

# Designing With Opamps.

*This page is under construction. (Still) Proceed with caution.*

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## INTRODUCTION.

Audio design has for many years relied on a very small number of opamp types. The TL072 and the 5532, numbers that will be immediately familiar to anyone involved in audio electronics, have dominated the small-signal scene for many years.

These numbers are the dual opamp versions; the single equivalents are TL071 and 5534. Dual opamps are used almost universally, as in production the package containing two is usually cheaper than the package containing one, simply because it is more popular. All the IC numbers mentioned here are duals unless stated otherwise.

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## A VERY BRIEF HISTORY OF OPAMPS.

The first opamp to get real exposure in the UK was the National 709, a fairly primitive item which required quite complicated external compensation (which did not seem easy to get right) and was devoid of output short-circuit protection. One slip of the probe and an expensive IC was gone; I for one found this most discouraging, and gave up on the 709 at once. If you're going to quit, do it early.

To my mind, the first really practical opamp was the National 741. See the separate page devoted to it: [The 741 bipolar opamp](#)

There have however been other types that have made some impact:

#### The LM324.

This was one of the first quad op-amps. Its linearity was and is poor, mainly due to the rudimentary output stage, which seemed to have poor current-sourcing capability. No noise-performance specs appear in the manufacturer's data sheet, which is not encouraging. It had some popularity because it was cheap, internally-compensated, and a quad. It may, like the 741, have some historical interest, but I will not be consider it further at present.

#### OPAMP THEORY.

Still in preparation. (ie I haven't started)

#### BASIC OPAMP SPECS.

Just to get the feel of things, here are the vital statistics of the most common audio opamps. Figures are all for +/-15V rails, and all specs are typical, not min or max.

TABLE 1.	uA741	TL072	NE5534A	NJM4556	OPA2134	
Input	BJT	FET	BJT	BJT	FET	
Max rails	+/-15	+/-18	+/-20	+/-18	+/-18	V
Output range	+/-13	+/-13.5	+/-13	+/-11*	+/-17	V
CM range	+/-13	<b>+15 -12</b>	+/-13	+/-14	+/-13	V
En	**	18	4	8	8	nV/rtHz
In	**	0.01	0.7	**	.003	pA/rtHz
Ibias	80	.065	500	50	+0.005	nA
Slew rate	+/-0.5	+/-13	+/-9	+/-3	+/-20	V/us
* with 150 Ohm load			** No spec available			

Some opamp properties in order.

In order of voltage noise density: (@ 1 kHz)

.	en	Input Type
TL072	18 nV/rtHz	FET
OPA604	11 nV/rtHz	FET
NJM4556	8 nV/rtHz	BJT
OPA2134	8 nV/rtHz	FET
OP275	6 nV/rtHz	BJT+FET
OPA627	5.2 nV/rtHz	FET
LM833	4.5 nV/rtHz	BJT
5532/4	4 nV/rtHz	BJT
OP270	3.2 nV/rtHz	BJT
OP27	3.0 nV/rtHz	BJT
AD797	0.9 nV/rtHz	BJT

If you want the lowest voltage noise, it has to be a bipolar input. The differences are however not huge. A modern FET-input opamp such as the OPA2134 is only 6 dB noisier than the old faithful 5532. The AD797 seems to be out on its own here.

#### In order of slew rate:

LM741	0.5 V/us
OP270	2.4 V/us
OP27	2.8 V/us
NJM4556	3 V/us
LM833	7 V/us
5532	9 V/us
TL072	13 V/us
OPA2134	20 V/us
AD797	20 V/us
OP275	22 V/us
OPA604	25 V/us
OPA627	55 V/us

Clearly slew rates vary more than some other parameters; a range of 100:1 is shown here. There are of course faster ways to handle a signal, such as current-feedback architectures, but they usually fall down on linearity. In any case, a maximum slewrate greatly in excess of what is required appears to confer no benefits.

#### OPAMP PROPERTIES: MAXIMUM SUPPLY RAILS

This parameter does not vary much across the usual opamps.

The normal practice when powering a system including TL072s and 5532s is to use +/-17V. This usually allows +20 dBu (7.75 Vrms) signals to be used internally, which is often a handy 20 dB or more above the nominal operating level, and gives a small

but comforting safety margin inside the  $\pm 18V$  rating of the TL072s.

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#### **OPAMP PROPERTIES: COMMON MODE RANGE**

This is simply the range over which the inputs can be expected to work as proper differential inputs. It usually covers most of the range between the rail voltages, but... Those of you viewing in colour will note that Table 1 shows the common-mode range for the TL072 in red. This is to highlight the deadly trap this IC contains for the unwary. Most opamps, when they hit their CM limits, simply show some sort of clipping. The TL072, however, when it hits its negative limit, promptly inverts its phase, so your circuit either latches up, or shows nightmare clipping behaviour with the output bouncing between the rails. The positive limit is in contrast trouble-free. See below \*\* for more details. Other BiFET opamps show similar behaviour; for example the OP-42, OP-249, OP-282, AD711 and AD712. You are however unlikely to meet these parts in audio applications.

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#### **OPAMP PROPERTIES: NOISE**

Table 1 shows how FET input opamps have more voltage noise but less current noise than bipolar input opamps.

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#### **OPAMP PROPERTIES: BIAS CURRENT**

FET input opamps have very low bias current at room temperature; however it doubles for every 10 degree Centigrade rise. This can cause serious trouble in precision DC circuitry that must operate over a wide environmental range, but is pretty unlikely to cause trouble in audio applications.

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#### **OPAMP PROPERTIES: SLEW RATE**

TL072 slewrate is typically  $\pm 13 V/\mu s$

The 5532 slewrate is typically  $\pm 9 V/\mu s$ . This version is internally compensated for unity-gain stability, not least because there are no spare pins for compensation when you put two opamps in an 8-pin dual package. The single-amp version, the 5534, can afford a couple of compensation pins, and so is made to be stable only for gains of 3x or more. The basic slewrate is therefore higher at  $\pm 13 V/\mu s$ .

Compared with power-amplifier specs, which often quote 100 V/ $\mu s$  or more, this may appear rather sluggish. In fact it is not, even  $\pm 9 V/\mu s$  being more than fast enough. Assume you are running your opamp from  $\pm 18V$  rails, and that it can give a  $\pm 17V$  swing on its output, For most opamps this is distinctly optimistic, but never mind. To produce a full-amplitude 20 kHz sine wave you only need 2.1 V/ $\mu s$ , so even in the worst case there is a safety-margin of at least four times.

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## OPAMP CIRCUITS.

There are two basic voltage amplifier configurations: series and shunt feedback.

### SERIES FEEDBACK.

The standard series-feedback opamp gain stage is shown at its simplest in Fig 6. This stage gives a gain of four times (+12dB) and something similar is widely used for fader post-amplifiers in mixing consoles, and after the volume control in hifi preamps. Note that I have assumed that DC-blocking will be required for audio use; hence the input and output capacitors. These are shown as electrolytics as a large value is usually required, especially on the output.

The input capacitor  $C_{in}$  could be non-electrolytic, if  $R_{in}$  is made large enough. If  $R_{in} = 22K$  as shown, a  $1\mu F$  capacitor would give an LF rolloff 3 dB down at 7.2 Hz, which would usually be about right- IF this is not just one stage in a chain of many. 3 dB down at 7.2 Hz means 1dB down at 14 Hz, and 0.2 dB down at 30 Hz, which is definitely inside the audio band. If many of these stages are cascaded (as in a mixer) then the 0.2 dBs-worth gradually build up and you get a very saggy bottom-end to the frequency response.

It is therefore normal practice to make each LF cutoff frequency so low that it has negligible effect in the audio band. If the LF response needs to be defined, which is a good thing, it is in done in one specific stage. Hence the  $47\mu F$  input capacitor here; the -3 dB frequency is 0.2 Hz, giving an attenuation of about 0.0001 dB at 30 Hz. You can therefore cascade any number of similar stages without having to worry about the response sagging.

The output capacitor must be large enough not only to give adequate LF response, but also to avoid capacitor distortion. If the output load is 1K (and this will require something more than a TL072 to drive it with low distortion) then  $C_{out}$  will need to be either  $47\mu F$  (-3 dB at 3.4 Hz) or  $100\mu F$  (-3 dB at 1.6 Hz)

The larger value is desirable, to reduce the signal voltage across the component and so prevent capacitor distortion; this effect determines the capacitor value more than the desired frequency response does.

The series-feedback configuration has the following characteristics:

- High input impedance.
- Minimum gain is unity.
- Less noisy than the shunt configuration, as the Noise Gain ( $q_v$ )\*\* need be no greater than the signal gain.

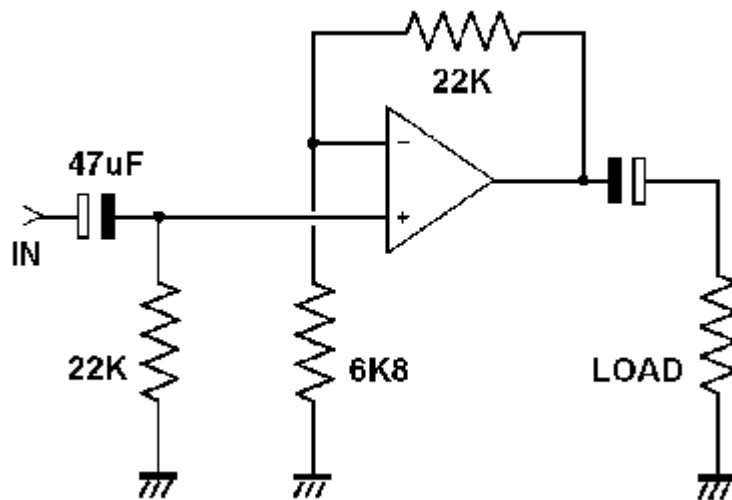


Fig 6

Series feedback opamp stage with gain of 4x. The feedback network values give suitably light loading for a TL072. If a 5532 is used instead the resistor values can be much reduced to minimise Johnson noise.

(opamp2s.gif)

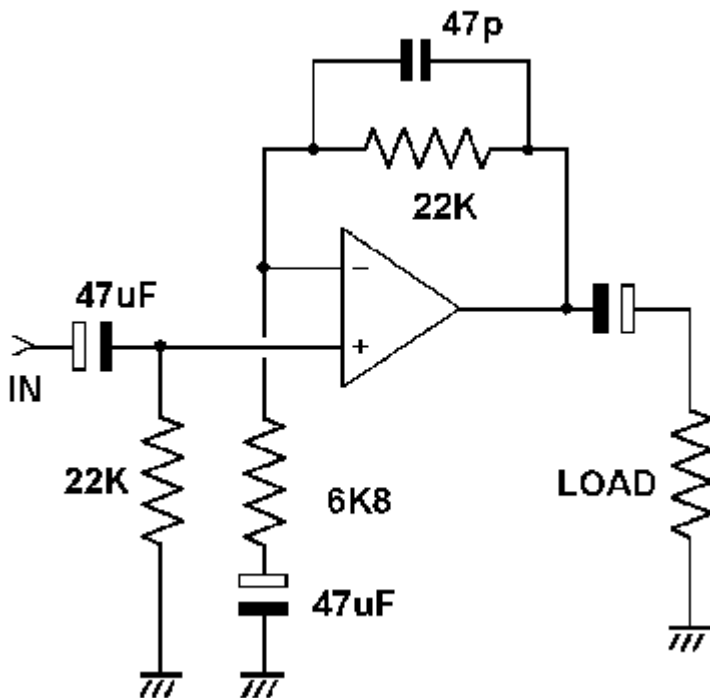


Fig 7

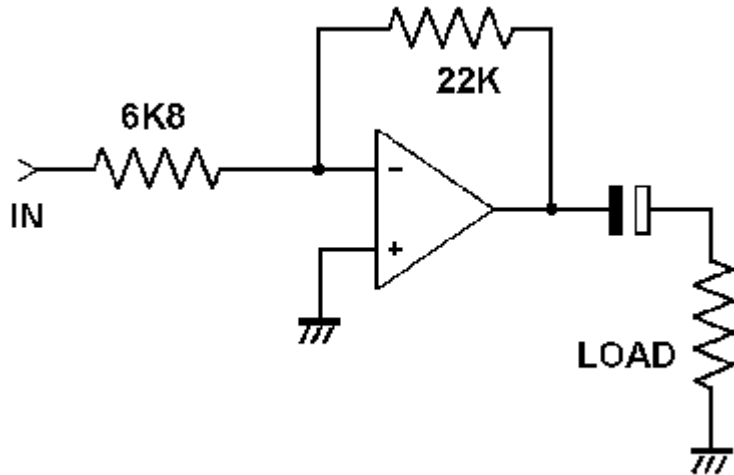
Feedback capacitor  $C_{fb}$  added, so gain is reduced to unity at DC. This is not usually necessary at low gains, but will be required with high gain to prevent input offsets being amplified to the point where they reduce the output swing. 6K8 and 47uF give a -3 dB point at 0.5 Hz, which is low enough to prevent capacitor distortion.

(opamp1s.gif)

### SHUNT FEEDBACK.

The shunt-feedback configuration has the following characteristics:

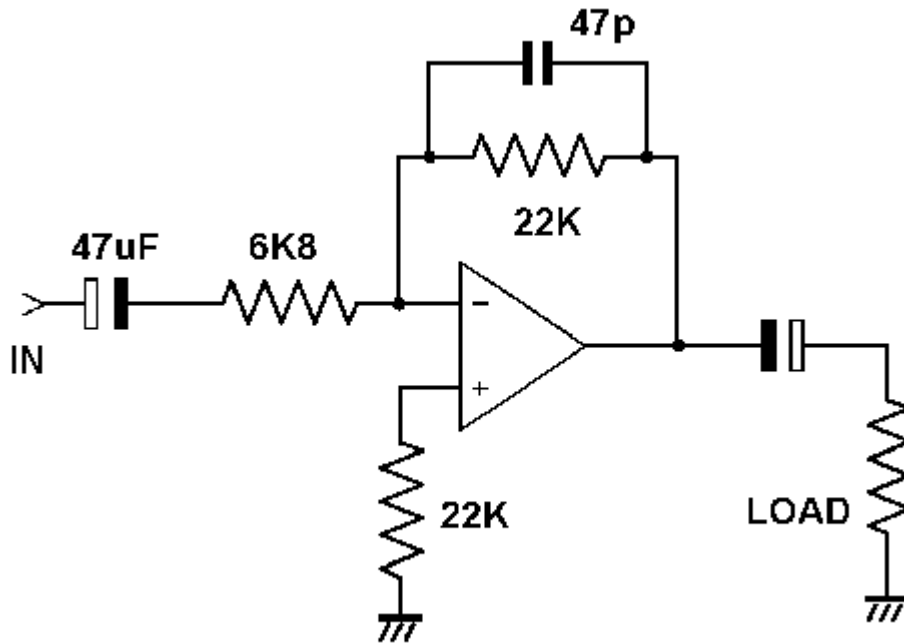
- Low to medium input impedance.
- Minimum gain is zero.
- Noisier than the series configuration, as the noise gain ( $q_v$ ) is always one more than the signal gain. The noise gain of Fig 8 is 4 times.



**Fig 8**

The simplest possible shunt feedback opamp stage with gain of three. No input DC-blocking is shown, but there is a output blocking capacitor.

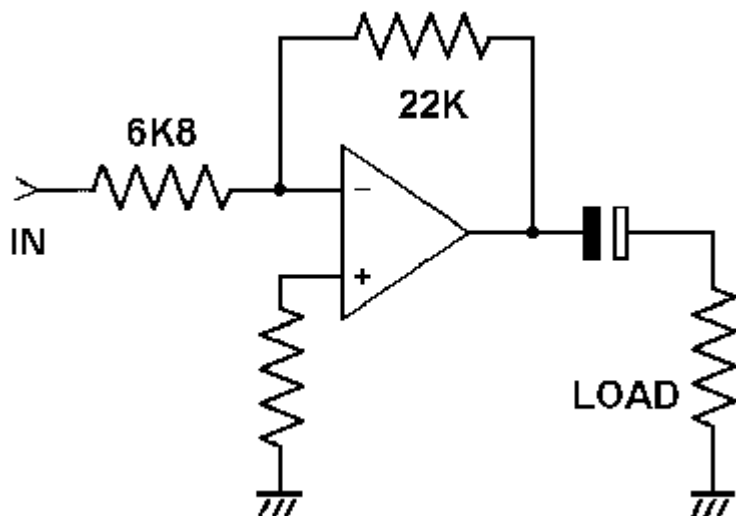
(opamp5s.gif)



**Fig 9**

A shunt feedback capacitor is added, and gain reduced to unity at DC.

(opamp4s.gif)



**Fig 10**

The bias-current causes a voltage drop in R. offset compensation.

opamp3s.gif

### DRIVING HEAVY LOADS.

O/P current boosting for headphone drivers etc.

From the above, it will be clear that the TL072 is only suitable for light loading, and even then its linearity is not good enough for the most demanding applications. The 5532 is much better, but only goes down to 500 Ohm loads.

If you need to drive a load below 500 Ohms, then IC opamps begin to look less attractive. Opamps do exist with a greater load-driving capability, for example the NJM4556A from JRC is capable of driving 150 Ohms, but this device seems so far to have achieved little market penetration. This is may be because the linearity into more common 500 Ohm loads is distinctly inferior to the 5532.

See here for NJM4556 details: [The 4556 bipolar opamp](#)

In some circumstances paralleled 5532 stages are appropriate, as in Fig 12. The distortion for the single section is very high for a 5532, and it is clearly running out of current ability. Adding the second section drops the THD back to almost nothing; this can be a very simple and cost-effective way to solve the problem of driving medium loads.

The gains of the paralleled voltage-follower stages are very closely equal, so there is no current-hogging, the series output resistors allowing for any minor gain mismatches.

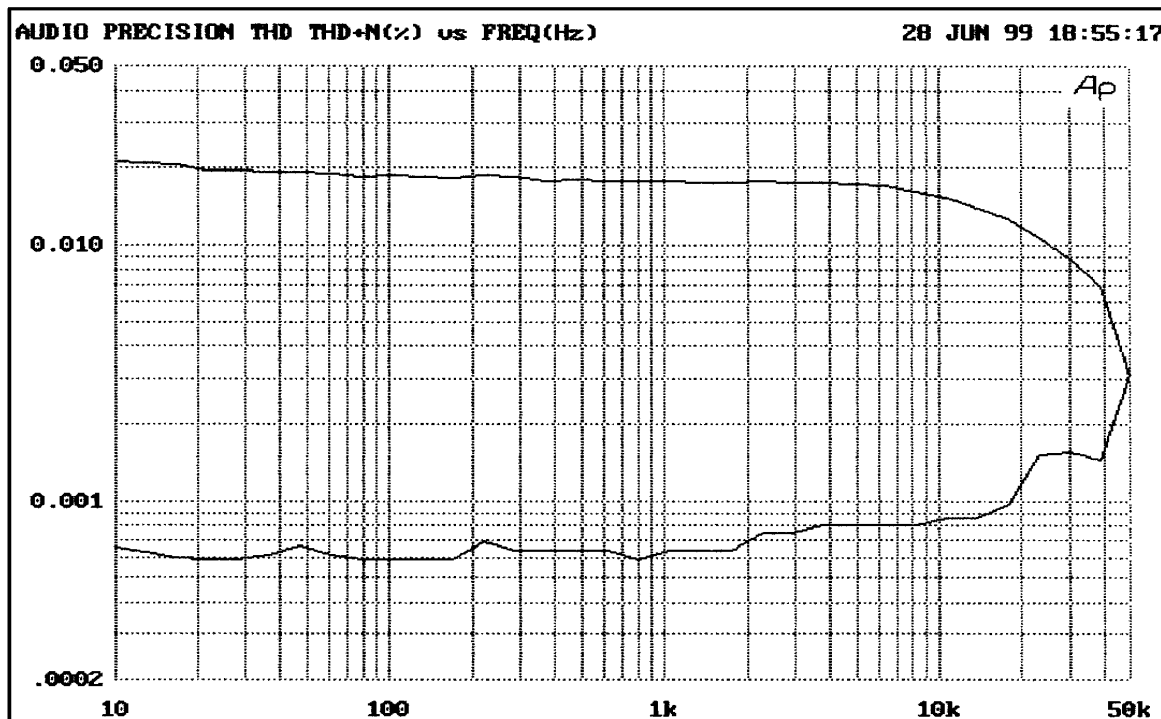
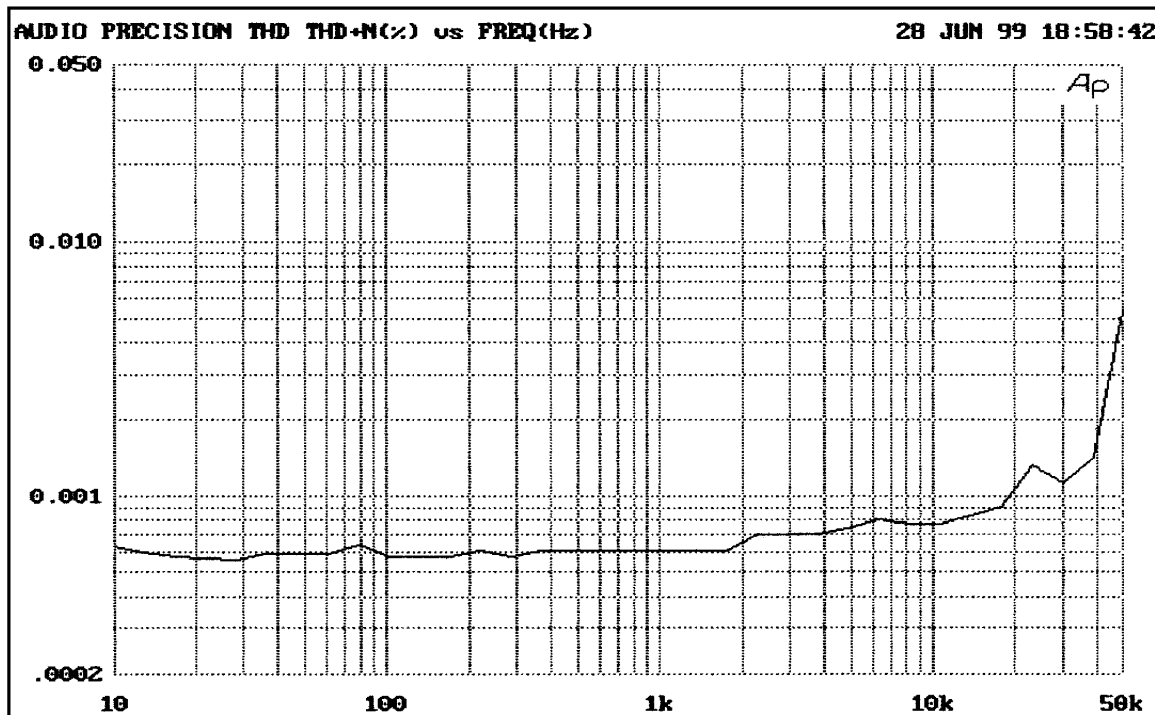


Fig 12  
One and two 5532 section attempt to drive 5Vrms into 22Ω Ohms.

5532x2



Fig 13



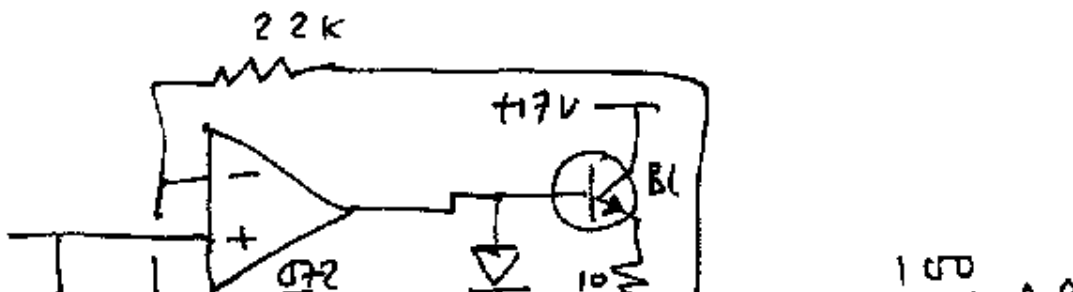
Paralle four 55 section drive 1 Ohms Vrms. plot is almost identical two 55 section driving Ohms 12 abo and it appear as mar be use paralle require

(opamj

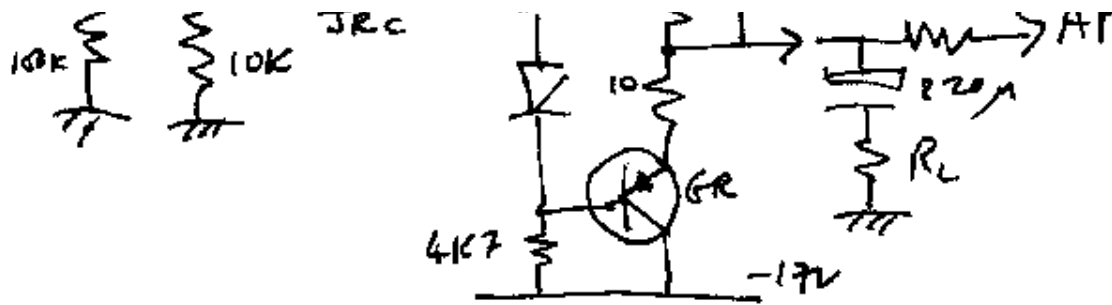
For loads beyond the capabilities of the two halves of a 5532 in parallel, it is usually more economical to adopt a hybrid circuit. These are "hybrid" circuits in that they combine IC opamps with discrete transistors; the name does not refer to thick-film construction or anything like that.

The usual procedure is to add a Class-B output stage after the opamp. A Class-A output stage is perfectly feasible if ultimate quality is required, though the power consumption is naturally much higher.

Fig 14



Combin a TL072 with a discrete Class-E output stage. 7 output devices are TO9 small-signal



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high be

Forgive  
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Bob Pe  
style of  
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time  
being.

hybcct'

The output stage in Fig 14 is the simplest possible version of Class-B, but it really works quite well. Bias is fixed by the two silicon diodes. (eg 1N4148) Inserting extra stages into feedback loops must be done with great care, to avoid adding extra phase-shifts that may cause HF instability; here there seem to be no problems, and no extra stabilising components are required.

To my eye at least, the 4K7 resistor that sets the current through the bias diodes is just begging for bootstrapping; this would minimise current variations in the diodes ought to give better sinking ability. It has to be recorded, however, that with this particular circuitry it seems to make no difference at all to the linearity.

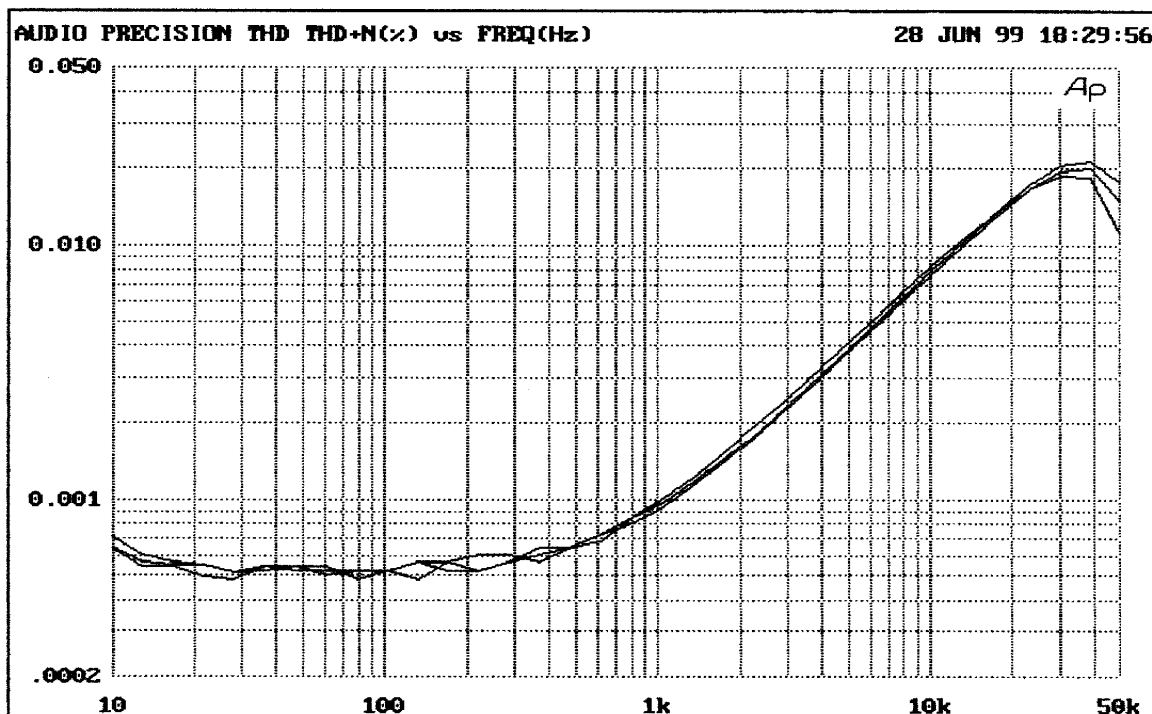


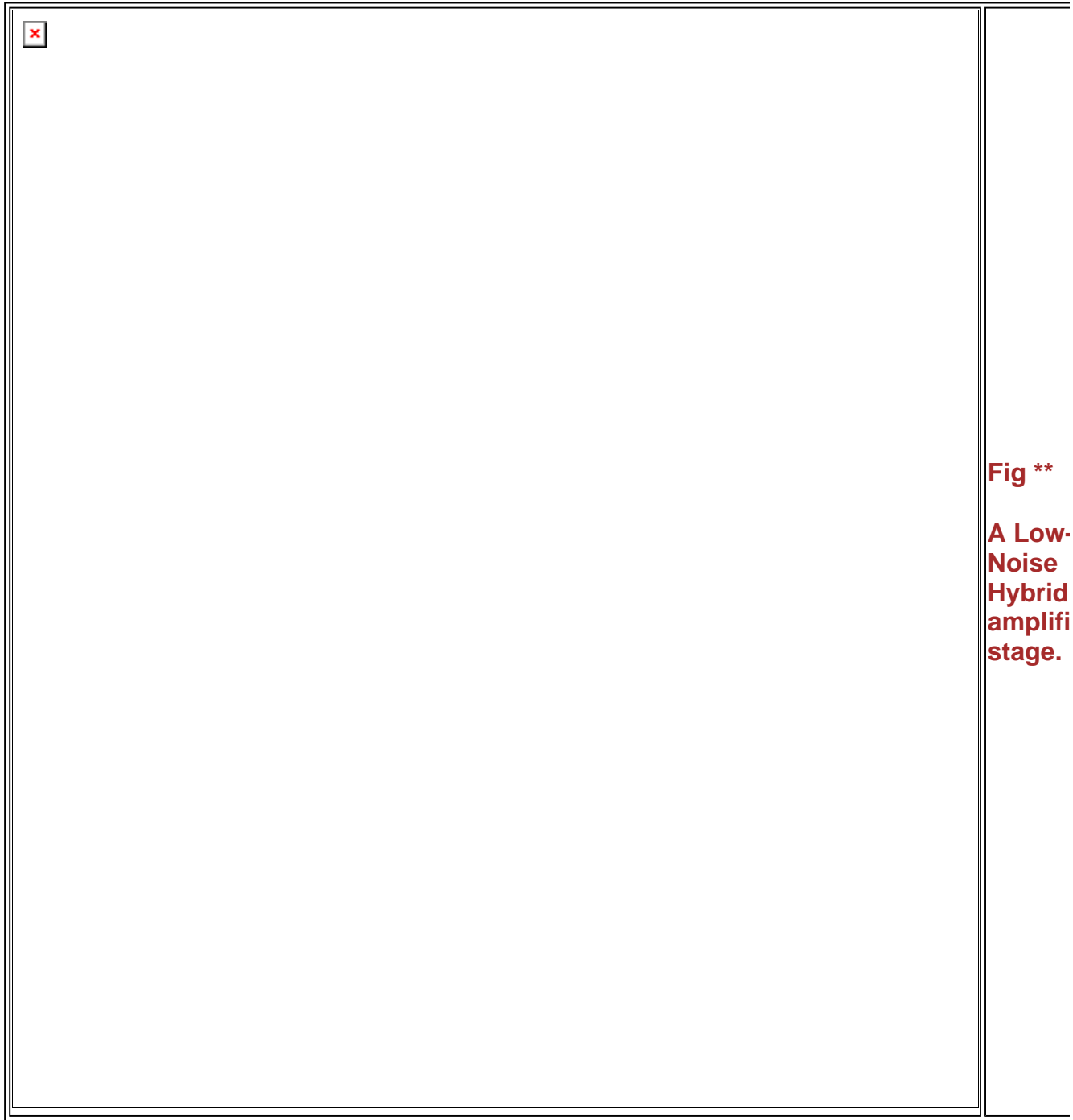
Fig 15

THD  
against  
load for  
TL072  
with  
discrete  
Class-E  
output  
stage. I  
load,  
470R at  
220R  
loading  
Gain 3x  
output  
level  
7.75Vrn

hyb072

**LOW-NOISE HYBRID STAGES.**

Opamps are not capable of the very best noise performance, largely due to the compromises inherent in the manufacture of an integrated circuit.



**Fig \*\***  
**A Low-Noise Hybrid amplifier stage.**

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