PRACTICAL FILTER DESIGN – PART 9

by H. Baggott

Following last month's discussion of Chebishev filters with a ripple of 0.1 dB in the pass band, this month's article deals with Chebishev networks with a 0.5 dB ripple. These have an even steeper cut-off profile than the 0.1 dB types but, as explained last month, the ringing becomes more pronounced.

As in previous articles, five tables are given that contain all the information for the calculation of Chebishev filters with a 0.5 dB ripple in the pass band. As was the case with Table 11, Table 15 can not be used for the computation of an even-order section with equal input and output impedances. For π sections, the table is valid for a ratio of 2:1, whereas for T sections the ratio is 1:2. It all depends on which resistance is used as a reference.

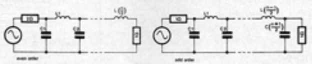
The specific properties of the 0.5 dB Chebishev filter are again shown most clearly by the characteristics in Fig. 47, 48 and 49. The ripple is very evident in Fig. 47, although it should be borne in mind that the left-hand part of the scale has been 'stretched'. Things are therefore not as bad as they may seem: it is only when the ripple exceeds 1 dB that operation becomes troublesome.

The cut-off profile is steep: the attenuation of a fourth-order filter at $2f_k$ is about 33 dB.

It is interesting to note that the number of 'rings' is the same as the order of the filter.

The delay time characteristic in Fig. 48 shows why the Chebishev filter is not suitable for use in phase linear (audio) applications.

The step response in Fig. 49 shows the ringing, which is comparable to that in



n	C1	L1	C2	L2	C3	L3	C4	L4	C5	L5
2	0.1564	0.3347								
3	0.2966	0.2038	0.2966							
4	0.1345	0.4329	0.1971	0.3159						
5	0.2876	0.2073	0.4283	0.2073	0.2876					
6	0.1321	0.4304	0.2055	0.4571	0.1969	0.3113				
7	0.2848	0.2063	0.4325	0.2204	0.4325	0.2063	0.2848			
8	0.1313	0.4284	0.2066	0.4637	0.2094	0.4584	0.1963	0.3095		
9	0.02589	0.2056	0.4323	0.2216	0.4414	0.2216	0.4323	0.2056	0.02589	
10	0.1309	0.4273	0.2053	0.4642	0.2108	0.4678	0.2099	0.4581	0.1959	0.3087
	L1	C1	L2	C2	L3	C3	L4	C4	L5	C5

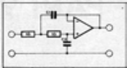
Table 15. Standardized component values for passive low-pass filters with an input impedance to output impedance ratio of 2:1 for even-order sections and 1:1 for odd-order sections.

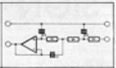
n	L1	C1	L2	C2	L3	C3	L4	C4	L5	C5
2	0.208	0.1551								
3	0.2502	0.2416	0.1483							
4	0.2286	0.3006	0.2421	0.1453						
5	0.2594	0.2769	0.3058	0.2409	0.1438					
6	0.2327	0.3151	0.2833	0.3064	0.24	0.1429				
7	0.262	0.2829	0.3232	0.2848	0.3062	0.2393	0.1424			
8	0.2341	0.3187	0.2904	0.3253	0.2851	0.3059	0.2388	0.1421		
9	0.2631	0.2847	0.3274	0.2926	0.326	0.285	0.3066	0.2384	0.1418	
10	0.2348	0.32	0.2926	0.33	0.2934	0.3262	0.285	0.3053	0.2382	0.1416

Table 16. Standardized component values for passive low-pass sections with negligible source impedance.

n	real part $-\alpha$	imaginary part $\pm\beta$
2	0.502	0.7278
3	0.2654	0.8913
	0.5309	
4	0.1594	0.9509
	0.3849	0.3939
5	0.1053	0.9788
	0.2756	0.6049
	0.3406	
6	0.07437	0.9941
	0.2032	0.7278
	0.2776	0.2664
7	0.05522	1.0034
	0.1547	0.8047
	0.2236	0.4466
	0.2482	
8	0.04257	1.0094
	0.1212	0.8557
	0.1814	0.5718
	0.214	0.2008
9	0.03379	1.0136
	0.09731	0.8913
	0.1491	0.6616
	0.1829	0.352
	0.1946	
10	0.02747	1.0165
	0.07971	0.917
	0.1242	0.7278
	0.1564	0.4672
	0.1734	0.161

Table 14. Pole locations of Chebishev filters with a 0.5 dB ripple.





n	C1	C2	C1	C2	C3
2	0.3104	0.104			
3			1.7873	0.3581	0.01424
4	0.992	0.02868			
	0.4109	0.2069			
5	0.5059	0.01821			
			1.0889	0.5279	0.04827
6	2.1327	0.01258			
	0.781	0.05957			
	0.5717	0.3057			
7	2.8759	0.0092			
	1.0259	0.03866			
			1.2689	0.7135	0.0748
8	3.7322	0.007017			
	1.311	0.02728			
	0.8757	0.0844			
	0.7425	0.4054			
9	4.7014	0.005531			
	1.6329	0.02036			
	1.0659	0.05442			
			1.522	0.904	0.09963
10	5.7869	0.004472			
	1.9942	0.01584			
	1.2809	0.03829			
	1.0159	0.1078			
	0.8167	0.5063			

Table. 17. Standardized component values for active filters with single feedback path.

Fig. 44.

A worked example

This time we give only one example, but it has two possible solutions.

Design an active band-pass filter with a a –3 dB bandwidth extending from 11.5 kHz to 12.5 kHz. The attenuation at 8 kHz and 18 kHz must be not smaller than 40 dB.

The aim is to keep the circuit as simple as possible. Since no mention was made of the permitted ripple in the pass band, we choose a 0.5 dB Chebishev section, because this has the best cut-off profile.

First, we calculate the centre frequency, f_c:

$$f_c = \sqrt{(f_1 f_h)} = 11{,}990 \text{ Hz.}$$

Next, we must ascertain the complementary frequencies for the –40 dB points to obtain the steepest cut-off combination.

The lower frequency (8 kHz) is complemented by a frequency of:

$$f_2 = 11990^2 / 8000 = 17{,}970 \text{ Hz.}$$

The higher frequency (18 kHz) is complemented by a frequency of:

$$f_1 = 11990^2 / 18000 = 7987 \text{ Hz.}$$

The optimum combination is, therefore, 8000 Hz and 17970 Hz, although the differences are so small that we could use either combination. The –40 dB bandwidth is, therefore, 17970 – 8000 = 9970 Hz.

From the characteristics we must determine how this bandwidth may be achieved with the smallest number of sections.

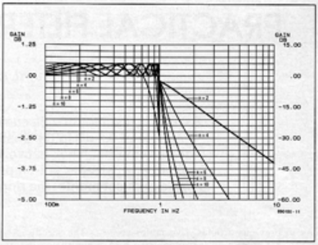


Fig. 47. Gain vs frequency characteristics of Chebishev filters with a 0.5 dB ripple.

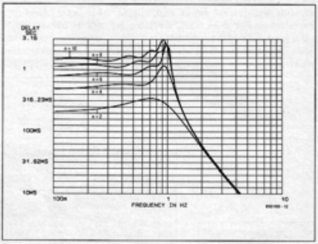


Fig. 48. Delay time vs frequency characteristics of Chebishev filters with a 0.5 dB ripple.

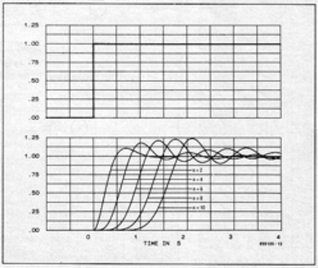


Fig. 49. Step response of Chebishev filters with a 0.5 dB ripple.

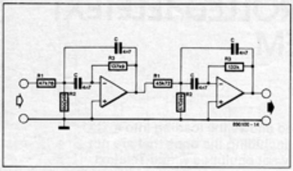


Fig. 50. A second-order active band-pass filter with only one opamp per stage. At higher Qs, as in the worked example, problems soon occur.

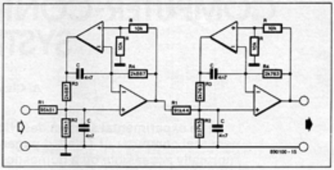


Fig. 51. The same filter as in Fig. 50, but configured as a two-stage double opamp circuit.

For this, we take the ratio of the bandwidth at –40 dB and that at –3 dB:

9970 : 1000 = 9.97.

Using this value in Fig. 47, the attenuation of a second-order filter is seen to be about 42 dB, amply meeting the requirement.

In the first instance, an opamp with multiple feedback paths as in Fig. 30 (Part 5) is chosen. Two of these must be cascaded as in Fig. 50 to obtain a second-order filter.

Before the component values can be calculated, the poles must be ascertained from Table 14:

$-\alpha = 0.502;$

$\pm\beta = 0.7278.$

The Q factor of the filter must be:

$Q = 11990 / 1000 = 11.99.$

The calculations to arrive at the centre frequency, Q value, amplification, and so on, can then be carried out, resulting in:

$C = 0.7817$
$Q_s = 23.89$
$D = 1.022$
$f_{sa} = 11{,}731$ Hz
$f_{sb} = 12{,}254$ Hz
$A_{sa} = 1.444$
$A_{sb} = 1.444$

The component values are then calculated with the aid of the formulas given in Part 5. The value of the capacitor is taken as 4.7 nF.

First stage:
$R_1 = 47.76$ kΩ
$R_2 = 60.48$ Ω
$R_3 = 137.9$ kΩ

Second stage:
$R_1 = 45.72$ kΩ
$R_2 = 57.89$ Ω
$R_3 = 132$ kΩ

In practice, this circuit will function, but the Q of each stage is fairly high. Moreover, the voltage attenuation at the inputs is high enough to cause hum and noise problems unless the highest quality opamps are used.

To obviate these difficulties, a two-stage section based on Fig. 31 (Part 5) as shown in Fig. 51 may be used. This circuit is able to cope with the high Qs.

The calculations to arrive at the centre frequency, Q value, amplification, and so on, remain as for Fig. 50, but the component values will have to be recalculated.

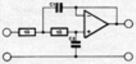
First stage:
$R_1 = 95.51$ kΩ
$R_2 = 248.1$ kΩ
$R_3 = R_4 = 2.887$ kΩ

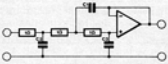
Second stage:
$R_1 = 91.44$ kΩ
$R_2 = 237.5$ kΩ
$R_3 = R_4 = 2.763$ kΩ

There is no noticeable attenuation at the inputs of this network. It is, however, necessary that the components used are close tolerance types (1%), otherwise the characteristics of the practical filter will not be identical to those of the calculated network.

Correction to Part 8

The two circuits shown below were omitted from the top of Table 13 in Part 8. Sorry!





ELECTRONICS SCENE

Analogue Touch Sensors

Analogue touch sensors that use surface chemistry and surface electronics for input via visual display units (VDUs) have been developed by John McGavin & Co.

The sensors consist of two conductive coatings applied to a substrate of polyester or polycarbonate. The faces are separated by clear dielectric spacer dots and are brought into electrical contact only when actuated by the pressure of a finger.

Simulator for Satellite Signals

A simulator that does a job similar to those used to train aircraft pilots has been developed by STC to check on the accuracy of Global Positioning Systems (GPS) used worldwide for navigating both civil and military craft on land, sea and in the air.

The company says that its STR2700 simulator will contribute to still more accurate navigation from satellite signals.

Global Positioning Systems relay on signals from 18–21 special navigational satellites in orbit around the earth, of which the average user can 'see' up to five at any given moment.