

Output Impedance Control

Variable Loudspeaker Damping Without Alteration of Output Level

By THOMAS RODDAM

WHENEVER the Editor feels rather lonely in his eyrie overlooking the South Bank, and wants readers to write to him, he publishes an article on the loudspeaker damping problem. As the best "damping factor" depends on the loudspeaker design, letters pour in, and he feels that it must be Christmas again. Although no one seems to have used this simile, the choice of a damping factor is very much like the adjustment of a swing door: with too little damping the door swings to and fro several times after it is released; with too much damping it shuts very slowly, leaving a most unfriendly draught blowing for some seconds after each person comes in. The loudspeaker cone behaves in the same way: too little damping and it oscillates on its own whenever it receives a shock; too much, and transients are lost completely. At this point the usual thing is to jump in and quote a magic figure for damping factor, which will solve all problems. I don't propose to do this, because I'm pretty certain that all types of loudspeaker require different answers. Some, I suggest, are like galvanometers I have encountered, and need negative resistance to provide critical damping.

The obvious thing to do is to change the damping factor until it sounds right. There are rather more complicated ways of checking the damping factor, but if you can't hear the difference, why worry; your friends won't be impressed! In this article I shall show how an amplifier can be constructed with a variable output impedance, with the rather important feature that as you vary the impedance the output stays the same. You can alter the impedance with a signal on and listen to the effect, without any disturbing level changes or distortion: the distortion actually varies slightly, but it is low enough to be disregarded anyway. The impedance can be brought right down to zero, or even made negative, but of course if the negative output impedance is bigger than the load the amplifier becomes an oscillator:

this effect is easily detected by the pragmatic test: you can hear it!

I shall assume that the reader has a file of back numbers of *Wireless World* and that before he goes any further he will read "Cathode Ray's" article in the February 1946 issue. In this, the effect of negative feedback on the output impedance of the amplifier is explained. Summarizing, negative voltage feedback reduces the output impedance, while negative current feedback increases it. By applying the reasoning which leads to these results it is easy to show that positive current feedback will reduce the output impedance. We therefore have two ways of reducing the impedance, one of which, negative feedback, is very commonly used. Within certain limits we could use only negative feedback, but the disadvantage for our present purpose is that as we alter the feedback we alter the overall gain of the amplifier. This does no harm if we are adjusting the circuit once for all, but if we are studying the way different damping factors sound, it is not desirable to have to adjust the level each time we change the impedance. In addition, we are restricted in the range over which the impedance can be adjusted.

Writing A for the voltage amplification without negative feedback, and B for the fraction of the output voltage fed back, the gain of the amplifier is $A/(1 + AB)$ with feedback. So long as A is large we can take $(1 + AB) \approx AB$, and the gain is just $1/B$. This is a good approximation in most practical cases: for example, in a two-stage amplifier we may have $A = 1,000$ and $B = 1/100$, giving $AB = 10$. The voltage amplification is then exactly 90.1, or approximately 100, a difference of only 0.9 db. If A increases to 4,000, the gain increases to 97.7 times, or by 0.7 db. Thus by using enough feedback to reduce the gain 20 db we keep the gain constant within $\pm \frac{1}{2}$ db however we increase A .

We can make use of this by applying negative

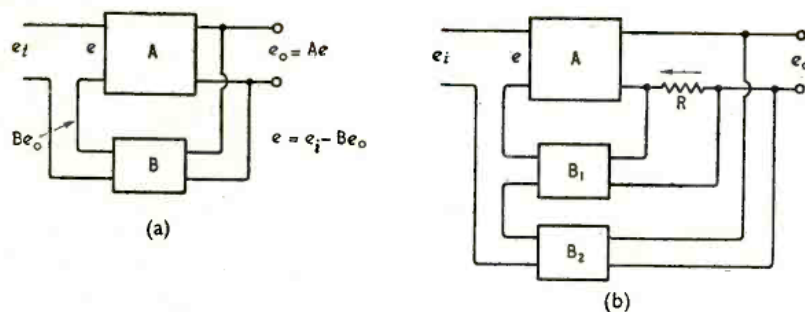
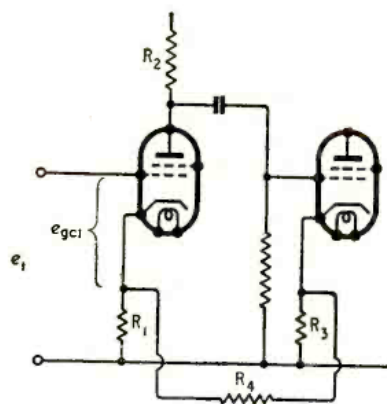


Fig. 1. (a) Normal connections in a negative voltage feedback amplifier. (b) Mixed voltage and current feedback. Fig. 2. (right) Basic positive feedback circuit.



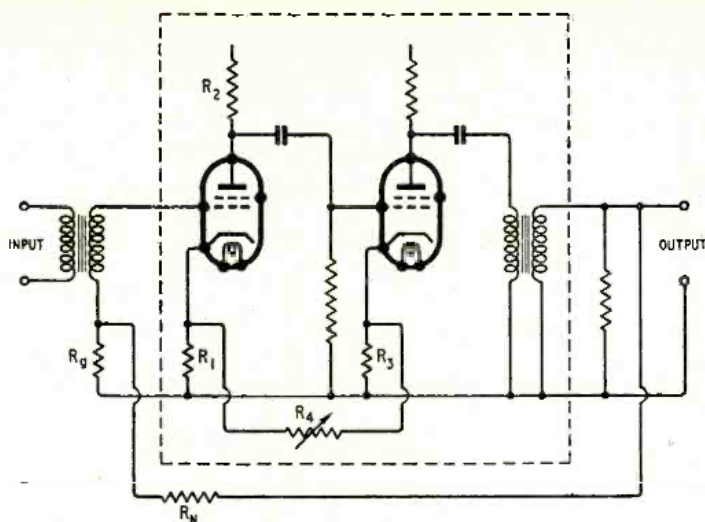


Fig. 3. Combined feedback circuit of amplifier with variable output impedance. R_4 is the control; suitable values are suggested in the text.

feedback round the whole amplifier, and at the same time putting positive current feedback round an inner loop. Fig. 1 shows a normal negative voltage feedback amplifier and an amplifier having two feedback paths, B_1 for current feedback and B_2 for voltage feedback. For this amplifier the input voltage e will be $e_i + B_1 iR - B_2 e_o$, where B_1 is the positive current feedback path and B_2 the negative voltage feedback path. I shall not develop the equations, because this particular arrangement is easily seen to be inconvenient as soon as earths are to be applied to the circuit. Instead, let us consider the circuits of Fig. 2.

Design Relationships

In this two-stage pentode amplifier, the first valve has a mutual conductance g_1 , and the second g_2 . The current in the anode load of the first valve will be $g_1 e_{gc1}$, producing a voltage at the grid of the second valve equal to $-g_1 e_{gc1} R_2$. For this valve, we have

$$e_{gc2} = -\frac{g_1 e_{gc1} R_2}{1 + g_2 R_3}$$

Across the cathode load R_3 we have a voltage $g_2 e_{gc2} R_3$, of which a fraction $R_1/(R_1 + R_4)$ appears across the cathode resistance of the first valve, so long as R_4 is much larger than R_2 . The input voltage e_1 required to produce the grid-cathode voltage e_{gc1} is therefore

$$e_1 = e_{gc1} + e_{gc1} g_1 R_1 - \frac{R_1}{R_1 + R_4} \cdot \frac{g_1 e_{gc1} R_2}{1 + g_2 R_3}$$

We can have a finite value of e_{gc1} for $e_1 = 0$ by making

$$1 + g_1 R_1 = \frac{R_1}{R_1 + R_4} \cdot \frac{g_1 R_2}{1 + g_2 R_3}$$

This means that we have infinite gain, which is the condition for zero impedance to appear at the anode of V_2 . To simplify this expression, let us take $g_1 = g_2$, $R_1 = R_3$ and $g_1 R_1 = g_2 R_3 = 1$, with $g_1 R_2 = 100$.

Then

$$\frac{R_4}{R_1} + 1 = \frac{1}{2} \cdot \frac{100}{2} = 25$$

or $R_4 = 24 R_1$

Now let us look at Fig. 3. If this is compared with the top diagram in Fig. 1 it will be seen that the circuit inside the dotted box is simply an amplifier A, and the B circuit is now R_g and R_n , with a value of $B = R_g/(R_g + R_n)$ or $\approx R_g/R_n$. As we saw, we can increase the gain A inside the box as much as we like without affecting the overall gain, which stays very close to $R_n/R_g = 1/B$. (The gain due to the input transformer is neglected at the moment). We are therefore free to alter R_4 , which alters the output impedance, without altering the overall level, unless, of course, we make the circuit unstable. If we fix a minimum value of R_4 at about 20 times R_1 we can persuade the output impedance to go just negative, and by increasing R_4 we can produce a range of output impedances up to a maximum of $[r_a/(1 + AB)]\sqrt{n}$ where r_a is the anode impedance of the valve and n is the output transformer ratio.

At this point I feel a certain diffidence. My landlord occupies the flat above me, and the temptation to build one of those nice 100-watt audio amplifiers has always been sternly repressed. In fact, as I write the loudspeaker is operating at a pleasant 50 mW. My work on this variable-impedance amplifier has been based on a 1-watt output level, using a single-sided amplifier. The valves used were a 6J7 and a 6L6, because the foreign customer to whom the equipment is to be sold refuses to be committed to valves from one particular maker. He hasn't any dollars, but by using American types he can get a much wider choice of suppliers than if he has valves on the British Spring 1949 base which will go out of fashion sooner than did the New Look. With these valves, R_2 in Fig. 3 was 33 kΩ, R_1 620Ω, R_3 220Ω, and R_4 a 100-kΩ variable resistor. No trouble was experienced due to small bias changes caused by the d.c. which flows through R_4 . With this circuit an output impedance of less than one-tenth of the load impedance was easily obtained.

There is another use for this circuit. If you like having the same programme in all the rooms in your house, if you have a house and can't make one speaker heard all through it, this low impedance amplifier is very useful. By feeding a line from a very low-impedance amplifier, additional loudspeakers can be added without altering the level at those already connected. Obviously the amplifier must have sufficient power available to drive the maximum number of loudspeakers, but if this is so the amplifier adjusts itself to deliver constant voltage irrespective of the load.

Examination of the Williamson amplifier circuit (Aug. 1949 issue) suggests that it should be possible to apply positive feedback from V_5 to V_3 and from V_6 to V_4 . This involves splitting R_{10} into two 780-ohm resistors, and R_{22} into two 300-ohm resistors. Equal amounts of feedback must be provided, but readers who have constructed this amplifier may find the experiment of interest.