056 20th-Order Measurement Filter

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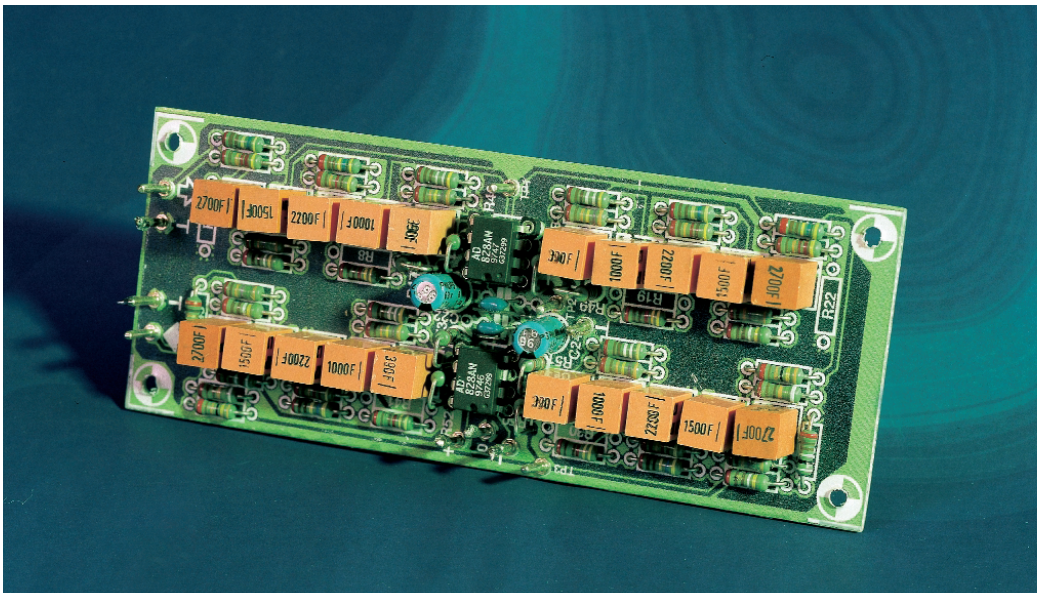
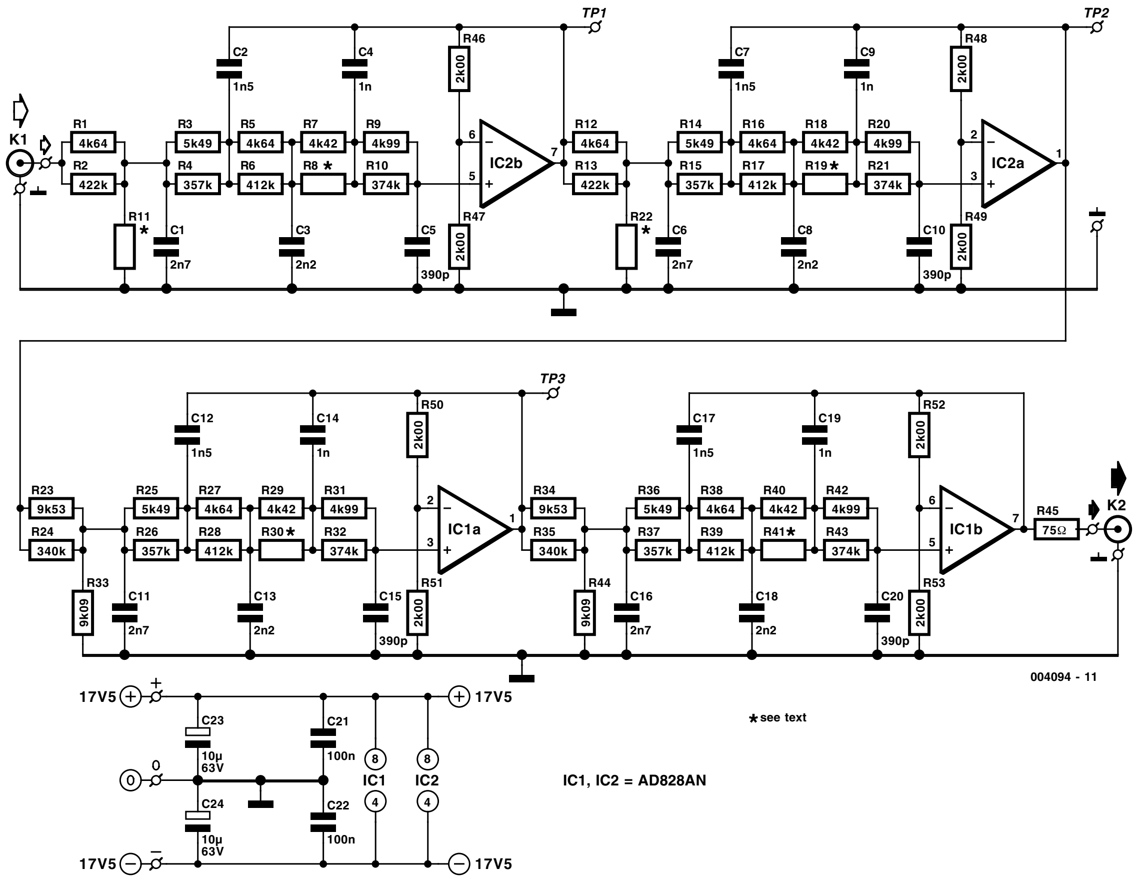


This circuit is based on the configuration of a fifth-order Butterworth filter using only one opamp (see p 116 of the 1995 Summer Circuits issue). Here we achieve a 20th-order filter by connecting four fifth-order sections in series. The first three sections are tapped off at TP1, TP2 and TP3. As you will see, the transfer characteristic is not a pure 20th-order Butterworth, but it does have the steepness of such a filter. The desired bandwidth for the whole filter is achieved by adjusting the turnover point of each section to a higher value. The –3 dB bandwidth of the total filter is theoretically set to 22 kHz, which means that a value of 26 kHz must be used for each section. The measured total bandwidth of the prototype is 20.9 kHz. In this regard, we have to point out that all components must be selected with a tolerance of less than 0.1 percent, since it is otherwise pointless to try to copy the circuit. Excessive tolerances in the component values will degrade the characteristics of the filter. There are 12 components per section that must be selected within this tolerance (with each parallel network counting as one component)! Even with selected components, the practical implementation will always vary a bit from the theoretical behaviour (with a somewhat lower turnover point, for example).



The filter calculations employ exact E12 values for the capacitors, which produces rather 'strange' values for the resistors. It is necessary to connect resistors with E96 values in parallel to achieve the necessary resistance values. **Table 1** summarises the resistor values.

The choice of opamp is even more critical than the precision of the components. The opamps must have a very large bandwidth and low distortion in the audio band, and they must be able to supply enough current. This last factor comes from the fact that the dimensions of the filter components represent a compromise between the amount of noise generated by the impedance of the filter network itself, the load on the opamp due to the negative feedback and the load of any following network. In practice, a video amplifier must be used to avoid affecting the filter characteristics. The chosen opamp, an Analog Devices AD828AN, does not however have the desired distortion specifications. It is only possible to achieve better specifications by using a discrete amplifier specially designed for this application. With such an amplifier, it is possible to significantly reduce the impedance of the filter network and increase the maximum current, in order to improve the specifications.

This circuit was originally intended to be used to measure codecs, for example. Their specifications are often given only for the audio band, for which a steep measurement filter is used. The mixer products with the sampling frequency, which lie outside the audio band, are often not attenuated by any more than 50 to 70 dB by digital filtering.

In order to produce a 5th-order filter using the illustrated arrangement, each section must have a gain of 2. In order to prevent the amplification of the overall filter from becoming to large, extra attenuators have been added to the last two sections. We chose 2 V_{eff} as the maximum allowable signal level. The attenuators form the first resistances of the filter sections, which means that the parallel impedance of R23, R24 and R33 is equal to that of R1 and R2. The printed circuit board layout allows such networks to be used for all four sections (with positions R11 and R22 open). If the measured values of R7, R18, R29 and R40 match the desired theoretical value (which falls within the tolerance range of a 1% 4k42-Ω resistor), no parallel resistors are necessary in these positions. Make sure that the signal source has DC coupling. It is recommended to use a very good audio opamp in series with the input, to provide a well-defined input impedance.

The brief specifications of the filter are as follows:

supply voltage	±17.5 V
bandwidth (–3 dB)	20.9 kHz
suppression (40 kHz, 2 V_{eff} in)	78 dB
THD+N (1 kHz, 1 V_{eff} in)	0.005 %
THD+N (1 kHz, 2 V_{eff} in)	0.009 %
S/N (2 V_{eff} in)	94 dB
gain (10 kΩ load)	7.75
output impedance	75 Ω
current consumption	28 mA

Figure 3 shows the measured characteristics of each of the cumulative sections. The ultimate suppression is around 94 dB before the signal disappears below the noise level. The gain of the first section is naturally 6 dB lower.

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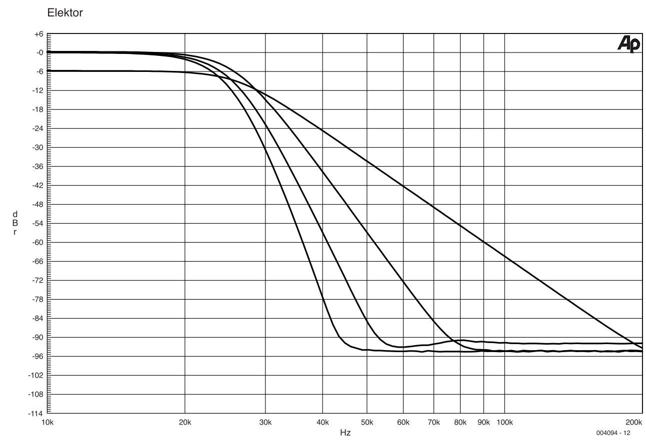

Table 1

Resistors (A = 2 x)		Parallel	Theoretical
R1, R12	= 4k64		
R2, R13	= 422 k	4k5895	(4k58974)
R3, R14, R25, R36	= 5k49		
R4, R15, R26, R37	= 357 k	5k4069	(5k40684)
R5, R16, R27, R38	= 4k64		
R6, R17, R28, R39	= 412 k	4k5883	(4k58787)
R7, R18, R29, R40	= 4k42		
R8, R19, R30, R41	= (5M62)	4k4200	(4k41649)
R9, R20, R31, R42	= 4k99		
R10, R21, R32, R43	= 374 k	4k9243	(4k92361)
R11, R22	= open		
Alternative values:			
R7, R18, R29, R40	= 4k53		
R8, R19, R30, R41	= 178 k	4k4176	(4k41649)
Extra 6 dB attenuation:			
R23, R34	= 9k53		
R24, R35	= 340 k		
R33, R44	= 9k09	4k5896	(4k58974)