

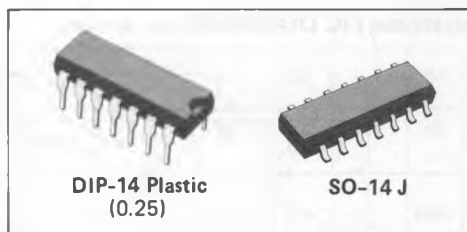
HIGH PERFORMANCE QUAD OPERATIONAL AMPLIFIERS

- SINGLE OR SPLIT SUPPLY OPERATION
- VERY LOW POWER CONSUMPTION
- SHORT CIRCUIT PROTECTION
- LOW DISTORTION, LOW NOISE
- HIGH GAIN-BANDWIDTH PRODUCT
- HIGH CHANNEL SEPARATION

range, and it is particularly intended for professional and telecom applications (active filters, etc.).

The patented input stage circuit allows small input signal swings below the negative supply voltage and prevents phase inversion when the input is over driven.

The LS404 is a high performance quad operational amplifier with frequency and phase compensation built into the chip. The internal phase compensation allows stable operation as voltage follower in spite of its high gain-bandwidth product. The circuit presents very stable electrical characteristics over the entire supply voltage



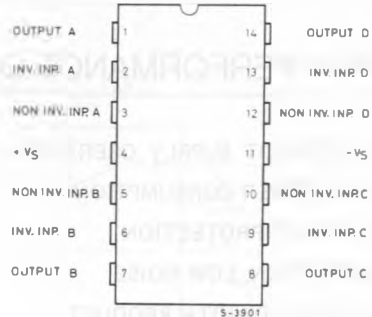
ABSOLUTE MAXIMUM RATINGS

V_s	Supply voltage		± 18	V
V_i	Input voltage	(positive)	$+ V_s$	
		(negative)	$-V_s - 0.5$	V
V_i	Differential input voltage		$\pm (V_s - 1)$	
T_{op}	Operating temperature	LS 404	-25 to + 85	°C
		LS 404C	0 to + 70	°C
P_{tot}	Power dissipation	($T_{amb} = 70^\circ\text{C}$)	400	mW
T_{stg}	Storage temperature		-55 to + 150	°C

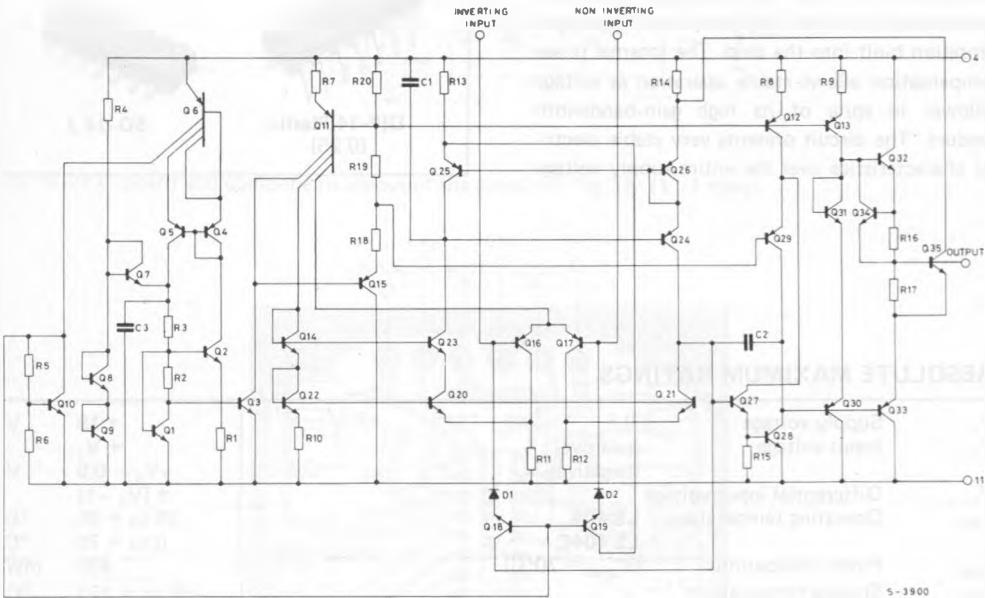
CONNECTION DIAGRAM AND ORDERING NUMBERS

(top view)

Type	DIP 14	SO-14
LS 404 LS 404C	— LS 404CB	LS 404M LS 404CM
LS 8404 LS 8404C	— —	LS 8404M LS 8404CM



SCHEMATIC DIAGRAM (one section)



THERMAL DATA

			DIP 14	SO-14
$R_{thj-amb}$	Thermal resistance junction-ambient	max	200°C/W	200°C/W*

(*) Measured with the device mounted on a ceramic substrate (25 x 16 x 0.6 mm.)

ELECTRICAL CHARACTERISTICS ($V_s = \pm 12V$, $T_{amb} = 25^\circ C$, unless otherwise specified)

Parameter	Test conditions	LS 404			LS 404C			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
I_s Supply current			1.3	2		1.5	3	mA
I_b Input bias current			50	200		100	300	nA
R_i Input resistance	$f = 1KHz$		0.7	2.5		0.5	5	M Ω
V_{os} Input offset voltage	$R_g = 10K\Omega$		1			1		mV
$\frac{\Delta V_{os}}{\Delta T}$ Input offset voltage drift	$R_g = 10K\Omega$ $T_{min} < T_{op} < T_{max}$		5			5		$\mu V/^\circ C$
I_{os} Input offset current			10	40		20	80	nA
$\frac{\Delta I_{os}}{\Delta T}$ Input offset current drift	$T_{min} < T_{op} < T_{max}$		0.08			0.1		$\frac{nA}{^\circ C}$
I_{sc} Output short circuit current			23			23		mA
G_v Large signal open loop voltage gain	$R_L = 2K\Omega$ $V_s = \pm 12V$ $V_s = \pm 4V$	90	100 95		86	100 95		dB
B Gain-bandwidth product	$f = 20KHz$	1.8	3		1.5	2.5		MHz
e_N Total input noise voltage	$f = 1KHz$ $R_g = 50\Omega$ $R_g = 1K\Omega$ $R_g = 10K\Omega$		8 10 18	15		10 12 20		$\frac{nV}{\sqrt{Hz}}$
d Distortion	unity gain $R_L = 2K\Omega$ $V_o = 2V_{pp}$ $f = 1 KHz$ $f = 20 KHz$		0.01 0.03	0.04		0.01 0.03		%
V_o DC output voltage swing	$R_L = 2K\Omega$ $V_s = \pm 12V$ $V_s = \pm 4V$	± 10	± 3		± 10	± 3		V
V_o Large signal voltage swing	$f = 10KHz$ $R_L = 10 K\Omega$ $R_L = 1 K\Omega$		22 20			22 20		V _{pp}
SR Slew rate	unity gain $R_L = 2K\Omega$	0.8	1.5			1		V/ μs
CMR Comm. mode rejection	$V_i = 10V$	90	94		80	90		dB
SVR Supply voltage rejection	$V_i = 1V$ $f = 100Hz$	90	94		86	90		dB
CS Channel separation	$f = 1KHz$	100	120			120		dB

Fig. 1 - Supply current vs. supply voltage

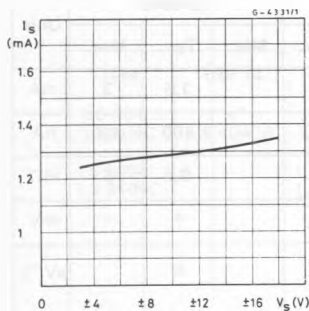


Fig. 2 - Supply current vs. ambient temperature

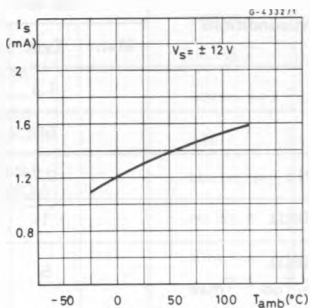


Fig. 3 - Output short circuit current vs. ambient temperature

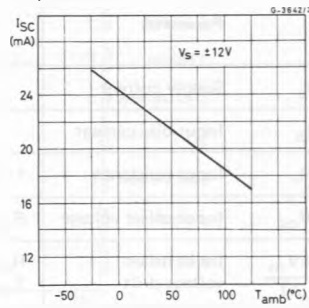


Fig. 4 - Open loop frequency and phase response

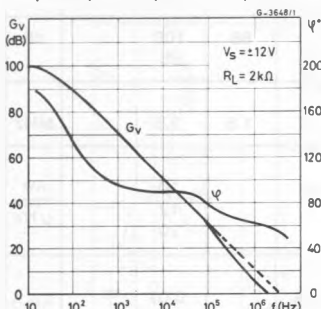


Fig. 5 - Open loop gain vs. ambient temperature

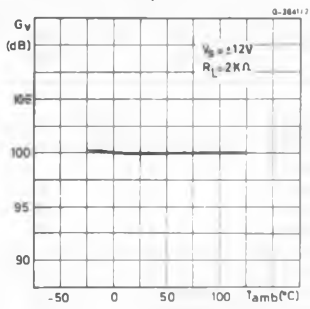


Fig. 6 - Supply voltage rejection vs. frequency

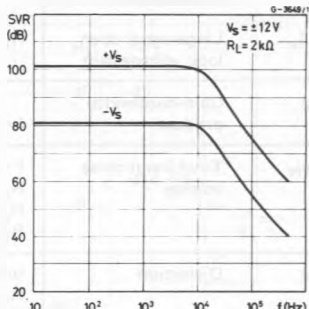


Fig. 7 - Large signal frequency response

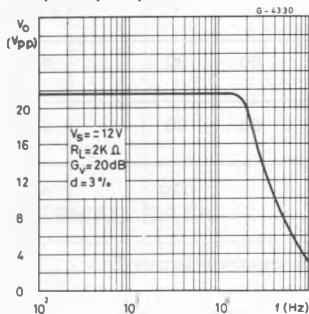


Fig. 8 - Output voltage swing vs. load resistance

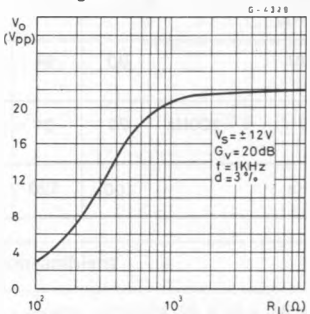
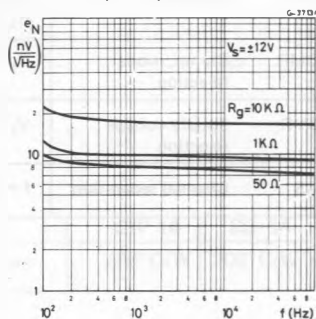


Fig. 9 - Total input noise vs. frequency



APPLICATION INFORMATION

Active low-pass filter:

BUTTERWORTH

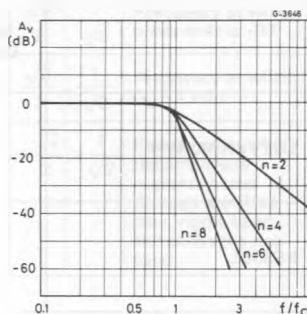
The Butterworth is a “maximally flat” amplitude response filter. Butterworth filters are used for filtering signals in data acquisition systems to prevent aliasing errors in sampled-data applications and for general purpose low-pass filtering.

The cutoff frequency, f_c , is the frequency at which the amplitude response is down 3 dB. The attenuation rate beyond the cutoff frequency is $-n$ dB per octave of frequency where n is the order (number of poles) of the filter.

Other characteristics:

- Flattest possible amplitude response.
- Excellent gain accuracy at low frequency end of passband.

Fig. 10 – Amplitude response



BESSEL

The Bessel is a type of “linear phase” filter. Because of their linear phase characteristics, these filters approximate a constant time delay over a limited frequency range. Bessel filters pass transient waveforms with a minimum of distortion. They are also used to provide time delays for low pass filtering of modulated waveforms and as a “running average” type filter.

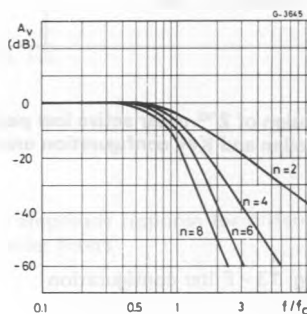
The maximum phase shift is $\frac{n\pi}{2}$ radians where n is the order (number of poles) of the filter. The cutoff frequency, f_c , is defined as the frequency at which the phase shift is one half to this value. For accurate delay, the cutoff frequency should be twice the maximum signal frequency. The following table can be used to obtain the -3 dB frequency of the filter.

	2 pole	4 pole	6 pole	8 pole
-3 dB frequency	$0.77 f_c$	$0.67 f_c$	$0.57 f_c$	$0.50 f_c$

Other characteristics:

- Selectivity not as great as Chebyshev or Butterworth.
- Very small overshoot response to step inputs
- Fast rise time.

Fig. 11 – Amplitude response



CHEBYSHEV

Chebyshev filters have greater selectivity than either Bessel or Butterworth at the expense of ripple in the passband.

Chebyshev filters are normally designed with peak-to-peak ripple values from 0.2 dB to 2 dB.

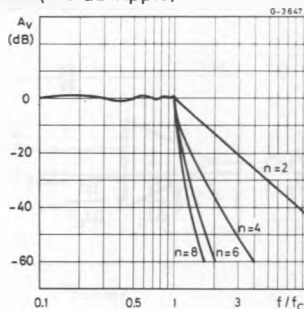
Increased ripple in the passband allows increased attenuation above the cutoff frequency.

The cutoff frequency is defined as the frequency at which the amplitude response passes through the specified maximum ripple band and enters the stop band.

Other characteristics:

- Greater selectivity
- Very nonlinear phase response
- High overshoot response to step inputs.

Fig. 12 – Amplitude response (± 1 dB ripple)



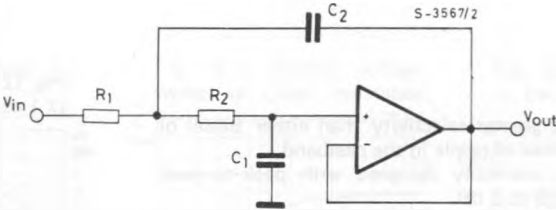
APPLICATION INFORMATION (continued)

The table below shows the typical overshoot and settling time response of the low pass filter to a step input.

	NUMBER OF POLES	PEAK OVERSHOOT	SETTLING TIME (% of final value)		
		% Overshoot	± 1%	± 0.1%	± 0.01%
BUTTERWORTH	2	4	1.1/f _c sec.	1.7/f _c sec.	1.9/f _c sec.
	4	11	1.7/f _c	2.8/f _c	3.8/f _c
	6	14	2.4/f _c	3.9/f _c	5.0/f _c
	8	16	3.1/f _c	5.1/f _c	7.1/f _c
BESSEL	2	0.4	0.8/f _c	1.4/f _c	1.7/f _c
	4	0.8	1.0/f _c	1.8/f _c	2.4/f _c
	6	0.6	1.3/f _c	2.1/f _c	2.7/f _c
	8	0.3	1.6/f _c	2.3/f _c	3.2/f _c
CHEBYSCHEV (RIPPLE ± 0.25 dB)	2	11	1.1/f _c	1.6/f _c	—
	4	18	3.0/f _c	5.4/f _c	—
	6	21	5.9/f _c	10.4/f _c	—
	8	23	8.4/f _c	16.4/f _c	—
CHEBYSCHEV (RIPPLE ± 1 dB)	2	21	1.6/f _c	2.7/f _c	—
	4	28	4.8/f _c	8.4/f _c	—
	6	32	8.2/f _c	16.3/f _c	—
	8	34	11.6/f _c	24.8/f _c	—

Design of 2nd order active low pass filter
(Sallen and Key configuration unity gain op-amp)

Fig. 13 - Filter configuration



$$\frac{V_o}{V_i} = \frac{1}{1 + 2\xi \frac{S}{\omega_c} + \frac{S^2}{\omega_c^2}}$$

where:
 $\omega_c = 2\pi f_c$ with f_c = cutoff frequency
 ξ = damping factor.

APPLICATION INFORMATION (continued)

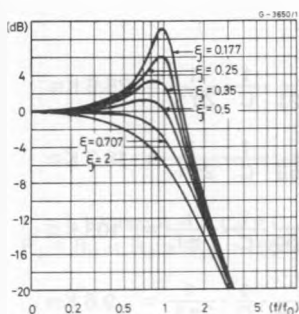
Three parameters are needed to characterize the frequency and phase response of a 2nd order active filter: the gain (G_v), the damping factor (ξ) or the Q-factor ($Q = (2\xi)^{-1}$), and the cutoff frequency (f_c).

The higher order responses are obtained with a series of 2nd order sections. A simple RC section is introduced when an odd filter is required. The choice of ' ξ ' (or Q-factor) determines the filter response (see table).

TAB. 1

Filter response	ξ	Q	Cutoff frequency f_c
Bessel	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{3}}$	Frequency at which phase shift is -90°
Butterworth	$\frac{\sqrt{2}}{2}$	$\frac{1}{\sqrt{2}}$	Frequency at which $G_v = -3$ dB
Chebyshev	$< \frac{\sqrt{2}}{2}$	$> \frac{1}{\sqrt{2}}$	Frequency at which the amplitude response passes through specified max. ripple band and enters the stop band

Fig. 14 – Filter response vs. damping factor



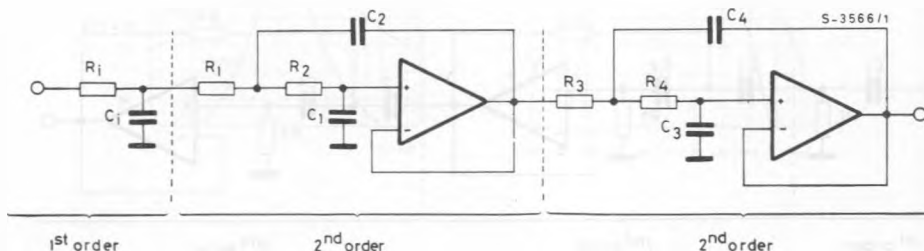
Fixed $R = R_1 = R_2$, we have (see fig. 13)

$$C_1 = \frac{1}{R} \frac{\xi}{\omega_c}$$

$$C_2 = \frac{1}{R} \frac{1}{\xi \omega_c}$$

The diagram of fig. 14 shows the amplitude response for different values of damping factor ξ in 2nd order filters.

EXAMPLE:

Fig. 15 – 5th order low pass filter (Butterworth) with unity gain configuration.

APPLICATION INFORMATION (continued)

In the circuit of fig. 15, for $f_c = 3.4$ KHz and $R_i = R_1 = R_2 = R_3 = R_4 = 10$ K Ω , we obtain:

$$C_i = 1.354 \cdot \frac{1}{R} \cdot \frac{1}{2\pi f_c} = 6.33 \text{ nF}$$

$$C_1 = 0.421 \cdot \frac{1}{R} \cdot \frac{1}{2\pi f_c} = 1.97 \text{ nF}$$

$$C_2 = 1.753 \cdot \frac{1}{R} \cdot \frac{1}{2\pi f_c} = 8.20 \text{ nF}$$

$$C_3 = 0.309 \cdot \frac{1}{R} \cdot \frac{1}{2\pi f_c} = 1.45 \text{ nF}$$

$$C_4 = 3.325 \cdot \frac{1}{R} \cdot \frac{1}{2\pi f_c} = 15.14 \text{ nF}$$

The attenuation of the filter is 30 dB at 6.8 KHz and better than 60 dB at 15 KHz.

Tab. II

Damping factor for low-pass Butterworth filters

Order	C _i	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈
2		0.707	1.41						
3	1.392	0.202	3.54						
4		0.92	1.08	0.38	2.61				
5	1.354	0.421	1.75	0.309	3.235				
6		0.966	1.035	0.707	1.414	0.259	3.86		
7	1.336	0.488	1.53	0.623	1.604	0.222	4.49		
8		0.98	1.02	0.83	1.20	0.556	1.80	0.195	5.125

The same method, referring to Tab. II and fig. 16, is used to design high-pass filter. In this case the damping factor is found by taking the reciprocal of the numbers in Tab. II. For $f_c = 5$ KHz and $C_i = C_1 = C_2 = C_3 = C_4 = 1$ nF we obtain:

$$R_i = \frac{1}{1.354} \cdot \frac{1}{C} \cdot \frac{1}{2\pi f_c} = 23.5 \text{ K}\Omega$$

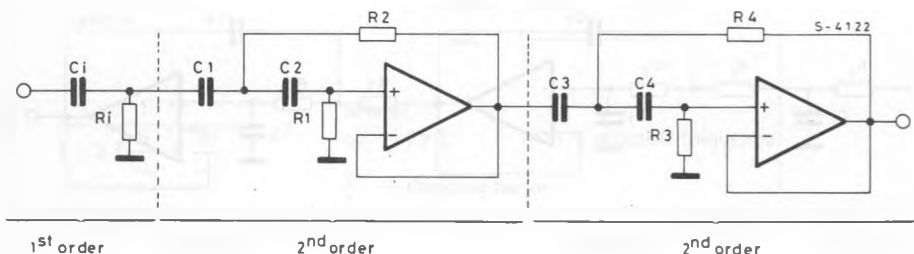
$$R_1 = \frac{1}{0.421} \cdot \frac{1}{C} \cdot \frac{1}{2\pi f_c} = 75.6 \text{ K}\Omega$$

$$R_2 = \frac{1}{1.753} \cdot \frac{1}{C} \cdot \frac{1}{2\pi f_c} = 18.2 \text{ K}\Omega$$

$$R_3 = \frac{1}{0.309} \cdot \frac{1}{C} \cdot \frac{1}{2\pi f_c} = 103 \text{ K}\Omega$$

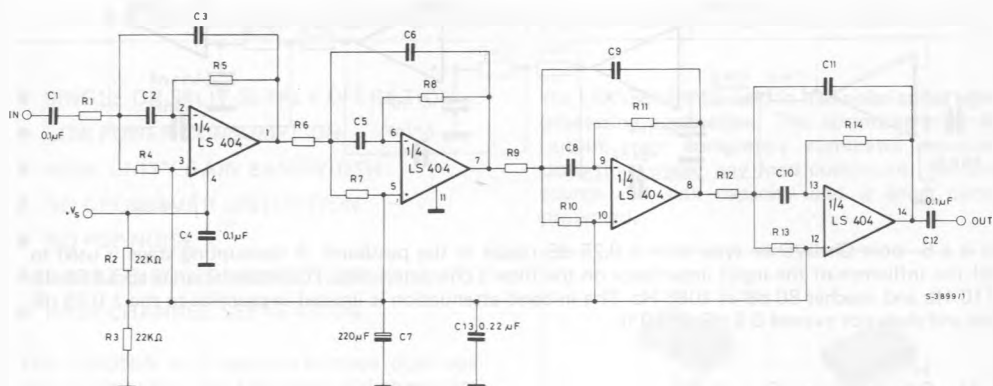
$$R_4 = \frac{1}{3.325} \cdot \frac{1}{C} \cdot \frac{1}{2\pi f_c} = 9.6 \text{ K}\Omega$$

Fig. 16 - 5th order high-pass filter (Butterworth) with unity gain configuration.



APPLICATION INFORMATION (continued)

Fig. 17 - Multiple feedback 8-pole bandpass filter.



$f_c = 1.180\text{Hz}$; $A = 1$; $C_2 = C_3 = C_5 = C_6 = C_8 = C_9 = C_{10} = C_{11} = 3.300\text{ pF}$;
 $R_1 = R_6 = R_9 = R_{12} = 160\text{ K}\Omega$; $R_5 = R_8 = R_{11} = R_{14} = 330\text{ K}\Omega$; $R_4 = R_7 = R_{10} = R_{13} = 5.3\text{ K}\Omega$

Fig. 18 - Frequency response of band-pass filter

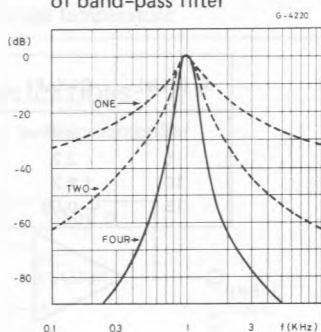
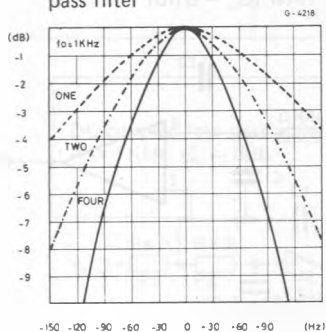
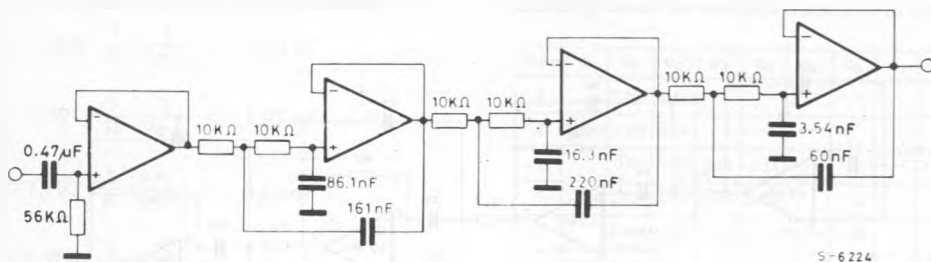


Fig. 19 - Bandwidth of band-pass filter

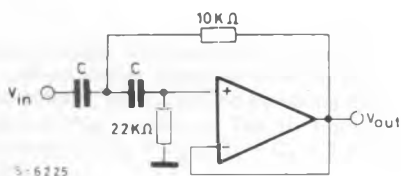


APPLICATION INFORMATION (continued)

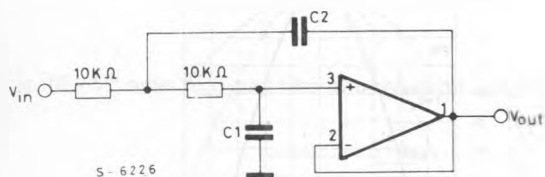
Fig. 20 – Six-pole 355 Hz low-pass filter (Chebychev type)



This is a 6- pole Chebychev type with ± 0.25 dB ripple in the passband. A decoupling stage is used to avoid the influence of the input impedance on the filter's characteristics. The attenuation is about 55 dB at 710 Hz and reaches 80 dB at 1065 Hz. The in band attenuation is limited in practice to the ± 0.25 dB ripple and does not exceed 0.5 dB at 0.9 f_c .

Fig. 21 – Subsonic filter ($G_v = 0$ dB)

f_c (Hz)	C (μ F)
15	0.68
22	0.47
30	0.33
55	0.22
100	0.1

Fig. 22 – High cut filter ($G_v = 0$ dB)

f_c (KHz)	C1 (nF)	C2 (nF)
3	3.9	6.8
5	2.2	4.7
10	1.2	2.2
15	0.68	1.5