CLASS 'S'

A novel approach to amplifier distortion

If the load presented to the voltage amplifier by the power output stage appears very high, crossover distortion can be reduced and the voltage amplifier is much easier to design.

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A basic cause of distortion in power amplifiers is quite simply that they have to drive loads, something which is clearly seen in Fig. 1 (b), when the higher resistance load of 2.4Ω can have ±25 volts of swing generated across it whilst the low resistance load of 0.8Ω can have only ±10 volts across it before it limits. Another way of looking at the situation is to try and generate ±25 volts across the 0.8Ω resistor, when severe distortion in the form of limiting will occur. In other words, it is much easier to drive a high-resistance load than a low-resistance one.

The object of Class 'S' is to perform the task of making a low-resistance or impedance load appear to the voltage amplifier as a high, ideally infinite impedance.

Basic configuration

Let V_o (Fig. 2) represent the voltage output of the voltage amplifier and $I_{L'}$ the output of the subsidiary current amplifier which also provides load power. R_m is a small resistor which develops a voltage V_m proportional to the load current I_L. R_L is the load resistance.

If V_m is used to make the subsidiary amplifier develop a current $I_{L'}$ as close in value to I_L as possible then $I_L - I_{L'} = 0$ and Z_{in} will tend to infinity.

This is the simple idea behind a whole family of circuits, one of which will now be described.

Basic circuit

This consists, as seen in Fig. 3, of a voltage amplifier, comprising a standard operational amplifier with feedback (A_1,R_1,R_2) and a voltage-controlled, high-impedance output current amplifier (A_2 with its associated bridge of R_m, $R_{m'}$, R_G, $R_{G'}$).

As the non-inverting (+) and inverting (−) inputs to A_2 are virtually at the same potential, irrespective of what this potential is (a basic property of operational amplifiers), it follows that the bridge must be in balance and that, ideally, since $I_L = I_{L'}$, A_1 sees an infinite load.

Demonstration circuit

The circuit of Fig. 4 works on the principle of the basic circuit, with the addition of a complementary push-pull pair at the output (Tr_1, Tr_2) to provide more current than the second 741 and its voltage follower Tr_3 is a capable of.

During the crossover region time when, say, Tr_1 stops conducting and Tr_2 has not yet started to conduct, Tr_3 provides the output voltage and the impedance it sees

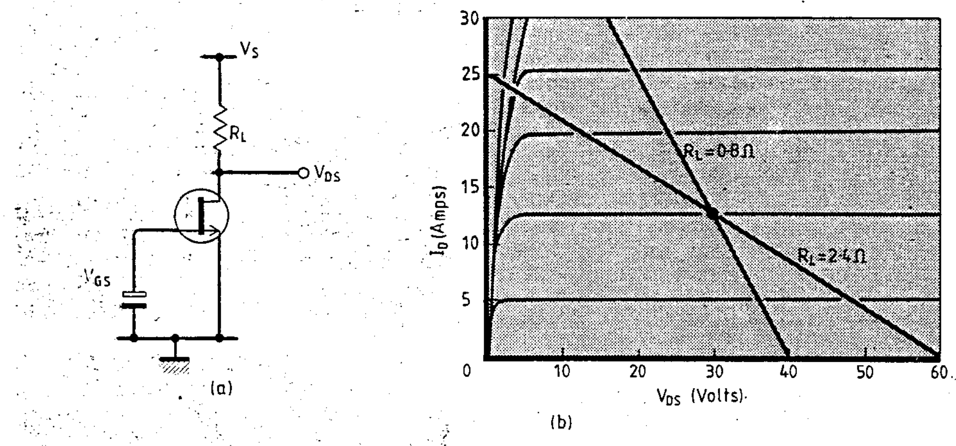

Fig. 1. In the basic voltage-amplifier stage, a high-resistance load provides a larger swing with less distortion.

The author

Mr Sandman was born in 1933 of Jewish parents and almost become a tailor. After gaining City and Guilds Full Technological Certificate in 1957, he obtained his M.Phil. degree from London University in 1978.

Many years ago, he published a scheme for automating the railways as part of a scheme for road traffic automation – he tells us that his chief pleasure lies in the invention of new schemes such as a bandwidth compression system, currently in the pipeline and "Error Take Off," a method of reducing amplifier distortion published in Wireless World *in October 1974.*

A deeply held, though hardly novel belief is that we shall never resolve our problems as a country until, we pay our engineers about twice as much as we do now.

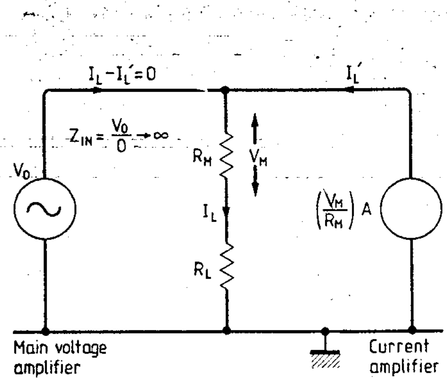

***Fig. 2.** If the current from the current amplifier equals that into the load R_1, the voltage amplifier sees an infinite impedance. Voltage V_M controls the current amplifier.*

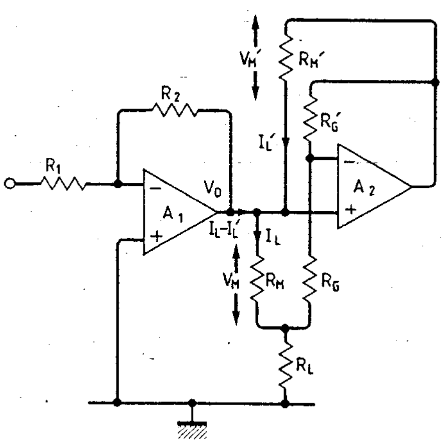

***Fig. 3.** Basic circuit of Class A amplifier. A_2 is current amplifier.*

...from, ideally, infinity to 122Ω. ...ever, this is only for a small excursion ...e and current and so Tr_3 can easily ... it. What is more important is that ...the transition is completed, the im...ce seen switches from low to high ...dance, which will produce a voltage ...at the output.

...wever, this spike is of very low am...de due to the low output impedance of ...rst 741 and its voltage follower and, ...to the point, at least one other class ...rcuit, which will not be described at ...time, exists in which this minor prob... does not occur to a measurable degree. ...sistor R_2 may be taken to the junction ...e 22Ω, 100Ω and 6.2kΩ resistors, so ...ing the output impedance to zero.

...e crossover distortion of A_2, Tr_2, Tr_1 ... has a very small effect on the output ... and this effect (W3) is less than 6mV ...e voltage) at the virtual earth of A, ...sponding to 12mV at the output ...wing for attenuation by the two 10kΩ ...tors). That is 12mV in 24V p-p, or ...%.

...cuit analysis

...erring to Fig. 3,

$$V_M' = V_M\left(\frac{A_2}{1+A_2\beta}\right) - V_M$$

...ere $\beta = \frac{R_G}{R_G+R_G'}$, (1)

...ence $V_M' = V_M\left(\left[\frac{1}{\beta\left(1+\frac{1}{A_2\beta}\right)}\right]-1\right)$

... $I_L' = \frac{V_M'}{R_M'}$

$$= V_M\left(\left[\frac{1}{\beta\left(1+\frac{1}{A_3\beta}\right)}\right]-1\right)\left(\frac{1}{R_M'}\right).$$

But $V_M = V_0\left(\frac{R_M}{R_M+R_L}\right)$,

therefore $I_L' = V_0\left(\frac{R_M}{R_M+R_L}\right)$

$$\left(\left[\frac{1}{\beta\left(1+\frac{1}{A_2\beta}\right)}\right]-1\right)\left(\frac{1}{R_M'}\right).$$

$$I_L = \frac{V_0}{R_M+R_L}$$

$$R_{in} = \frac{V_0}{I_L-I_L'}$$

...ence $R_{in} =$

$$\frac{R_M+R_L}{1-\left(\frac{R_M}{R_M'}\right)\left(\left[\frac{1}{\beta\left(1+\frac{1}{A_2\beta}\right)}\right]-1\right)} \quad (2)$$

...proximations

$A_2\beta \gg 1$

$$\beta = \frac{R_G}{R_G+R_G'},$$

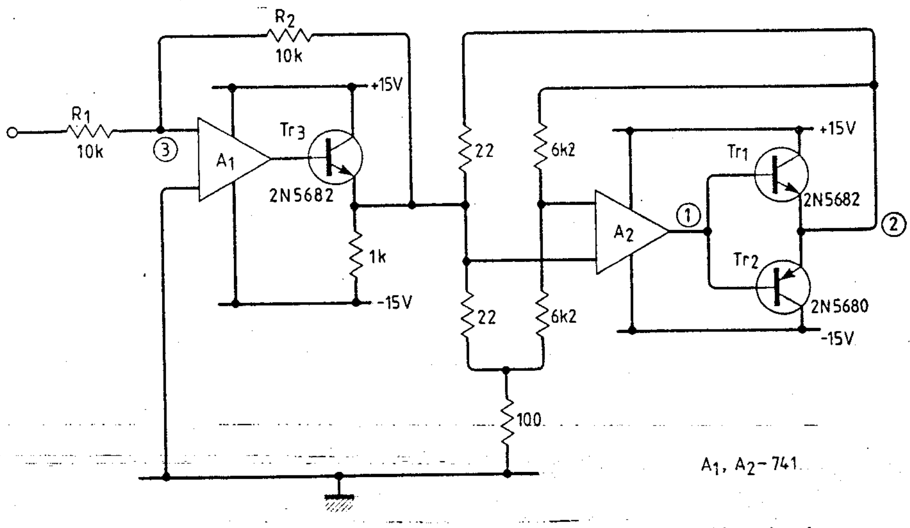

Fig. 4. Addition of power stage to augment A_2 output current forms working circuit.

Let $R_G=R_G'$ and $R_M=R_M'$

whence $R_{in} = \frac{R_M+R_G}{1-\left[\left(\frac{1}{\frac{1}{2}\left(1-\frac{2}{A_2}\right)}\right)-1\right]}$ (3)

Therefore $R_{in} \approx \frac{A_2(R_M+R_L)}{4}$ (4)

from (3), and applying Binomial Theorem.

$A_2\to\infty$

$$R_MR_G' = R_M'R_G \quad (5)$$

$$R_{in} = \frac{R_M+R_L}{1-\left(\frac{R_M}{R_L'}\right)\left[\left(\frac{1}{\beta}\right)-1\right]}$$ from (2),

whence $R_{in} = \frac{R_M+R_L}{1-\frac{R_MR_G'}{R_M'R_G}}$,

therefore $R_{in}\to\infty$

$A_2\to\infty$

$$R_G = R_G'(1+\Delta)$$

$$R_M = R_M'(1+p)$$

whence, from (1) and (2),

$$R_{in} = \frac{R_M+R_L}{1-\left(\frac{R_M'(1+p)R_G'}{R_M'R_G'(1+\Delta)}\right)}$$

and thus, by binomial approximation,

$$R_{in} \approx \frac{R_M+R_L}{\Delta-p} \quad (6)$$

which, for $\Delta=-p=0.01$ (1% resistors), gives $R_{in} \approx (R_M+R_L)/0.02 = 50\,(R_M+R_L)$, so that for $R_M + R_L = 8+1 = 9\Omega$, the load appears as 450Ω to A_1. The formulae (4) (5) and (6) are useful as initial design guides, but the full formula (2) should be used for the final calculations.

The circuit is a stable one and has the great advantage of dealing with the problem of crossover distortion whilst not needing any setting-up, even though a class B amplifier is employed in the subsidiary amplifier. It is also insensitive to the effects of temperature, specimen and ageing variations on cross-over performance, unlike the standard class B amplifier.

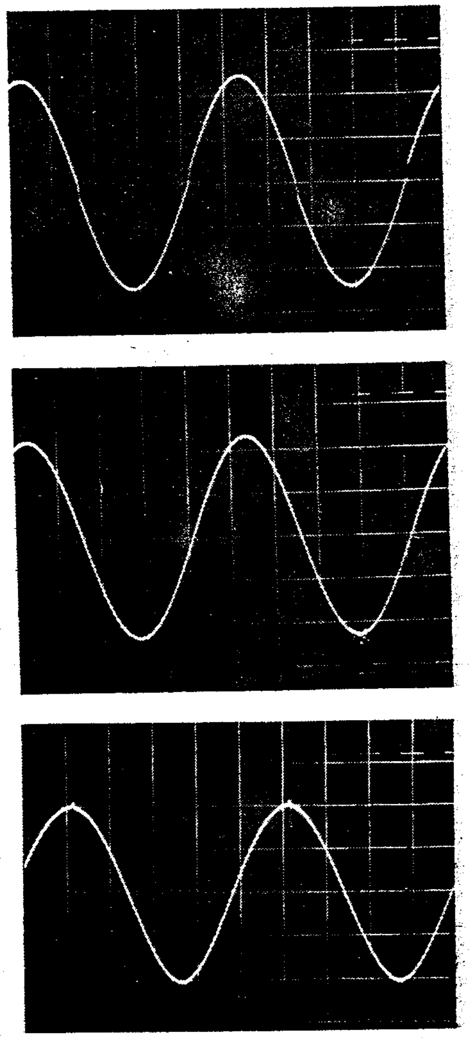

Fig. 5. Waveforms in circuit of Fig. 4. Top shows crossover distortion at output of driver stage, middle picture showing that output of current amplifier is clear. Bottom trace shows small spike at input of voltage amplifier caused by both output transistors coming back into conduction after being cut off during crossover.

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