DESIGN WITH DISCRETE TRANSISTORS.

TWO-TRANSISTOR SHUNT-FEEDBACK GAIN STAGES.

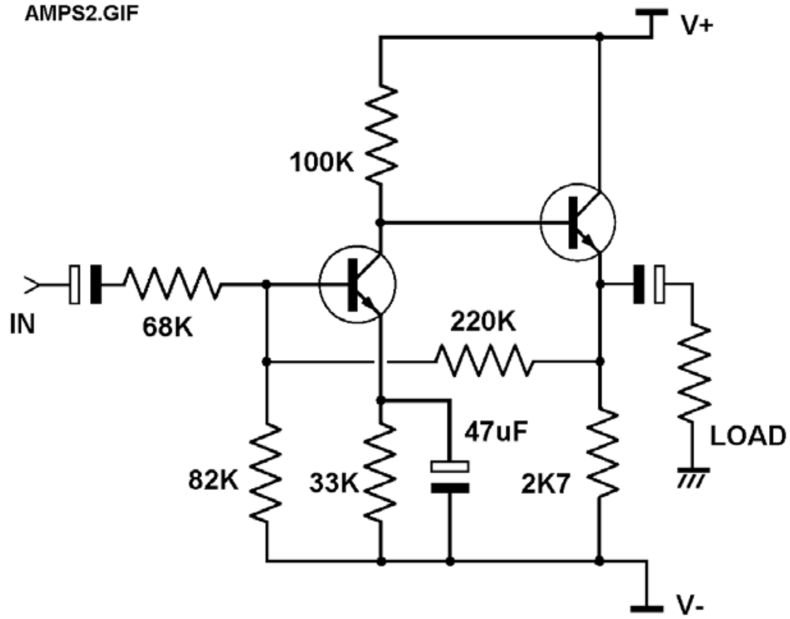


Fig 19 Two-transistor gain stage with shunt-feedback. Gain is three. amps2.gif

Before the advent of the opamp, inverting stages were required for tone controls and virtual-earth summing amplifier. The one-transistor amplifier stage is deficient in many respects, but mainly in the areas of distortion and load-driving capability. A better amplifier can be made with two devices. All the voltage gain is still generated by TR1, but now TR2 buffers it from external loading. The collector load can therefore be of a higher impedance, giving more open-loop gain, and more NFB.

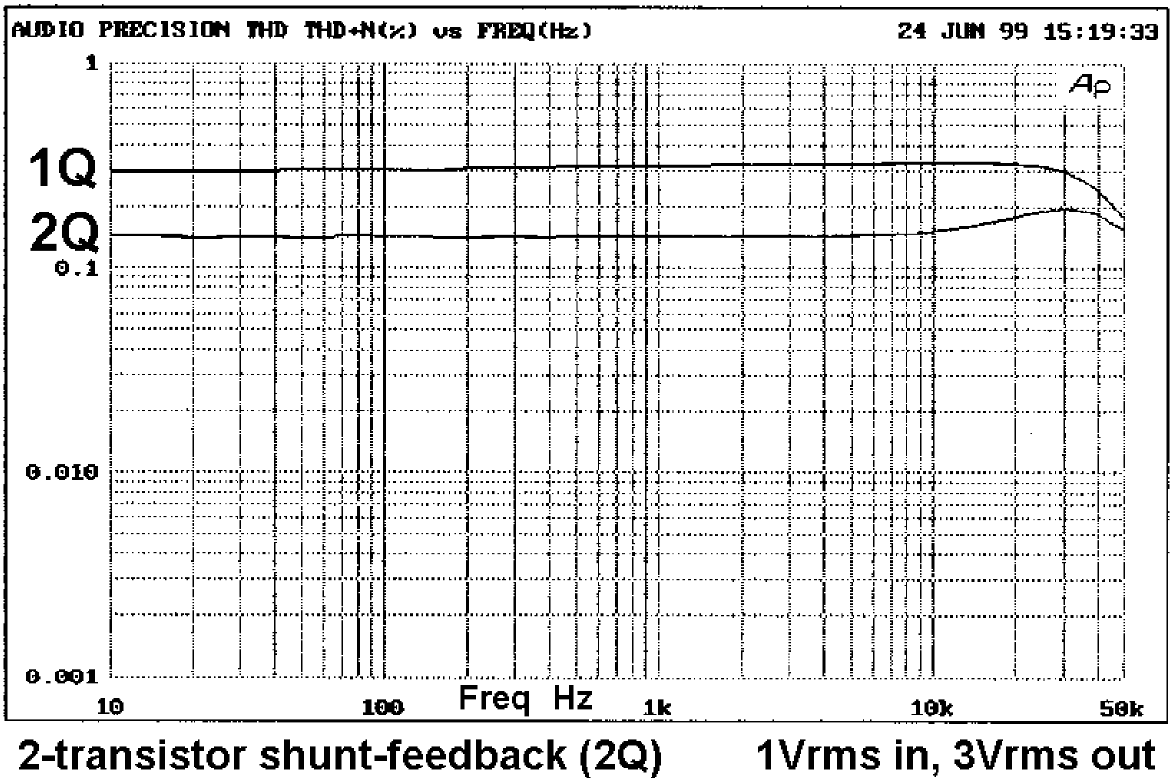


Fig 20: Distortion of two-transistor shunt stage versus freq. (2Q) Distortion of one-transistor version (1Q) is also shown. The two transistor version is only twice as good, which seems a poor return for the extra active device. 12b

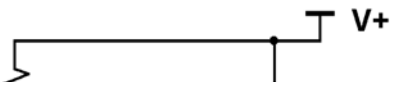
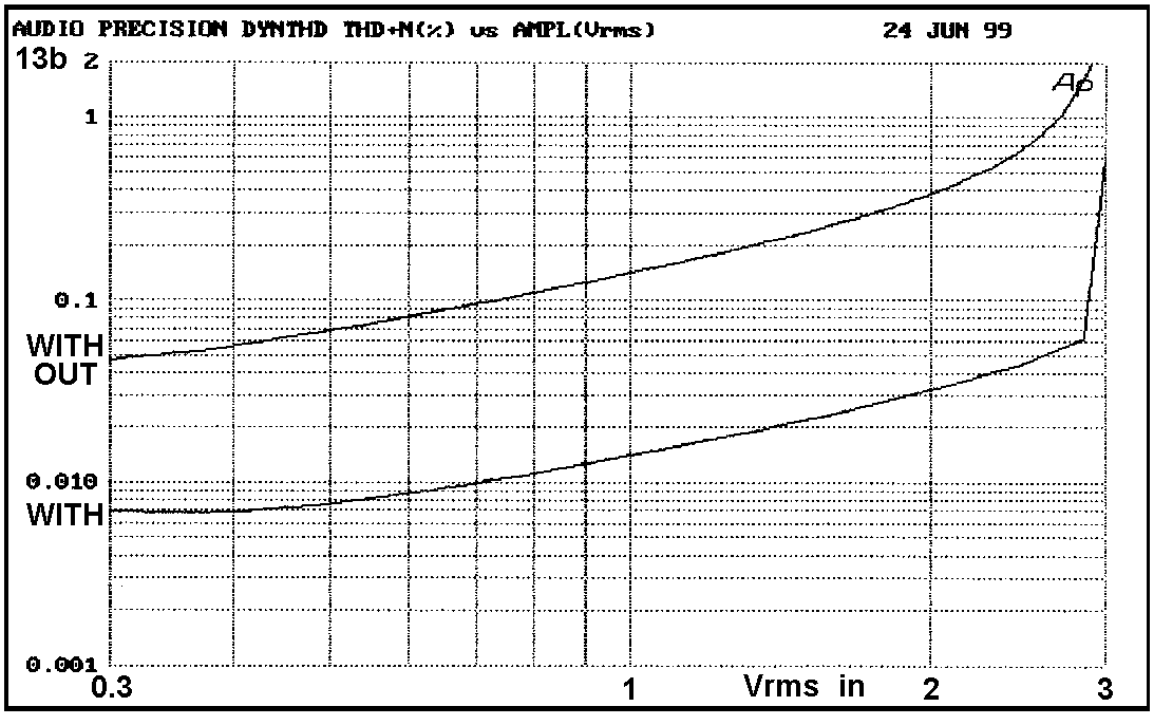


Fig 21: Two-transistor shunt-feedback

stage, with bootstrapping added to the first stage to improve linearity. amps4.gif

With the addition of bootstrapping, the 2-transistor stage has its performance transformed. Fig 22 below shows how THD is reduced by a factor of ten; 0.15% at 1 Vrms in, 3 Vrms out becomes 0.015%, which is much more respectable. The improvement is due to the increased voltage-gain of the first stage. THD is still approximately proportional to level, as the distortion products are mainly second harmonic. As the Fig 25 plot below shows, THD can be further reduced to .002% by reducing the impedance at which the stage is working.
Clipping occurs abruptly at 2.9 vrms in, 8.7 Vrms out. Abrupt clipping onset is characteristic of stages with a high NFB factor.



2-transistor shunt stage, with/without bootstrapping

Fig 23: Distortion of two-transistor shunt stage versus level, with and without bootstrapping. X-axis is INPUT level; output is three times this. (13b)

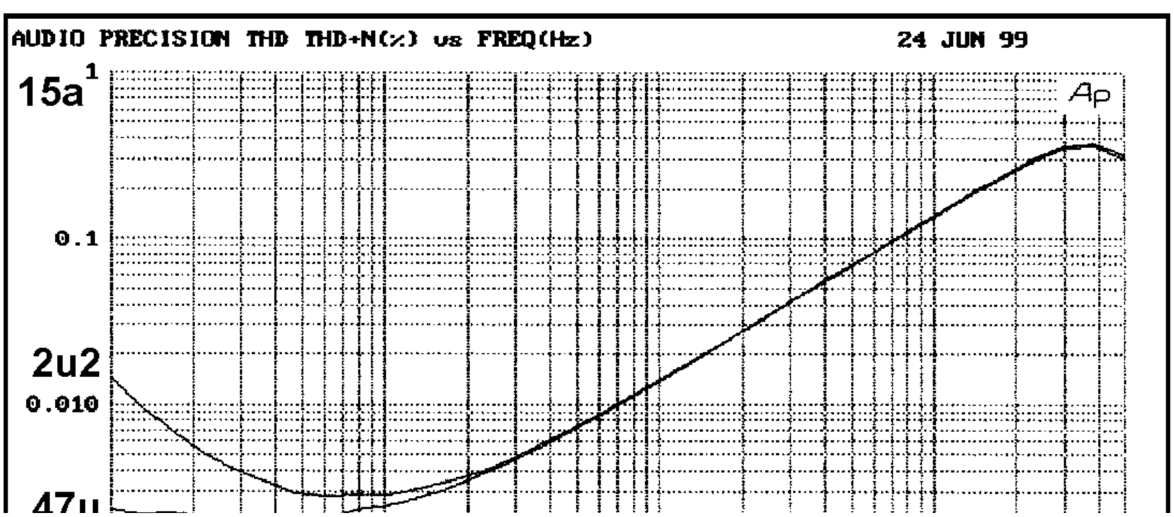


Fig 24: With bootstrapping, the distortion varies strongly with frequency. There is an LF rise if the bootstrap capacitor is too small.

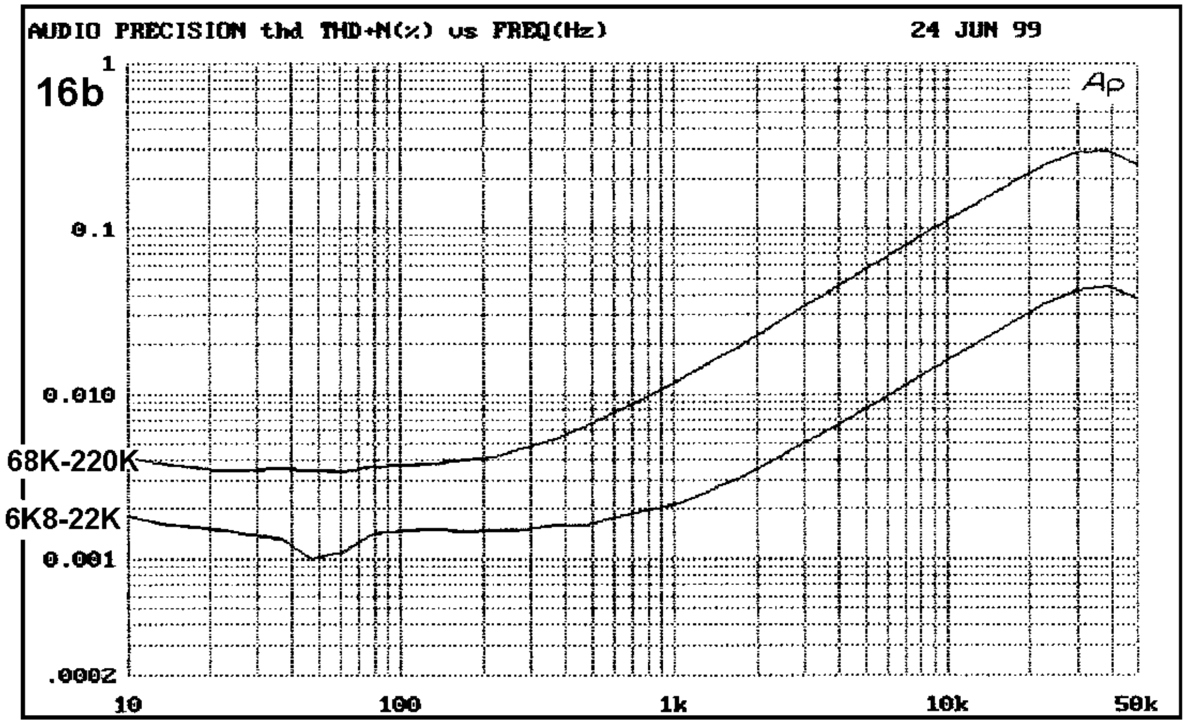


Fig 25: The distortion is reduced by a further factor of at least 5 if the impedance of the input and feedback networks is reduced by 10 times, as shown here. This is because SPICE simulation shows that the input impedance of the first transistor is rather non-linear. With bootstrapping. (16b)

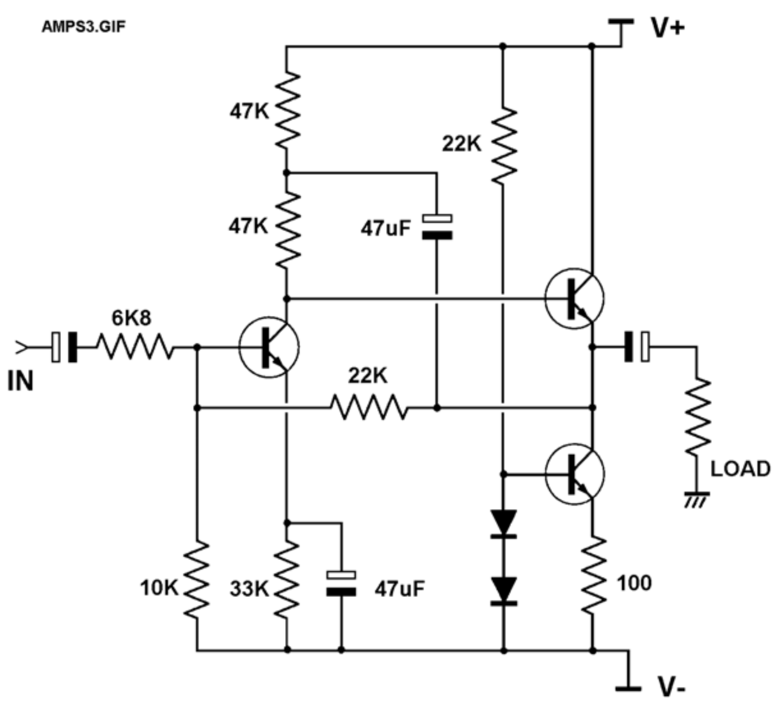


Fig 26: Two-transistor shunt-feedback stage, with current-source output to improve load driving. Note that the input and feedback resistors have been scaled down by a factor of 10. (amps3.gif)

This configuration, like the emitter-followers, can be enhanced to give more output drive capability. A constant-current source or a push-pull output can be grafted on without problems.

TWO-TRANSISTOR SERIES-FEEDBACK GAIN STAGES.

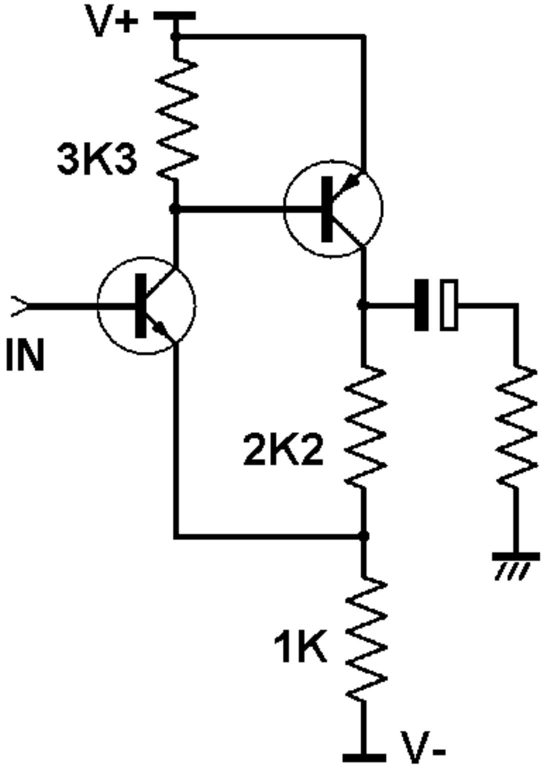


Fig 27 Two-transistor gain stage, series-feedback. Gain once more approximately three. (cfp4.scm)

This circuit clearly has a close family relationship with the CFP emitter-follower, which is simply one of these stages configured for unity gain. The crucial difference here is that the output is separated from the input emitter, so the closed-loop gain is set by the divider ratio.
Only limited NFB is available, so closed-loop gains of two or three times are usually the limit.
It is less easy to adapt this circuit to improve load-driving capability, because the feedback resistive divider must be retained.
Fig 28 below shows that distortion performance depends strongly on the value of the first transistor's collector load, Rc. The optimal value (for linearity, though not necessarily for other performance parameters such as noise) is clearly between 4K7 and Infinity, and appears to be 22K. This does however give an increase in THD above 20 kHz.

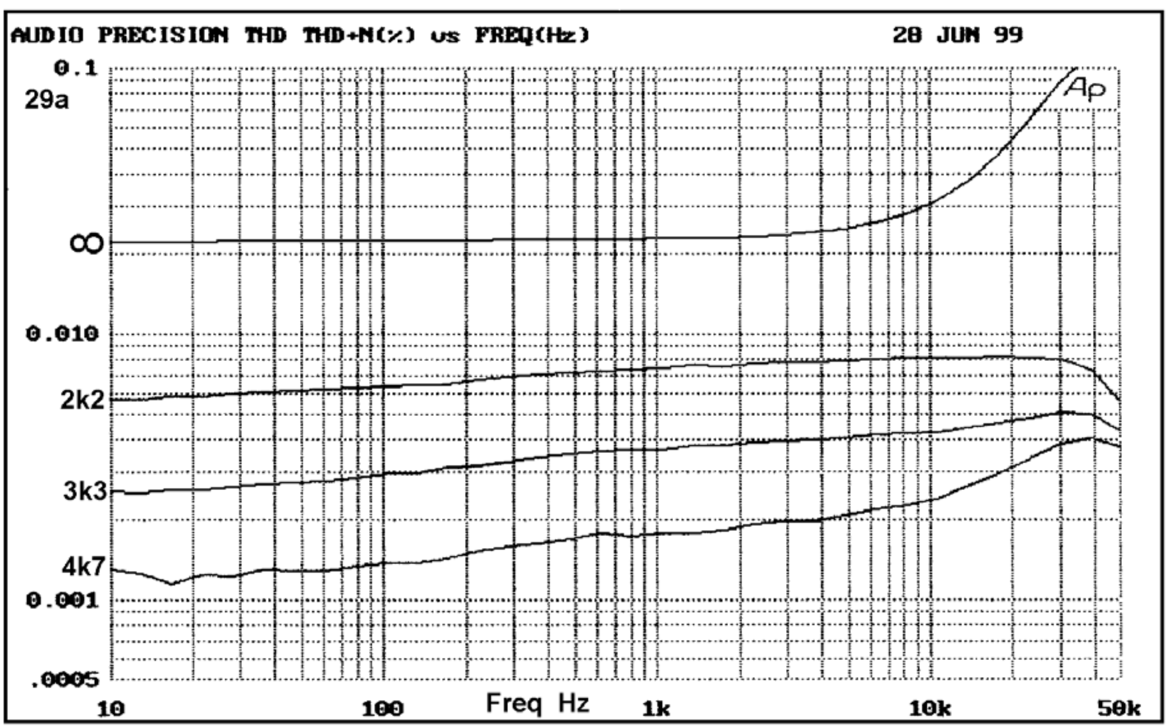


Fig 28 Two-transistor series-feedback stage. THD varies strongly with value of Rc. (29A)

MORE TRANSISTORS: FURTHER ENHANCEMENTS.
Cascoding. The combination of a common-emitter amplifier stage with a common-base transistor

as shown in Fig 29.

Current injection. Sometimes it is desirable (at least I have found it so) to run the two transistors of a cascode at different collector currents. This is easily done as shown in Fig 30.

Sorry: Figs 29,30 not available yet.
