STAN CURTIS* looks afresh at some points raised in the Great Amplifier Debate

Amplifier Noise & Clipping

THE first two contributions to the 'Great Amplifier Debate' in the January 1978 issue of *HFN/RR* proved to be very readable, thought-provoking stuff, but unsupported by any scientific rationale. Ralph West's thoughts on noise were particularly unusual, so I think the subject of amplifier noise should be briefly examined before we look at Ralph's new theory.

There are three main types of noise encountered in electronic circuits. These are thermal noise, low-frequency (*l/f*) noise, and shot noise. Thermal noise is the most familiar effect, and is the result of random thermally excited vibration by charge carriers in a conductor, as first observed by J. B. Johnson in 1927. For this reason it is often called 'Johnson noise'. Thermal noise is composed of frequency components that have the same power in each Hertz of bandwidth; thus a Fourier analysis gives a flat plot of noise versus frequency. This noise can be termed 'white noise'. A simple equation defines the thermal noise generated in a conductor:

The RMS noise voltage

$$E_r = \sqrt{4KTR\Delta f}$$

Where Δf = noise bandwidth of the measuring system

$4KT = 1{\cdot}61\times10^{-20}$ at room temp (290°K)

R = resistance of the conductor

The wider the bandwidth the more noise is measured, more or less indefinitely, following the old theory—'open the window wider and more muck flies in' (see fig. 1). Equally, the higher the *resistance* of the conductor, the higher the level of noise. So, theoretically, capacitors and inductors generate no thermal noise. In practice, of course, both have some internal DC resistance (e.g. dielectric losses in a capacitor) so these components cannot be considered entirely free of noise. Resistors generate an additional type of noise termed 'excess noise'. This usually occurs when a direct current flows through a granular material such as that in a carbon resistor. It can be visualised as electric current arcing across between the individual granules, giving a form of low-frequency noise. Carbon resistors are particularly noisy in this respect. Progressively better are carbon films, metal-films, thin films, and wirewound resistors—the latter generating practically no excess noise.

The second classification of noise, low-frequency or *l/f*, is also known variously as 'flicker noise', 'pink noise', 'semiconductor noise' and 'contact noise'. Its main characteristic is that its intensity increases, without limit, as the frequency decreases. Researchers have measured *l/f* noise as low as 6×10^{-5} Hz, which corresponds to a cyclic period of some 4½ hours. One can almost visualise the DC-coupled system where some awful event happens five times a day!

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Fig. 1 (a) WIDEBAND WHITE NOISE

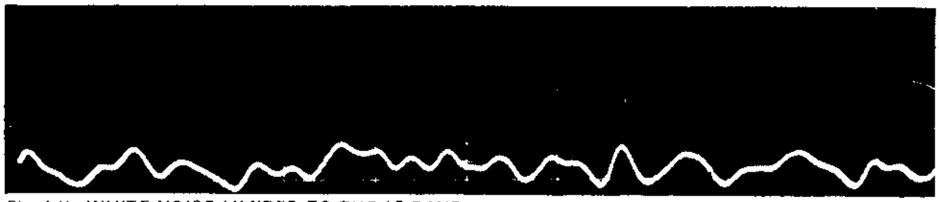

Fig. 1 (b) WHITE NOISE LIMITED TO THE LF BAND

This *l/f* noise is quite common, being found in most electronic components, e.g., valves, transistors, diodes, resistors, etc, so it is impossible to build an amplifier which is totally free of low-frequency noise.

The third classification is 'shot noise', which is observed in both valves and semiconductors. The origin of such noise can be described as follows. Current flow through, say, a valve, is not smooth and continuous but is made up of pulses of carriers each carrying an electric charge. The pulsing is irregular and is referred to as 'shot noise'. A similar potential barrier (anode to cathode) exists in the transistor, most importantly the emitter-base junction where the same pulsing movements of charge carriers take place.

However, as Ralph West correctly points out, valves have a 'space charge' between their electrodes and this tends to smooth out the current flow. In doing so it reduces the shot noise to less important levels. To avoid confusion, however, it should be remembered that despite its emotive name shot noise is white noise having equal power across the frequency band, and not, as is often thought, a particularly nasty form of low frequency noise.

Let us consider a transistor amplifying stage and its sources of noise. Firstly, thermal noise is contributed by the resistors in the circuit, particularly the base biasing resistors. As far as the transistor itself is concerned the two main noise sources are: (i) thermal noise of the base-resistance, and (ii) shot noise of the collector current times the emitter resistance. Thus low noise can be ensured by selecting a transistor with a low base resistance and by operating it at a low collector current (e.g. less than 100 μA). The level of low frequency noise is again dependent upon keeping the base resistance low. This *l/f* noise is caused by charge carriers being interrupted in their flow by impurities and defects in the surface of the transistor. Thus it is dependent upon the manufacturing process and the encapsulation of the 'chip'. It is preferable to use a transistor encapsulated in a hermetically sealed metal can, and not to substitute transistors from a different manufacturer to the original. Another help in reducing low-frequency noise is to limit the LF bandwidth at the second or later stage, to roll-off the lower frequency components of the noise.

As Ralph West again points out, the use of RIAA equalisation on the most sensitive input (with its 19 dB boost at 20 Hz) increases the level of *l/f* noise and low-frequency components of the white noise. When a low-level signal is passed through a noisy amplifier it will look fuzzy and hazy (fig. 2), but when that same signal is subjected to RIAA equalisation the effect is disconcerting (fig. 3).

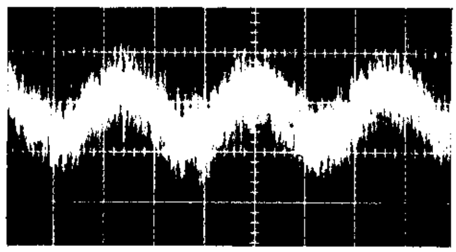

Fig. 2: SINE WAVE SIGNAL IN WHITE NOISE

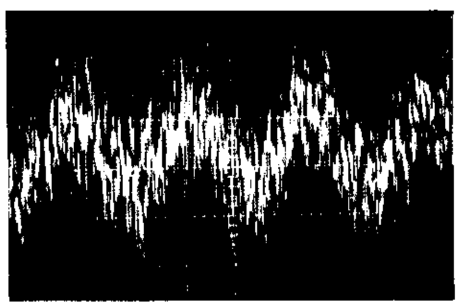

Fig. 3: SINE WAVE SIGNAL IN WHITE NOISE AFTER RIAA EQUALISATION

Some other considerations arise in relation to RIAA correction. Referring to fig. 4, if the LF bandwidth is determined primarily by C1, then the *l/f* noise generated by A1 is allowed through to

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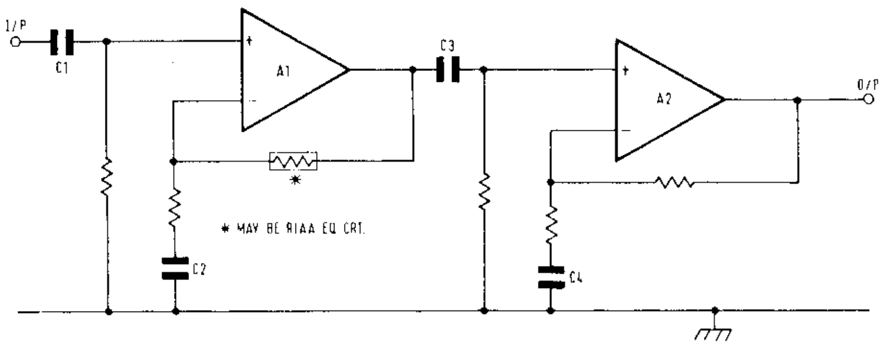
FIG. 4 EFFECTS OF INPUT STAGE COMPONENTS (SEE TEXT)



stage A2. This does not happen if the overall LF bandwidth is set by C3 and C4. However, it may be desired to limit A1 input bandwidth because of its poor overload capability at ultra-low frequencies, in which case some compromise may be necessary, although a better solution would be a linear input stage with RIAA equalisation at a *second* stage.

Returning to white noise in general, let us now consider whether this noise can account for the difference in 'sound' between a valve and a transistor amplifier. In a correctly designed system the signal-to-noise ratio is determined by the first stage, so let us consider that. The first transistor will normally be operated at low collector current, say 100 μA. Now this is a standing DC current and will be increased or decreased as the signal current is added, so let us assume that the collector current varies over the range 50–150 μA. How does this affect the noise? Fig. 5 shows the dependence of noise figure on collector current for several source resistances and typical low-noise transistors. If we assume the optimum source resistance to be 1 Kohm, then the variance in noise figure would be less than 1 dB. Also, the curves show that this small degree of NF variance is true whether the source resistance be 200 ohms or 10 Kohms, and only worsens above 10 Kohms and a higher noise frequency bandwidth. It is likely, therefore, that such a change would be swamped by the other static noise in that stage. It can be seen that the variance in noise level will be even less at lower signal levels. So it seems that Ralph's 'modulation noise', attractive though it is as a concept, must go out of the window. Assuming, that is, that the amplifier in question is of a half-decent design—and most are!

Now to look at the problem of 50 Hz and 100 Hz hum. I cannot comment too deeply on the results of the modifications made to Ralph West's Quad II valve amplifier, but if time permits I will try the modifications on my own Quad IIs. Only one thing worries me: are original condition Quad amps worth more than 'improved' and modernised versions? I suggest that the improvement in sound quality will be found to be due to more than a reduction in HT ripple. It is always dangerous to make an assumption when so many variables have been changed, e.g. ripple rejection, output valve bias, HT supply level, supply impedance, etc.

However, if we assume for a moment that ripple is the culprit, can the same improvement be expected with a transistor amplifier? If we examine a typical good quality transistor amplifier (with its nasty, crude power-supply) we will usually find that it is designed as a balanced symmetrical differential device. In such an amplifier, ripple rejection is virtually dependent upon the balance of the first stage. It must be admitted that some amplifiers are poor in this respect and as a result will be found to have a low-level (but just audible) 100 Hz saw-tooth waveform at the output. As the output rises, more current is drawn from the supply, the ripple increases dramatically, and the output ripple rises and so helps to make the sound generally more muddy and edgy. Whereas noise may often be masked during loud passages (a factor most noise-reduction systems rely on), the same is not completely true for 100 Hz ripple. Noise is random, whereas hum is a repetitive signal that the ear can lock onto. In my own experience I found this to be a problem with the Cambridge P50 unless care was taken to match the r_e of the input-stage transistors in the power-amplifier. In all fairness, though, I have found several Japanese models to be far worse than the old Cambridge amp.

However, modern power amplifiers have ripple-rejection of 90 dB or more, so the problem is not normally encountered. I have tried operating such an amplifier with a much improved power supply and there was no audible change in noise level or 'openess'. The bass 'sound' changed in character, but that was a function of the power supply having a lower output impedance and better regulation. (Again, be careful of false assumptions.)

To be fair to Ralph, I have found some amplifiers to have excellent ripple-rejection under quiescent conditions but to have far worse rejection under large signal conditions. Intermodulation can then occur between the ripple and the signal to produce sidebands, with a consequent loss of definition. But as I feel that Ralph West's ideas (on this occasion) are more armchair thoughts than the result of research, I decided it would be useful to try some crude tests to probe the theories.

A listening test was set up using a Quad II amplifier system. Arrangements were made to inject LF noise of below

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FIG. 5 NOISE FIGURE DEPENDENCY ON COLLECTOR CURRENT AND SOURCE RESISTANCE

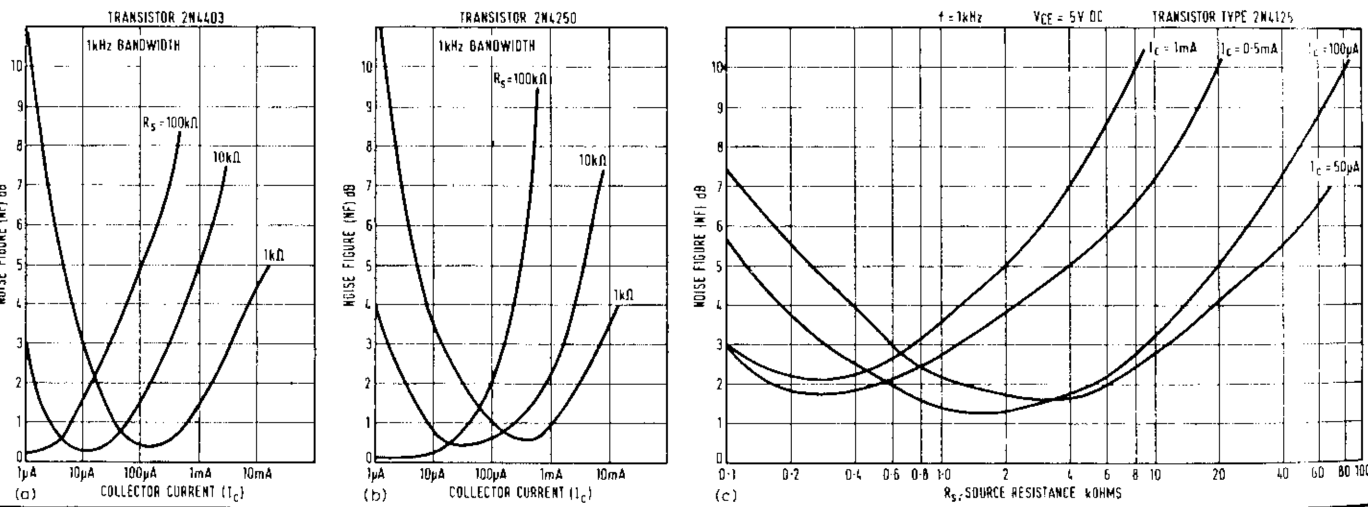
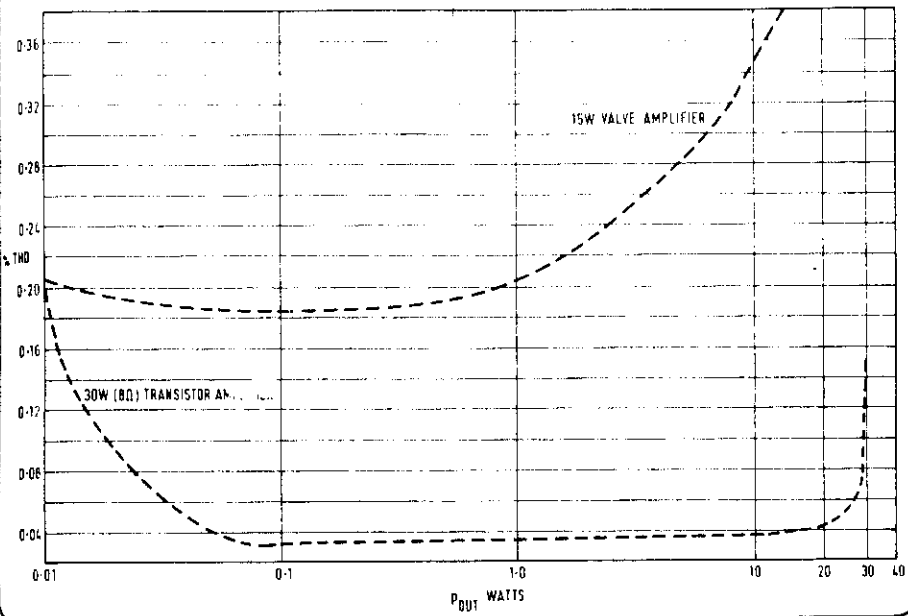


FIG. 6 COMPARISON OF LIMITING CHARACTERISTICS

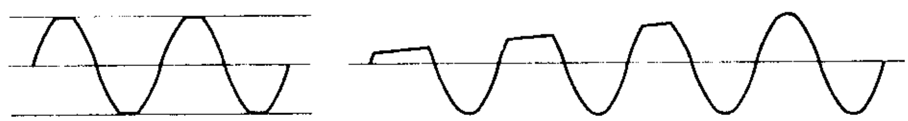


40 Hz (generated by a transistor stage) into the control unit. The music was played with no LF noise added and then the noise level was gradually raised. The low-frequency noise eventually became objectionable, but at no point made the valve-amplifier sound 'different'. In fact it sounded like a valve amplifier with a faulty electrolytic capacitor in the signal path.

And so to overload. In his article which accompanied M. West's, Richard Oliver seems to suggest that the audible 'differences' between some transistor amplifiers and some valve amplifiers could be due to overload problems. The only point made, though, is that a 15 W (rated) valve amplifier can give a subjectively higher output than a 15 W transistor amplifier. This only shows the fallacy of our traditional methods of quoting specifications. At Mission Electronics we are quoting the output of our new power amp in terms of the undistorted (< 1%) signal voltage that can be sustained across a given range of output loads for periods of 10 mS, 100 mS, one second, and continuously. This information summarises an amplifier's capability of handling a momentary peak and of driving a 'difficult' loudspeaker.

One well-known difference between valve and transistor amplifiers is their behaviour when the signal is driven into clipping. A comparison drawn in fig. 6 shows that a valve amplifier clips 'softly' against the 'hard' clipping of a transistor circuit. The comparatively high amount of negative feedback used in transistor amplifiers effectively linearises the transfer characteristic until a stage runs out of current. Suddenly, the output voltage ceases to follow the input voltage and momentarily the output *is* the DC supply rail with no AC component of the signal. A well designed amplifier will recover immediately the signal level is reduced. Unfortunately, a number of amplifiers exist that tend to

FIG. 7 STATIC AND DYNAMIC CLIPPING



(a)
STATIC CLIPPING OF SINE-WAVE SIGNAL

(b)
ASSYMMETRICAL CLIPPING OF SINE-WAVE TONE BURST FED TO THE SAME AMPLIFIER, CAUSED BY A SHIFT IN DC BIAS CONDITIONS UNDER INITIAL LARGE SIGNAL CONDITIONS

'latch-up' (or take a finite time to recover) when they are driven into clipping suddenly. Tone-burst testing brings out these defects (see fig. 7).

Rather than cover the whole subject of clipping in depth, I will quickly describe another crude test. A monitoring system was set up using a Radford STA 100 valve system. A transistor stage was inserted into the signal path such that 'hard' limiting occured at an equivalent output of 50 W. And, yes, the amplifier did lose its effortless quality. The Radford was now replaced by a specially modified Lecson AP3 Mk II capable of 200 W output. A single valve stage was inserted into the input signal path and its HT supply set so that the THD rose to 5% at 170 W output, i.e. the AP3 had 'soft limiting'. Although there was a slight drop in detail at low levels, at high levels the reproduction seemed to go 'soft' and bass drums lost their sharpness. The simple tests subsequently became more detailed, accurate and exhaustive, but with interesting results. However, that's for another occasion.

Although Ralph West, Richard Oliver, and other contributors are to be encouraged in their attempts, I have so far found that differences between amplifiers (where they exist—which isn't always) cannot be blamed on overload, noise, Class-A *vs* Class-B, etc, in isolation, but are usually due to the interactions of several effects. It is therefore important that conclusions should not be drawn from incomplete information. Comparative tests become long and exhausting before: (i) the perceived 'differences' can be always detected, and (ii) the quantified differences in electronic performances are always found to give the predicted effect. But then, any good excuse for spending the weekend listening to music!●