TECHNICAL NOTE 137

SGS-ATES

AUDIO DESIGN REFERENCE

Extracts from the forthcoming SGS-ATES Audio Handbook

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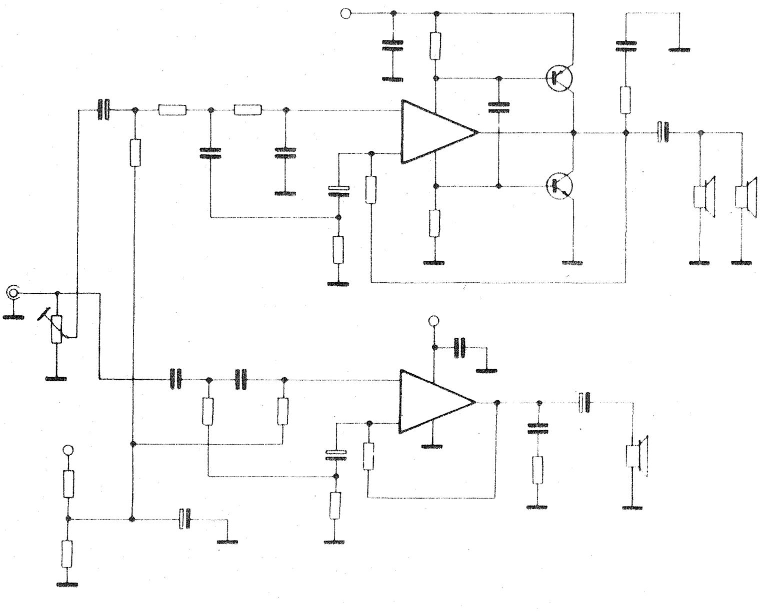


CONTENTS

Output voltage and current versus output power

P_o (W)	$R_L = 4\Omega$				$R_L = 8\Omega$			
	V_o (V)	V_{peak} (V)	I_o (A)	I_{peak} (A)	V_o (V)	V_{peak} (V)	I_o (A)	I_{peak} (A)
1.0	2.00	2.83	0.50	0.71	2.83	4.00	0.35	0.50
1.5	2.45	3.46	0.61	0.87	3.46	4.90	0.43	0.61
2.0	2.83	4.00	0.71	1.00	4.00	5.66	0.50	0.71
2.5	3.16	4.47	0.79	1.12	4.47	6.32	0.56	0.79
3.0	3.46	4.90	0.87	1.22	4.90	6.93	0.61	0.87
3.5	3.74	5.29	0.94	1.32	5.29	7.48	0.66	0.94
4.0	4.00	5.66	1.00	1.41	5.66	8.00	0.71	1.00
4.5	4.24	6.00	1.06	1.50	6.00	8.49	0.75	1.06
5.0	4.47	6.32	1.12	1.58	6.32	8.94	0.79	1.12
5.5	4.69	6.63	1.17	1.66	6.63	9.38	0.83	1.17
6.0	4.90	6.93	1.22	1.73	6.93	9.80	0.87	1.22
7.0	5.29	7.48	1.32	1.87	7.48	10.58	0.94	1.32
8.0	5.66	8.00	1.41	2.00	8.00	11.31	1.00	1.41
9.0	6.00	8.49	1.50	2.12	8.49	12.00	1.06	1.50
10.0	6.32	8.94	1.58	2.24	8.94	12.65	1.12	1.58
12.0	6.93	9.80	1.73	2.45	9.80	13.86	1.22	1.73
15.0	7.75	10.95	1.94	2.74	10.95	15.49	1.37	1.94
20.0	8.94	12.65	2.24	3.16	12.65	17.89	1.58	2.24
25.0	10.00	14.14	2.50	3.54	14.14	20.00	1.77	2.50
30.0	10.95	15.49	2.74	3.87	15.49	21.91	1.94	2.74
35.0	11.83	16.73	2.96	4.18	16.73	23.66	2.09	2.96
40.0	12.65	17.89	3.16	4.47	17.89	25.30	2.24	3.16
45.0	13.42	18.97	3.35	4.74	18.97	26.83	2.37	3.35
50.0	14.14	20.00	3.54	5.00	20.00	28.28	2.50	3.54
60.0	15.49	21.91	3.87	5.48	21.91	30.98	2.74	3.87
70.0	16.73	23.66	4.18	5.92	23.66	33.47	2.96	4.18
80.0	17.89	25.30	4.47	6.32	25.30	35.78	3.16	4.47
90.0	18.97	26.83	4.74	6.71	26.83	37.95	3.35	4.74
100.0	20.00	28.28	5.00	7.07	28.28	40.00	3.54	5.00
120.0	21.91	30.98	5.48	7.75	30.98	43.82	3.87	5.48
150.0	24.49	34.64	6.12	8.66	34.64	48.99	4.33	6.12
200.0	28.28	40.00	7.07	10.00	40.00	56.57	5.00	7.07
300.0	34.64	48.99	8.66	12.25	48.99	69.28	6.12	8.66
400.0	40.00	56.57	10.00	14.14	56.57	80.00	7.07	10.00

Fig. 1 - Output power vs. input voltage and gain ($R_L = 8\Omega$)

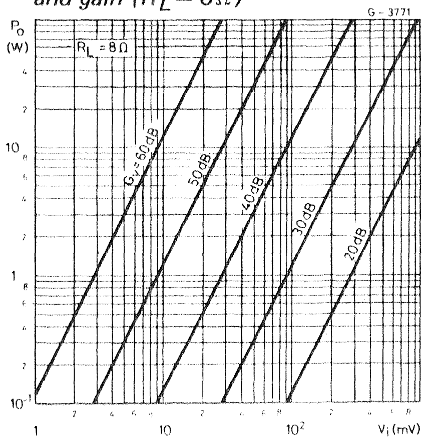


Fig. 2 - Output power vs. input voltage and gain ($R_L = 4\Omega$)

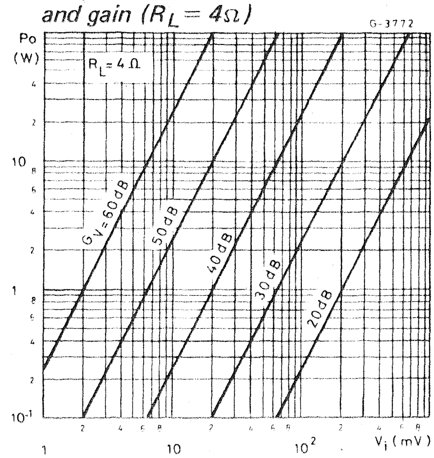


Fig. 3 - Output voltage versus output power and load (R_L)

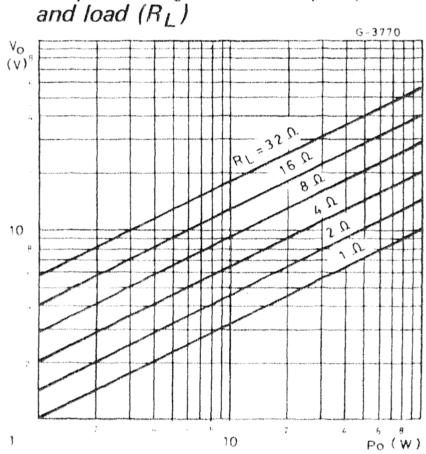
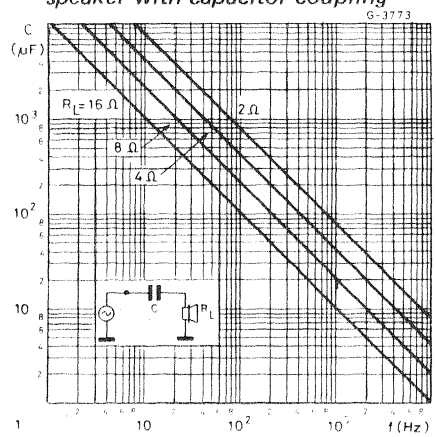


Fig. 4 - Low frequency cutoff for loud-speaker with capacitor coupling



SLEW-RATE

Introduction

The slew-rate of an amplifier is the maximum rate of change of the output signal which the amplifier is capable of delivering.
Normally it's specified in volts per microsecond. For example, a 10V/μs slew-rate means that the output voltage rises or falls no faster than 10V every microsecond.
Slew rate is also sometimes specified indirectly as output voltage swing versus frequency or as voltage follower large signal pulse response.
The slew-rate results from the fact that the compensation capacitor (C_L) in the amplifier has a finite current (I_p) for charging and discharging. With a sinusoidal signal, the maximum rate of change occurs at the zero crossing as:

$$V_o = V_p \sin 2\pi f$$

The maximum sinusoidal frequency amplified without significant "slew" distortion is therefore a function of the peak output voltage and of the slew rate as:

$$f_{max} = \frac{SR}{2\pi V_p}$$

The f_{max} is also named Power Bandwidth or large signal response (-3 dB).
In a simple application using an operational amplifier with a typical slew-rate of 0.5V/μs and an output swing of ± 15V we have:

$$\frac{30V}{0.5V/\mu s} = 60\ \mu s$$

If the full output of ± 15V is requested, the input signal must have at least 60 μs between zero crossings.
That is, the maximum input signal frequency should be 1/(2x60 μs) or 8 KHz assuming 50% duty cycle.
Even at that frequency, the output is triangular instead of square wave.

If a step signal is applied at the input of an ideal amplifier through a simple RC filter (6 dB/octave), the output signal is "slew" limited according to the cutoff frequency of the filter.
The maximum slew-rate values of the output voltage are also related to the peak output voltage as shown in the diagram of fig. 6.

Fig. 5 - Amplifier's slew-rate vs. I_p and C_L

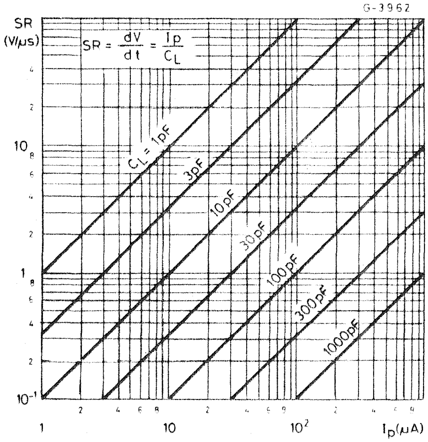
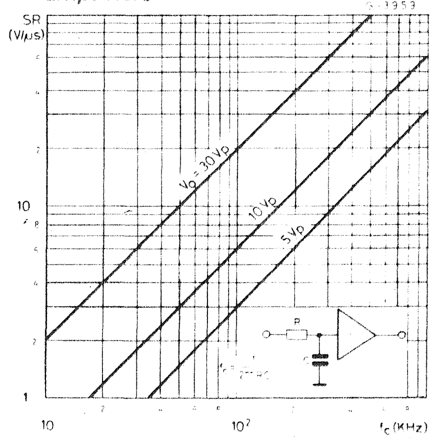


Fig. 6 - Maximum slew-rate for filtered amplifiers



Slew and transient intermodulation distortion

The application of strong negative feedback in audio amplifiers has become standard pratice because transformerless transistor and integrated circuits have enabled it easy use.
In the tube amplifier era, it was the output transformer which, due to its complex transfer function, precluded the use of more than some 20-30 dB feedback.
Even then, amplifier designers were discussing a particolar "sound" of amplifiers using too strong negative feedback.
Later, the inherent nonlinearity of early transistor amplifiers forced designers to use strong negative feedback to copė with the requirements of low harmonic distortion.
The apparent ease of the use of feedback as a cure-all for almost all amplifier sicknesses continued and commercial power amplifiers having 60-80 dB feedback are not rare today.
After years of intensive research on "transistor sound" and Hi-Fi, at least one basic distortion mechanism has been discovered.
Pratically, if a feedback amplifier is "slew" limited, the effect is than that the feedback is inoperative during the open-loop rise time of the power amplifier, so that when the amplifier receives an input signal containing high frequency components the input stages are driven into overload.
Caused by the integrating effect of the feedback loop, the overload condition tends to hold for a longer period than the open loop rise time of the amplifier, the overall result being burst of 100% intermodulation distortion.
This type of distortion is know as "Transient Intermodulation" or TIM.
Measurements of pratical amplifiers have shown that the onset of TIM distortion may occur well below the slew-rate of the amplifier, often at 1/3 to 1/5 of the slew-rate.
A good criteria for design of Hi-Fi amplifiers (see fig. 9 to 12) is that the cricuit must have a slew-rate in the 0.5V/μs to 1V/μs **per volt** (peak output voltage).
A simple and very effective method of avoiding transient intermodulation is the use of an RC filter at the input of the amplifier.
The diagram of fig. 8 shows the results of measurements made on four commercial amplifiers at half rated output power.
With a cutoff frequency of only 40 KHz the improvement is already clear.

Fig. 7 - Overshoot phenomenon in feedback amplifier

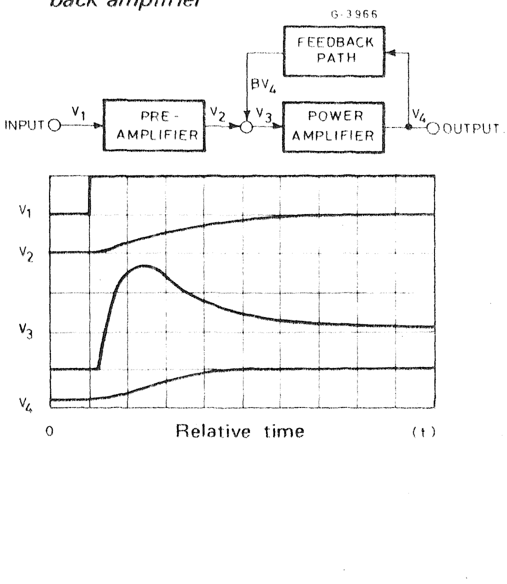


Fig. 8 - Transient intermodulation vs. cutoff frequency of input RC filter

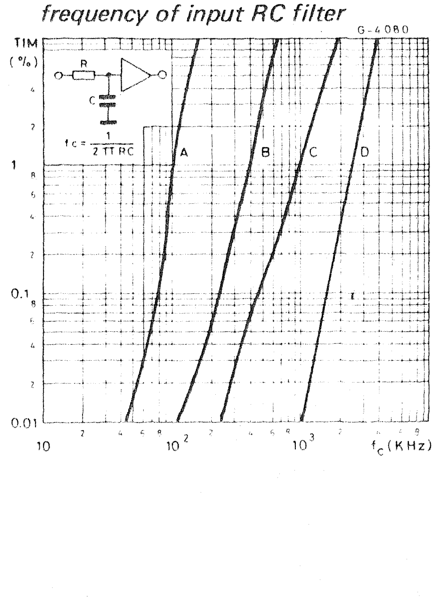


Fig. 9 - Slew-rate vs. peak output voltage (optimum design area for Hi-Fi)

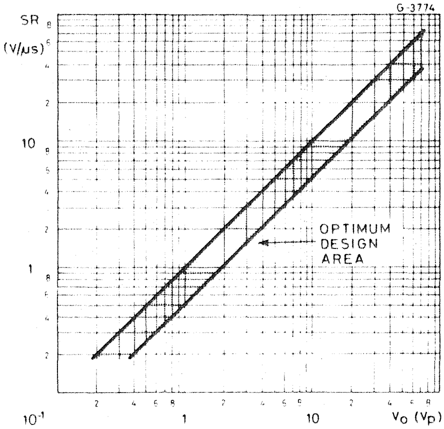


Fig. 10 - Slew-rate and power bandwidth vs. peak output voltage (with optimum design area for Hi-Fi)

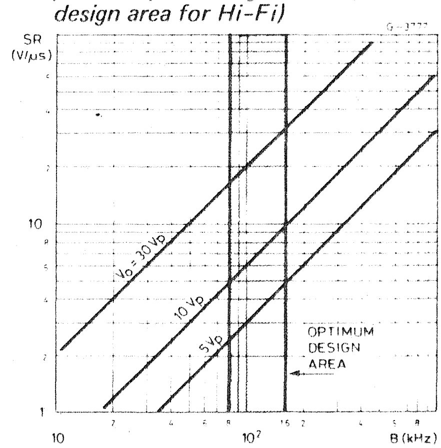


Fig. 11 - Slew-rate and power bandwidth vs. output power for $R_L = 8\Omega$ (with optimum design area for Hi-Fi)

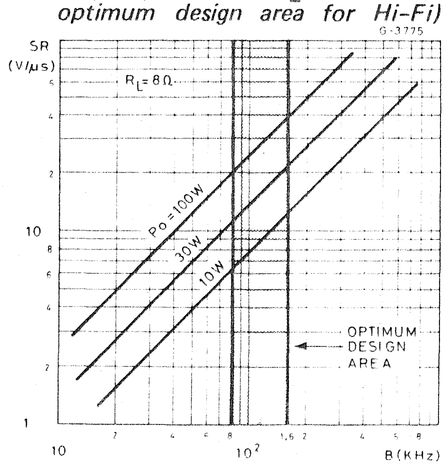
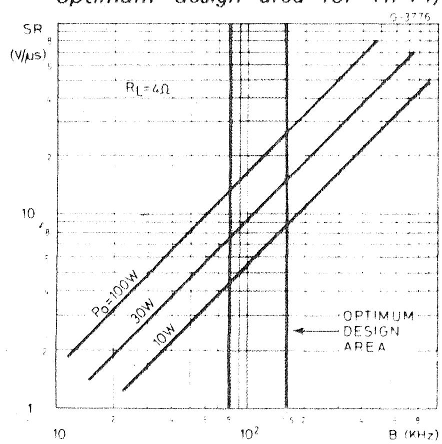


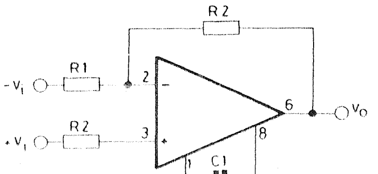
Fig. 12 - Slew-rate and power bandwidth vs. output power for $R_L = 4\Omega$ (with optimum design area for Hi-Fi)



OPERATIONAL AMPLIFIER COMPENSATION

SINGLE POLE

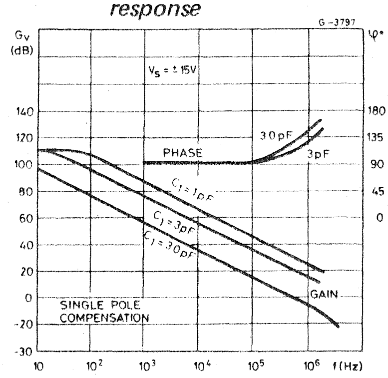
Fig. 13



$C1 \geq \frac{R1\ C_S}{R1 + R2}$

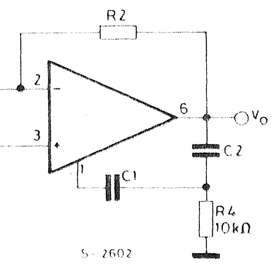
$C_S = 30pF$

Fig. 14 - Open loop frequency response



TWO POLE

Fig. 17

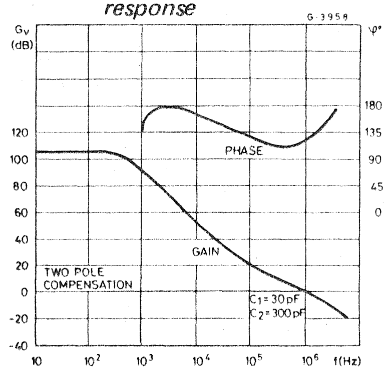


$C1 \geq \frac{R1\ C_S}{R1 + R2}$

$C_S = 30pF$

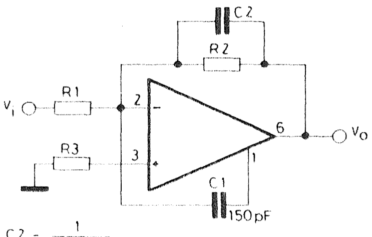
$C2 = 10\ C1$

Fig. 18 - Open loop frequency response



FEED FORWARD

Fig. 21



$C2 = \frac{1}{2\pi f_o R2}$

$f_o = 3MHz$

Fig. 22 - Open loop frequency response

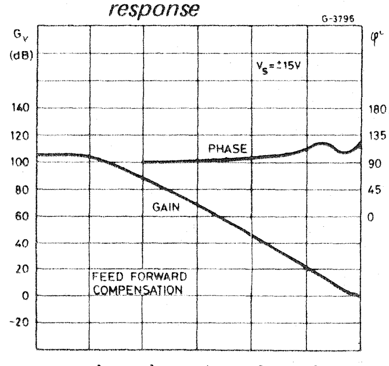


Fig. 15 - Large signal frequency response

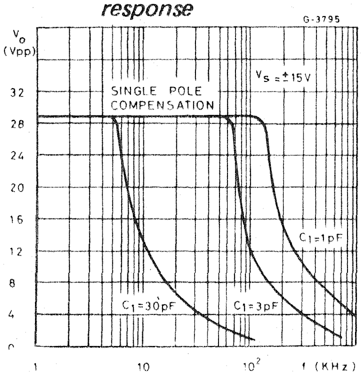


Fig. 16 - Pulse response

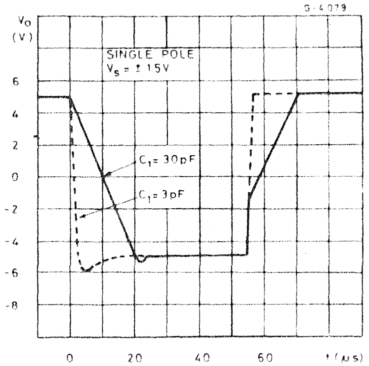


Fig. 19 - Large signal frequency response

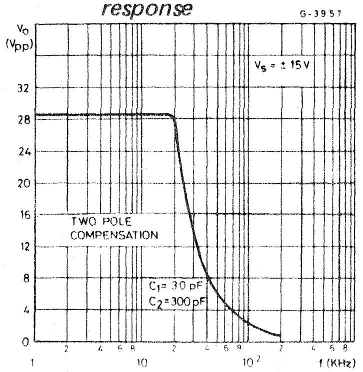


Fig. 20 - Pulse response

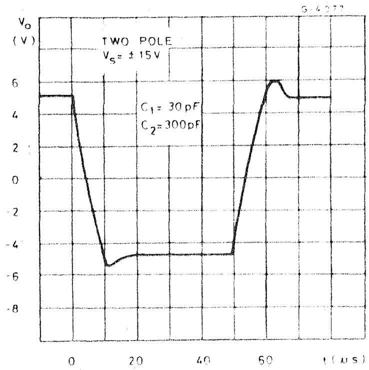


Fig. 23 - Large signal frequency response

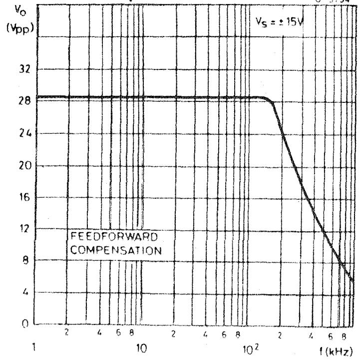
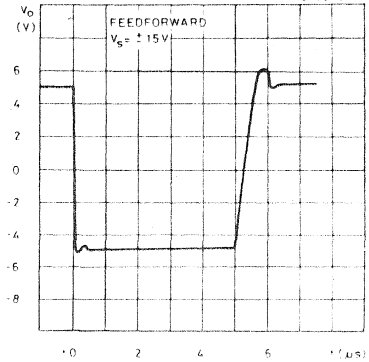


Fig. 24 - Pulse response



NOISE

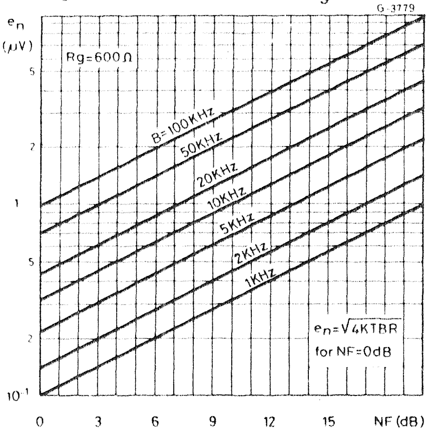


Fig. 25 - Total input noise voltage vs. noise figure and bandwidth (R_g= 600Ω)

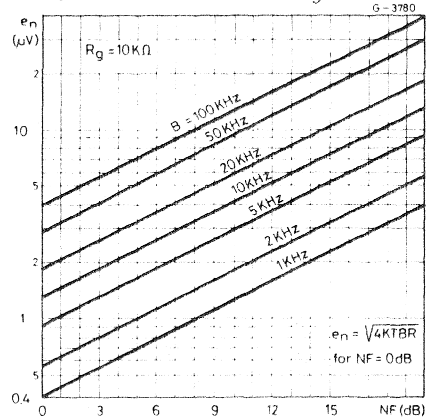


Fig. 26 - Total input noise voltage vs. noise figure and bandwidth (R_g= 10KΩ)

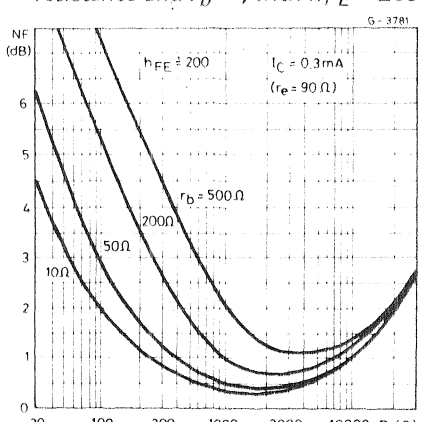


Fig. 27 - Input stage noise figure vs. source resistance and r_b (*), with h_{FE}= 200

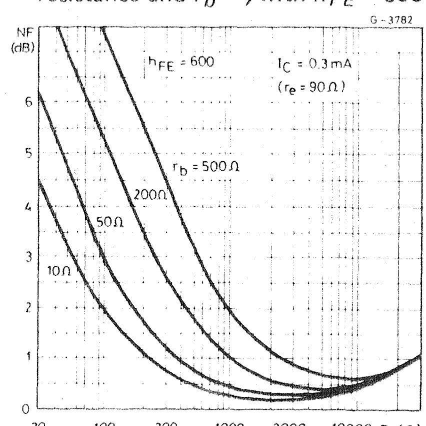


Fig. 28 - Input stage noise figure vs. source resistance and r_b (*), with h_{FE}= 600

$$NF = 10 \log \left[1 + \frac{r_b}{R_g} + \frac{r_e}{2 R_g} + \frac{(r_b + r_e + R_g)^2}{2 R_g r_e h_{FE}} \right]$$

Note (*) r_b is the base resistance of the input transistor

Amplifier noise figure including 2nd stage noise contribution (*)

First Stage		Second Stage Noise Figure (F_2)						
Gain G_1 (dB)	Noise figure(F_1) (dB)	3 dB	5 dB	8 dB	10 dB	12 dB	15 dB	20 dB
30	8.0	8.001	8.002	8.004	8.006	8.011	8.021	8.068
	5.0	5.001	5.003	5.007	5.012	5.020	5.041	5.131
	3.0	3.002	3.004	3.011	3.019	3.032	3.066	3.220
	1.5	1.504	1.508	1.518	1.529	1.547	1.594	1.796
	0.8	0.803	0.807	0.818	0.831	0.852	0.908	1.143
20	8.0	8.007	8.015	8.040	8.060	8.100	8.026	8.633
	5.0	5.014	5.030	5.070	5.120	5.200	5.401	6.183
	3.0	3.022	3.050	3.110	3.190	3.310	3.620	4.750
	1.5	1.539	1.570	1.660	1.770	1.930	2.352	3.807
	0.8	0.835	0.876	1.021	1.113	1.305	1.785	3.408
15	8.0	8.022	8.047	8.114	8.190	8.310	8.620	9.750
	5.0	5.043	5.093	5.225	5.370	5.600	6.160	7.989
	3.0	3.068	3.146	3.351	3.580	3.920	4.718	7.098
	1.5	1.596	1.705	1.988	2.300	2.750	3.767	6.574
	0.8	0.911	1.039	1.367	1.722	2.231	3.365	6.368
10	8.0	8.070	8.150	8.350	8.580	8.920	9.718	12.098
	5.0	5.140	5.290	5.670	6.090	6.670	7.941	11.160
	3.0	3.210	3.450	4.030	4.620	5.420	7.039	10.754
	1.5	1.800	2.120	2.890	3.640	4.620	6.508	10.536
	0.8	1.144	1.517	2.388	3.226	4.293	6.298	10.454
7	8.0	8.140	8.290	8.670	9.090	9.670	10.941	14.160
	5.0	5.270	5.560	6.260	6.950	7.870	9.672	13.601
	3.0	3.410	3.850	4.850	5.790	6.950	9.088	13.374
	1.5	2.070	2.660	3.930	5.060	6.410	8.764	13.256
	0.8	1.463	2.131	3.544	4.768	6.196	8.640	13.213

Fig. 29 - Thermal noise voltage of a resistance vs. bandwidth

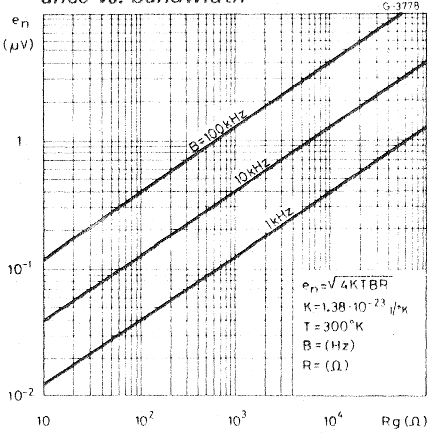
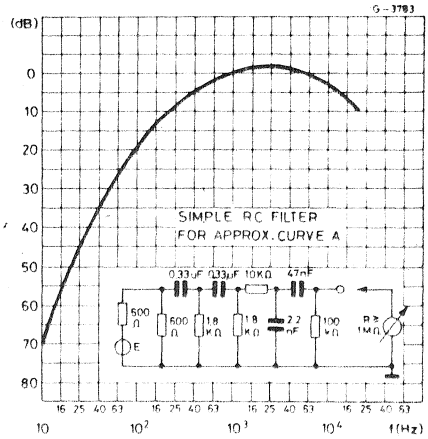


Fig. 30 - Psophometric weighting (curve A)



Note (*) $F = F_1 + \frac{F_2 - 1}{G_1}$

Fig. 31 - RIAA disc equalization curve

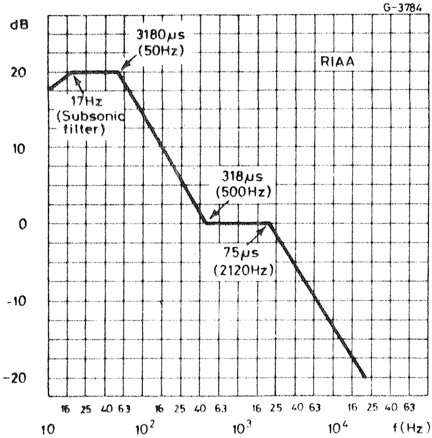


Fig. 32 - DIN/NAB playback equalization for cassette tape

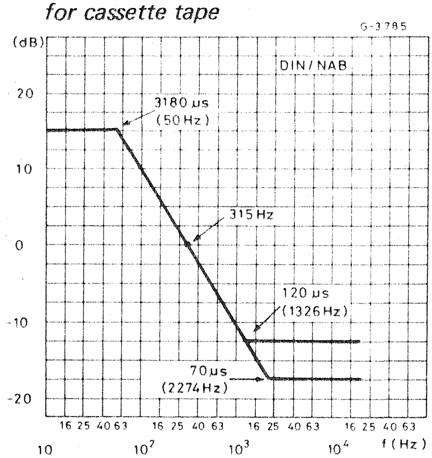
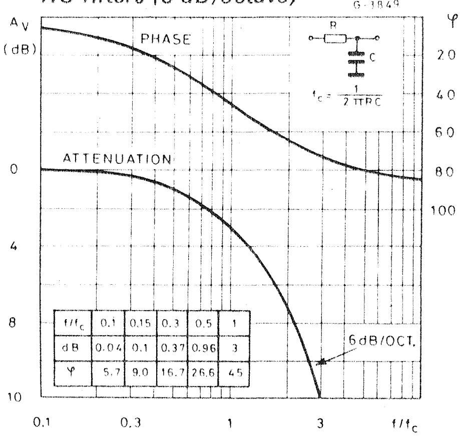
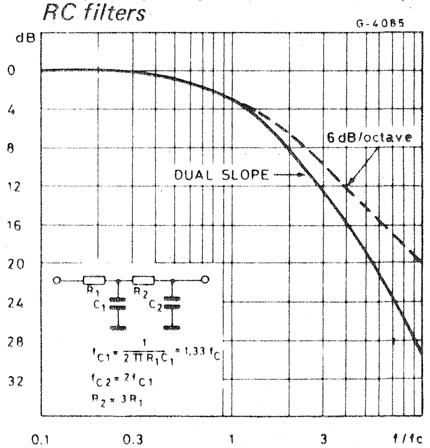


Fig. 33 - Frequency and phase response of RC filters (6 dB/octave)



f/f_c	0.1	0.15	0.3	0.5	1
dB	0.04	0.1	0.37	0.96	3
φ	5.7	9.0	16.7	26.6	45

Fig. 34 - Frequency response of dual slope RC filters



Cutoff frequency of 6 dB/octave RC filters (kHz)

R (kΩ)	C (nF)												
	1	1.2	1.5	1.8	2.2	2.7	3.3	3.9	4.7	5.6	6.8	8.2	10
1	159.1	132.6	106.1	88.42	72.34	58.95	48.23	40.81	33.86	28.42	23.41	19.41	15.92
1.2	132.6	110.5	88.42	73.68	60.29	49.12	40.19	34.01	28.22	23.68	19.50	16.17	13.26
1.5	106.1	88.42	70.74	58.95	48.23	39.30	32.15	27.21	22.58	18.95	15.60	12.94	10.61
1.8	88.42	73.68	58.95	49.12	40.19	32.75	26.79	22.67	18.81	15.79	13.00	10.78	8.84
2.2	72.34	60.29	48.23	40.19	32.88	26.79	21.92	18.55	15.39	12.92	10.64	8.82	7.23
2.7	58.95	49.12	39.30	32.75	26.79	21.83	17.86	15.11	12.54	10.53	8.67	7.19	5.89
3.3	48.23	40.19	32.15	26.79	21.92	17.86	14.61	12.37	10.26	8.61	7.09	5.88	4.82
3.9	40.81	34.01	27.21	22.67	18.55	15.11	12.37	10.46	8.68	7.29	6.00	4.98	4.08
4.7	33.86	28.22	22.58	18.81	15.39	12.54	10.26	8.68	7.20	6.05	4.98	4.13	3.39
5.6	28.42	23.68	18.95	15.79	12.92	10.53	8.61	7.29	6.05	5.08	4.18	3.47	2.84
6.8	23.41	19.50	15.60	13.00	10.64	8.67	7.09	6.00	4.98	4.18	3.44	2.85	2.34
8.2	19.41	16.17	12.94	10.78	8.82	7.19	5.88	4.98	4.13	3.47	2.85	2.37	1.94
10	15.92	13.26	10.61	8.84	7.23	5.89	4.82	4.08	3.39	2.84	2.34	1.94	1.59
12	13.26	11.05	8.84	7.37	6.03	4.91	4.02	3.40	2.82	2.37	1.95	1.62	1.33
15	10.61	8.84	7.07	5.89	4.82	3.93	3.21	2.72	2.26	1.89	1.56	1.29	1.06
18	8.84	7.37	5.89	4.91	4.02	3.27	2.68	2.27	1.88	1.58	1.30	1.08	0.88
22	7.37	6.03	4.82	4.02	3.29	2.68	2.19	1.85	1.54	1.29	1.06	0.88	0.72
27	5.89	4.91	3.93	3.27	2.68	2.18	1.79	1.51	1.25	1.05	0.87	0.72	0.59
33	4.82	4.02	3.21	2.68	2.19	1.79	1.46	1.24	1.03	0.86	0.71	0.59	0.48
39	4.08	3.40	2.72	2.27	1.85	1.51	1.24	1.05	0.87	0.73	0.60	0.50	0.41
47	3.39	2.82	2.26	1.88	1.54	1.25	1.03	0.87	0.72	0.60	0.50	0.41	0.34
56	2.84	2.37	1.89	1.58	1.29	1.05	0.86	0.73	0.60	0.51	0.42	0.35	0.28
68	2.34	1.95	1.56	1.30	1.06	0.87	0.71	0.60	0.50	0.42	0.34	0.28	0.23
82	1.94	1.62	1.29	1.08	0.88	0.72	0.59	0.50	0.41	0.35	0.28	0.24	0.19
100	1.59	1.33	1.06	0.88	0.72	0.59	0.48	0.41	0.34	0.28	0.23	0.19	0.16

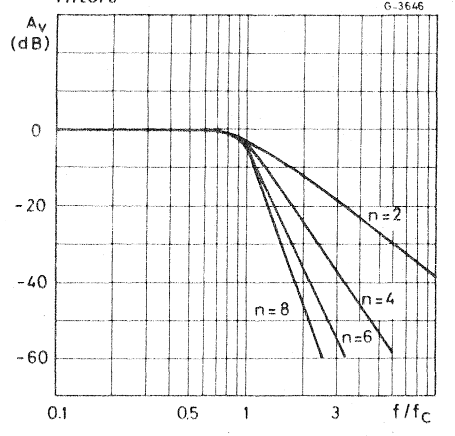
Active low-pass filters

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 -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. 35 - Frequency response of Butterworth filters



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.

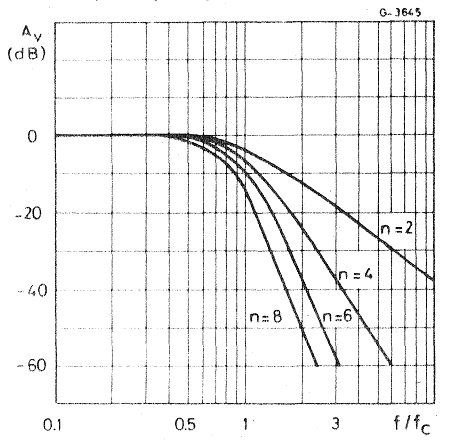
The maximum phase shift is $\frac{-n\pi}{2}$ radians where n is the order (number of poles) of the filter. The cutoff frequency, f_c, is defined as the frequency at which the phase shift is one half of this value. For accurate delay, the cutoff frequency should be twice the maximum signal frequency.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

Fig. 36 - Frequency response of Bessel filters

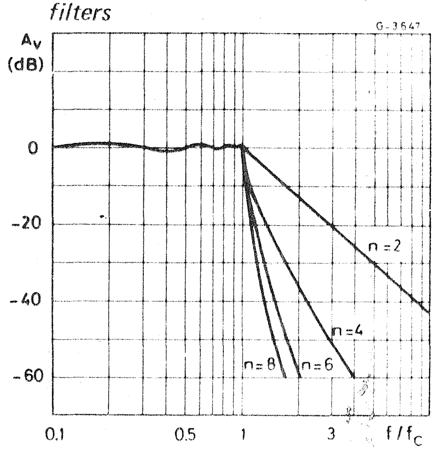


Chebyschev

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. 37 - Frequency response of Chebyschev filters

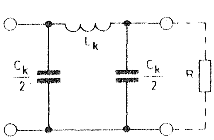


Overshoot and settling time response of a low pass filters to a step input

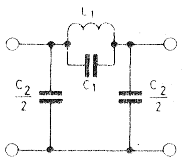
	NUMBER OF POLES	PEAK OVERSHOOT	SETTLING TIME (% of final value)		
		% Overshoot	± 1%	± 0.1%	± 0.01%
BUTTERWORTH	2	4	1.1/f_c sec.	1.7/f_c sec.	1.9/f_c sec.
	4	11	1.7/f_c	2.8/f_c	3.8/f_c
	6	14	2.4/f_c	3.9/f_c	5.0/f_c
	8	16	3.1/f_c	5.1/f_c	7.1/f_c
BESSEL	2	0.4	0.8/f_c	1.4/f_c	1.7/f_c
	4	0.8	1.0/f_c	1.8/f_c	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	-

LC passive filters

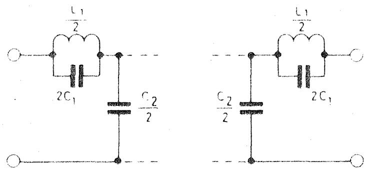
Fig. 38 – Low-pass filters



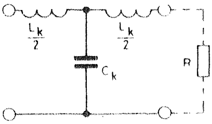
Constant-k π section



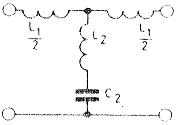
m – derived π section



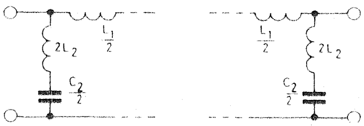
m – derived end sections for use with intermediate π section



Constant-k π T section



m – derived T section



m – derived end sections for use with intermediate T section

$$L_k = \frac{R}{\pi f_c} \qquad C_k = \frac{1}{\pi f_c R}$$

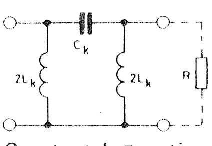
$$L_1 = mL_k \qquad C_1 = \frac{1-m^2}{4m} C_k$$

$$L_2 = \frac{1-m^2}{4m} L_k \qquad C_2 = mC_k$$

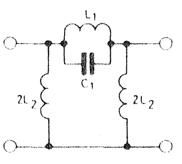
$$L_1 = mL_k \qquad C_1 = \frac{1-m^2}{4m} C_k$$

$$L_2 = \frac{1-m^2}{4m} L_k \qquad C_2 = mC_k$$

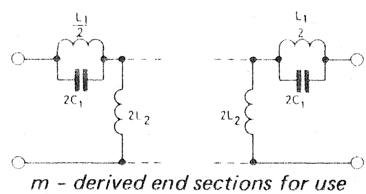
Fig. 39 – High-pass filters



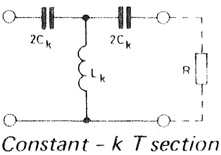
Constant-k π section



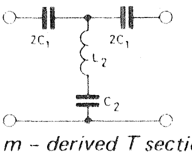
m – derived π section



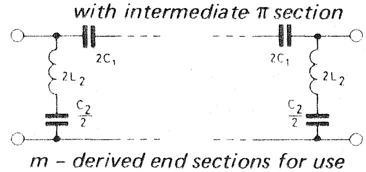
m – derived end sections for use with intermediate π section



Constant – k T section



m – derived T section



m – derived end sections for use with intermediate T section

$$L_k = \frac{R}{4\pi f_c} \qquad C_k = \frac{1}{4\pi f_c R}$$

$$L_1 = \frac{4m}{1-m^2} L_k \qquad C_1 = \frac{C_k}{m}$$

$$L_2 = \frac{L_k}{m} \qquad C_2 = \frac{4m}{1-m^2} C_k$$

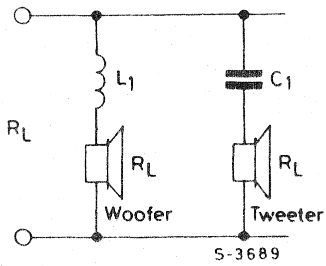
$$L_1 = \frac{4m}{1-m^2} L_k \qquad C_1 = \frac{C_k}{m}$$

$$L_2 = \frac{L_k}{m} \qquad C_2 = \frac{4m}{1-m^2} C_k$$

Note: $m = \sqrt{1 - (f_2/f_\infty^2)}$

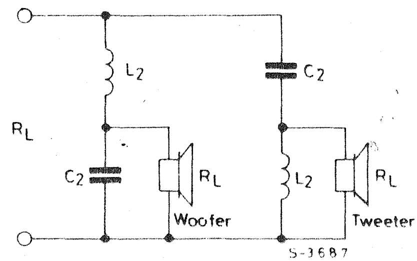
Loudspeakers crossover filters

Fig. 40 - Two way (6 dB/octave)



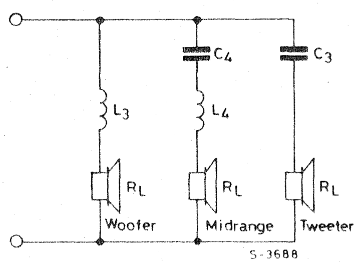
$$L_1 = \frac{R_L}{2\pi f_c} \qquad C_1 = \frac{1}{2\pi f_c R_L}$$

Fig. 41 - Two way (12 dB/octave)



$$L_2 = \frac{R_L \sqrt{2}}{2\pi f_c} \qquad C_2 = \frac{1}{2\pi f_c R_L \sqrt{2}}$$

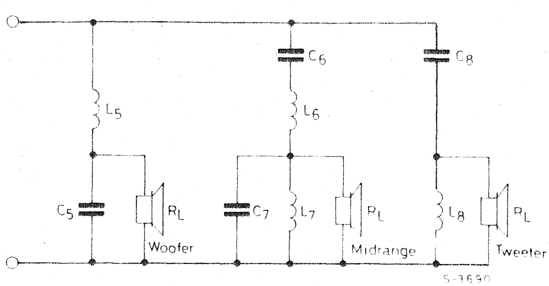
Fig. 42 - Three way (6 dB/octave)



$$L_3 = \frac{R_L}{2\pi f_1} \qquad C_3 = \frac{1}{2\pi f_2 R_L}$$

$$L_4 \cong \frac{R_L}{2\pi f_2} \qquad C_4 \cong \frac{1}{2\pi f_1 R_L}$$

Fig. 43 - Three way (12 dB/octave)



$$L_5 = \frac{R_L \sqrt{2}}{2\pi f_1}; \qquad C_5 = \frac{1}{2\pi f_1 R_L \sqrt{2}}$$

$$L_6 \cong \frac{R_L \sqrt{2}}{2\pi f_2}; \qquad C_6 \cong \frac{1}{2\pi f_1 R_L \sqrt{2}}$$

$$L_7 \cong \frac{R_L \sqrt{2}}{2\pi f_1}; \qquad C_7 \cong \frac{1}{2\pi f_2 R_L \sqrt{2}}$$

$$L_8 = \frac{R_L \sqrt{2}}{2\pi f_2}; \qquad C_8 = \frac{1}{2\pi f_2 R_L \sqrt{2}}$$

Note : When the two complementary filters (HP and LP) are correctly terminated, the impedance presented at their common input will be a constant resistance equal to R_L over the passband.

Fig. 44 – Frequency response of two way crossover filters (6 dB/octave)

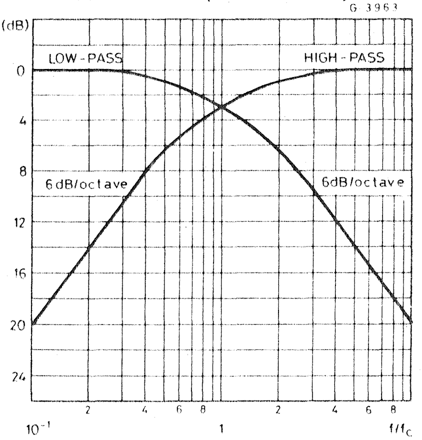


Fig. 45 – Frequency response of two way crossover filters (12 dB/octave)

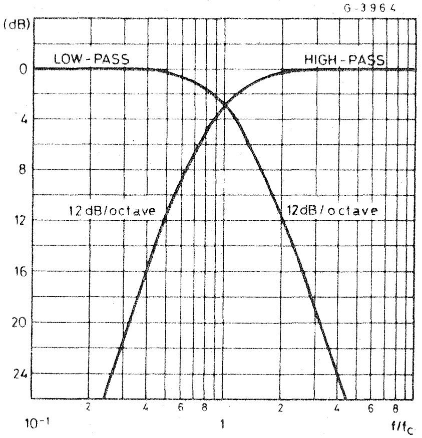


Fig. 46 – Phase response of two way cross-over filters (6 dB/octave)

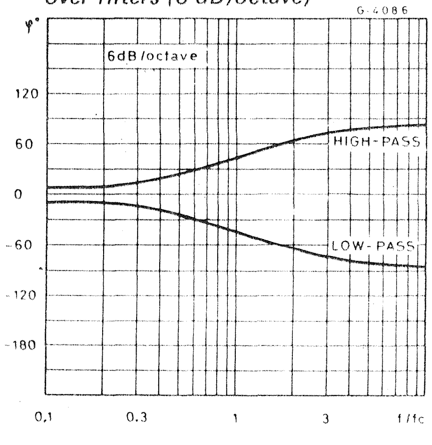


Fig. 47 – Phase response of two way cross-over filters (12 dB/octave)

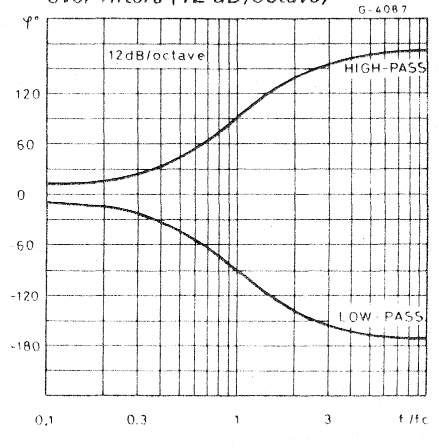


Fig. 48 - Constant resistance two way cross-over filters for $R_L = 8\Omega$ (6 dB/octave)

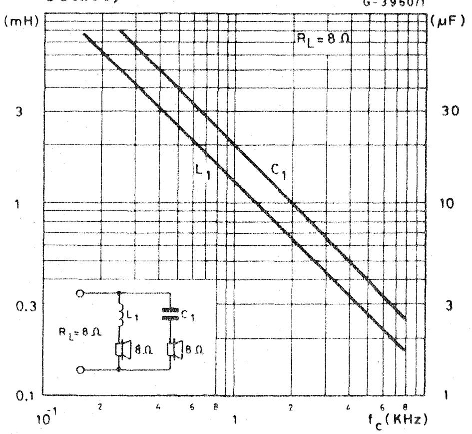


Fig. 49 - Constant resistance two way cross-over filters for $R_L = 4\Omega$ (6 dB/octave)

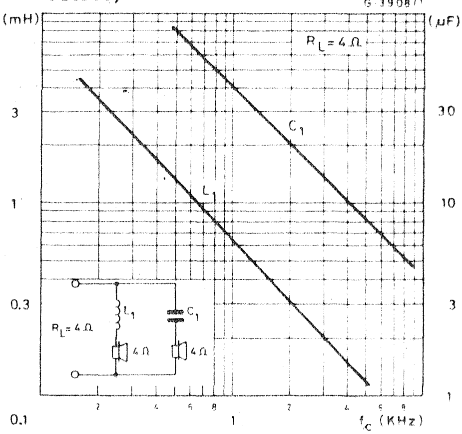


Fig. 50 - Constant resistance two way cross-over filters for $R_L = 8\Omega$ (12 dB/octave)

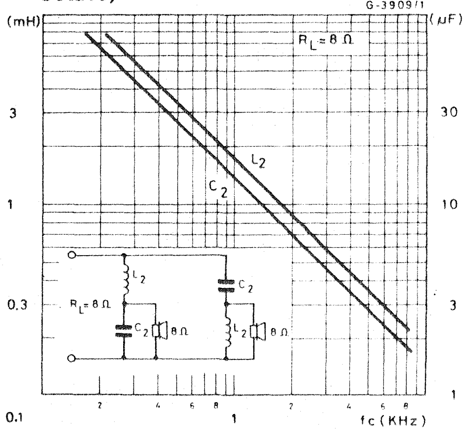


Fig. 51 - Constant resistance two way cross-over filters for $R_L = 4\Omega$ (12 dB/octave)

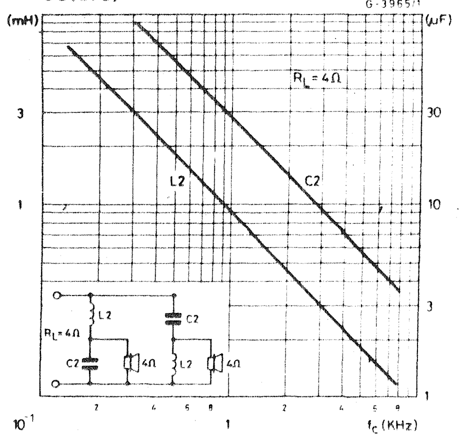


Fig. 52 - Normalized Q and phase of Notch Filters vs. frequency

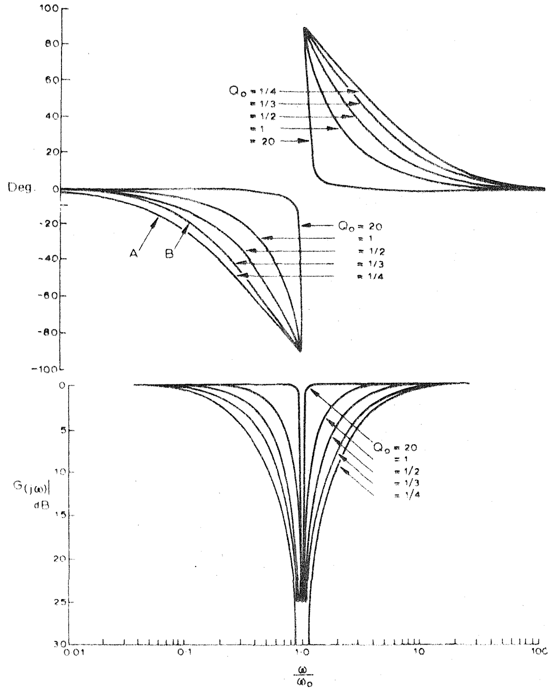


Fig. 53 - Notch frequency of a Wien-bridge as a function of R and C

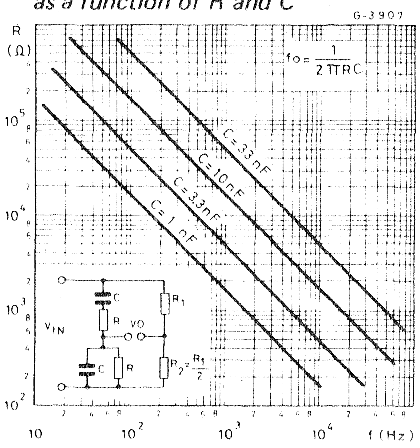
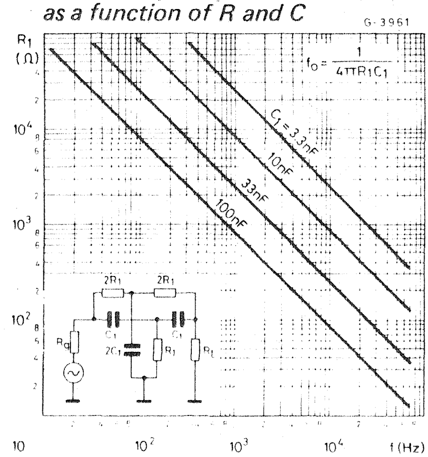
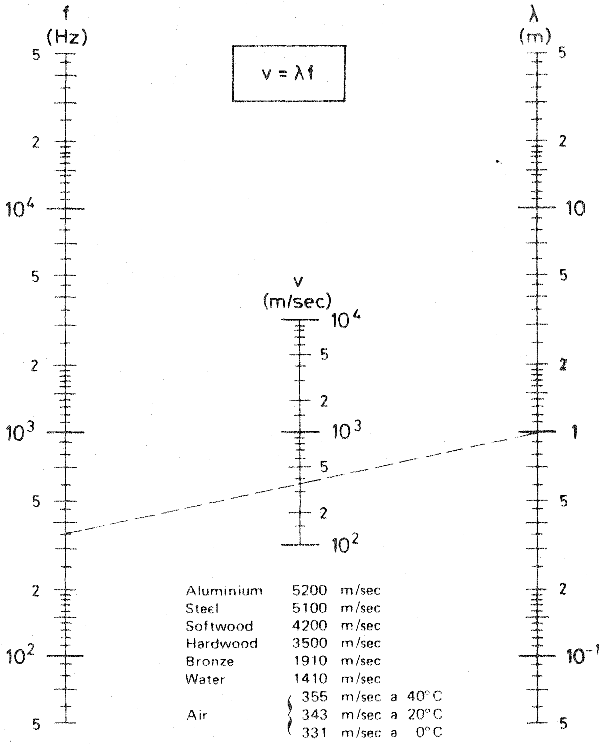


Fig. 54 - Notch frequency of a twin-T filter as a function of R and C



SOUND

Fig. 55 – Frequency, wavelength and sound velocity



Aluminium	5200	m/sec
Steel	5100	m/sec
Softwood	4200	m/sec
Hardwood	3500	m/sec
Bronze	1910	m/sec
Water	1410	m/sec
Air	355	m/sec a 40°C
	343	m/sec a 20°C
	331	m/sec a 0°C

Fig. 56 – Sound wavelengths

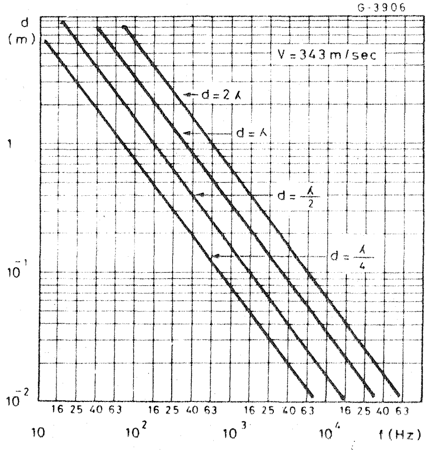
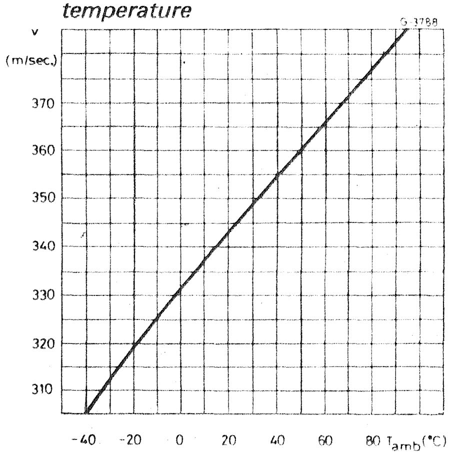


Fig. 57 – Sound velocity in air vs. ambient temperature



Typical sound pressures

Sound level dB	Intensity W/m²	Environment conditions
150	1000	
140	100	Close to jet aircraft
130	10	Threshold of pain
120	1	Pneumatic drill
110	—	Loud auto horn (at 1m)
100	10^{-2}	Subway, train passing
90	—	Noisiest spot at Niagara falls (92 dB)
80	10^{-4}	Inside motor bus
70	—	Average traffic (Big city)
60	10^{-6}	High volume TV
50	—	Conversational speech
40	10^{-8}	Living room
30	—	Library
20	10^{-10}	Speech (low level)
10	—	Broadcasting studio
0	10^{-12}	Threshold of hearing

Note : 0 dB is equal to 0.0002 μ bar, which is the weakest sound pressure to be detected by an "average" person at 1000 Hz and corresponds, by international agreement, to 20 μ pascal (20 μ Pa).

Fig. 58 - Equal loudness curves

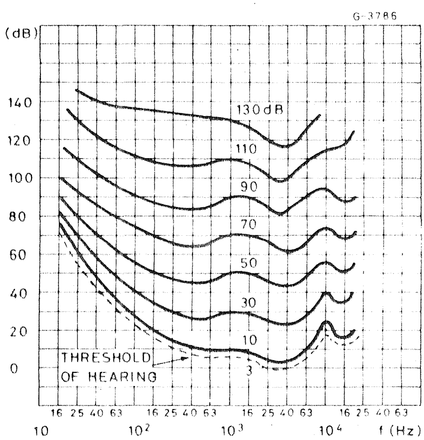
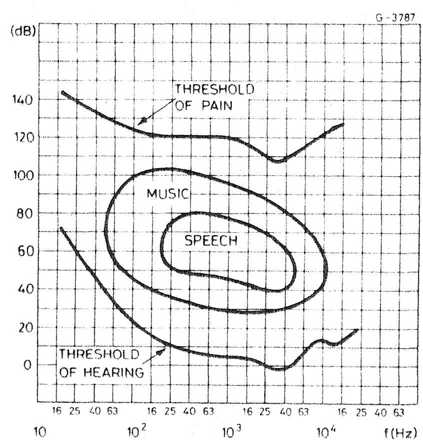


Fig. 59 - Hearing area for speech and music



Loudspeakers efficiency

If we assume spherical free space with an omnidirectional source radiating freely outwards from the centre, source power emission can thus be calculated from:

$$P_O = 4\pi W_M d^2$$

where P_O is the source emission in acoustical watts, W_M the mean power in W/m² and d the distance from the source in metres.

Under true free-field conditions and assuming an omnidirectional source an intensity of 96 dB at 1 metre requires an acoustical emission of 50 mW.

Pratically, the efficiency measurement (as Din. 45500) are made under hemispherical free space conditions (anechoic chamber, with radiation in the form of half a sphere in front of the loudspeaker box and no emission from the rear).

In these conditions, an intensity of 96 dB at 1 metre is obtained with 25 mW acoustical power. With an electrical input power of 1W, 89 dB means 0.5% efficiency and 86 dB -0.25% efficiency.

Fig. 60- Electrical power (P_O) and loudspeaker efficiency (dB) required for a given room volume (m³)

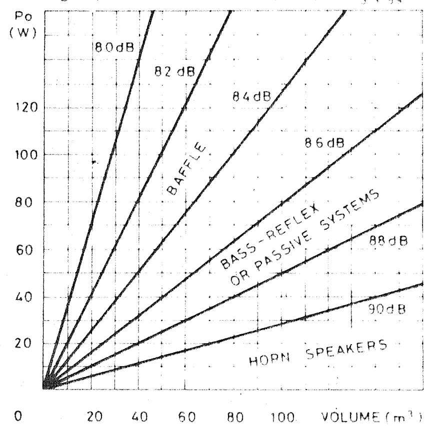


Fig. 61 - Dynamic range of disc music (sound pressure referred to threshold of audibility or 20 μPa)

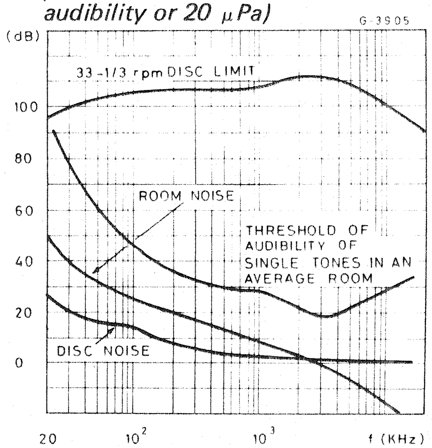
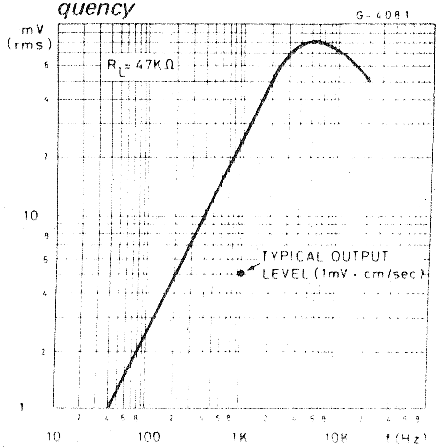


Fig. 62 - Maximum output level of High Quality magnetic cartridge vs. frequency



dB and Power Ratio

dB	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	1.000	1.023	1.047	1.072	1.096	1.122	1.148	1.175	1.202	1.230
1	1.259	1.288	1.318	1.349	1.380	1.413	1.445	1.479	1.514	1.549
2	1.585	1.622	1.660	1.698	1.738	1.778	1.820	1.862	1.905	1.950
3	1.995	2.042	2.089	2.138	2.188	2.239	2.291	2.344	2.399	2.455
4	2.512	2.570	2.630	2.692	2.754	2.818	2.884	2.951	3.020	3.090
5	3.162	3.236	3.311	3.388	3.467	3.548	3.631	3.715	3.802	3.890
6	3.981	4.074	4.169	4.266	4.365	4.467	4.571	4.677	4.786	4.898
7	5.012	5.129	5.248	5.370	5.495	5.623	5.754	5.888	6.026	6.166
8	6.310	6.457	6.607	6.761	6.918	7.079	7.244	7.413	7.586	7.762
9	7.943	8.128	8.318	8.511	8.710	8.913	9.120	9.333	9.550	9.772
10	10.00	10.23	10.47	10.72	10.96	11.22	11.48	11.75	12.02	12.30
11	12.59	12.88	13.18	13.49	13.80	14.13	14.45	14.79	15.14	15.49
12	15.85	16.22	16.60	16.98	17.38	17.78	18.20	18.62	19.05	19.50
13	19.95	20.42	20.89	21.38	21.88	22.39	22.91	23.44	23.99	24.55
14	25.12	25.70	26.30	26.92	27.54	28.18	28.84	29.51	30.20	30.90
15	31.62	32.36	33.11	33.88	34.67	35.48	36.31	37.16	38.06	38.90
16	39.81	40.74	41.69	42.66	43.65	44.67	45.71	46.77	47.86	49.98
17	50.12	51.29	52.48	53.70	54.95	56.23	57.54	58.88	60.26	61.66
18	63.10	64.57	66.07	67.61	69.18	70.79	72.44	74.13	75.86	77.62
19	79.43	81.28	83.18	85.11	87.10	89.13	91.20	93.33	95.50	97.72
20	100.0	102.3	104.7	107.2	109.6	112.2	114.8	117.5	120.2	123.0

dB and Voltage Ratio

dB	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	1.000	1.012	1.023	1.035	1.047	1.059	1.072	1.084	1.097	1.109
1	1.122	1.135	1.148	1.161	1.175	1.188	1.202	1.216	1.230	1.244
2	1.259	1.274	1.288	1.303	1.318	1.333	1.349	1.365	1.380	1.396
3	1.413	1.430	1.445	1.462	1.479	1.496	1.515	1.532	1.550	1.567
4	1.585	1.604	1.621	1.640	1.659	1.679	1.699	1.718	1.739	1.758
5	1.778	1.799	1.819	1.840	1.862	1.884	1.906	1.927	1.950	1.972
6	1.995	2.019	2.041	2.065	2.089	2.113	2.139	2.163	2.189	1.212
7	2.239	2.266	2.290	2.317	2.344	2.371	2.400	2.427	2.456	2.483
8	2.512	2.542	2.570	2.600	2.630	2.660	2.693	2.723	2.756	2.786
9	2.818	2.852	2.883	2.917	2.950	2.984	3.021	3.055	3.091	3.125
10	3.162	3.200	3.235	3.273	3.311	3.349	3.390	3.428	3.469	3.507
11	3.548	3.591	3.630	3.672	3.715	3.757	3.803	3.846	3.892	3.935
12	3.981	4.029	4.073	4.120	4.168	4.216	4.268	4.315	4.367	4.415
13	4.467	4.521	4.570	4.623	4.678	4.731	4.789	4.842	4.900	4.954
14	5.012	5.072	5.127	5.187	5.248	5.308	5.373	5.435	5.498	5.558
15	5.623	5.690	5.752	5.820	5.887	5.955	6.028	6.095	6.168	6.236
16	6.310	6.386	6.455	6.531	6.607	6.682	6.764	6.840	6.922	6.998
17	7.080	7.165	7.243	7.328	7.413	7.498	7.590	7.675	7.767	7.852
18	7.943	8.038	8.126	8.221	8.316	8.412	8.515	8.610	8.713	8.809
19	8.913	9.020	9.118	9.225	9.332	9.439	9.555	9.662	9.778	9.885
20	10.00	10.12	10.23	10.35	10.47	10.59	10.72	10.84	10.97	11.09

dBμV and Voltage Level

dBμV	μV	dBμV	μV	dBμV	μV	dBμV	mV	dBμV	mV	dBμV	mV
1	1.122	21	11.22	41	112.2	61	1.122	81	11.22	101	112.2
2	1.259	22	12.59	42	125.9	62	1.259	82	12.59	102	125.9
3	1.413	23	14.13	43	141.3	63	1.413	83	14.13	103	141.3
4	1.585	24	15.85	44	158.5	64	1.585	84	15.85	104	158.5
5	1.778	25	17.78	45	177.8	65	1.778	85	17.78	105	177.8
6	1.995	26	19.95	46	199.5	66	1.995	86	19.95	106	199.5
7	2.239	27	22.39	47	233.6	67	2.239	87	22.39	107	223.9
8	2.512	28	25.12	48	251.2	68	2.512	88	25.12	108	251.2
9	2.818	29	28.18	49	281.8	69	2.818	89	28.18	109	281.8
10	3.162	30	31.62	50	316.2	70	3.162	90	31.62	110	316.2
11	3.548	31	35.48	51	354.9	71	3.548	91	35.48	111	354.8
12	3.981	32	39.81	52	398.1	72	3.981	92	39.81	112	398.1
13	4.467	33	44.67	53	446.7	73	4.467	93	44.67	113	446.7
14	5.012	34	50.12	54	501.2	74	5.012	94	50.12	114	501.2
15	5.623	35	56.23	55	562.3	75	5.623	95	56.23	115	562.3
16	6.310	36	63.10	56	631.0	76	6.310	96	93.10	116	631.0
17	7.080	37	70.80	57	708.0	77	7.080	97	70.80	117	708.0
18	7.943	38	79.43	58	794.3	78	7.943	98	79.43	118	794.3
19	8.918	39	89.13	59	891.3	79	8.913	99	89.13	119	891.3
20	10.000	40	100.00	60	1000.0	80	10.000	100	100.00	120	1000.0

Fig. 63 – Reactance of capacitors versus frequency

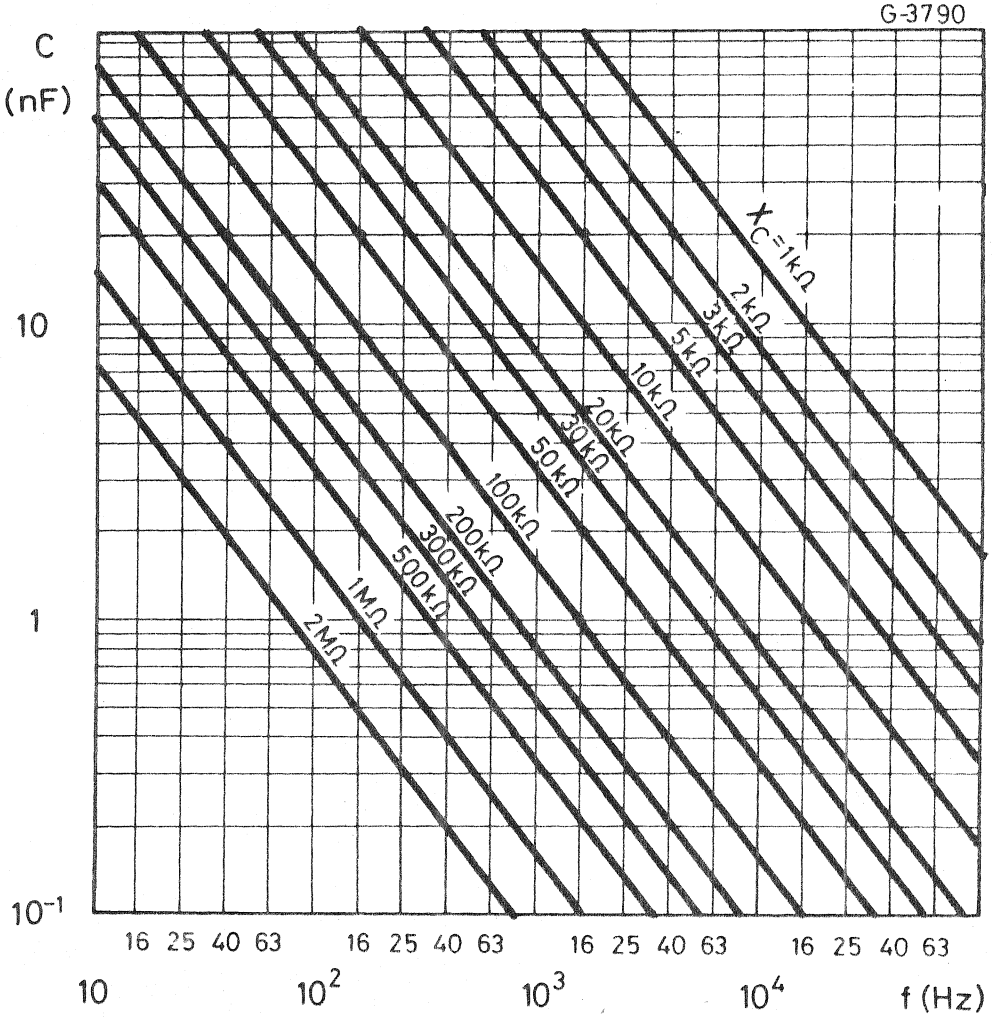


Fig. 64 - Reactance of inductors versus frequency

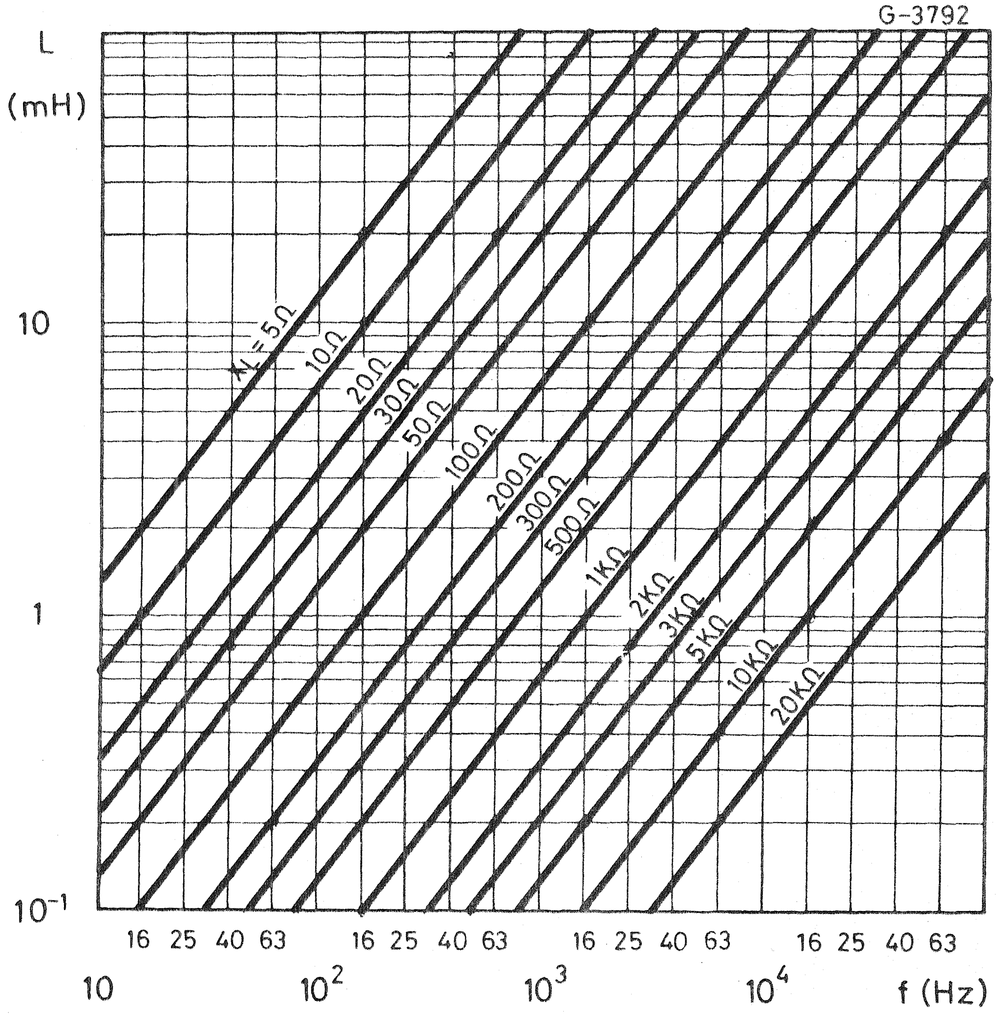


Fig. 65 - Resistivity as a function of printed circuit line width

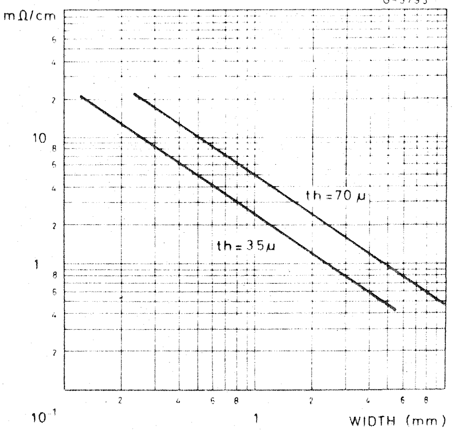
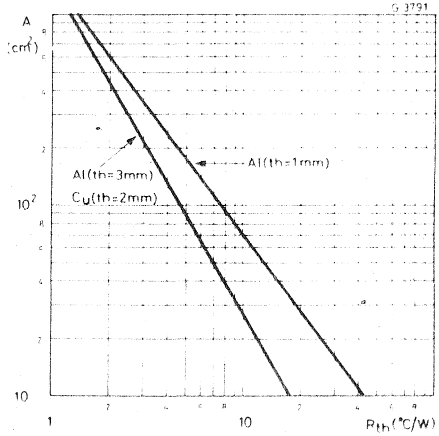
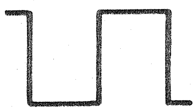


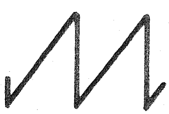
Fig. 66 - Thermal resistance vs. heatsink area



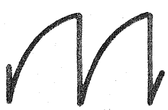
Spectra of square, linear sawtooth and exponential sawtooth waveforms



Frequency	f_o	$2f_o$	$3f_o$	$4f_o$	$5f_o$	$6f_o$	$7f_o$	$8f_o$	$9f_o$
Relative level	1	0	0.33	0	0.20	0	0.14	0	0.11



Frequency	f_o	$2f_o$	$3f_o$	$4f_o$	$5f_o$	$6f_o$	$7f_o$	$8f_o$	$9f_o$
Relative level	1	0.5	0.33	0.25	0.20	0.16	0.14	0.125	0.11



Frequency	f_o	$2f_o$	$3f_o$	$4f_o$	$5f_o$	$6f_o$	$7f_o$	$8f_o$	$9f_o$
Relative level	1	0.63	0.45	0.34	0.28	0.23	0.20	0.18	0.16

Keyboard frequencies for electronic organs (*)

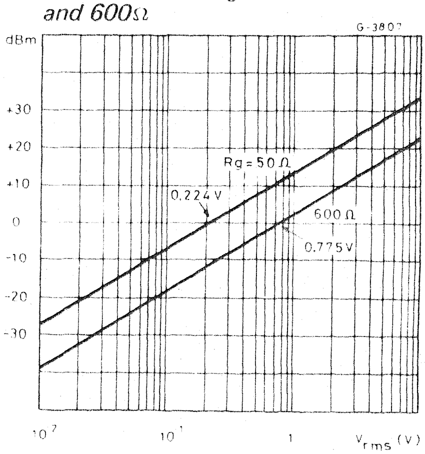
NOTE		OCTAVES								
		0	1	2	3	4	5	6	7	8
DOH	C	16.3516	32.7032	65.4064	130.813	261.626	523.251	1046.50	2093.00	4186.01
	C#	17.3239	34.6478	69.2957	138.591	277.183	554.365	1108.73	2217.46	4434.92
RAY	D	18.3540	36.7081	73.4162	146.832	293.665	587.330	1174.66	2349.32	4698.64
	D#	19.4454	38.8909	77.7817	155.563	311.127	622.254	1244.51	2489.02	4978.03
ME	E	20.6017	41.2034	82.4069	164.814	329.628	659.255	1318.51	2637.02	5274.04
FAH	F	21.8268	43.6536	87.3071	174.614	349.228	698.456	1396.91	2793.83	5587.65
	F#	23.1247	46.2493	92.4986	184.997	369.994	739.989	1479.98	2959.96	5919.91
SOH	G	24.4997	48.9994	97.9989	195.998	391.995	783.991	1567.98	3135.96	6271.93
	C#	25.9565	51.9131	103.826	207.652	415.305	830.609	1661.22	2322.44	6644.88
LA	A	27.5000	55.0000	110.000	220.000	440.000	880.000	1760.00	3520.00	7040.00
	A#	29.1352	58.2705	116.541	233.082	466.164	932.328	1864.66	3729.31	7458.62
TE	B	30.8671	63.7354	123.471	246.942	493.883	987.767	1975.53	3951.07	7902.13

(*) These frequencies can be obtained from a 999680 Hz (or multiples) master oscillator by the following division ratios, and subsequent repeated division by 2

C#	÷ 451	G#	÷ 301
D	÷ 426	A	÷ 284
E^b	÷ 402	B^b	÷ 268
E	÷ 379	B	÷ 253
F	÷ 358	C	÷ 239
F#	÷ 338		
G	÷ 319		

The frequency error in these approximations is less than + 0.069%.

Fig. 67 - dBm and voltage level on 50Ω and 600Ω

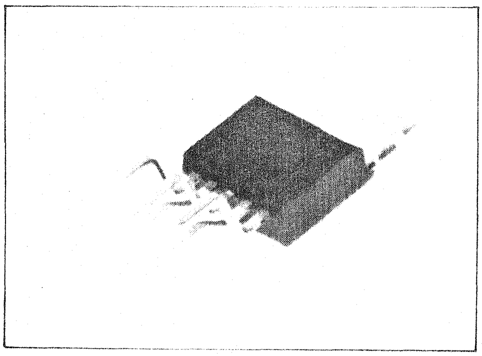


SGS-ATES AUDIO POWER INTEGRATED CIRCUITS

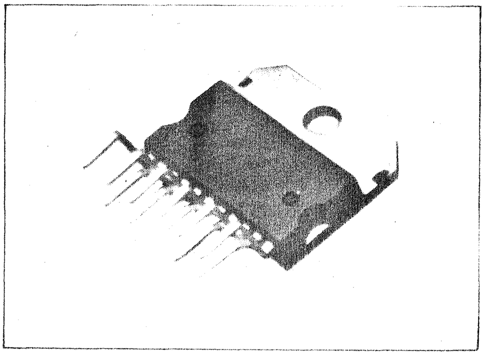
Supply Voltage (V)	Device	Package	Output Power (W) (*)			Typical Applications
			2Ω	4Ω	8Ω	
6	TAA 611A	Metal Can/Dip		0.5	0.35	PORTABLE RADIO
	TBA 820M	Minidip		0.75	0.45	
	TBA 810S	Findip		1		
9	TAA 611A/B	Metal Can/Dip		1.8	1.15	
	TBA 810P	Findip	3,4	·2,5		
	TBA 820M	Minidip		1.6	1.2	
	TCA 830S	Findip		2	1.25	
	TDA 1905	Powerdip		2.5	1.3	
12	TAA 611C	Dip + exter. bar		3	2.1	
	TBA 820	Dip			2	
	TCA 830S	Findip		3.4	2.3	
14.4	TBA 810 P/CB	Findip	7	6		CAR RADIO
	TDA 1905	Powerdip		5.4	3	
	TDA 1908	Findip		5.8	3	
	TDA 2003	Pentawatt	10	6		
	TDA 2004	Multiwatt	10	6.5		
	TDA 2005	Multiwatt			20(**)	
18	TBA 800	Findip			4.5	TV AUDIO AND MUSIC CENTER
	TCA 940N	Findip		9	5	
	TDA 1905	Powerdip			5.5	
	TDA 1908	Findip		9	5	
24	TDA 1905	Powerdip			5.3(°)	
	TDA 1908	Findip			5 (°)	
	TDA 1910	Multiwatt		10	7	Hi-Fi (d ≤ 1%)
± 14	TDA 2006	Pentawatt		12	8	
	TDA 2010	Dip		12	9	
	TDA 2030	Pentawatt		14	9	
± 18	TDA 2020	Dip		20	16.5	

(*) d = 10% @ 1KHz; (**) Bridge Circuit; (°) R_L = 16Ω.

PENTAWATT PACKAGE



MULTIWATT PACKAGE



SGS-ATES GROUP OF COMPANIES
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