

AUDIO AMPLIFIERS

Designing an amplifier is like re-inventing the wheel. There are thousands of published designs and possibly as many as 100 different types of monolithic amplifiers as well as lot of off-the-shelf modules to choose from. If you design the amplifier yourself (or use someone else's design) you will probably encounter problems such as heat, noise, instability, distortion, power rating etc, etc. In this article Tim Orr sets out to help you cope.

NOT SURPRISINGLY, power amplifiers get hot. When they are delivering power to a load the amplifier is also dissipating a considerable amount of heat itself. A reasonable rule of thumb is that both the amplifier and the load dissipate the same power, except when there is no output signal. Then the amplifier is the only thing that is getting hot.

To get very low crossover distortion it is usually necessary to run the output transistors in an amplifier in class A or AB. This means that the transistors are biased on (or partly on for AB operation). Thus they consume lots of current and get hot. Therefore designing power amplifiers is a compromise between heat production and distortion.

IC power amplifiers, because of their small size, go for low heat generation and hence higher crossover distortion. Discrete component power amplifiers can use large heat sinks sometimes with forced air cooling and thus obtain THD figures from 0.1% to 0.01%.

Some IC power amplifiers get rid of their heat down the IC legs to suitably large areas of copper on the printed circuit board. There are also 'Stick On' heat sinks for DIL packages. Also, when the going gets a bit hot some amplifiers employ a thermal shutdown mechanism. Generally though, high temperature operation means that the device life time is greatly shortened. Thus it is not surprising that the components that fail most regularly are the power transistors in amplifiers and power supplies.

Stability

The only difference between amplifiers and oscillators is the phase of the feedback and so it is hardly surprising that problems can appear. When the phase of the feedback becomes positive then oscillation can occur if the gain of the amplifier is then greater than unity. The gap between a good amplifier and an oscillator is known as the phase margin. When the phase margin is reduced to zero, oscillations will occur.

More feedback when the phase shift is positive will increase the risk of instability. Less feedback when the phase shift is positive will make the amplifier more stable.

However, less negative feedback means more distortion. It is a compromise between stability and distortion. It is possible to increase the phase margin and thus stabilise the amplifier with a suitably placed capacitor. However, in the IC (monolithic) design this is not possible because this capacitor would probably occupy twice the area as the rest

of the integrated circuit. So, the designers of IC power amplifiers usually make this stabilising capacity small and set the amplifier gain high (less negative feedback).

You end up with a power amplifier that is only stable with high values of gain and which has a relatively high distortion. Even so, most monolithic designs need additional capacitors on their inputs and their outputs to maintain stable operation. Other stability problems are:

1) Amplifier gain and phase margin depend on power supply voltages. Thus, an amplifier may not be stable under varying conditions of supply voltage. Turning the power up, the amplifier may emit a squeak or a whoosh, due to high frequency instability.

2) Amplifier gain and phase margin depend on temperature. Thus as the amplifier warms up it may then become unstable, oscillate, the output transistors get very hot and the amplifier burn out.

Alternatively, the amplifier may be unstable only when cold. So you switch on and it squeaks (oscillates), warms up, stops oscillating, cools down, oscillates (squeaks), warms up, etc. etc. (Breaks the ice at parties!).

3) The load put on an amplifier will affect the phase margin. Designing an amplifier that will drive any load is difficult. Often a power amplifier will have a capacitor resistor network from its output to ground. This network is used to increase the phase margin.

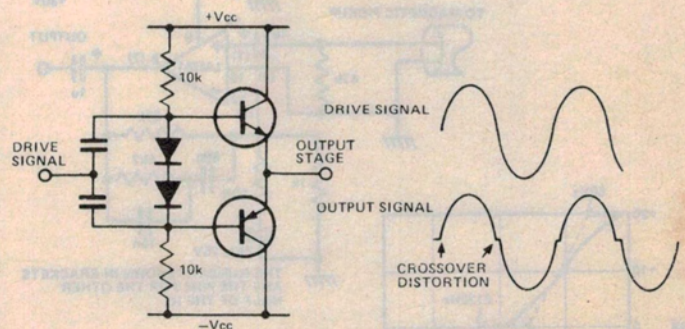


Fig 1 (above) is the classical output pair that produces the equally classical crossover distortion illustrated below. Carefully biasing of the output pair can reduce the effect but it is usually present in most amplifiers of this type.

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Distortion

If you put a pure sine wave into an amplifier and you get out of it the same sine wave plus some harmonics, then you have got distortion. Any other spurious signals are not distortion products and are not included in THD calculations.

Crossover distortion is usually generated by the output transistor pair (Fig. 2). This is caused by one of the transistors switching off before the other one can switch on. The result is a 'lump' in the output waveform which gives the sound a 'buzzy' quality. The distortion can be reduced by turning the output transistors on a bit more, by biasing their bases further apart. This increases the quiescent current and thus more power is dissipated: Also, overall negative feedback can be used to iron out the kinks, but this will increase the chance of instability.

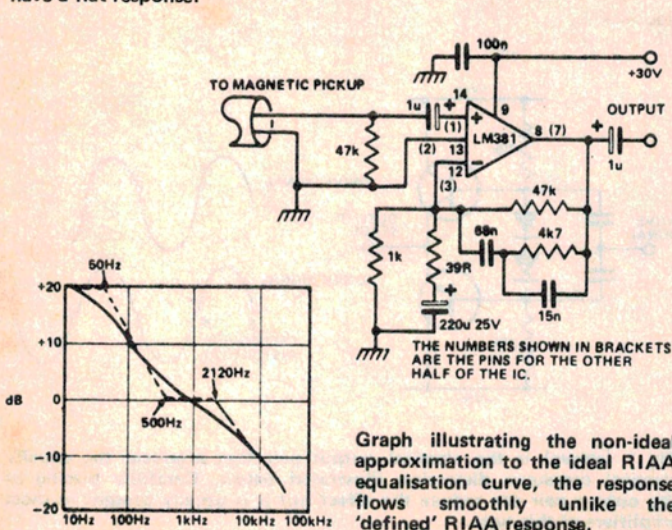
Another type of distortion is harmonic distortion. An amplifier, used in open loop is usually fairly non linear. This non-linearity will cause any signal passing through the amplifier to be distorted. Negative feedback is used to iron out the non-linearities and so reduce this source of harmonic distortion.

It is interesting to note that the hi-fi market wants low THD figures of 0.1% to 0.01% but the music market actually prefers (in some cases) higher figures of about 2%.

Record Player - Magnetic Pickup

If you were to amplify the signal from a magnetic pickup on a record player and listen to it the sound would be terrible. It would be all treble and no bass. This is because the pickup is magnetic and gives an output voltage which is velocity sensitive. That is the faster the needle wiggles in the record groove, the larger the output voltage, or rather the output voltage (for the same amplitude of excursion) is proportional to frequency. To restore the natural sound, the signal must be equalised with a frequency response as specified by the RIAA.

This play back equalisation gives 20 dB lift at low frequencies and 20 dB attenuation at high frequencies and is 0 dB at 1 kHz. No equalisation is required if you use one of the cheaper ceramic pickups, which have a flat response.



Noise

Noise is generally not a problem in power amplifiers but it is in the pre-amplifier stages of an audio system. An overall system signal to noise ratio of 70 dB (3 000 to 1), is quite good and not very difficult to achieve. Better than this is studio or professional quality. When amplifiers are used to reproduce stored signals, such as from a disc, radio or tape recorder, then an overall S/N ratio of 70 dB is quite adequate. This is because the S/N ratio for these storage or transistor systems is quite low.

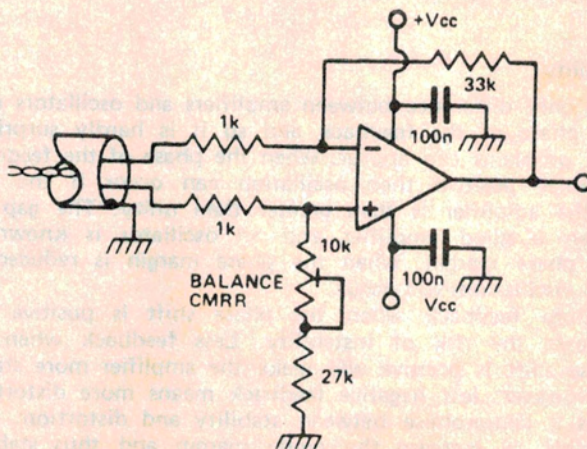
For example the best disc technology will only give us a 60 dB S/N ratio. The best studio quality tape recorder (unprocessed), will give 56 dB. Radio transmissions are about 50 dB on FM, and cheap cassette players only clock up 30 dB's.

The most demanding situations where the noise of a pre-amplifier will be important are in amplifying the signals from low impedance microphones, magnetic cartridges for record players and tape recorder pickup heads. In the following sections there are several examples of low noise pre-amplifier designs.

As tapes and discs are used then their S/N ratio deteriorates. Also, most listening environments have a high background noise level (air conditioning, street noise, jets etc.).

Electronic Balanced Input Microphone Amplifier

It is possible to simulate the balanced performance of a transformer electronically with a differential amplifier. By adjusting the presets the resistor ratio can be balanced so that the best CMRR is obtained. It is possible to get a better CMRR than the one you would obtain from a transformer. Also, a transformer can itself pick up mains hum, it is expensive and heavy. So electronic balancing can be quite competitive. One problem is obtaining a truly differential low noise amplifier. I would suggest a RC4136 which is a quad low noise op amp.

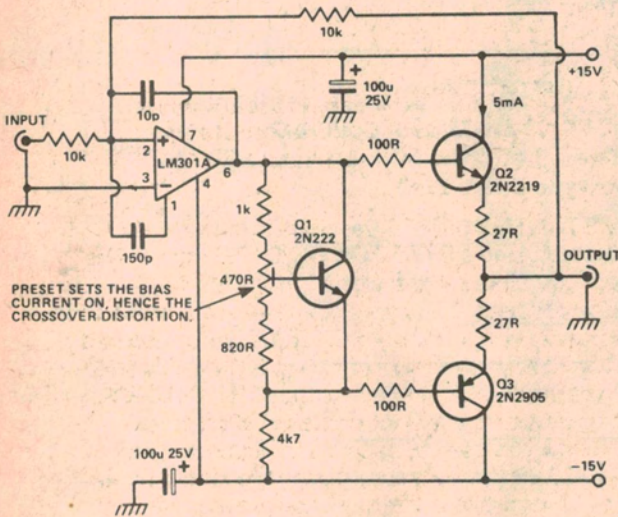


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Unbalanced Line Driver

The high open loop gain of an op amp is combined with the power handling capabilities of discrete transistors to produce a line driver amplifier. The output driver stage (Q1,2,3) is included in the overall feedback, and acts as a power booster on the output of the op amp. Transistor Q1 is used as a V_{BE} multiplier. That is, it sets up a voltage of about 1.5 V between its collector and emitter. The actual voltage can be set by the preset connected to its base. The bases of Q2 and Q3 can be biased apart by a set amount, just sufficient to make them work in class B operation.

If there are any ambient temperature changes, Q1 automatically adjusts the bias voltages to Q2,3 to maintain a constant bias current. There is overall negative feedback from the output, providing a voltage gain of 0 dB (x1). The output is partly short circuit protected by the 27 ohm emitter resistors. This amplifier can deliver high level, low distortion signals into low impedance loads. It could be used as an output driver in an unbalanced audio mixer.



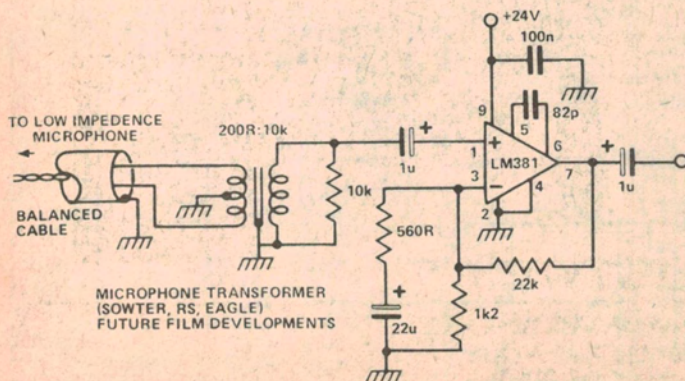
PRESET SETS THE BIAS CURRENT ON, HENCE THE CROSSOVER DISTORTION.

Balanced Microphone Preamplifier

Professional audio equipment generally uses balanced inputs and outputs. This means that the inputs and outputs are differential, which is usually obtained by having balancing input and output transformers.

The advantage of using a balanced system is that any unit can be connected to any other unit without any ground loop problems. A balanced system eliminates these problems. Also, mains hum pick up is reduced. A balanced audio cable has an outer screen and a twisted pair of wires in the centre. Any mains hum (or other signal) which is picked up on the twisted pair will have the same amplitude on each of these central wires. This is a common mode signal. The microphone signal applied to these two wires is a differential signal. Thus, when the microphone signal plus mains hum is connected to the transformer, the differential signal appears at the output windings and the common mode signal is rejected. Thus the mains hum is suppressed.

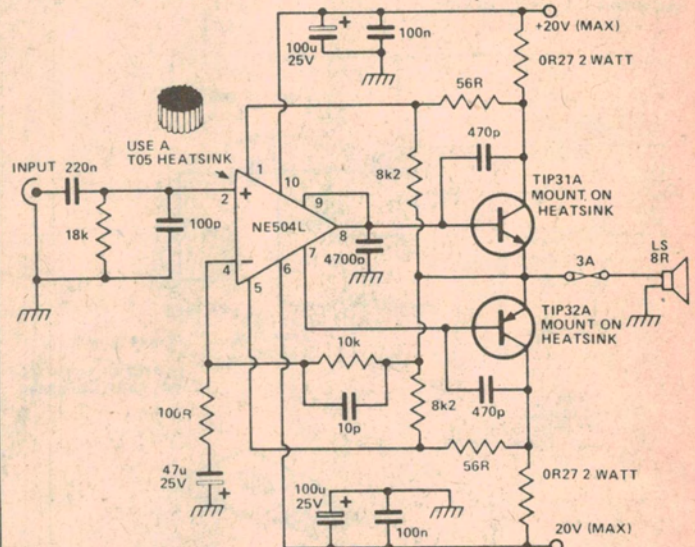
The transformer also provides a voltage gain, and the LM 381 provides a low noise amplification of about 32 dB (x40).



20 Watt Amplifier

An audio power amplifier can be constructed from a power driver op amp plus a pair of transistors. The power driver is a NE540 made by Signetics. It generates quite a bit of internal heat and so a T05 heat sink is required. Note that this design uses five stabilising capacitors.

The amplifier works quite well once any stability problems have been sorted out and the power output is quite adequate for a domestic amplifier system.



50 Ohm Driver

When you want to buffer a test generator to the outside world it is often very difficult to get an amplifier with sufficient bandwidth and power handling to do the job. The circuit is a very simple unity gain buffer. It has a fairly high input impedance, a 50 ohm output impedance, a wide bandwidth and high slew rate.

The circuit is simply two pairs of emitter followers. The base emitter voltages of Q1 and Q2 cancel out, and so do those of Q3 and Q4. The preset is used to zero out any small dc offsets due to mismatching in the transistors.

