7-ELEMENT CHEBYSHEV FILTERS FOR TEMPEST TESTING

Introduction

An article in last year's **ITEM** [1] discussed the design of passive LC 7-element Chebyshev filters and their applications in TEMPEST testing. The design and construction of these filters were greatly simplified by the use of tables of pre-calculated designs requiring only standard-value capacitors. Thirty lowpass and thirty highpass 50-ohm designs were tabulated with the filter cutoff frequencies covering the 3-50 kHz range in small increments so virtually any desired cutoff frequency could be approximated. After this article was published, the computer program used to generate the filter tables was improved and expanded, and these improvements were incorporated in several recently published articles [2, 3, 4]. In this year's ITEM article, the improvements developed over the past year are included in the two comprehensive filter tables presented in this article. One table lists lowpass filters and the other lists highpass filters, and each consists of 178 designs over the 1 to 10 MHz range.

Because the computer program used to generate last year's filter tables was not completely developed in time to meet the publication deadline, all of the possible combinations of standard-capacitor values were not included. This omission has been corrected in the new tables presented in this article. All possible capacitor values up to a ratio of 2-to-1 [equivalent to a filter reflection coefficient (RC) of 8.1%] are included for all feasible combinations of the twenty-four standard-capacitor values of the 5% series (10, 11, 12, 13, 15, 16, 18, 20 etc.). This permits a total of 178 lowpass and 178 highpass designs to be realized between reflection coefficients of zero (equivalent to a Butterworth) and 8.1%.

Because the maximum permissible impedance variation in a 50-ohm detection system is ±10 ohms (corresponding to a maximum VSWR of 1.2), the 8.1% RC value was selected as the upper limit because it corresponds to a filter VSWR of 1.17. Also, for an RC = 8.1%, one of the two capacitor values of the lowpass and highpass filters is exactly double that of the other. In some cases this may facilitate the filter construction if six capacitors having the same value are available.

Although the tabulated designs are based on a 50-ohm impedance system over the 1 to 10 MHz range, filters with standard-value capacitors *for any impedance level and cut-off frequency* are easily determined from the filter tables by using simplified scaling procedures. Because of the comprehensiveness of the lowpass and highpass tables, and because of the convenience of needing only standard-value capacitors, these pre-calculated designs should be used whenever equally-terminated 7-element C-input/output Chebyshev filters are required.

Recommended Filters For TEMPEST Testing

The 50-ohm filters in Tables 1 and 2 (lowpass and highpass) are recommended for TEMPEST testing because of their relatively constant input impedance (a consequence of their low reflection coefficient), adequate selectivity and ease of construction. The reflection coefficient of most of the filters is less than four percent (VSWR less than 1.083), the attenuation slope is better than 42-dB/octave, and the designs are easily assembled because only standard-value capacitors are required.

The appropriate filter schematic diagram and the typical attenuation response both appear above the beginning of the lowpass and highpass tables. This format is used so the proper schematic diagram and response is included with the first page of the table if the tables are copied. Details of the lowpass tabulation (Table 1) will be discussed, and these comments, where applicable, will also apply to the highpass tabulation.

Table 1, Lowpass Filters

Figures 1(A) and 1(B) are the schematic diagram and attenuation response corresponding to the design parameters and component values listed in Table 1. Note that the C1, C3, C5, and C7 designations in Figure 1(A) indicate the physical placement within the filter of the capacitors whose values are tabulated under the headings of C1, 7 and C3, 5. Because C1 and C7 are identical, the values of C1 and C7 are listed in a single column. The same is true for capacitors C3 and C5. The inductor circuit placement and tabulation are presented in a similar manner.

For easy identification, each filter design has a corresponding filter number, and these numbers are listed in the first and last columns of both tables. In the following discussion, a particular design will be referred to by an "LP" or "HP" designation (signifying lowpass or highpass) followed by the filter number.

The frequencies in the attenuation response curve [Figure 1(B)] correspond to the attenuation levels at A_p, 1, 3, 6, 30 and 50-dB and they are listed (in MHz) under the appropriate headings of Table 1. The A_p-dB frequency is listed because this is the value used to calculate all the other parameters for a particular design. The 1-dB frequency is listed because one may wish to know at what frequency the attenuation begins to become significant. The 3 and 6-dB frequencies are listed because these frequencies are commonly used as a cutoff frequency specification. The 30 and 50-dB frequencies give the user an indication of the filter stopband performance.

The parameter that defines a particular Chebyshev design is the reflection coefficient (RC), and this parameter is listed in percent under the "R.C. (%)" heading of the tables 1 and 2. An exponential format is used to express this parameter because of its extremely wide variation. For example, the smallest value of RC is 0.554×10^{-6}% (see LP #44), and this is virtually identical to a Butterworth design. The maximum RC is 8.1%. By selecting particular values of RC and A_p-cutoff frequency, it is possible to generate a filter design that uses only standard-value capacitors. This accounts for the apparently odd values of RC and A_p-cutoff frequency that are listed in the tables.

Because of the small increments in the 3-dB cutoff frequency from one design to the next, virtually any required cutoff frequency in the 1-10 MHz decade can be obtained.

Although the cutoff frequencies in the A_p 1, 3 and 6-dB columns generally increase with increasing filter number, there is an occasional regression in the cutoff frequency as the RC values change from a high value in one group to a low value in the next group. Thus, when searching for a particular cutoff frequency, be sure to examine at least two consecutive groups to find a design having the desired cutoff frequency. Also note that the same cutoff frequency may be obtained with different designs. For example, designs LP #14 and LP #17 both have a 3-dB cutoff frequency of 1.26 MHz, but filter #14 has a 5.78% RC while #17 has a 0.233% RC. Although filter #14 has a slightly steeper attenuation response than #17, it is not significantly better than #17. If a choice had to be made between these two designs, it might be based on the fact that design #17 is more convenient to assemble because its capacitor values (1500 and 4700 pF) are more commonly available than the values of design #14 (2400 and 5100 pF).

Table 2, Highpass Filters

Most of the explanation of the lowpass filters in Table 1 is applicable to the highpass filters in Table 2. In both cases, the 3-dB cutoff frequencies of the tables start and end at approximately one and ten megahertz. Another similarity is that if the same capacitor values are used in the lowpass and highpass designs the RC value of both designs will be identical. For example, filter design LP #154 (RC = 1.0%) has capacitor values of 300 and 820 pF for C1, 7 and C3, 5, while design HP #138 has the same capacitor and RC values, except the values of C1, 7 and C3, 5 are reversed. Other differences are that for each group of highpass designs, the RC values start high (with a maximum of 8.1%) and gradually decrease to a minimum value, whereas the reverse is true in the lowpass table. Also, as the highpass filter attenuation increases, the corresponding frequencies decrease, whereas in the lowpass table the attenuation and frequency both increase with increasing attenuation. Other minor differences and similarities can be found between the two tables, and these differences and similarities should be recognized as being normal.

Verification Of Filter Tables

Before the reader uses tabulated data, such as presented in Tables 1 and 2, some attempt should be made to first check the correctness of the data. If the data of one design can be demonstrated to be correct, then it is reasonable to expect that all the designs will be correct because they were generated by the same computer program.

The attenuation versus frequency data can be quickly checked by estimating the filter attenuation slope. It is common knowledge that a Butterworth attenuation response has a slope of 6-dB/octave for each element, and since each filter in the tables has seven elements, the attenuation slope should be near 7 × 6-dB/octave = 42-dB/octave for those designs approximating a Butterworth design (RC values less than 0.1%). For higher RC values, the slope will be a few dB greater than 42-dB/octave. For example, referring to design LP #44 (RC = $.554 \cdot 10^{-6}$%, if the 30 and 50-db frequencies are plotted on semi-log paper, the slope between 2.84 and 3.95 MHz can be verified to be 42.5-dB/octave, and this is a satisfactory check on the attenuation versus frequency parameters.

In a similar manner, the correctness of the capacitor and inductor values can be independently verified. This is done by using previously published normalized C and L values. By scaling the normalized values to the impedance and A_p-cutoff frequency used in a particular design, it can be demonstrated that the independently calculated values will be identical to the tabulated values in Tables 1 and 2. Previously published normalized data for the Chebyshev filter are available from several authoritative sources [5, 6], and either of the references provide normalized C and L data for reflection coefficients of 1, 2, 3, 4, 5, 8, and 10 percent and higher. However, for a meaningful comparison to be made, it is necessary to use a tabulated design that has an RC value that closely approximates one of the published RC values. Design LP #154 has an RC value of 1.00%, and this matches one of the published RC values. Because of this, it will be used to demonstrate the validity of the tabulated computer-calculated C and L values. The A_p-cutoff frequency of LP #154 is 5.68 MHz, and this parameter will be used in the scaling process required to transform the normalized filter component values (normalized for an A_p-cutoff frequency of one radian per second and an impedance of one ohm) to the A_p-cutoff frequency and impedance level (5.68 MHz and 50 ohms) of filter design LP #154. From the normalized tables of either Saal or Zverev, the normalized component values for C1 and C3 are 0.5354 and 1.464 farads. The normalized values for L2 and L4 are 1.179 and 1.500 henries. Based on a new impedance and cutoff frequency of 50 ohms and 5.68 MHz, the C and L L scaling factors are:

$C_S = 1/R\omega$, where R = 50 ohms and $\omega = 2\pi f_{A_p}$, with $f_{A_p} = 5.68 \cdot 10^6$ and $\omega = 35.6885 \cdot 10^6$.

$$C_S = 1/1(1784.425 \cdot 10^6) = 560.4 \cdot 10^{-12}.$$
$$L_S = R/\omega = 50/(35.6885 \cdot 10^6) = 1.401 \cdot 10^{-6}.$$

The normalized C and L values are scaled to the desired impedance and cutoff frequency by multiplying them by their corresponding scaling factors:

$$C1 = 0.5354F \cdot (560.4) \cdot 10^{-12} = 300pF$$
$$C3 = 1.464F \cdot (560.4) \cdot 10^{-12} = 820\ pF$$

$$L2 = 1.179H \cdot (1.401) \cdot 10^{-6} = 1.65\ \mu H$$
$$L4 = 1.500H\ (1.401) \cdot 10^{-6} = 2.10\ \mu H$$

These independently calculated values of C and L are identical with the tabulated values of LP #154; consequently, the correctness of the tabulated values is verified. Since the same computer program was used to calculate all the designs, the correctness of all the designs is confirmed.

HOW TO USE THE TABLES

For 50-ohm Filters

A suitable lowpass or highpass filter is selected by entering the appropriate table under the 3 or 6-dB column heading, and by searching for the desired cutoff frequency. Because the TEMPEST specification is relatively lenient regarding the permissible range of the 6-dB cutoff frequency, several different designs will usually be suitable. Examine the component values, and, if possible, select the design which has convenient capacitor values and a low-value of RC.

If the desired cutoff frequency is outside the tabulated 1-10 MHz frequency range, then a simple procedure is used to scale the tabulated data to the desired frequency decade. This involves shifting the decimal points of the frequency and component values to the right or left. To find lowpass or highpass filter designs for the 10-100 or 100-1000 MHz range, multiply all tabulated frequencies by 10 or 100, respectively, and divide all C and L values by the same number. The RC values remain unchanged. For example, to find a lowpass filter having a 10.4 MHz 3-dB cutoff frequency, multiply all the tabulated frequencies by ten and divide the component values by ten. For this particular application, design LP #1 is suitable, and the corresponding C and L component values ar 150 and 560 pH and 1.011 and 1.526 μH.

To scale the filter tables to cover the 1-10 kHz, 10-100 kHz or .1-1 MHz decade, divide the tabulated frequencies by 1000, 100 or 10, respectively, and multiply the component values by the same number. For example, to find a lowpass filter having a 1.79 kHz 3-dB cutoff frequency, change Table 1 to a 1-10 kHz decade by dividing all tabulated frequencies by 1000 and multiplying all component values by the same number. In this particular case, design LP #46 would be suitable, and the C and L values are 1.0 and 3.3 μF and 6.30 and 8.80 mH. Regardless of the scaling factor used, the capacitor values will always be standard as long as the capacitance does not exceed one microfarad.

For Filter Impedance Levels Other Than 50 ohms

Although filters are most frequently used with 50-ohm receivers, there may be occasions when the output signals of transmitters must be filtered to attenuate harmonics. In this case, impedances other than 50 ohms may be encountered. The ability to quickly and accurately design filters using standard-value capacitors for any impedance level is very useful, and a simple scaling procedure using Tables 1 and 2 will be explained as follows:

(1) For any desired filter impedance in ohms, Z_x, select the desired 3-dB cutoff frequency in Hz, F_3^x.

(2) Calculate $F_3^{50} = F_3^x (Z_x/50)$.

(3) From Tables 1 or 2, select the design (lowpass or highpass) that has a 3-dB cutoff frequency closest to the F_3^{50} value calculated in (2). Record the tabulated capacitor values of the selected design as they will be the C1, 7 and C3, 5 values of the new filter. Also note the inductor values.

(4) Calculate the inductor values of the new filter by multiplying the inductor values noted in (3) by the square of $Z_x/50$.

(5) Calculate the frequencies of the new filter at A_p, 1, 3, 6, 30 and 50-dB by multipling the tabulated frequencies of the selected filter by $50/Z^x$. This concludes the scaling procedure. An example will demonstrate the impedance scaling procedure.

Assume it is desired to find a 75-ohm lowpass filter having a 3.0 MHz 3-dB cutoff frequency. The calculation steps previously explained follow:

(1) Z_x = 75 ohms and F_3^x = 3.0 MHz.

(2) F_3^{50} = 3(75/50) MHz = 4.5 MHz.

(3) From Table 1, the lowpass design having F_3^{50} closest to 4.5 MHz is LP #115, and this design is selected for scaling. The C1, 7 and C3, 5 capacitor values of the new 75-ohm filter will be 360 and 1300 pF, respectively. The L2, 6 and L4 inductor values of 2.39 and 3.52 μH are noted.

(4) The 75-ohm filter inductor values are calculated:
L2, 6 = $2.39\,(75/50)^2$ μH = 5.38 μH,
L4 = $3.52\,(75/50)^2$ μH = 7.92 μH.

(5) The A_p, 1, 3, 6, 30 and 50-dB frequencies for the new filter are calculated by scaling the corresponding frequencies of design LP #115 to the new 75-ohm impedance level. The scaling factor = $50/Z_x$ = 50/75 = 0.6667. Thus, for F_{A_p} of LP #115 = 2.17 MHz, the corresponding F_{A_p} of the new 75-ohm 3.0 MHz lowpass filter is 2.17(0.6667) = 1.45 MHz. In a similar way, the F1, 3, 6, 30 and 50-dB frequencies of the 75-ohm filter are 2.75, 2.99, 3.21, 4.71 and 6.47 MHz. Note that the desired 3-dB cutoff frequency was 3.0 MHz, but the closest that could be obtained from Table 1 was a design with a 2.99 MHz cutoff frequency.

In a similar manner, highpass filters having impedance levels other than 50 ohms may be calculated. For example, if a 75-ohm 3-dB 3.0 MHz highpass filter is desired, design HP #19 (F_3^{50} = 4.49 MHz) would be used, and the C1, 7 and C3, 5 capacitor values would be 1500 and 390 pF, respectively. The L2, 6 and L4 inductor values would be 3.08 and 2.00 μH for the 75-ohm filter. The F_{A_p} frequency of design HP #119 is 13.35 MHz, and the corresponding F_{A_p} frequency of the new 75-ohm 3.0 MHz highpass filter is 13.35 (.6667) MHz = 8.90 MHz. In a similar way, the F1, 3, 6, 30 and 50-dB frequencies of the new 75-ohm filter are 3.27, 2.99, 2.78, 1.86 and 1.35 MHz.

Capacitor And Inductor Recommendations For Filter Construction

Using Tables 1 and 2 eliminates most of the problems associated with the selection of suitable filter designs; however, the problem of component selection still remains. The capacitor type most suitable for general purpose filtering applications above 100 kHz is the polystyrene type, and it is recommended for contructing the filter designs listed in Tables 1 and 2. Fortunately, the 2.5% tolerance of the Mallory Type SXM polystyrene capacitor makes it possible to use this part as purchased. Because of its tight tolerance there is no need to individually measure and select capacitors, as each capacitor is close enough to its nominal value so it can be used directly in any design requiring its nominal value. The type SXM capacitor is available in a capacity rating up to .056 μF; consequently, 50-ohm filter can be constructing using this capacitor and having a 3-dB cutoff frequency as low as 100 kHz. For filters having a cutoff frequency below 100 kHz and requiring capacitors larger than .056 μF, the Mylar®* capacitor is more attractive than polystyrene because of its smaller size and lower cost. However, the Mylar capacitor usually has a tolerance of ten percent, and each one should be measured and selected for its particular application.

The inductors required to build filters in the frequency range above 10 kHz are usualy hand-wound for expediency. Up to about 100 kHz, molybdenum permalloy cores are used, and above 100 kHz, powdered iron cores are used. A detailed discussion of inductor construction suggestions is beyond the scope of this article, and the interested reader is referred to references 1, 7 and 8 for further information.

Lowpass And Highpass Filters Used To Get A Bandpass Response

In addition to the usual lowpass and highpass filtering application, most of the filter designs of tables 1 and 2 may be cascaded to achieve a bandpass response. This procedure is especially useful when the passband is required to be extremely wide (more than one decade of frequency). In this case, it is often more convenient to treat the design separately as individual lowpass and highpass filtering requirements instead of treating it as a bandpass filter design. The use of separate lowpass and highpass filters to achieve a bandpass response will seldom give any trouble as long as the passband is greater than an octave wide. Below this width, however, the design becomes increasing critical because of interaction between the two filters.

Each filter will operate as expected if it is correctly terminated, but neither filter will see this condition unless the other one has a very constant terminal impedance. For this reason, any filters intended for connection in cascade should have low values of reflection coefficient and VSWR. An RC value of less than 5% is suggested. [See reference 9, p. 51.]

If a standard bandpass filter design is required to obtain a passband less than an octave wide (but not less than about 10% of the center frequency), the standard lowpass-to-bandpass transformation procedure should be used. See reference 10 for an example of this procedure. Of course, the lowpass designs of Table 1 could be used to select a lowpass design suitable for transformation to a bandpass response, but the number of components (7 capacitors and 7 inductors) would be excessive for TEMPEST applications. A more practical bandpass design can be obtained by transforming a four or five element lowpass filter, and in this case, the number of elements will be either eight or ten, and therefore more reasonable.

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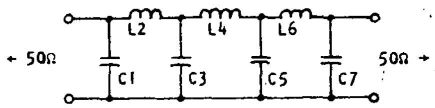
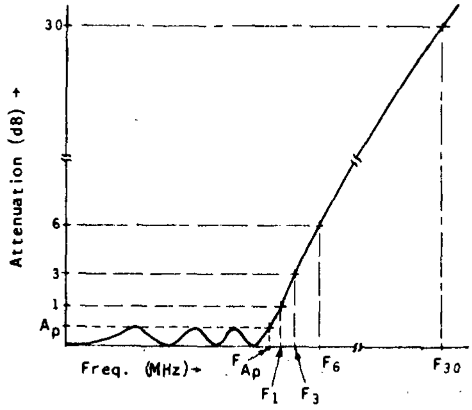
Figure 1. Lowpass Filter Schematic Diagram and Attenuation Response Curve



(A) Schematic Diagram



(B) Typical Attenuation Response

Table 1. Lowpass 50-ohm 7-Element Chebyshev Filters, Design Parameters and Component Values

FLTR NO.	FREQ. (MHZ) AT AP, 1, 3, 6, 30 & 50 DB AP-DB	1-DB	3-DB	6-DB	30-DB	50-DB	R.C. (%)	C1,7 (PF)	C3,5 (PF)	L2,6 (UH)	L4 (UH)	FLTR NO.
1	.430	.951	1.04	1.12	1.65	2.28	.455E-02	1500	5600	10.11	15.26	1
2	.559	.966	1.05	1.12	1.63	2.23	.339E-01	1600	5600	10.43	15.08	2
3	.714	.991	1.06	1.13	1.60	2.17	.255E 00	1800	5600	10.92	14.77	3
4	.812	1.01	1.08	1.14	1.58	2.11	.806E 00	2000	5600	11.23	14.44	4
5	.886	1.04	1.10	1.15	1.56	2.08	.178E 01	2200	5600	11.36	14.04	5
6	.949	1.07	1.12	1.17	1.56	2.06	.327E 01	2400	5600	11.31	13.54	6
7	1.04	1.12	1.16	1.21	1.58	2.06	.663E 01	2700	5600	10.90	12.57	7
8	.302	1.03	1.13	1.22	1.83	2.54	.173E-03	1300	5100	8.98	14.05	8
9	.663	1.07	1.15	1.23	1.78	2.43	.630E-01	1500	5100	9.61	13.66	9
10	.755	1.08	1.16	1.24	1.76	2.39	.184E 00	1600	5100	9.86	13.51	10
11	.881	1.11	1.18	1.25	1.73	2.33	.720E 00	1800	5100	10.20	13.19	11
12	.972	1.14	1.20	1.26	1.72	2.28	.176E 01	2000	5100	10.34	12.79	12
13	1.05	1.17	1.23	1.28	1.71	2.26	.341E 01	2200	5100	10.29	12.29	13
14	1.12	1.21	1.26	1.31	1.72	2.26	.578E 01	2400	5100	10.04	11.66	14
15	.336	1.12	1.23	1.32	1.99	2.75	.206E-03	1200	4700	8.28	12.94	15
16	.596	1.14	1.24	1.33	1.96	2.69	.143E-01	1300	4700	8.62	12.73	16
17	.842	1.18	1.26	1.34	1.91	2.58	.233E 00	1500	4700	9.14	12.41	17
18	.918	1.20	1.28	1.35	1.89	2.54	.500E 00	1600	4700	9.32	12.25	18
19	1.03	1.23	1.30	1.36	1.86	2.49	.147E 01	1800	4700	9.52	11.88	19
20	1.12	1.27	1.33	1.39	1.86	2.45	.312E 01	2000	4700	9.50	11.40	20
21	1.21	1.31	1.37	1.42	1.87	2.45	.560E 01	2200	4700	9.27	10.78	21
22	.378	1.22	1.34	1.45	2.17	3.00	.251E-03	1100	4300	7.58	11.83	22
23	.674	1.25	1.36	1.46	2.13	2.93	.185E-01	1200	4300	7.92	11.63	23
24	.836	1.27	1.37	1.46	2.10	2.87	.104E 00	1300	4300	8.20	11.47	24
25	1.03	1.31	1.40	1.48	2.06	2.77	.643E 00	1500	4300	8.58	11.15	25
26	1.10	1.33	1.41	1.49	2.04	2.73	.116E 01	1600	4300	8.68	10.97	26
27	1.21	1.38	1.45	1.51	2.03	2.69	.280E 01	1800	4300	8.71	10.51	27
28	1.31	1.43	1.49	1.55	2.04	2.68	.540E 01	2000	4300	8.50	9.91	28
29	.429	1.35	1.48	1.60	2.39	3.31	.314E-03	1000	3900	6.89	10.73	29
30	.771	1.38	1.50	1.61	2.35	3.22	.247E-01	1100	3900	7.22	10.53	30
31	.954	1.41	1.52	1.61	2.31	3.14	.138E 00	1200	3900	7.49	10.37	31
32	1.08	1.43	1.53	1.62	2.28	3.08	.397E 00	1300	3900	7.69	10.21	32
33	1.25	1.48	1.57	1.65	2.25	2.99	.151E 01	1500	3900	7.90	9.85	33
34	1.32	1.51	1.59	1.66	2.24	2.97	.244E 01	1600	3900	7.91	9.62	34
35	1.44	1.57	1.64	1.71	2.25	2.95	.516E 01	1800	3900	7.73	9.04	35
36	.369	1.46	1.60	1.73	2.60	3.60	.593E-04	910	3600	6.31	9.93	36
37	.791	1.49	1.62	1.74	2.55	3.50	.162E-01	1000	3600	6.62	9.74	37
38	1.02	1.53	1.64	1.75	2.51	3.41	.123E 00	1100	3600	6.89	9.58	38
39	1.17	1.55	1.66	1.76	2.47	3.34	.397E 00	1200	3600	7.10	9.43	39
40	1.28	1.58	1.68	1.77	2.45	3.28	.892E 00	1300	3600	7.23	9.26	40
41	1.44	1.64	1.73	1.81	2.43	3.21	.271E 01	1500	3600	7.29	8.82	41
42	1.52	1.68	1.76	1.83	2.43	3.20	.411E 01	1600	3600	7.22	8.54	42
43	1.66	1.77	1.84	1.90	2.47	3.22	.810E 01	1800	3600	6.86	7.83	43
44	.208	1.58	1.74	1.88	2.84	3.95	.554E-06	820	3300	5.73	9.14	44
45	.839	1.63	1.27	1.90	2.79	3.83	.130E-01	910	3300	6.04	8.94	45
46	1.09	1.66	1.79	1.91	2.74	3.73	.108E 00	1000	3300	6.30	8.80	46
47	1.27	1.70	1.81	1.92	2.70	3.64	.397E 00	1100	3300	6.51	8.64	47
48	1.40	1.73	1.83	1.93	2.67	3.57	.949E 00	1200	3300	6.64	8.47	48
49	1.51	1.76	1.86	1.95	2.65	3.53	.182E 01	1300	3300	6.69	8.26	49
50	1.68	1.85	1.93	2.01	2.65	3.49	.471E 01	1500	3300	6.58	7.72	50
51	1.77	1.90	1.98	2.05	2.68	3.50	.684E 01	1600	3300	6.40	7.37	51

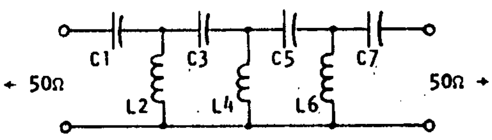
Table 1. Lowpass 50-ohm 7-Element Chebyshev Filters (continued)

FLTR NO.	FREQ. (MHZ) AT AP, 1, 3, 6, 30 & 50 DB AP-DB	1-DB	3-DB	6-DB	30-DB	50-DB	R.C. (%)	C1,7 (PF)	C3,5 (PF)	L2,6 (UH)	L4 (UH)	FLTR NO.
52	.322	1.74	1.92	2.07	3.12	4.34	.623E-05	750	3000	5.23	8.30	52
53	.889	1.78	1.94	2.08	3.07	4.22	.978E-02	820	3000	5.47	8.15	53
54	1.21	1.83	1.97	2.10	3.01	4.10	.110E 00	910	3000	5.73	7.99	54
55	1.40	1.87	1.99	2.11	2.97	4.01	.397E 00	1000	3000	5.91	7.85	55
56	1.56	1.91	2.02	2.13	2.93	3.93	.102E 01	1100	3000	6.04	7.68	56
57	1.68	1.95	2.05	2.15	2.91	3.87	.204E 01	1200	3000	6.09	7.47	57
58	1.79	2.00	2.09	2.18	2.91	3.84	.351E 01	1300	3000	6.05	7.21	58
59	1.99	2.12	2.20	2.29	2.96	3.86	.810E 01	1500	3000	5.72	6.52	59
60	.452	1.94	2.13	2.30	3.47	4.81	.326E-04	680	2700	4.72	7.46	60
61	1.06	1.99	2.16	2.32	3.40	4.67	.162E-01	750	2700	4.96	7.31	61
62	1.34	2.03	2.19	2.33	3.35	4.56	.112E 00	820	2700	5.16	7.19	62
63	1.58	2.08	2.22	2.35	3.29	4.44	.449E 00	910	2700	5.34	7.05	63
64	1.75	2.12	2.25	2.37	3.26	4.35	.111E 01	1000	2700	5.45	6.89	64
65	1.89	2.18	2.29	2.40	3.24	4.29	.232E 01	1100	2700	5.48	6.68	65
66	2.02	2.24	2.34	2.44	3.24	4.26	.411E 01	1200	2700	5.41	6.40	66
67	2.15	2.31	2.41	2.50	3.27	4.27	.658E 01	1300	2700	5.26	6.06	67
68	.761	2.20	2.41	2.60	3.88	5.37	.590E-03	620	2400	4.25	6.59	68
69	1.27	2.25	2.44	2.61	3.81	5.23	.277E-01	680	2400	4.45	6.47	69
70	1.59	2.30	2.47	2.63	3.75	5.09	.174E 00	750	2400	4.63	6.36	70
71	1.81	2.34	2.50	2.64	3.70	4.98	.520E 00	820	2400	4.76	6.25	71
72	2.01	2.40	2.54	2.67	3.65	4.88	.135E 01	910	2400	4.86	6.09	72
73	2.17	2.46	2.59	2.71	3.64	4.82	.271E 01	1000	2400	4.86	5.88	73
74	2.33	2.55	2.66	2.77	3.65	4.79	.495E 01	1100	2400	4.77	5.59	74
75	2.49	2.65	2.76	2.86	3.70	4.82	.810E 01	1200	2400	4.57	5.22	75
76	.685	2.39	2.62	2.83	4.25	5.88	.148E-03	560	2200	3.87	6.06	76
77	1.36	2.45	2.66	2.85	4.16	5.71	.242E-01	620	2200	4.07	5.94	77
78	1.70	2.50	2.69	2.86	4.10	5.57	.148E 00	680	2200	4.23	5.84	78
79	1.96	2.56	2.73	2.88	4.03	5.43	.508E 00	750	2200	4.36	5.73	79
80	2.16	2.61	2.76	2.91	3.99	5.34	.117E 01	820	2200	4.44	5.61	80
81	2.35	2.68	2.82	2.95	3.97	5.26	.258E 01	910	2200	4.46	5.41	81
82	2.52	2.77	2.89	3.01	3.98	5.23	.471E 01	1000	2200	4.38	5.15	82
83	2.72	2.90	3.01	3.12	4.04	5.26	.810E 01	1100	2200	4.19	4.78	83
84	.775	2.63	2.88	3.11	4.67	6.47	.181E-03	510	2000	3.52	5.51	84
85	1.47	2.69	2.92	3.13	4.59	6.29	.203E-01	560	2000	3.69	5.41	85
86	1.88	2.75	2.96	3.15	4.50	6.12	.154E 00	620	2000	3.85	5.31	86
87	2.15	2.81	3.00	3.17	4.44	5.98	.494E 00	680	2000	3.96	5.22	87
88	2.38	2.87	3.04	3.20	4.39	5.86	.124E 01	750	2000	4.04	5.09	88
89	2.57	2.94	3.09	3.24	4.37	5.79	.243E 01	820	2000	4.06	4.93	89
90	2.78	3.05	3.18	3.32	4.38	5.75	.474E 01	910	2000	3.99	4.68	90
91	2.99	3.18	3.31	3.43	4.45	5.79	.810E 01	1000	2000	3.81	4.35	91
92	1.12	2.94	3.22	3.46	5.16	7.13	.124E-02	470	1800	3.21	4.93	92
93	1.69	3.00	3.25	3.48	5.08	6.97	.277E-01	510	1800	3.34	4.85	93
94	2.11	3.06	3.29	3.50	5.00	6.79	.163E 00	560	1800	3.47	4.78	94
95	2.43	3.13	3.34	3.53	4.92	6.63	.566E 00	620	1800	3.58	4.68	95
96	2.67	3.20	3.38	3.56	4.87	6.51	.131E 01	680	1800	3.64	4.57	96
97	2.89	3.29	3.45	3.61	4.85	6.42	.271E 01	750	1800	3.65	4.41	97
98	3.09	3.39	3.54	3.69	4.87	6.39	.478E 01	820	1800	3.59	4.21	98
99	1.53	3.33	3.63	3.90	5.78	7.96	.522E-02	430	1600	2.89	4.36	99
100	2.11	3.40	3.68	3.93	5.68	7.76	.614E-01	470	1600	3.01	4.29	100
101	2.47	3.46	3.72	3.94	5.60	7.59	.229E 00	510	1600	3.11	4.23	101
102	2.78	3.53	3.76	3.97	5.53	7.43	.664E 00	560	1600	3.19	4.15	102
103	3.07	3.62	3.82	4.02	5.47	7.29	.160E 01	620	1600	3.24	4.03	103
104	3.30	3.72	3.90	4.08	5.46	7.21	.309E 01	680	1600	3.24	3.88	104
105	3.55	3.86	4.02	4.18	5.49	7.19	.565E 01	750	1600	3.15	3.67	105
106	1.30	3.52	3.86	4.15	6.20	8.57	.938E-03	390	1500	2.67	4.11	106
107	2.11	3.61	3.91	4.18	6.09	8.33	.366E-01	430	1500	2.80	4.04	107
108	2.56	3.68	3.95	4.20	5.99	8.14	.181E 00	470	1500	2.90	3.97	108
109	2.87	3.75	4.00	4.23	5.92	7.98	.494E 00	510	1500	2.97	3.91	109
110	3.17	3.83	4.05	4.26	5.86	7.83	.119E 01	560	1500	3.03	3.82	110
111	3.45	3.93	4.13	4.33	5.82	7.71	.257E 01	620	1500	3.04	3.69	111
112	3.69	4.06	4.24	4.42	5.84	7.67	.464E 01	680	1500	2.99	3.52	112
113	3.99	4.25	4.41	4.57	5.93	7.72	.810E 01	750	1500	2.86	3.26	113

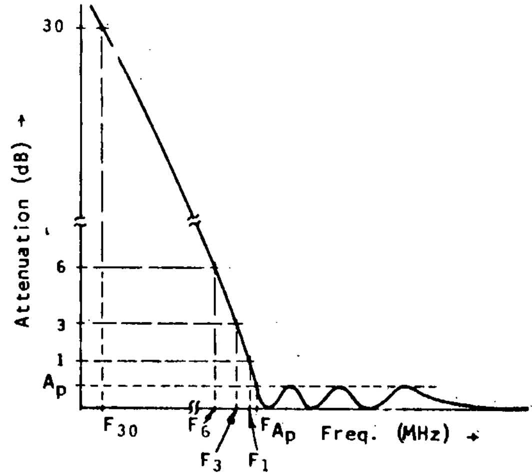
Table 1. Lowpass 50-ohm 7-Element Chebyshev Filters (concluded)

FLTR NO.	FREQ. (MHZ) AT AP,1,3,6,30 & 50 DB AP-DB	1-DB	3-DB	6-DB	30-DB	50-DB	R.C. (%)	C1,7 (PF)	C3,5 (PF)	L2,6 (UH)	L4 (UH)	FLTR NO.
114	1.11	4.04	4.43	4.78	7.19	9.96	.106E-03	330	1300	2.28	3.58	114
115	2.17	4.13	4.49	4.81	7.07	9.71	.148E-01	360	1300	2.39	3.52	115
116	2.72	4.21	4.54	4.84	6.97	9.50	.908E-01	390	1300	2.47	3.47	116
117	3.20	4.30	4.59	4.87	6.86	9.26	.363E 00	430	1300	2.56	3.41	117
118	3.54	4.38	4.65	4.90	6.78	9.08	.901E 00	470	1300	2.61	3.34	118
119	3.81	4.47	4.72	4.95	6.73	8.96	.176E 01	510	1300	2.64	3.26	119
120	4.10	4.60	4.82	5.03	6.72	8.87	.338E 01	560	1300	2.62	3.14	120
121	4.43	4.79	4.98	5.18	6.78	8.86	.623E 01	620	1300	2.54	2.94	121
122	.805	4.36	4.79	5.18	7.81	10.84	.623E-05	300	1200	2.09	3.32	122
123	2.28	4.47	4.86	5.21	7.67	10.5	.119E-01	330	1200	2.19	3.25	123
124	2.95	4.56	4.92	5.24	7.55	10.3	.908E-01	360	1200	2.28	3.20	124
125	3.39	4.64	4.97	5.27	7.45	10.1	.294E 00	390	1200	2.35	3.16	125
126	3.80	4.74	5.03	5.31	7.35	9.86	.831E 00	430	1200	2.41	3.09	126
127	4.13	4.84	5.11	5.36	7.29	9.70	.174E 01	470	1200	2.43	3.01	127
128	4.40	4.96	5.20	5.44	7.28	9.61	.309E 01	510	1200	2.43	2.91	128
129	4.72	5.13	5.35	5.57	7.32	9.59	.550E 01	560	1200	2.37	2.76	129
130	2.40	4.87	5.30	5.68	8.38	11.5	.907E-02	300	1100	2.00	2.99	130
131	3.22	4.97	5.36	5.72	8.23	11.2	.908E-01	330	1100	2.09	2.94	131
132	3.73	5.07	5.42	5.75	8.12	11.0	.320E 00	360	1100	2.16	2.89	132
133	4.10	5.16	5.48	5.78	8.03	10.8	.752E 00	390	1100	2.20	2.84	133
134	4.49	5.28	5.57	5.85	7.96	10.6	.172E 01	430	1100	2.23	2.76	134
135	4.82	5.42	5.68	5.94	7.94	10.5	.320E 01	470	1100	2.22	2.66	135
136	5.12	5.59	5.83	6.06	7.98	10.5	.530E 01	510	1100	2.18	2.54	136
137	2.52	5.34	5.82	6.25	9.24	12.7	.628E-02	270	1000	1.81	2.72	137
138	3.54	5.47	5.90	6.29	9.06	12.3	.908E-01	300	1000	1.90	2.67	138
139	4.15	5.58	5.97	6.33	8.92	12.0	.353E 00	330	1000	1.97	2.62	139
140	4.59	5.69	6.04	6.37	8.81	11.8	.867E 00	360	1000	2.01	2.57	140
141	4.93	5.80	6.13	6.43	8.75	11.7	.169E 01	390	1000	2.03	2.51	141
142	5.33	5.97	6.26	6.54	8.73	11.5	.334E 01	430	1000	2.02	2.41	142
143	5.69	6.18	6.44	6.70	8.79	11.5	.573E 01	470	1000	1.97	2.29	143
144	2.40	5.83	6.37	6.86	10.2	14.1	.219E-02	240	910	1.63	2.49	144
145	3.79	6.00	6.47	6.91	9.97	13.6	.744E-01	270	910	1.72	2.43	145
146	4.55	6.13	6.56	6.95	9.80	13.2	.349E 00	300	910	1.79	2.39	146
147	5.08	6.26	6.65	7.01	9.68	13.0	.926E 00	330	910	1.83	2.34	147
148	5.49	6.40	6.75	7.08	9.61	12.8	.188E 01	360	910	1.85	2.28	148
149	5.84	6.56	6.88	7.18	9.60	12.7	.327E 01	390	910	1.84	2.20	149
150	6.28	6.81	7.09	7.37	9.67	12.7	.591E 01	410	910	1.79	2.07	150
151	2.97	6.50	7.09	7.62	11.3	15.5	.487E-02	220	820	1.48	2.23	151
152	4.08	6.64	7.17	7.66	11.1	15.2	.572E-01	240	820	1.54	2.20	152
153	5.05	6.81	7.28	7.71	10.9	14.7	.344E 00	270	820	1.61	2.15	153
154	5.68	6.97	7.39	7.78	10.7	14.4	.100E 01	300	820	1.65	2.10	154
155	6.17	7.14	7.52	7.88	10.7	14.1	.213E 01	330	820	1.66	2.04	155
156	6.60	7.34	7.68	8.01	10.7	14.0	.381E 01	360	820	1.65	1.96	156
157	7.01	7.58	7.89	8.20	10.7	14.0	.614E 01	390	820	1.61	1.86	157
158	3.13	7.10	7.74	8.32	12.3	17.0	.374E-02	200	750	1.35	2.05	158
159	4.48	7.26	7.84	8.37	12.1	16.6	.598E-01	220	750	1.41	2.01	159
160	5.30	7.40	7.93	8.42	11.9	16.2	.241E 00	240	750	1.46	1.98	160
161	6.12	7.59	8.06	8.49	11.8	15.8	.867E 00	270	750	1.51	1.93	161
162	6.72	7.79	8.21	8.61	11.7	15.5	.204E 01	300	750	1.52	1.87	162
163	7.23	8.03	8.40	8.77	11.7	15.4	.386E 01	330	750	1.51	1.79	163
164	7.72	8.32	8.66	9.00	11.8	15.4	.646E 01	360	750	1.46	1.69	164
165	3.29	7.81	8.53	9.18	13.6	18.8	.264E-02	180	680	1.22	1.86	165
166	4.97	8.01	8.65	9.24	13.4	18.3	.630E-01	200	680	1.28	1.82	166
167	5.94	8.18	8.76	9.29	13.2	17.8	.278E 00	220	680	1.33	1.79	167
168	6.61	8.33	8.86	9.35	13.0	17.4	.720E 00	240	680	1.36	1.76	168
169	7.36	8.58	9.04	9.48	12.9	17.1	.193E 01	270	680	1.38	1.70	169
170	7.98	8.86	9.28	9.68	12.9	16.9	.393E 01	300	680	1.37	1.62	170
171	8.58	9.22	9.60	9.96	13.0	17.0	.687E 01	330	680	1.32	1.52	171
172	2.91	8.51	9.32	10.0	15.0	20.8	.544E-03	160	620	1.10	1.70	172
173	5.28	8.76	9.48	10.1	14.7	20.1	.484E-01	180	620	1.16	1.67	173
174	6.48	8.96	9.60	10.2	14.4	19.5	.267E 00	200	620	1.21	1.63	174
175	7.29	9.15	9.73	10.3	14.2	19.1	.758E 00	220	620	1.24	1.60	175
176	7.91	9.34	9.87	10.4	14.1	18.8	.159E 01	240	620	1.26	1.56	176
177	8.67	9.68	10.1	10.6	14.1	18.6	.362E 01	270	620	1.25	1.49	177
178	9.39	10.10	10.5	10.9	14.2	18.6	.676E 01	300	620	1.20	1.39	178

Figure 2. Highpass Filter Schematic Diagram and Attenuation Response Curve



(A) Schematic Diagram



(B) Typical Attenuation Response

Table 2. Highpass 50-ohm 7-Element Chebyshev Filters, Design Parameters and Component Values

FLTR NO.	FREQ.(MHZ) AT AP,1,3,6,30 & 50 DB AP-DB	1-DB	3-DB	6-DB	30-DB	50-DB	R.C. (%)	C1,7 (PF)	C3,5 (PF)	L2,6 (UH)	L4 (UH)	FLTR NO.
1	1.09	1.01	.971	.935	.717	.549	.684E 01	3300	1600	5.15	4.48	1
2	1.16	1.05	1.00	.961	.724	.550	.411E 01	3600	1600	4.99	4.22	2
3	1.23	1.08	1.02	.977	.725	.547	.244E 01	3900	1600	4.93	4.06	3
4	1.34	1.10	1.04	.990	.721	.539	.115E 01	4300	1600	4.95	3.92	4
5	1.47	1.13	1.06	.999	.713	.529	.500E 00	4700	1600	5.04	3.84	5
6	1.65	1.15	1.07	1.00	.705	.519	.184E 00	5100	1600	5.17	3.78	6
7	2.02	1.17	1.08	1.01	.693	.506	.339E-01	5600	1600	5.37	3.71	7
8	3.51	1.20	1.10	1.02	.680	.491	.544E-03	6200	1600	5.64	3.64	8
9	1.13	1.06	1.02	.985	.760	.583	.810E 01	3000	1500	4.92	4.31	9
10	1.22	1.11	1.06	1.02	.771	.587	.471E 01	3300	1500	4.70	4.01	10
11	1.30	1.14	1.09	1.04	.774	.584	.271E 01	3600	1500	4.63	3.83	11
12	1.39	1.17	1.11	1.05	.771	.578	.151E 01	3900	1500	4.63	3.71	12
13	1.52	1.20	1.12	1.06	.763	.568	.643E 00	4300	1500	4.70	3.62	13
14	1.71	1.22	1.14	1.07	.754	.556	.233E 00	4700	1500	4.82	3.55	14
15	2.00	1.24	1.15	1.08	.743	.544	.630E-01	5100	1500	4.97	3.50	15
16	2.80	1.27	1.16	1.08	.730	.530	.455E-02	5600	1500	5.19	3.44	16
17	1.34	1.25	1.20	1.15	.883	.676	.658E 01	2700	1300	4.17	3.62	17
18	1.45	1.30	1.24	1.19	.892	.676	.351E 01	3000	1300	4.03	3.38	18
19	1.57	1.34	1.27	1.21	.891	.670	.182E 01	3300	1300	4.00	3.24	19
20	1.69	1.37	1.29	1.22	.885	.660	.892E 00	3600	1300	4.04	3.16	20
21	1.85	1.39	1.30	1.23	.875	.648	.397E 00	3900	1300	4.12	3.10	21
22	2.17	1.42	1.32	1.24	.862	.633	.104E 00	4300	1300	4.26	3.05	22
23	2.78	1.45	1.33	1.25	.848	.617	.143E-01	4700	1300	4.43	3.00	23
24	5.06	1.48	1.35	1.25	.835	.603	.173E-03	5100	1300	4.62	2.95	24
25	1.41	1.33	1.28	1.23	.950	.729	.810E 01	2400	1200	3.94	3.45	25
26	1.55	1.40	1.34	1.28	.966	.734	.411E 01	2700	1200	3.74	3.16	26
27	1.68	1.44	1.37	1.31	.966	.727	.204E 01	3000	1200	3.70	3.01	27
28	1.82	1.48	1.40	1.32	.959	.716	.949E 00	3300	1200	3.73	2.92	28
29	2.01	1.51	1.41	1.33	.948	.703	.397E 00	3600	1200	3.80	2.86	29
30	2.27	1.53	1.43	1.34	.936	.689	.138E 00	3900	1200	3.91	2.82	30
31	2.91	1.57	1.44	1.35	.920	.670	.185E-01	4300	1200	4.07	2.77	31
32	5.35	1.61	1.46	1.36	.905	.653	.206E-03	4700	1200	4.26	2.72	32
33	1.54	1.45	1.39	1.34	1.04	.795	.810E 01	2200	1100	3.61	3.16	33
34	1.65	1.51	1.44	1.39	1.05	.801	.495E 01	2400	1100	3.46	2.95	34
35	1.80	1.57	1.49	1.42	1.05	.795	.232E 01	2700	1100	3.39	2.78	35
36	1.97	1.61	1.52	1.44	1.05	.782	.102E 01	3000	1100	3.41	2.68	36
37	2.19	1.65	1.54	1.46	1.03	.766	.397E 00	3300	1100	3.49	2.63	37
38	2.51	1.68	1.56	1.46	1.02	.750	.123E 00	3600	1100	3.59	2.58	38
39	3.06	1.71	1.57	1.47	1.01	.733	.247E-01	3900	1100	3.71	2.55	39
40	5.67	1.75	1.60	1.48	.987	.713	.251E-03	4300	1100	3.90	2.50	40
41	1.70	1.59	1.53	1.48	1.14	.875	.810E 01	2000	1000	3.28	2.87	41
42	1.82	1.66	1.59	1.53	1.16	.881	.471E 01	2200	1000	3.14	2.67	42
43	1.95	1.71	1.63	1.56	1.16	.877	.271E 01	2400	1000	3.08	2.55	43
44	2.15	1.77	1.67	1.59	1.15	.862	.111E 01	2700	1000	3.10	2.45	44
45	2.41	1.81	1.69	1.60	1.14	.843	.397E 00	3000	1000	3.17	2.39	45
46	2.81	1.85	1.72	1.61	1.12	.823	.108E 00	3300	1000	3.28	2.34	46
47	3.56	1.88	1.73	1.62	1.10	.803	.162E-01	3600	1000	3.40	2.31	47
48	6.05	1.92	1.76	1.63	1.09	.785	.314E-03	3900	1000	3.54	2.27	48

Table 2.   Highpass 50-ohm 7-Element Chebyshev Filters   (continued)

FLTR NO.	FREQ. (MHZ) AT AP,1,3,6,30 & 50 DB AP-DB	1-DB	3-DB	6-DB	30-DB	50-DB	R.C. (%)	C1,7 (PF)	C3,5 (PF)	L2,6 (UH)	L4 (UH)	FLTR NO.
49	2.00	1.83	1.75	1.68	1.27	.968	.474E 01	2000	910	2.85	2.43	49
50	2.15	1.89	1.80	1.72	1.28	.963	.258E 01	2200	910	2.81	2.31	50
51	2.31	1.93	1.83	1.74	1.27	.951	.135E 01	2400	910	2.81	2.24	51
52	2.61	1.99	1.86	1.76	1.25	.929	.449E 00	2700	910	2.88	2.18	52
53	3.08	2.03	1.88	1.77	1.23	.905	.110E 00	3000	910	2.98	2.13	53
54	4.02	2.07	1.91	1.78	1.21	.881	.130E-01	3300	910	3.11	2.10	54
55	8.39	2.12	1.93	1.79	1.19	.859	.593E-04	3600	910	3.25	2.06	55
56	2.22	2.03	1.94	1.86	1.41	1.07	.478E 01	1800	820	2.57	2.19	56
57	2.41	2.10	2.00	1.91	1.41	1.07	.243E 01	2000	820	2.53	2.08	57
58	2.61	2.15	2.03	1.93	1.41	1.05	.117E 01	2200	820	2.54	2.01	58
59	2.85	2.20	2.06	1.95	1.39	1.03	.520E 00	2400	820	2.58	1.97	59
60	3.41	2.25	2.09	1.96	1.37	1.00	.112E 00	2700	820	2.68	1.92	60
61	4.63	2.31	2.12	1.98	1.34	.975	.978E-02	3000	820	2.81	1.89	61
62	18.02	2.37	2.15	1.99	1.32	.948	.554E-06	3300	820	2.95	1.85	62
63	2.26	2.12	2.04	1.97	1.52	1.17	.810E 01	1500	750	2.46	2.16	63
64	2.38	2.19	2.10	2.02	1.54	1.17	.565E 01	1600	750	2.38	2.05	64
65	2.60	2.28	2.17	2.08	1.55	1.17	.271E 01	1800	750	2.31	1.91	65
66	2.83	2.35	2.22	2.11	1.54	1.15	.124E 01	2000	750	2.32	1.84	66
67	3.13	2.40	2.25	2.13	1.52	1.13	.508E 00	2200	750	2.35	1.80	67
68	3.53	2.45	2.28	2.14	1.50	1.11	.174E 00	2400	750	2.43	1.77	68
69	4.74	2.51	2.31	2.16	1.47	1.07	.162E-01	2700	750	2.55	1.73	69
70	13.98	2.58	2.35	2.18	1.44	1.04	.623E-05	3000	750	2.69	1.69	70
71	2.69	2.45	2.34	2.25	1.70	1.30	.464E 01	1500	680	2.13	1.81	71
72	2.82	2.50	2.39	2.28	1.71	1.29	.309E 01	1600	680	2.10	1.75	72
73	3.10	2.59	2.45	2.33	1.70	1.27	.131E 01	1800	680	2.10	1.67	73
74	3.46	2.65	2.49	2.35	1.68	1.25	.494E 00	2000	680	2.14	1.63	74
75	3.97	2.71	2.52	2.37	1.65	1.22	.148E 00	2200	680	2.21	1.60	75
76	4.88	2.76	2.54	2.38	1.63	1.19	.277E-01	2400	680	2.29	1.58	76
77	12.21	2.84	2.59	2.40	1.59	1.15	.326E-04	2700	680	2.43	1.54	77
78	2.84	2.63	2.52	2.43	1.86	1.42	.623E 01	1300	620	1.98	1.71	78
79	3.16	2.77	2.64	2.52	1.87	1.41	.257E 01	1500	620	1.91	1.58	79
80	3.33	2.82	2.67	2.54	1.87	1.40	.160E 01	1600	620	1.91	1.54	80
81	3.74	2.90	2.72	2.58	1.84	1.37	.566E 00	1800	620	1.95	1.49	81
82	4.34	2.97	2.76	2.59	1.81	1.34	.154E 00	2000	620	2.01	1.46	82
83	5.45	3.03	2.79	2.61	1.78	1.30	.242E-01	2200	620	2.09	1.44	83
84	8.95	3.10	2.83	2.62	1.75	1.27	.590E-03	2400	620	2.19	1.41	84
85	3.19	2.94	2.82	2.71	2.06	1.57	.550E 01	1200	560	1.77	1.52	85
86	3.39	3.03	2.89	2.77	2.07	1.57	.338E 01	1300	560	1.73	1.45	86
87	3.81	3.15	2.98	2.83	2.06	1.54	.119E 01	1500	560	1.73	1.37	87
88	4.06	3.20	3.01	2.85	2.05	1.52	.664E 00	1600	560	1.75	1.35	88
89	4.77	3.28	3.05	2.87	2.01	1.48	.163E 00	1800	560	1.82	1.32	89
90	6.17	3.36	3.09	2.89	1.97	1.44	.203E-01	2000	560	1.90	1.29	90
91	12.00	3.44	3.14	2.91	1.94	1.40	.148E-03	2200	560	1.99	1.27	91
92	3.53	3.23	3.10	2.98	2.26	1.73	.530E 01	1100	510	1.61	1.38	92
93	3.76	3.34	3.18	3.04	2.28	1.72	.309E 01	1200	510	1.58	1.31	93
94	4.01	3.42	3.24	3.09	2.27	1.71	.176E 01	1300	510	1.57	1.27	94
95	4.61	3.54	3.31	3.13	2.24	1.66	.494E 00	1500	510	1.61	1.22	95
96	5.03	3.58	3.34	3.15	2.22	1.64	.229E 00	1600	510	1.64	1.21	96
97	6.51	3.68	3.39	3.17	2.17	1.58	.277E-01	1800	510	1.72	1.18	97
98	12.81	3.78	3.44	3.19	2.13	1.54	.181E-03	2000	510	1.81	1.16	98
99	3.79	3.49	3.35	3.22	2.45	1.87	.573E 01	1000	470	1.49	1.28	99
100	4.07	3.62	3.45	3.30	2.47	1.87	.320E 01	1100	470	1.45	1.21	100
101	4.35	3.71	3.52	3.35	2.46	1.85	.174E 01	1200	470	1.45	1.17	101
102	4.68	3.78	3.57	3.38	2.45	1.83	.901E 00	1300	470	1.46	1.14	102
103	5.61	3.90	3.63	3.42	2.40	1.77	.181E 00	1500	470	1.52	1.11	103
104	6.39	3.96	3.66	3.43	2.37	1.74	.614E-01	1600	470	1.56	1.10	104
105	10.66	4.07	3.72	3.46	2.32	1.68	.124E-02	1800	470	1.65	1.07	105
106	4.12	3.80	3.65	3.51	2.68	2.05	.591E 01	910	430	1.37	1.18	106
107	4.42	3.94	3.76	3.60	2.70	2.04	.334E 01	1000	430	1.33	1.11	107
108	4.77	4.06	3.84	3.66	2.69	2.02	.172E 01	1100	430	1.33	1.07	108
109	5.16	4.14	3.90	3.70	2.67	1.99	.831E 00	1200	430	1.34	1.04	109
110	5.66	4.22	3.95	3.72	2.64	1.96	.363E 00	1300	430	1.37	1.02	110
111	7.45	4.35	4.02	3.76	2.58	1.88	.366E-01	1500	430	1.44	.999	111
112	9.60	4.42	4.05	3.77	2.55	1.85	.522E-02	1600	430	1.49	.987	112

Table 2. Highpass 50-ohm 7-Element Chebyshev Filters (concluded)

FLTR NO.	FREQ. (MHZ) AT AP,1,3,6,30 & 50 DB AP-DB	1-DB	3-DB	6-DB	30-DB	50-DB	R.C. (%)	C1,7 (PF)	C3,5 (PF)	L2,6 (UH)	L4 (UH)	FLTR NO.
113	4.52	4.18	4.01	3.86	2.95	2.26	.614E 01	820	390	1.24	1.07	113
114	4.89	4.35	4.15	3.97	2.98	2.25	.327E 01	910	390	1.21	1.01	114
115	5.27	4.48	4.24	4.04	2.97	2.23	.169E 01	1000	390	1.20	.970	115
116	5.75	4.58	4.31	4.08	2.94	2.19	.752E 00	1100	390	1.22	.944	116
117	6.39	4.67	4.36	4.11	2.91	2.15	.294E 00	1200	390	1.25	.926	117
118	7.34	4.75	4.40	4.13	2.87	2.10	.908E-01	1300	390	1.28	.913	118
119	13.35	4.91	4.49	4.17	2.79	2.02	.938E-03	1500	390	1.37	.889	119
120	4.86	4.51	4.33	4.17	3.19	2.44	.646E 01	750	360	1.15	.999	120
121	5.20	4.68	4.47	4.28	3.22	2.44	.381E 01	820	360	1.12	.942	121
122	5.64	4.83	4.58	4.37	3.22	2.42	.188E 01	910	360	1.11	.900	122
123	6.14	4.95	4.66	4.42	3.19	2.38	.867E 00	1000	360	1.12	.874	123
124	6.86	5.05	4.72	4.45	3.15	2.33	.320E 00	1100	360	1.15	.856	124
125	7.96	5.14	4.77	4.48	3.11	2.28	.908E-01	1200	360	1.18	.843	125
126	10.00	5.24	4.82	4.50	3.06	2.23	.148E-01	1300	360	1.23	.831	126
127	5.26	4.90	4.71	4.53	3.48	2.66	.687E 01	680	330	1.06	.924	127
128	5.67	5.10	4.87	4.67	3.51	2.67	.386E 01	750	330	1.03	.865	128
129	6.07	5.25	4.98	4.75	3.51	2.65	.213E 01	820	330	1.02	.830	129
130	6.65	5.39	5.08	4.82	3.49	2.60	.926E 00	910	330	1.03	.803	130
131	7.40	5.50	5.14	4.85	3.44	2.55	.353E 00	1000	330	1.05	.786	131
132	8.68	5.61	5.20	4.88	3.39	2.49	.908E-01	1100	330	1.09	.772	132
133	11.21	5.73	5.26	4.91	3.34	2.43	.119E-01	1200	330	1.13	.761	133
134	21.33	5.85	5.33	4.94	3.29	2.37	.106E-03	1300	330	1.17	.748	134
135	5.80	5.39	5.18	4.99	3.83	2.93	.676E 01	620	300	.965	.838	135
136	6.22	5.60	5.35	5.13	3.86	2.93	.393E 01	680	300	.933	.787	136
137	6.71	5.78	5.49	5.23	3.86	2.91	.204E 01	750	300	.924	.753	137
138	7.25	5.91	5.58	5.29	3.84	2.87	.100E 01	820	300	.931	.732	138
139	8.15	6.05	5.66	5.34	3.79	2.80	.349E 00	910	300	.954	.715	139
140	9.55	6.17	5.72	5.37	3.73	2.74	.908E-01	1000	300	.986	.702	140
141	12.79	6.31	5.80	5.40	3.66	2.66	.907E-02	1100	300	1.03	.690	141
142	34.95	6.46	5.88	5.44	3.60	2.60	.623E-05	1200	300	1.08	.678	142
143	6.46	6.00	5.77	5.55	4.25	3.25	.663E 01	560	270	.867	.752	143
144	6.98	6.26	5.97	5.72	4.30	3.26	.362E 01	620	270	.838	.704	144
145	7.50	6.44	6.10	5.82	4.29	3.23	.193E 01	680	270	.832	.676	145
146	8.18	6.59	6.21	5.89	4.26	3.18	.867E 00	750	270	.840	.656	146
147	9.07	6.72	6.29	5.93	4.21	3.11	.344E 00	820	270	.859	.643	147
148	10.87	6.88	6.37	5.97	4.13	3.03	.744E-01	910	270	.892	.631	148
149	14.92	7.03	6.45	6.01	4.06	2.95	.628E-02	1000	270	.931	.620	149
150	7.41	6.83	6.55	6.30	4.80	3.67	.578E 01	510	240	.762	.656	150
151	7.95	7.08	6.75	6.46	4.83	3.66	.327E 01	560	240	.743	.620	151
152	8.61	7.29	6.90	6.57	4.82	3.62	.159E 01	620	240	.740	.595	152
153	9.39	7.45	7.01	6.64	4.78	3.56	.720E 00	680	240	.750	.580	153
154	10.63	7.61	7.10	6.69	4.71	3.48	.241E 00	750	240	.771	.568	154
155	12.63	7.76	7.18	6.72	4.64	3.40	.572E-01	820	240	.797	.559	155
156	19.33	7.96	7.28	6.77	4.55	3.30	.219E-02	910	240	.837	.549	156
157	8.11	7.47	7.16	6.88	5.24	4.00	.560E 01	470	220	.697	.599	157
158	8.63	7.70	7.35	7.04	5.27	4.00	.341E 01	510	220	.681	.571	158
159	9.28	7.92	7.51	7.15	5.26	3.96	.178E 01	560	220	.678	.548	159
160	10.19	8.12	7.64	7.24	5.22	3.89	.758E 00	620	220	.687	.532	160
161	11.41	8.28	7.73	7.29	5.15	3.80	.278E 00	680	220	.704	.522	161
162	13.71	8.46	7.83	7.33	5.06	3.71	.598E-01	750	220	.730	.513	162
163	18.94	8.64	7.92	7.37	4.98	3.61	.487E-02	820	220	.761	.505	163
164	8.97	8.23	7.89	7.59	5.77	4.40	.540E 01	430	200	.632	.542	164
165	9.59	8.51	8.11	7.76	5.80	4.39	.312E 01	470	200	.618	.515	165
166	10.22	8.72	8.26	7.87	5.79	4.35	.176E 01	510	200	.616	.498	166
167	11.14	8.92	8.39	7.96	5.74	4.28	.806E 00	560	200	.623	.485	167
168	12.60	9.12	8.51	8.02	5.66	4.18	.267E 00	620	200	.640	.474	168
169	14.98	9.30	8.61	8.06	5.57	4.08	.630E-01	680	200	.663	.467	169
170	21.57	9.52	8.72	8.11	5.47	3.97	.374E-02	750	200	.694	.458	170
171	9.42	8.84	8.51	8.21	6.33	4.86	.810E 01	360	180	.590	.517	171
172	10.02	9.18	8.80	8.45	6.42	4.89	.516E 01	390	180	.567	.486	172
173	10.79	9.51	9.05	8.65	6.45	4.87	.280E 01	430	180	.555	.460	173
174	11.59	9.74	9.22	8.77	6.42	4.82	.147E 01	470	180	.555	.445	174
175	12.53	9.94	9.34	8.85	6.37	4.74	.720E 00	510	180	.562	.435	175
176	14.08	10.14	9.46	8.91	6.29	4.64	.255E 00	560	180	.577	.427	176
177	17.20	10.36	9.58	8.97	6.18	4.52	.484E-01	620	180	.600	.419	177
178	25.12	10.60	9.70	9.02	6.07	4.40	.264E-02	680	180	.627	.412	178

Conclusions

It is important that the test engineer be able to quickly and conveniently design and assemble low and high-pass filters over a wide range of cut-off frequencies. The pre-calculated 50-ohm filter designs presented in this article provide a wide selection of designs for virtually any cut-off frequency between 1 and 10 MHz.

By using these designs, the likelihood of calculation error is eliminated, and the filter construction is simplified because each design requires only standard-value capacitors. Although the designs are based on equal 50-ohm terminations in the 1 to 10 MHz range, designs for other termination resistances and other frequency ranges are easily calculated with simple scaling procedures while the advantage of standard-value capacitors is included in the new design.

Because most of the pre-calculated designs have a reflection coefficient less than four percent, the filter terminal impedance is relatively constant across the passband. This means that the lowpass and highpass filters can be cascaded to achieve a bandpass response with no difficulty as long as the passband is not less than one octave wide.

The design procedures discussed in this article should be useful to those responsible for performing TEMPEST testing, or for designing and constructing filters. Any comments, suggestions, or criticisms will be appreciated, and they should be addressed to the author, Ed Wetherhold, Honeywell Inc., POB 391, Annapolis, MD 21404.

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LOSSYLINE FLEXIBLE FILTER WIRE AND CABLE

INTRODUCTION

LOSSYLINE cable is a single conductor flexible wire which possesses the properties of a magnetically and electrically shielded low-pass line filter in its ability to remove electromagnetic interference. The *LOSSYLINE* wire or cable solves a number of problems in interference filtering. These include leakage and coupling through shielding, avoidance of standing waves in long lines, suppression of transient spikes and ringing, and effective EMI filtering and suppression above 10 MHz.

The evolution of the *LOSSYLINE* cable occurred in two stages. The first stage was the development of a short, rigid element possessing the desired characteristics of a low-pass, high-frequency dissipative/absorptive lossy electromagnetic unit. The second stage of evolution was to incorporate these filtering principles and characteristics into single conductor type wire and cable.

APPLICATIONS

Many existing devices which are subject to electromagnetic interference could be retrofitted with filters. However, the cost of such retrofitting is usually high, or else there is no available space for a conventional filter box. A less expensive, space-saving approach is to replace existing wiring with *LOSSYLINE* interference dissipative wire or cable. A cost reduction is effected because of the ease of installation of the cable.

Conventional wiring, though possessing state-of-the-art shielding, will pick up some radiated interference. For this reason, filters usually are placed in close proximity to the system components to be protected, and may be required at both ends. With filters, there still may be a problem of leakage or radiation of high frequencies from the conductor to other conductors. Shielding may prove unreliable or impractical. Replacement of the conductor with *LOSSYLINE* is a solution.

Leakage or pick-up by conductors may be prohibitive when they span considerable distances. It may not be practical or feasible to install sufficient filters along a great length. The use of *LOSSYLINE* cable may be the answer. It is flexible and also will provide magnetic dissipative isolation.

LOSSYLINE filters dissipate waveforms in proportion to their rise time. This provides the opportunity to remove individual spikes which might pass through a simple rejective filter and ring between reflective points. Shields may provide current paths through planes of contact between dissimilar metals or through minute perforations. The RF dissipative approach is a neater more direct solution.

Long conductors with and without filters possess inductive and capacitive reactance which requires matching for the passage of alternating current. Excessive standing wave voltages may appear along their length. Since it provides small reactance in the pass-band, and dissipation for higher frequencies, the RF dissipative approach provides a solution to the matching and standing wave problems.

With the greater use of frequencies above 10 MHz, the fall-off of attenuation with an increase of frequency cannot be disregarded. A purely dissipative filter, providing no leakage path as the wavelength becomes shorter is particularly helpful in the microwave region.