Improved hot audio

Having analysed Jeff Macaulay's valve power amplifier featured in the October 1995 issue of Electronics World, I have found an imbalance in the circuit that the following equations highlight.
In the equations,

u is V_{in}
i is change in Tr_1 emitter current from its quiescent value
I is change in Tr_2 emitter current from its quiescent value
m is the value of R_3
M is the value of R_4
p is potential at Tr_1 emitter
P is potential at Tr_1 emitter
$-E$ is potential of the negative rail
f is the value of R_2
F is the value of R_5
b is the value of R_{12}
B is the value of R_{13}
h is the value of R_{11}

Emitter current of Tr_1 is,

$$\frac{p-0}{m}+\frac{p-u}{f}$$

which in the quiescent state is,

$$E\frac{f}{b}\left(\frac{1}{m}+\frac{1}{f}\right)$$

and similarly the quiescent emitter current of Tr_2 is,

$$E\frac{F}{B}\left(\frac{1}{M}+\frac{1}{F}\right)$$

When V_{in} is instantaneously at some value u the emitter current of Tr_1 is,

$$\left(f\left(\frac{u}{f}+\frac{u}{b}+\frac{E}{b}+\frac{u}{h}\right)-0\right)\frac{1}{m}+\left(f\left(\frac{u}{f}+\frac{u}{b}+\frac{E}{b}+\frac{u}{h}\right)-u\right)\frac{1}{f}$$

which simplifies to,

$$\frac{Ef}{bm}+u\frac{f}{m}\left(\frac{1}{f}+\frac{1}{b}+\frac{1}{h}\right)+\frac{E}{b}+u\left(\frac{1}{b}+\frac{1}{h}\right)$$

and so the change of Tr_1 emitter current from its quiescent value is,

$$u\frac{f}{m}\left(\frac{1}{f}+\frac{1}{b}+\frac{1}{h}\right)+u\left(\frac{1}{b}+\frac{1}{h}\right)$$

and so we have,

$$i=u\left(\frac{1}{m}+\frac{f}{mb}+\frac{f}{mh}+\frac{1}{b}+\frac{1}{h}\right)$$

Similarly the instantaneous emitter current of Tr_2 is,

$$\left(F\left(\frac{E}{B}-\frac{u}{h}\right)-0\right)\frac{1}{M}+\left(F\left(\frac{E}{B}-\frac{u}{h}\right)-0\right)\frac{1}{F}$$

which simplifies to,

$$\frac{EF}{BM}-\frac{uF}{Mh}+\frac{E}{B}-\frac{u}{h}$$

and so the change of Tr_2 emitter current from its quiescent value is,

$$I=-u\left(\frac{F}{Mh}+\frac{1}{h}\right)$$

Applying the resistor values specified in the circuit (working in mA, V and kΩ),

$$i=u\left(\frac{1}{1.8}+\frac{10}{1.8\times 68}+\frac{10}{1.8\times 0.68}+\frac{1}{68}+\frac{1}{0.68}\right)=10.3u$$

and,

$$I=-u\left(\frac{10}{1.8\times 0.68}+\frac{1}{0.68}\right)=-9.6u$$

The ratio between these is 1.07 so the imbalance is higher than it need be. It could be improved with the circuit on the right. Components with functions similar to the original circuit have the same labels as the original circuit.

In the quiescent state the emitters of Tr_1 and Tr_2 are at ground or 0V. To allow quiescent current to flow the emitter resistors $R_{3,4}$ are not returned to ground but to an appropriate negative potential. With perfect balance the sum of the currents in $R_{3,4}$ will be constant, so this appropriate voltage is determined by R_{18} across which there will be a constant potential difference.

The value of R_{18} has been chosen to give the same quiescent current as the original circuit.

There are two ways of looking at the operation of the phase splitting arrangement.

The potential at the junction of the equal-valued resistors R_5 and R_{17} will be the average of the potentials at the transistor emitters so if phase splitting is perfectly balanced this potential will remain at 0V. By connecting this point to the inverting input of A_2, A_2 will control the potential at the emitter of Tr_2 so that the potential at the junction of R_5 and R_{17} is as close to 0V as its raw gain will permit. Hence the phase splitting is as well-balanced as possible.

The other way of looking at the circuit is to consider R_{17}, R_5, A_2 and Tr_2 to be a conventional amplifier with feedback which takes its input from the emitter of Tr_1. The gain of the amplifier is –1 so it straightforwardly inverts the potential at its input and so provides the opposite phase.

A_1 has 100% negative feedback applied so the potential of the emitter of Tr_1 will equal V_{in}, and that of Tr_2 will be $-V_{in}$.

In this circuit, let t = the value of R_3, R_4, r = value of R_5, R_{17} and s = the value of R_{18}.Quiescent emitter current of both Tr_1 and Tr_2 will be half that flowing through R_{18}, ie.

$$\frac{1}{2}\cdot\frac{E}{\left(s+\frac{t}{2}\right)}$$

or

$$\frac{E}{(2s+t)}$$

Potential at the junction of R_3, R_4 and R_8 will be

$$-\frac{E.t}{(2s+t)}.$$

Hence when $V_{in}=u$ and the emitter of Tr_1 is at potential u the emitter current of Tr_1 will be,

$$\frac{\left(u+\frac{E.t}{(2s+t)}\right)}{t}+\frac{u-0}{r}$$

which is,

$$\frac{u}{t}+\frac{E}{(2s+t)}+\frac{u}{r}$$

and so the change in current from the quiescent value is,

$$u\left(\frac{1}{t}+\frac{1}{r}\right)$$

Applying the resistor values specified (working in mA, volts and kΩ) the change in Tr_1 emitter current is

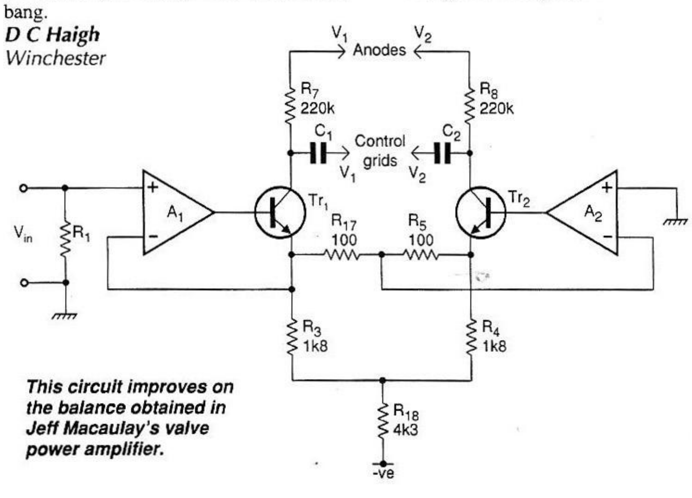
$$u\left(\frac{1}{1.8}+\frac{1}{0.1}\right)=10.6u$$

Similarly it can be shown that the change in Tr_2 emitter current is –10.6u.

I have not yet built this circuit but I would expect it to perform better than the original. Also its component count is lower.

Finally, I am a little worried about the voltage rating of C_5 and C_6. Allowing a 2V drop across the bridge rectifier, the peak on these capacitors will be 394V. This is perilously close to the specified voltage rating of 400. If the mains input voltage were to rise to 244V there might be an expensive bang.

D C Haigh
Winchester



This circuit improves on the balance obtained in Jeff Macaulay's valve power amplifier.