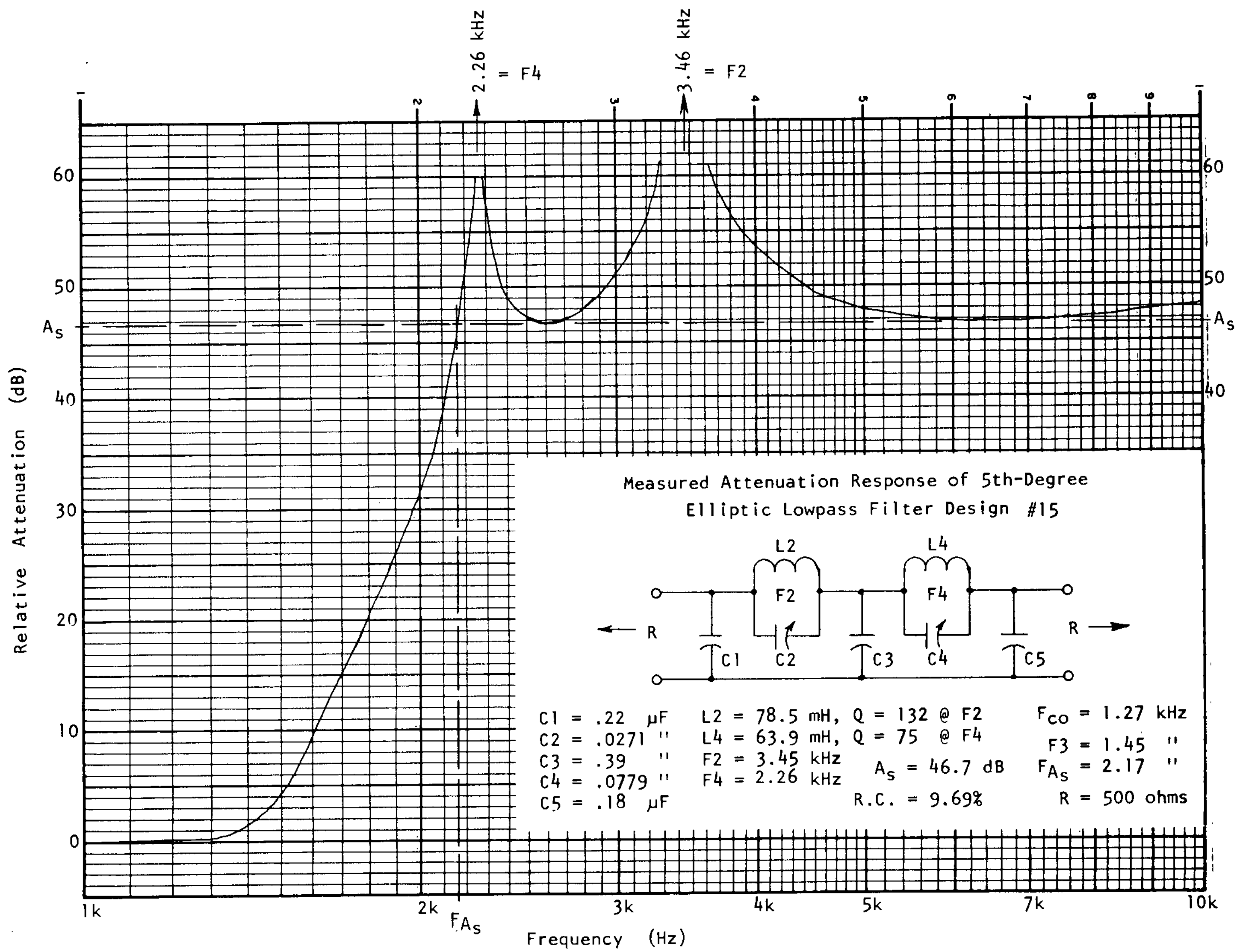


Figure 5.

Using the Tables to Calculate Designs for Impedance Levels Differing from 50 Ohms by a Factor Equal to a Non-integral Power of Ten

It was previously explained that the tabulated low-pass and high-pass filter designs could be scaled to other impedance levels, such as 5, 500 and 5k ohms, by simply shifting the decimal points of the component values. However, in order to use the tabulated data to obtain designs for impedance levels other than 5, 500 or 5k ohms, it is necessary to use a special scaling procedure that is explained below. An example of the procedure concludes the explanation.

1. Calculate the scaled impedance factor, $R = Z_X/50$ where Z_X is the desired new impedance level in ohms.
2. Calculate the cutoff frequency of a "trial" 50-ohm filter using the equation: $F50_{co} = R \cdot F_{Xco}$ where F_{Xco} is the desired cutoff frequency of the filter at the new impedance level.
3. From the 50-ohm tables, select a design having its cutoff frequency closest to the calculated $F50_{co}$ value. The tabulated capacitor values will be used directly, and the frequencies and inductance values will be scaled.
4. Calculate the exact values of $F_{Xco} = F'50_{co}/R$, where $F'50_{co}$ is the tabulated cutoff frequency. In a similar manner, calculate all the other frequencies.
5. Calculate the new inductance values for the new filter from $L_X = R^2 \cdot L_{50}$, where L_{50} is the tabulated inductance value of the trial filter design, and L_X is the inductance value of the scaled filter.

As an example of how this scaling procedure is used, assume that a 60-ohm, 1-MHz low-pass filter design is desired in which C1, C3 and C5 are all standard 10% values. Using the same previously numbered steps:

1. $R = 60/50 = 1.2$
2. $F50_{co} = 1.2(1.0\,\text{MHz}) = 1.20\,\text{MHz}$
3. From Table 2, design #15 has a cutoff frequency close to the $F50_{co}$ value, and the C1, C3 and C5 values are all of the 10% tolerance group. Also, the A_s and R.C. values are satisfactory. Design #15 will therefore be scaled to the required 60-ohm impedance level. The tabulated capacitor values of design #15 are copied directly. Thus, for the 60-ohm filter, C1, C3, C5, C2 and C4 = 2200, 3900, 1800, 271 and 779 pF, respectively.
4. The exact values of F_{Xco}, F_{X3} and F_{A_s} are calculated, and are equal to (1.27MHz)/1.2 = 1.058 MHz, (1.45MHz)/1.2 = 1.208 MHz and (2.17MHz)/1.2 = 1.808 MHz. In a similar manner, the F2 and F4 frequencies are calculated. Note how a filter cutoff frequency of 1 MHz was desired, but the closest suitable design after scaling had a cutoff frequency of 1.058 MHz. If the restraint that the C1, C3 and C5 capacitor values of 10% was removed, then several other designs (such as #4, 8 or 19) could be considered.
5. The L2 and L4 inductance values of the 60 ohm filter are calculated: $L2_X = (1.2)^2 \cdot 7.85\,\mu\text{H} = 11.3\,\mu\text{H}$, $L4_X = (1.2)^2 \cdot 6.39\,\mu\text{H} = 9.20\,\mu\text{H}$.

Validation of the Computer-Calculated Tables

One should always view tabulated data such as presented in Tables 2 and 3 with some skepticism until the validity of the data can be confirmed. This can be done by finding a tabulated 5th-degree elliptic design from Tables 2 and 3 that uses the same (or virtually the same) normalized component values that appear in many of the previously published authoritative references 18, 19, 20. By using the previously published normalized component and frequency values, and the standard scaling (de-normalizing) procedures with the tabulated cutoff frequency of the design being checked, it is possible to independently calculate the component values that appear in the table. If the independently calculated values agree within 0.5% with the tabulated values, then the tables very likely are correct because all the tabulated designs were computer-calculated from the same BASIC computer program.

Those who wish to check the validity of the low-pass and high-pass tables should use low-pass design #128 and high-pass design #105. These designs have reflection coefficients of 10% (virtually) and 20.0%, and the normalized component and frequency values for designs with these two reflection coefficients were published in all of the three previously cited references. Of course, the normalized values for the A_s listings in the references closest to 41.7 dB (for the low-pass) and 59.9 dB (for the high-pass), should be used. If the tabulated cutoff frequencies for the low-pass and high-pass designs are used, the independently calculated component and frequency values will be within 0.5% of the tabulated values, thus confirming the validity of the computer-calculated tabulations.

Summary

The Chebyshev filtering deficiencies of poor selectivity and lack of design flexibility were discussed. The 5th-degree elliptic function filter was recommended for those more stringent filtering applications where greater selectivity and design flexibility are required. Tables of low-pass and high-pass precalculated elliptic designs (144 designs per table) were presented in which the three non-resonating capacitors were all standard values. A sufficiently large number of designs were listed over one frequency decade so that virtually any desired cutoff frequency could be selected. In addition to the cutoff frequency, the F-3dB, F_{A_s}, F2 and F4 frequencies were calculated and listed for each design along with all component values.

Although all designs were for one frequency decade and were based on 50-ohm equal input/output terminations, it was explained how the tables could be used to easily find designs for other frequency decades and other equally terminated impedance levels. A filter design selected from the low-pass table was assembled, and its attenuation response was plotted to demonstrate the close agreement between the measured and tabulated values.

These 5th-degree elliptic low-pass and high-pass filter designs should be considered first whenever this filter type is required. The advantages of quickly reviewing the precalculated filter values and of using standard-value capacitors provide a strong incentive to first examine the tabulated designs before attempting to calculate an independent design.

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LOSSYLINE FILTERS

Filters offer simple means of improving the interference characteristics of electronic equipment, transmitters and receivers. However, low-pass filters of the reactive types can exhibit spurious responses. A simple and effective technique for eliminating or reducing these spurious responses is to add sections of an appropriate lossy transmission line in series with the conventional filter. Combining the lossy element with the conventional reactive elements increases attenuation and allows a significant size reduction of the conventional reactive EMI/RFI filters. Quick fixes of operational equipment can be accomplished, with LOSSY TRANSMISSION LINE FILTERS since they can usually be added without extensive modification of the equipment.

If the interference suppression filters are to be completely effective, the attenuation of the filters must be high and flat in the required rejection band. Unfortunately, many conventional filters exhibit regions of relatively low attenuation which often coincide with spurious responses. In some instances, the inherent reactance versus frequency of conventional interference elimination filters strongly favors the production of multiple resonances since the reactances of these filters are periodic functions of frequency. The periodic frequency behavior of a worst case conventional low-pass filter attenuation function is shown in Figure 1a. For EMI applications multiple spurious passbands of such filters are unacceptable.

A method of avoiding the spurious passbands is to employ a dissipative or absorptive mechanism or approach. The required frequency-sensitive attenuation can be provided by incorporating an absorptive/dissipative element whose attenuation is an increasing function of frequency. Several materials are suitable for use as these lossy elements; the particular material and composition selected are determined by the