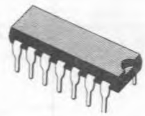
SGS-THOMSON MICROELECTRONICS

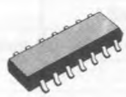
LS404

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



DIP14
(Plastic 0.25)



SO-14J

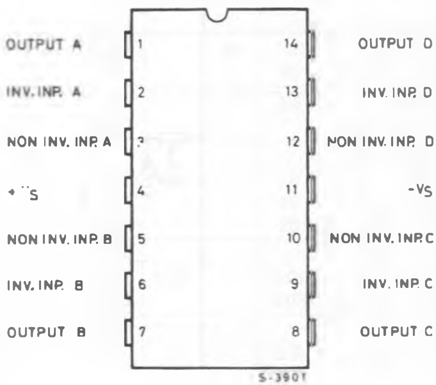
DESCRIPTION

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

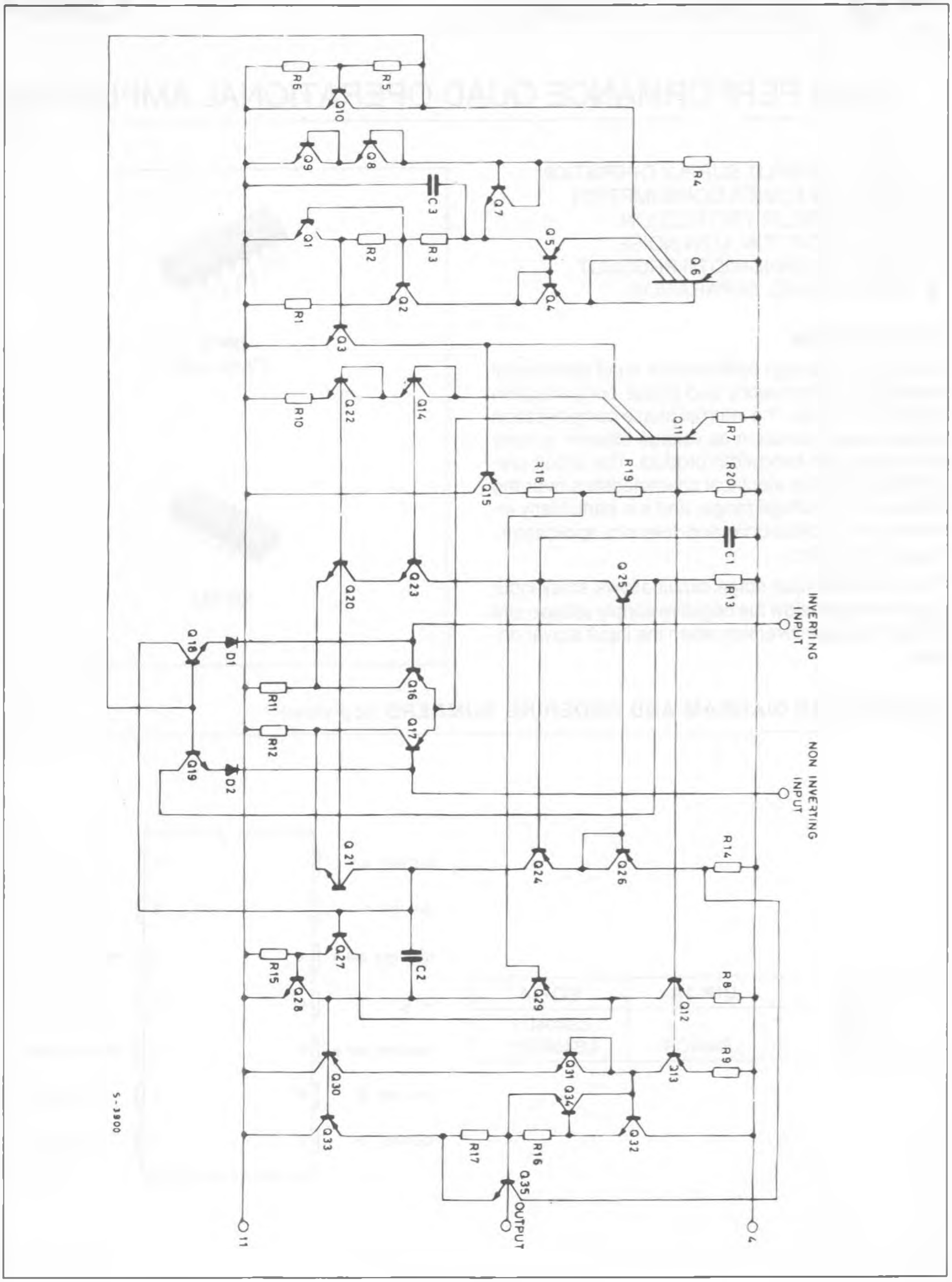
The patented input stage circuit allows small input signal swings below the negative supply voltage and prevents phase inversion when the input is over driven.

CONNECTION DIAGRAM AND ORDERING NUMBERS (top view)

Type	DIP 14	SO-14
LS404	–	LS404D1
LS404C	LS404CB	LS404CD1



SCHEMATIC DIAGRAM (one section)



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter		Value	Unit
V_s	Supply Voltage		± 18	V
V_i	Input Voltage	(positive) (negative)	+ V_s – V_s – 0.5	V
V_i	Differential Input Voltage		± (V_s – 1)	
T_{op}	Operating Temperature	**LS404** **LS404C**	– 25 to + 85 0 to + 70	°C °C
P_{tot}	Power Dissipation	(T_{amb} = 70°C)	400	mW
T_{stg}	Storage Temperature		– 55 to + 150	°C

THERMAL DATA

			DIP 14	SO–14 J
$R_{thj\text{-}amb}$	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 = ± 12 V, T_{amb} = 25 °C, unless otherwise specified)

Symbol	Parameter	Test Conditions		LS404			LS404C			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 = 1 KHz			0.7	2.5		0.5	5	MΩ
V_{os}	Input Offset Voltage	R_g = 10 KΩ			1			1		mV
$\frac{\Delta V_{os}}{\Delta T}$	Input Offset Voltage Drift	R_g = 10 KΩ $T_{min} < T_{op} < T_{max}$			5			5		µV/°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		nA/°C
I_{sc}	Output Short Circuit Current				23			23		mA
G_v	Large Signal Open Loop Voltage Gain	R_L = 2 KΩ	V_s = ± 12 V V_s = ± 4 V	90	100 95		86	100 95		dB
B	Gain-bandwidth Product	f = 20 KHz		1.8	3		1.5	2.5		MHz
e_N	Total Input Noise Voltage	f = 1 KHz R_g = 50 Ω R_g = 1 KΩ R_g = 10 KΩ			 8 10 18	 15		 10 12 20		$\frac{nV}{\sqrt{Hz}}$
d	Distortion	Unity Gain R_L = 2 KΩ V_o = 2 V_{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 = 2 KΩ	V_s = ± 12 V V_s = ± 4 V	± 10	 ± 3		± 10	 ± 3		V

ELECTRICAL CHARACTERISTICS (continued)

Symbol	Parameter	Test Conditions	LS404			LS404C			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	
V_o	Large Signal Voltage Swing	f = 10 KHz R_L = 10 KΩ R_L = 1 KΩ		22 20			22 20		V_{pp}
SR	Slew Rate	Unity Gain R_L = 2 KΩ	0.8	1.5			1		V/µs
CMR	Common Mode Rejection	V_i = 10 V	90	94		80	90		dB
SVR	Supply Voltage Rejection	V_i = 1 V f = 100 Hz	90	94		86	90		dB
CS	Channel Separation	f = 1 KHz	100	120			120		dB

Figure 1: Supply Current vs. Supply Voltage.

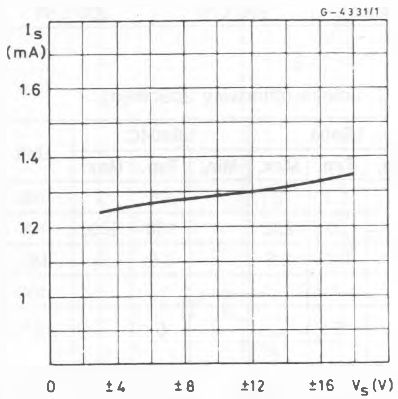


Figure 2 : Supply Current vs. Ambient Temperature.

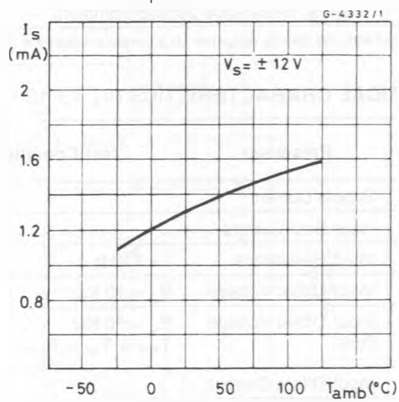


Figure 3 : Output Short Circuit Current vs. Ambient Temperature.

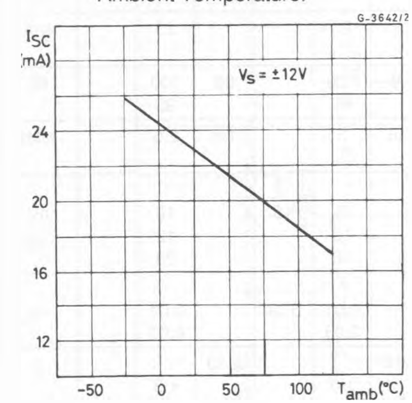


Figure 4: Open Loop Frequency and Phase Response.

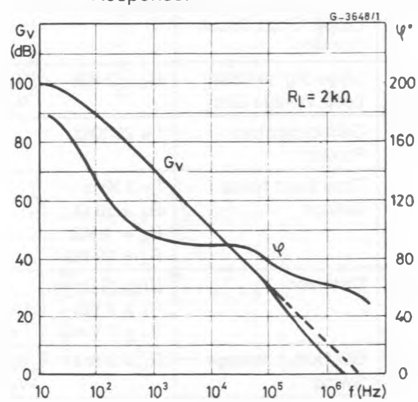


Figure 5: Open Loop Gain vs. Ambient Temperature.

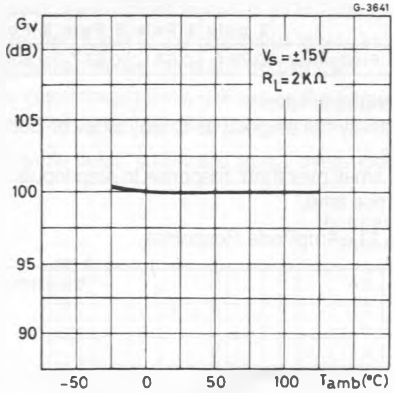


Figure 6 : Supply Voltage Rejection vs. Frequency.

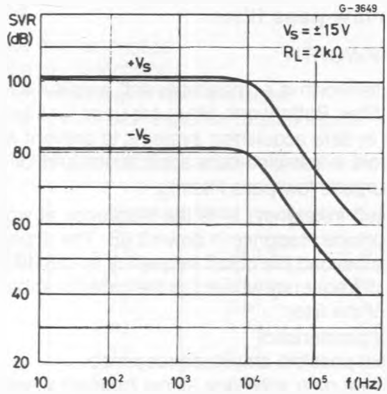


Figure 7 : Large Signal Frequency Response.

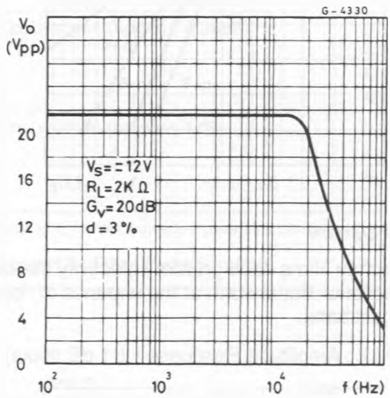


Figure 8 : Output Voltage Swing vs. Load Resistance.

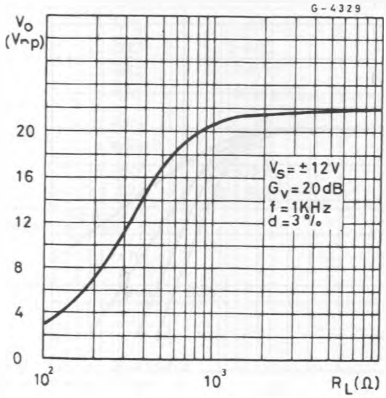
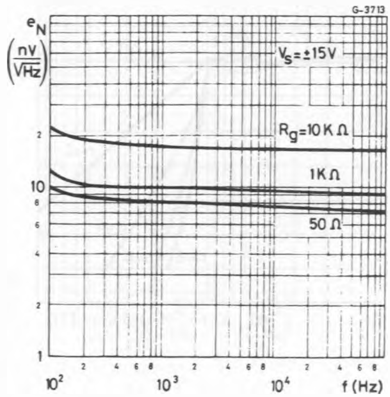


Figure 9 : Total Input Noise vs. Frequency.



APPLICATION INFORMATION

Active low-pass filter :

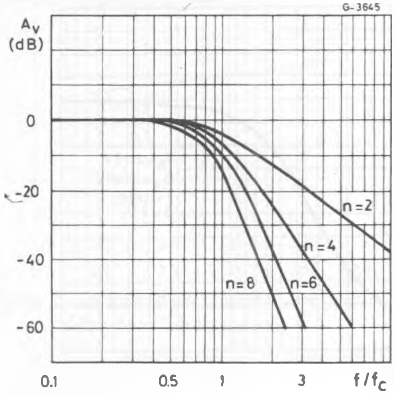
BUTTERWORTH

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 in down 3 dB. The attenuation rate beyond the cutoff frequency is - n6 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.

Figure 10 : Amplitude Response.



BESSEL

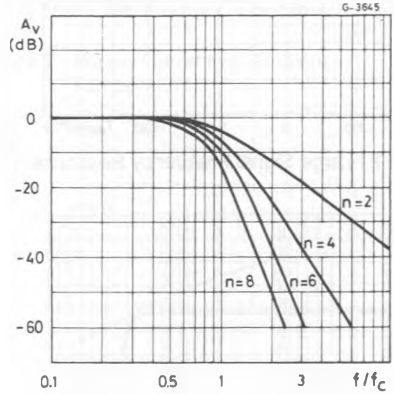
The Bessel is a type of "linear phase" filter. Because of their linear phase characteristics, these filters approximate a constant time delay over a limited frequency range. Bessel filters pass transient waveforms with a minimum of distortion. They are also used to provide time delays for low pass filtering 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
– 3dB Frequency	0.77 f_c	0.67 f_c	0.57 f_c	0.50 f_c

Other characteristics :
- Selectivity not as great as Chebyschev or Butterworth.
- Very small overshoot response to step inputs.
- Fast rise time.

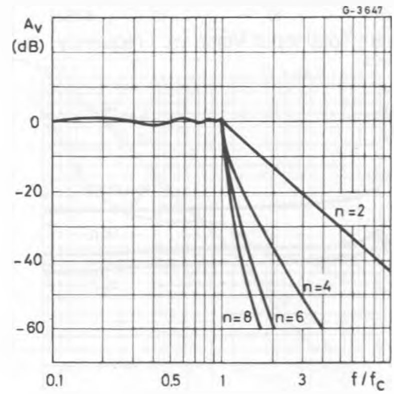
Figure 11 : Amplitude Response.



CHEBYSCHEV

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

Figure 12 : Amplitude Response (± 1 dB ripple).



APPLICATION INFORMATION (continued)

Chebyschev 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.

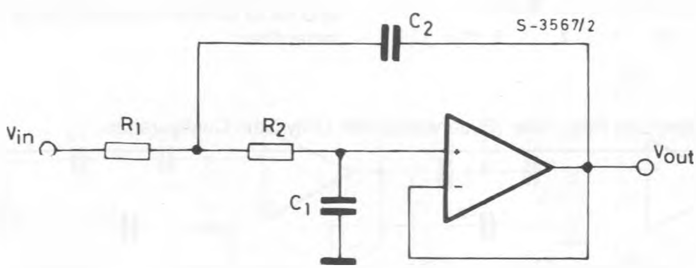
Other characteristics :
- Greater selectivity.
- Very nonlinear phase response.
- High overshoot response to step inputs.

The table below shows the typical overshoot and setting 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/fc	1.4/fc	1.7/fc
	4	0.8	1.0/fc	1.8/fc	2.4/fc
	6	0.6	1.3/fc	2.1/fc	2.7/fc
	8	0.3	1.6/fc	2.3/fc	3.2/fc
Chebyschev (ripple ± 0.25dB)	2	11	1.1/fc	1.6/fc	–
	4	18	3.0/fc	5.4/fc	–
	6	21	5.9/fc	10.4/fc	–
	8	23	8.4/fc	16.4/fc	–
Chebyschev (ripple ± 1dB)	2	21	1.6/fc	2.7/fc	–
	4	28	4.8/fc	8.4/fc	–
	6	32	8.2/fc	16.3/fc	–
	8	34	11.6/fc	24.8/fc	–

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

Figure 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).

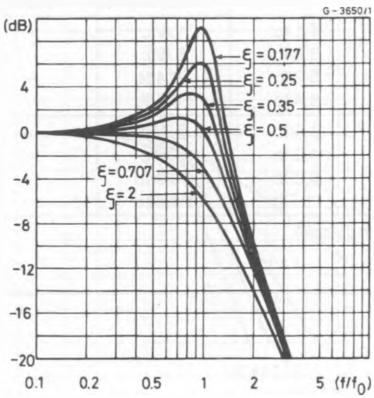
The higher order responses are obtained with a series of 2nd order sections. A simple RC section is introduced when an odd filter is required.

The choice of 'ξ' (or Q-factor) determines the filter response (see table).

Table 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°C
Butterworth	$\frac{\sqrt{2}}{2}$	$\frac{1}{\sqrt{2}}$	Frequency at which G_v = – 3dB
Chebyschev	$< \frac{\sqrt{2}}{2}$	$> \frac{1}{\sqrt{2}}$	Frequency at which the amplitude response passes through specified max. ripple band and enters the stop band.

Figure 14 : Filter Response vs. Damping Factor.



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

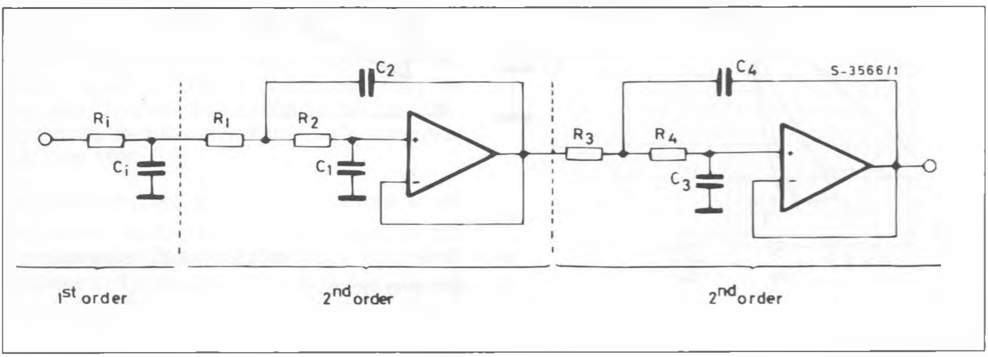
$$C_1 = \frac{1}{R}\,\frac{\xi}{\omega_c}$$

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

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

EXAMPLE

Figure 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 KΩ, 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.

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 :

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

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

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

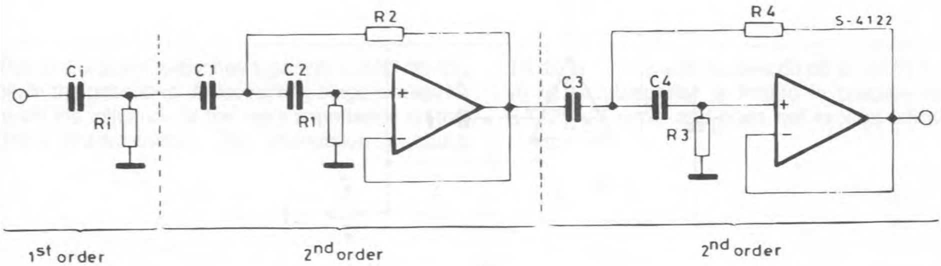
$$R_3 = \frac{1}{0.309} \cdot \frac{1}{C} \cdot \frac{1}{2\pi f_c} = 103\text{ K}\Omega$$

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

Table II : Damping Factor for Low-pass Butterworth Filters.

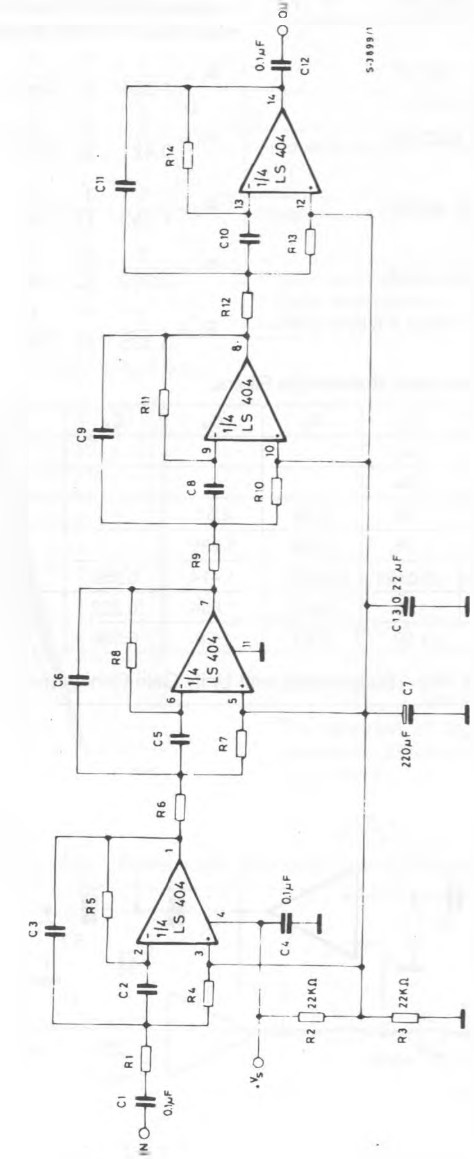
Order	C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
2		0.707	1.41						
3	1.392	0.202	3.54						
4		0.92	1.08	0.38	2.61				
5	1.354	0.421	1.75	0.309	3.235				
6		0.966	1.035	0.707	1.414	0.259	3.86		
7	1.336	0.488	1.53	0.623	1.604	0.222	4.49		
8		0.98	1.02	0.83	1.20	0.556	1.80	0.195	5.125

Figure 16 : 5th Order High-pass Filter (Butterworth) with Unity Gain Configuration.



APPLICATION INFORMATION (continued)

Figure 17 : Multiple Feedback 8-pole Bandpass Filter.



$f_c = 1.180$ Hz ; A = 1 ; $C_2 = C_3 = C_5 = C_6 = C_8 = C_9 = C_{10} = C_{11} = 3.300$ pF ;

$R_1 = R_6 = R_9 = R_{12} = 160$ KΩ ; $R_5 = R_8 = R_{11} = R_{14} = 330$ KΩ ; $R_4 = R_7 = R_{10} = R_{13} = 5.3$ KΩ

Figure 18 : Frequency Response of Band-pass Filter.

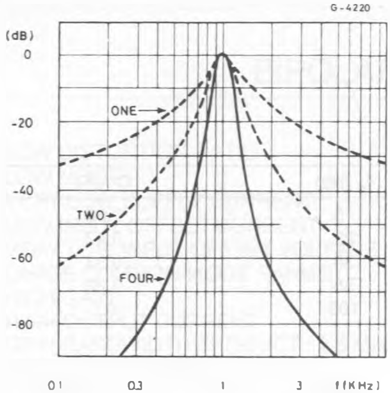


Figure 19 : Bandwidth of Band-pass Filter.

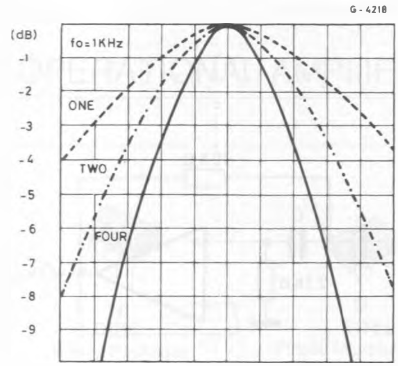
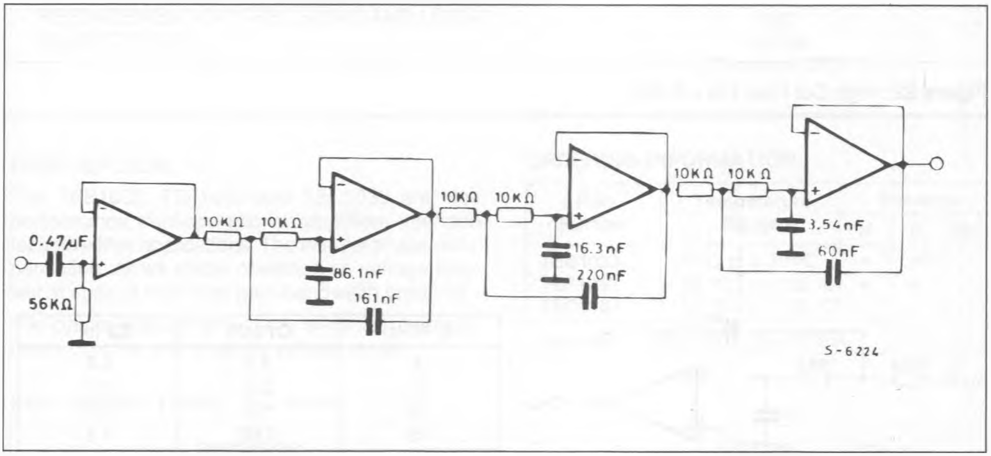
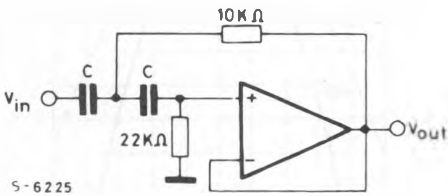


Figure 20 : Six-pole 355 Hz Low-pass Filter (chebychev type).



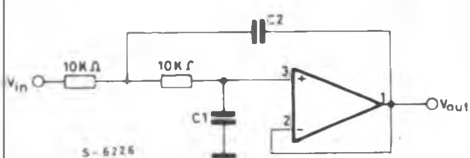
This is a 6-pole Chebychev type with ± 0.25 dB ripple in the passband. A decoupling stage is used to avoid the influence of the input impedance on the filter's characteristics. The attenuation is about 55 dB at 710 Hz and reaches 80 dB at 1065 Hz. The in band attenuation is limited in practice to the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

Figure 21 : Subsonic Filter (G_v = 0 dB).



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

Figure 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