**LS 404**
**LS 404C**

# LINEAR INTEGRATED CIRCUITS

## 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

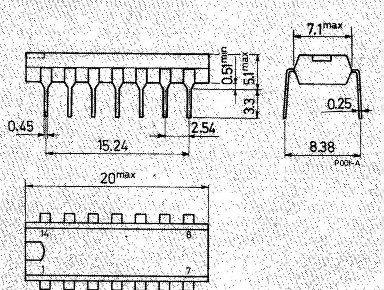
The LS 404 is a high performance quad operational amplifier with frequency and phase compensation built into the chip. The internal phase compensation allows stable operation as voltage follower in spite of its high gain-bandwidth product. The circuit presents very stable electrical characteristics over 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.
The LS 404 is available with hermetic gold chip (8000 series).

## ABSOLUTE MAXIMUM RATINGS

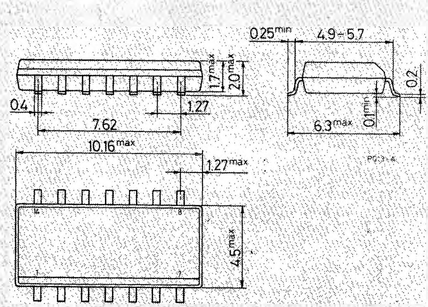
| | | | | |
|---|---|---|---|---|
| $V_s$ | Supply voltage | | ± 18 | V |
| $V_i$ | Input voltage | (positive) | $+V_s$ | |
| | | (negative) | $-V_s - 0.5$ | V |
| $V_i$ | Differential input voltage | | $\pm (V_s - 1)$ | |
| $T_{op}$ | Operating temperature | **LS 404** | -25 to + 85 | °C |
| | | **LS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

## MECHANICAL DATA

Dimensions in mm



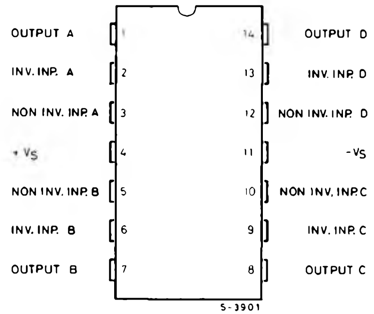

**DIP-14**



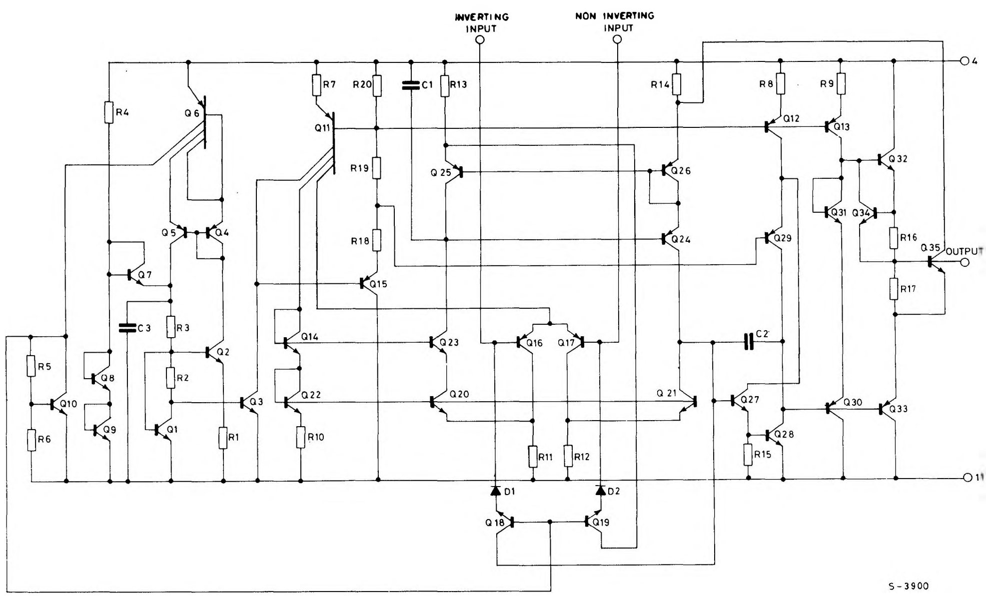

**SO-14**

## CONNECTION DIAGRAM AND ORDERING NUMBERS
(top view)

| Type | DIP 14 | SO-14 |
|---|---|---|
| LS 404<br>LS 404C | –<br>LS 404CB | LS 404M<br>LS 404CM |
| LS 8404<br>LS 8404C | –<br>– | LS 8404M<br>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 ($V_s = \pm 12V$, $T_{amb} = 25°C$, unless otherwise specified)

| | Parameter | Test conditions | LS 404 Min. | LS 404 Typ. | LS 404 Max. | LS 404C Min. | LS 404C Typ. | LS 404C Max. | Unit |
|---|---|---|---|---|---|---|---|---|---|
| $I_s$ | 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 | | | 0.5 | | MΩ |
| $V_{os}$ | Input offset voltage | $R_g$ = 10KΩ | | 1 | 2.5 | | 1 | 5 | mV |
| $\frac{\Delta V_{os}}{\Delta T}$ | Input offset voltage drift | $R_g$ = 10KΩ<br>$T_{min} < T_{op} < T_{max}$ | | 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 | $R_L$ = 2KΩ $V_s$ = ±12V<br>$V_s$ = ±4V | 90 | 100<br>95 | | 86 | 100<br>95 | | dB |
| B | Gain-bandwidth product | f = 20KHz | 1.8 | 3 | | 1.5 | 2.5 | | MHz |
| $e_N$ | Total input noise voltage | f = 1KHz<br>$R_g$ = 50Ω<br>$R_g$ = 1KΩ<br>$R_g$ = 10KΩ | | 8<br>10<br>18 | 15 | | 10<br>12<br>20 | | $\frac{nV}{\sqrt{Hz}}$ |
| d | Distortion | unity gain<br>$R_L$ = 2KΩ f = 1 KHz<br>$V_o$ = 2Vpp f = 20 KHz | | 0.01<br>0.03 | 0.04 | | 0.01<br>0.03 | | % |
| $V_o$ | DC output voltage swing | $R_L$ = 2KΩ $V_s$ = ± 12V<br>$V_s$ = ± 4V | ± 10 | ± 3 | | ± 10 | ± 3 | | V |
| $V_o$ | Large signal voltage swing | f = 10KHz $R_L$ = 10 KΩ<br>$R_L$ = 1 KΩ | | 22<br>20 | | | 22<br>20 | | Vpp |
| SR | Slew rate | unity gain<br>$R_L$ = 2KΩ | 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

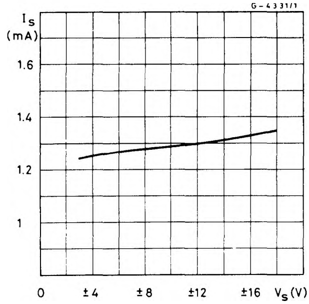



Fig. 2 - Supply current vs. ambient temperature

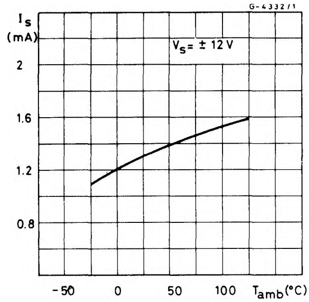



Fig. 3 - Output short circuit current vs. ambient temperature

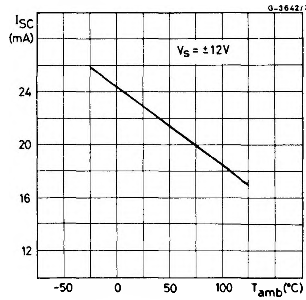



Fig. 4 - Open loop frequency and phase response

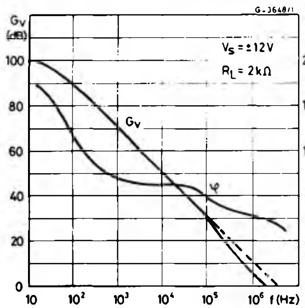



Fig. 5 - Open loop gain vs. ambient temperature

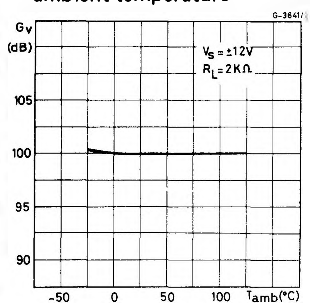



Fig. 6 - Supply voltage rejection vs. frequency

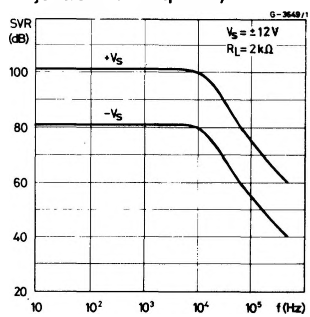



Fig. 7 - Large signal frequency response

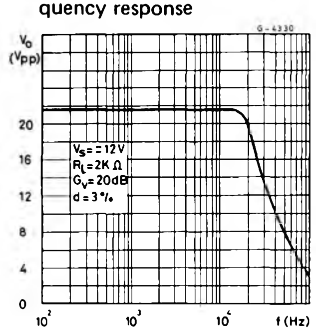



Fig. 8 - Output voltage swing vs. load resistance

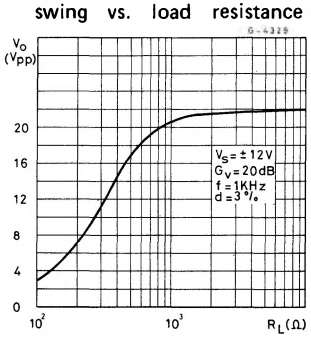
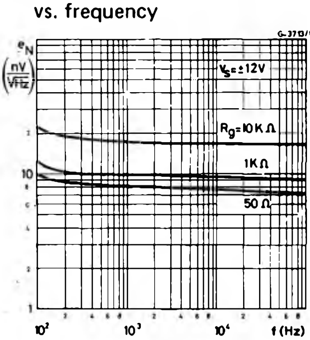



Fig. 9 - Total input noise vs. frequency



# APPLICATION INFORMATION

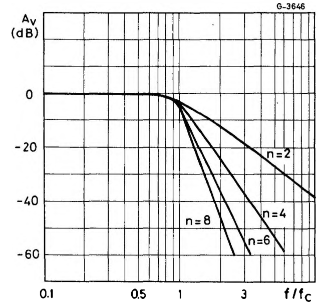
## Active low-pass filter:

### 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 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.

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.

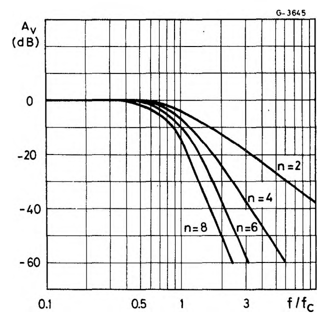
The maximum phase shift is $\frac{-n\pi}{2}$ radians where n is the order (number of poles) of the filter. The cutoff frequency, $f_c$, is defined as the frequency at which the phase shift is one half to this value. For accurate delay, the cutoff frequency should be twice the maximum signal frequency. 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 Chebyschev or Butterworth.
- Very small overshoot response to step inputs
- Fast rise time.

Fig. 11 - Amplitude response

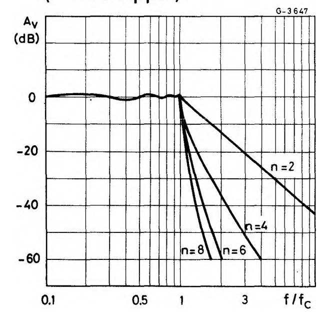



### CHEBYSCHEV

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

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



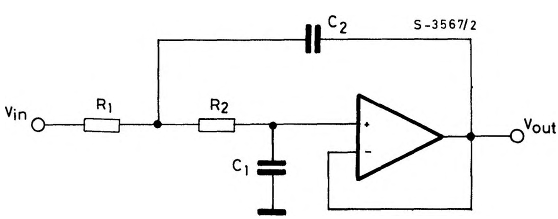
## APPLICATION INFORMATION (continued)

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

$\xi$ = 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 ($\xi$) or the Q-factor ($Q = (2\,\xi)^{-1}$), and the cutoff frequency ($f_c$).

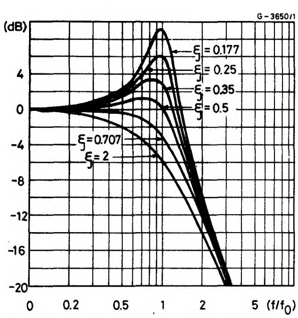
The higher order responses are obtained with a series of 2nd order sections. A simple RC section is introduced when an odd filter is required.

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

TAB. 1

| Filter response | $\xi$ | 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 |
| 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 |

Fig. 14 - Filter response vs. damping factor




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

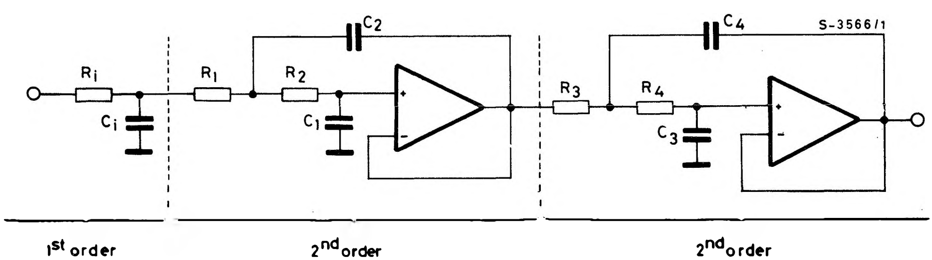
$$C_1 = \frac{1}{R}\,\frac{\xi}{\omega_c}$$

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

The diagram of fig. 14 shows the amplitude response for different values of damping factor $\xi$ 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 $R_i = R_1 = R_2 = R_3 = R_4 = 10\ K\Omega$, we obtain:

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

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

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

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

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

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 $f_c$ = 5KHz and $C_i = C_1 = C_2 = C_3 = C_4 = 1\ nF$ we obtain:

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

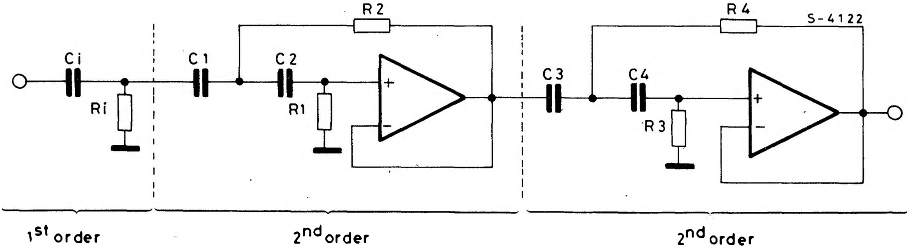
$$R_1 = \frac{1}{0.421} \cdot \frac{1}{C} \cdot \frac{1}{2\pi f_c} = 75.6\ K\Omega$$

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

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

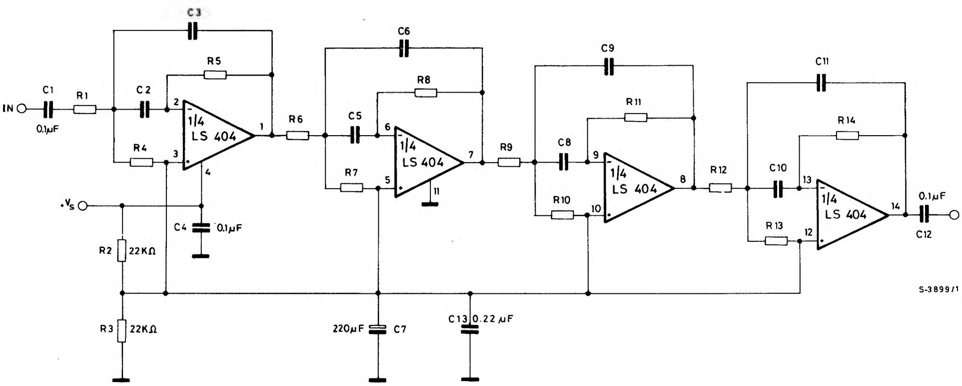
$$R_4 = \frac{1}{3.325} \cdot \frac{1}{C} \cdot \frac{1}{2\pi f_c} = 9.6\ K\Omega$$

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



## APPLICATION INFORMATION (continued)

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




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

Fig. 18 - Frequency response of band-pass filter

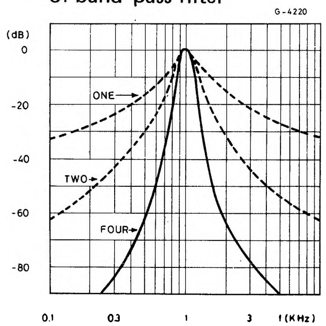



Fig. 19 - Bandwidth of band-pass filter