AUDIO OUT

By Jake Rothman

Railing against convention – Part 2

Shiftier

I didn't quite have space to finish off my comments on bias shift last month – so here are a few more thoughts.

As an alternative to full regulation on a single-rail supply, only the supply feeding the bias network, input stage and voltage amplifier stages is regulated and only the output stage is fed with the full unregulated voltage. In this case, the upper output transistor of the push-pull stage doubles as a series-pass voltage regulator, effectively blocking the ripple and droop. A voltage loss/headroom of around 10V at no output, reducing to 4V at full output, is necessary; reducing the power output. James Sugden described this in *Hi-Fi News* (*The Class Problem*, November 1967). His main expertise was class-A amplifiers, so voltage sag wasn't a problem, therefore the loss was less. If a separate higher voltage regulated rail is provided, this loss can be avoided altogether, but ripple break-through at clipping will still occur. With a typical power supply regulation figure of 20%, the output power is reduced to 65% – remember, power is proportional to V^2, and that is why the power loss seems excessive.

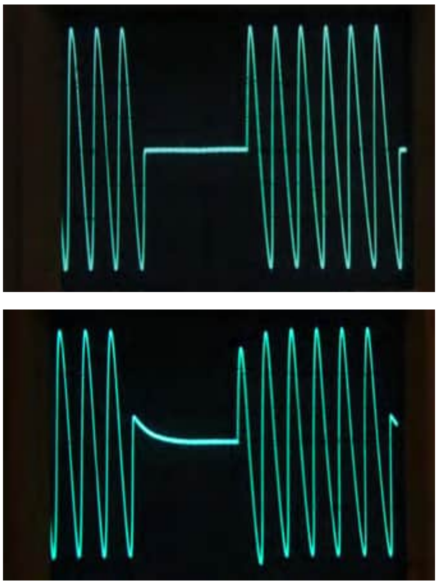

Fig.5 a) (top) Clean tone burst; and b) generation of a low-frequency envelope due to AC coupling.

Capacitor conundrums

Prolonged asymmetrical clipping can cause a DC charge to build up across output capacitors, moving the centre bias point. This is a problem with all capacitor coupling and bootstrapping, causing recovery problems after overload. This problem is compounded by the asymmetry of most music signals. However, this is less of a problem for Hi-Fi amps because they are generally not overloaded. All systems, including dual-rail, with differing AC and DC gains have this problem to some degree and will exhibit a low-frequency shift on the output under tone-burst testing. This is shown in Fig.5a and 5b. Another test is to use an unequal mark-space ratio square wave to see if there is any DC level-shift. (This should be checked with both extremes of mark-to-space ratio.) Any generated shift will often be seen as an odd excursion of the loudspeaker cone.

Asymmetry

In power amplifiers with low quiescent current (I_q), the output capacitor ensures the same I_q current flows through both output transistors in the push-pull stage, rather than some being diverted through the loudspeaker. In a directly coupled dual-rail amplifier, without an output capacitor, a small DC offset can unbalance the currents through the output transistors, increasing crossover distortion. This effect was discussed with regard to the Bailey Amplifier as early as 1969 (*Wireless World*, Oct 1969) and the Equin amplifier (*Elektor*, April 1976). An offset current flowing through the speaker also wastes power, which is bad in any battery-powered circuit.

Overcoming asymmetry in circuits is easily achieved in single-rail systems, since the bias point can simply be moved to ensure symmetrical clipping. To do this in a dual-rail circuit requires different rail voltages. Quad did this on their 34 pre-amplifier by having +8.6 and –9.4V rails. Circuit configurations that generate an offset voltage with dual-rail designs, such as a single transistor, JFET or the dual-complementary pair, will need this. Long-tailed pairs are invariably used for dual-rail amplifiers, increasing complexity and making life boring for the circuit designer.

Power losses

The electrolytic output capacitor (in single-rail systems) causes power loss at low frequencies due to its reactance and equivalent series resistance (ESR). For example, in the MX50 amplifier (*EPE*, May 2017) a

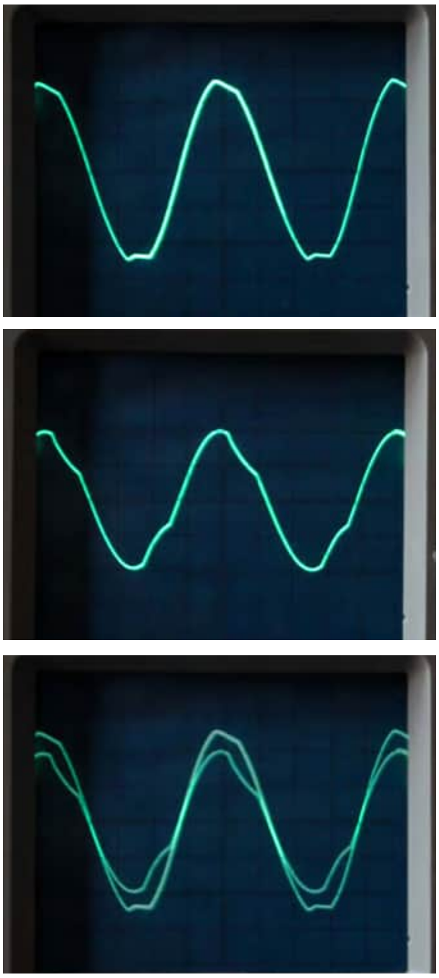

Fig.6. Demonstration of power-limited output caused by approx 2000µF coupling capacitor driving full power into a 4Ω load at 20Hz: a) (top) direct coupling (no capacitor); b) (middle) 2000µF capacitor coupling; and c (bottom) comparison of both curves.

Fig.7. The 'head-bang' test demonstrates the resonant frequency of a loudspeaker and damping effects – thanks to Isabella Rothman for modelling the technique.

non-polarised capacitor of 1880µF (4 × 470µF 35V in parallel) was inserted in series with the output. At 20Hz, and feeding a 4Ω load resistor, the maximum power of 78W_{rms} was reduced to 36W. Fig.6 shows these waveforms slightly clipped with the characteristic slope of reactive power limiting. The reactance caused most of the loss, being 4.23Ω and the ESR, 0.05Ω. In theory, the peak dissipation of the output devices could be increased due to phase shift between the current and voltage, but the capacitor's phase angle is generally much less than that due to the loudspeaker's varying impedance.

Single-rail circuitry does require more capacitors for DC blocking, and the half-rail polarising voltage is advantageous if tantalum types are employed, since their distortion is reduced.

(Do note that it's a myth that coupling capacitors can be completely avoided in dual-rail DC-coupled audio circuits, since switch clicks and pot scratching still occur due to small offsets. Capacitors still have to be used to block these.)

Fig.8. A massive output capacitor has no distortion, but distorts one's bank account.

Head banging and damping

Some engineers claim an output capacitor ruins the damping of the bass driver's fundamental resonance. This is not the case, since the impedance of the capacitor (X_c = 0.7Ω for 4700µF at 50Hz) is much less than the impedance of the voice coil at the speaker's resonant frequency. If you need practical proof of this, listen to the resonance of a speaker using the 'head bang test' (shown in Fig.7) by banging a speaker next to one's ear. This demonstrates the speaker's resonance, which will be heard as a short, low-frequency tone. Banging it again with the terminals short circuited (to simulate the low output impedance of an amplifier) will damp the speaker and it will sound completely dead. Doing it again, but with a 2200µF capacitor connected across the speaker terminals will be equally damped. This shows the subjective issues with output capacitors are not due to reduced damping.

Remember, the impedance of the speaker rises at resonance so the effect of the capacitor is even less at this frequency compared to the speakers nominal impedance. This gives rise to the paradox that for a given capacitor, the bass roll-off is at a lower frequency than that calculated for the speakers stated impedance value. Because of this effect, output capacitors are not as detrimental as believed when small closed-box Hi-Fi speakers are used. However, if the capacitor is too small there will be a bump in the frequency response at the resonant frequency and rapid bass loss below. There is an optimum value for a given speaker/box volume for best bass. This became a technique developed by KEF who included a bipolar electrolytic capacitor in series with the bass unit. (Note that ported enclosures are best driven directly – no output capacitor.)

Massive attack

The Sugden A48 went overboard in curing output power losses caused by the output capacitor. It used a huge 10,000µF output capacitor (hence, very low reactance) to enable the amplifier to drive low impedances. Doug Self also showed that making the output capacitor very large (100,000µF, eg the one shown in Fig.8.) meant that the capacitor distortion became insignificant.

Negative feedback

One way of reducing the problems associated with output capacitors (in single-rail designs) is to include them in the amplifier's negative feedback loop. Taking negative feedback after the output capacitor almost eliminates its detrimental effects, apart from the low frequency power loss. The basic idea is shown in Fig.9, where the negative feedback is split into a DC path and an AC path to set the gain via the output capacitor. To reduce the capacitor distortion effectively the resistance of the DC path needs to be 10x the AC path so there is 20dB of feedback remaining across the output capacitor. For dual-rail amplifiers (if a capacitor is used) a bipolar capacitor or two standard electrolytics connected back-to-back is needed since there is no polarising voltage.

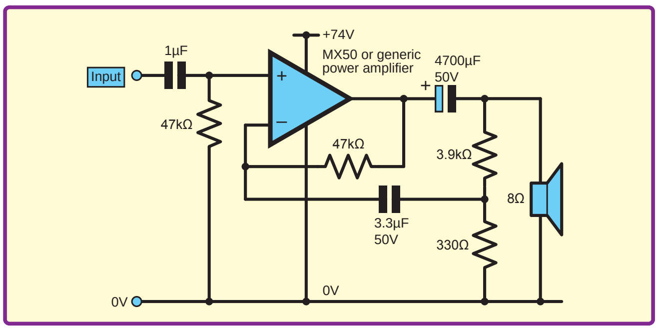

Fig.9. Incorporating a cheap output coupling capacitor in a feedback loop reduces its distortion and output impedance to that of a large expensive one. Engineering is often a case of brains vs material.

Next month

In Part 3 we will conclude this short series by applying some of the ideas discussed to the MX50 amplifer.

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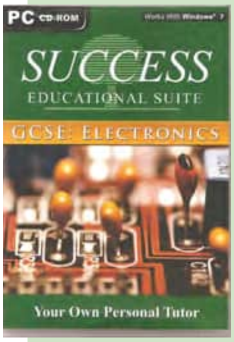

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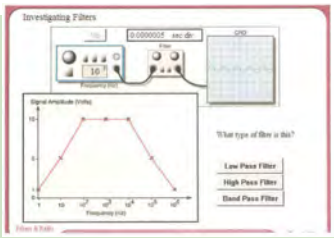

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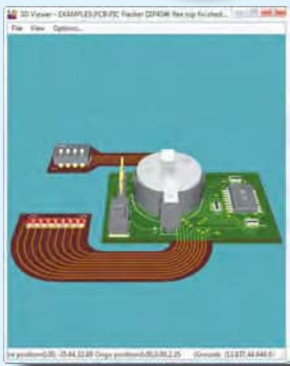

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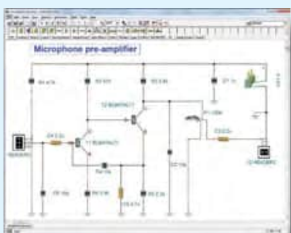

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