Let's Get Started 19:

MORE — OR LESS? — FEEDBACK

By **A. BLACKBURN**

ON THE WHOLE, LAST MONTH'S ARTICLE presented a rather glowing picture of the effect of negative feedback on amplifier performance. We discovered that it boasted of such advantages as increasing frequency response, decreasing hum occurring in the amplifier, and reducing distortion, all of which result, unfortunately, in loss of gain. We found, further, that the output performance is modified according to whether voltage or current feedback is used.

Our closing paragraph last time, however, hinted darkly that practical application of the system was not without its difficulties. As we shall see when we come to designing an amplifier, indiscriminate application of negative feedback will get us nowhere. Only by judicious handling and with due regard for the performance of the amplifier as it stands will we succeed in getting the utmost use from the system.

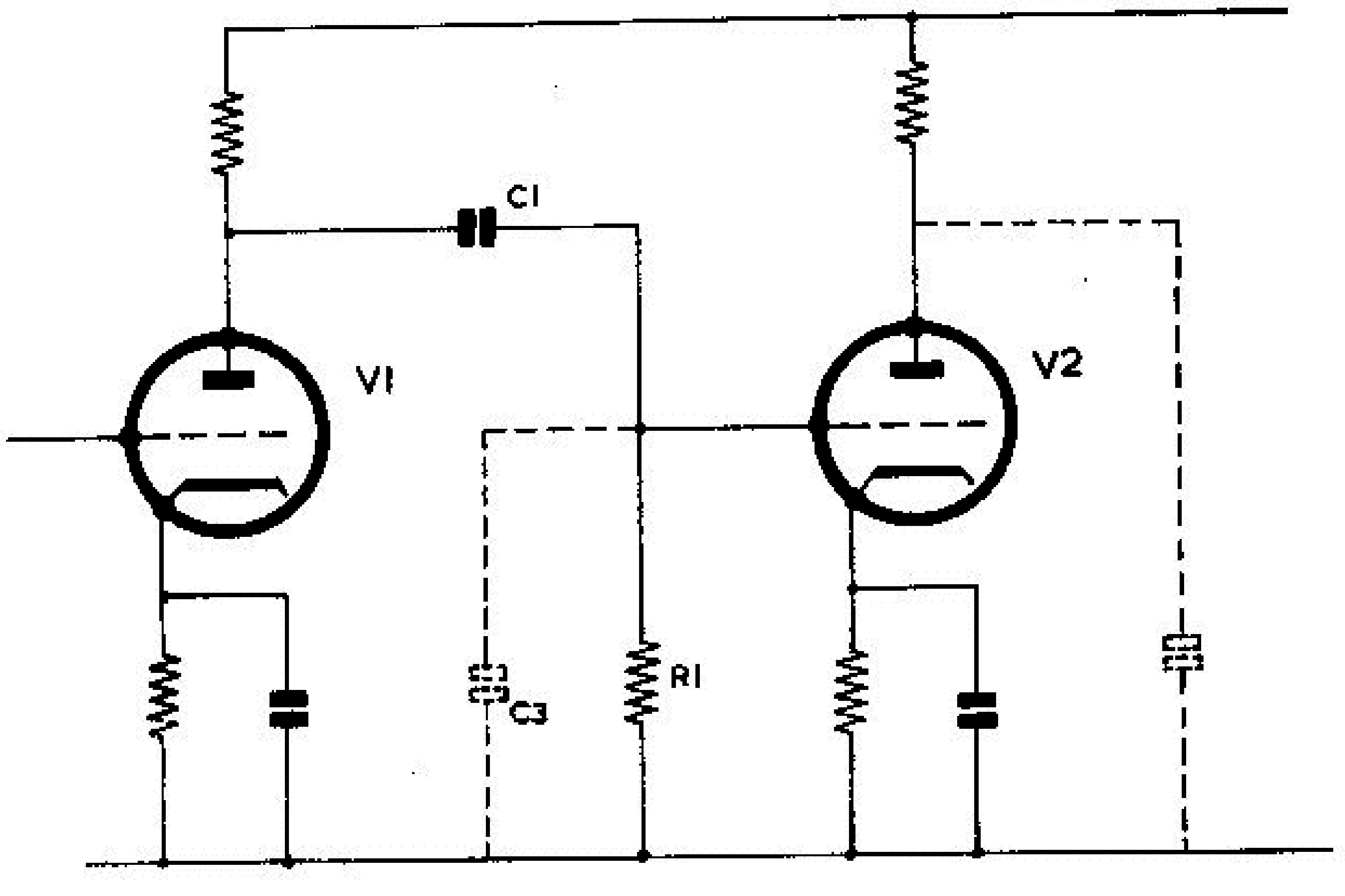

FIG. 1.

Overall Feedback

We already know that feedback may be applied over any number of stages, and frequently is applied from output to input. The important question is, how much feedback should be used? The obvious answer would seem to be as much as possible without unduly reducing the gain. Unfortunately, it isn't quite as simple as that. In a previous article we dealt with phase shift and its causes at some length, and it is this that throws the spanner in the works as far as feedback is concerned.

Fig. 1 shows two stages of an RC coupled amplifier. The dotted capacities are the strays produced by valve inter-electrode capacities and the wiring. Fig. 2a is typical of the frequency response curve for such an amplifier, and 2b shows what happens to the phase over the frequency range in one of the couplings, say, C_1–R_1–C_3. Don't forget that the voltages at the grid and anode of a valve are 180° out of phase. So in Fig. 1, if there were no strays and the coupling circuit introduced no phase shift, the output of V_2 would be in phase with the input to V_1. However, the phase shift caused by the strays and coupling modify, to an extent dependent upon frequency, this input-output relationship. Fig. 2b shows that the phase shift is zero over the middle range of frequencies, where the frequency response curve is flat. Try not to confuse the 180° shift produced by the valve with that produced by the components outside the valve.

For the moment we will stick to the idea that the feedback voltage is applied to the cathode of V_1, where the phase conditions are correct to produce negative feedback. Because the feedback voltage would be in phase with the input, connection between input and output of this amplifier would produce positive feedback over the flat portion of the frequency response curve.

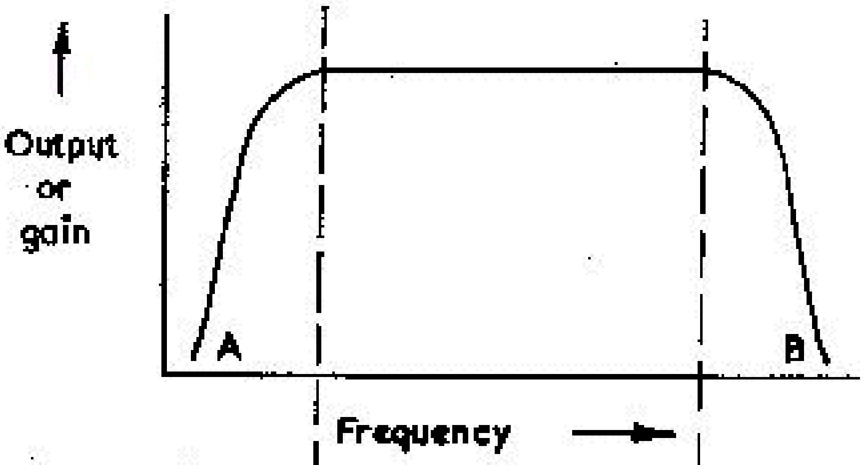

FIG. 2(a).
GAIN/STAGE

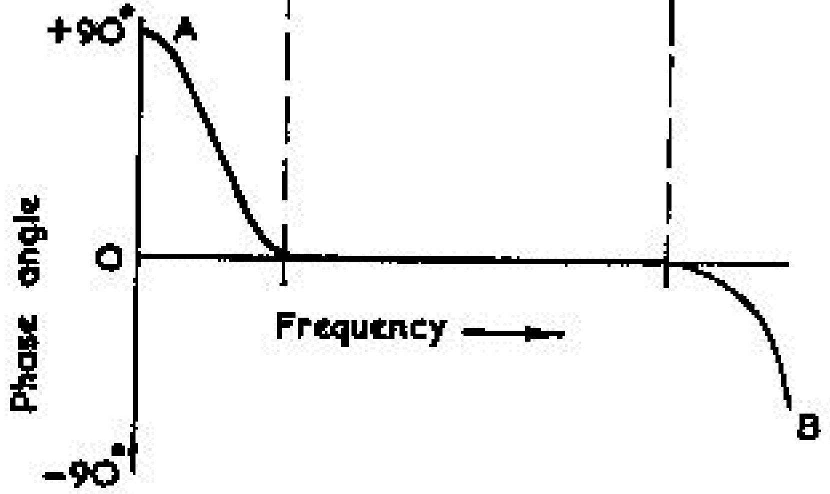

FIG. 2(b).
PHASE ANGLE/STAGE

But *only* over the flat portion. We can see from Fig. 2b that a phase shift of 90° occurs at points A and B, representing high and low frequencies respectively. Fig. 2b, however, only gives us the phase shift for one coupling circuit. In Fig. 1, though, we have two such couplings. At points A and B, the phase shifts are now doubled, and become 180°. This means that, although over the range of middle frequencies the feedback is negative, at the extreme ends of the band it will become positive. The gain at these frequencies has, however, dropped (Fig. 2a) to a very low level, but if there is sufficient gain left, the amplifier will oscillate. The likelihood of oscillation is also controlled by the amount of the output voltage fed back. If this were very small, the gain would have to be very high to enable oscillation to occur. But in this particular condition the gain happens to be very low.

And therein lies our first conclusion. If the amplifier has a poor frequency response, it will have a poor phase response, and the application of large doses of feedback will cause oscillation. So, before an attempt can be made to improve performance, it has to be pretty reasonable beforehand.

If continuous oscillation does not occur, it may be because there is just that tiny insufficiency of feedback voltage. In this case, if an input voltage of the right frequency were applied, oscillation would occur for the period over which this signal were present. This is quite common in amplifiers and often goes unnoticed, but the quality suffers for it.

With an even smaller feedback voltage, and the phase and frequency responses at either A or B, the positive feedback may cause a rise in the characteristic, as shown in Fig. 3. This again represents deterioration in performance.

With the increase in the number of stages is the increased danger of oscillation, since the phase shift increases as the gain rises.

So far, of course, we have only considered RC couplings. If transformers occur in the circuit, the phase shift is even further increased. A common practice is to derive the feedback voltage from the secondary of the output transformer, which, if it is of good design, may be a very satisfactory scheme, as it includes the transformer in the feedback loop and helps to offset any undesirable effect which it might have upon the performance.

If we use overall feedback, we are going to be faced with two seemingly irreconcilable conditions which it is possible to overcome. From what we have already said, we can see that we must make sure that the gain in the amplifier is too low to allow oscillation, when the phase shift is 180°. We have also seen that, as the gain drops, the phase shift will increase. There doesn't seem to be any way over this difficulty. It rather looks as though we shall have to put up with such a miserably small amount of feedback as to make it scarcely worth while bothering, anyway.

It has been shown, however, that if the various coupling circuits have different time constants, stage to stage, an improvement to this unhappy state of affairs can be effected. If one stage of the amplifier has a wider band than the others, considerably more feedback may be used than in the case where all stages are equal. To give the stage this extra bandwidth, it is necessary to reduce the anode load. If a transformer is included in the loop, the RC coupled stages should have a wider bandwidth than the stage with the transformer. The same principles apply at the low frequency end of the response also, except that an extended bandwidth at this end calls for larger coupling capacitors or higher grid leaks.

The Volume Control

We said last month that the output impedance of the amplifier was affected by feedback. This applies only in the overall case, when the feedback voltage is derived from, say, the secondary of the output transformer.

It was also explained that the extent of the change in output impedance was dependent upon the gain of the amplifier. If there is a volume control somewhere within that part of the amplifier over which feedback is applied, then operation of the control will change the output impedance. And we don't want that to happen because a large change in the setting of the control may cause considerable mismatching of the loudspeaker to the output valve, accompanied by loss of power, and possible distortion.

In some designs, feedback is applied over one or two stages only, a certain amount of overall feedback being applied and augmented by one or even two small loops within the amplifier itself. It is particularly undesirable to include a volume control within such an amplifier.

Tone Control

Fig. 4 shows a small amplifier with negative feedback applied between output transformer and input. This is not intended to be a particularly practical circuit, but merely as a demonstration. The factor $\frac{1}{1+\beta A}$ figured largely in last month's article, in showing how nearly everything depends on it. For example, the gain with feedback is:

$$\frac{\text{gain without feedback}}{1 - \beta \times \text{gain without feedback}}$$

Now β is determined by the resistors R1 and R2 in Fig. 4.

$$\beta = \frac{R2}{R1 + R2} = \frac{\text{Voltage fed back}}{\text{output voltage}}$$

Now suppose we insert a capacitor at the point marked C in Fig. 4. If this were a small capacity, the feedback circuit would become frequency sensitive, because the reactance of the capacitor would rise as the frequency dropped. β, therefore, would drop also, and the gain of the amplifier would rise, at the lower frequencies.

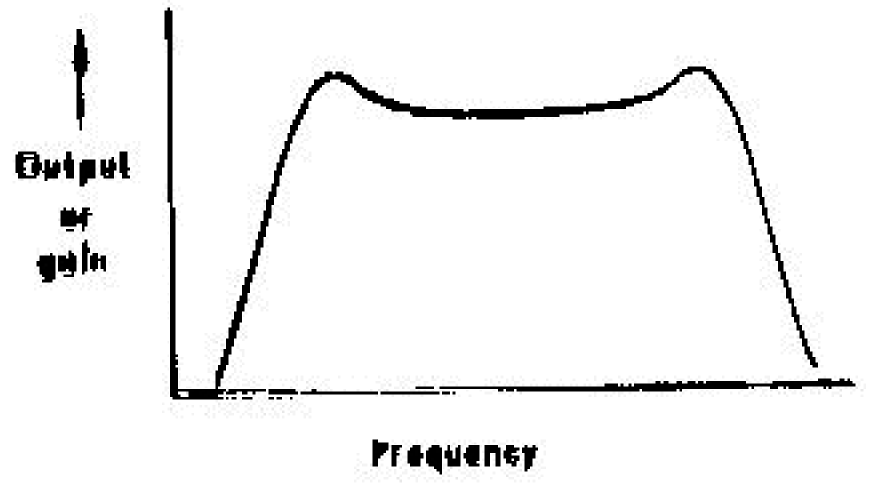

FIG. 3.

If, on the other hand, a capacitor were put in parallel with R2, its reactance would drop as the frequency were raised, and it would shunt R2. The potentiometer formed by R1 and R2 would introduce a higher attenuation of the feedback voltage, and β would decrease. The result would be a rise in gain, this time at the high frequency end of the band.

The point of all this is that, if the feedback circuit contains elements which cause it to be frequency sensitive, it may be used as a tone control. The danger lies, of course, in the fact that if the feedback circuit is frequency sensitive, it will also introduce phase shift. It would be particularly harmful to introduce such elements for tone control in overall feedback, although they may be used in the overall case to deliberately introduce phase shift in opposition to that occurring in the amplifier itself, thereby allowing more feedback to be applied without the consequent risk of oscillation.

Circuits

By now you probably feel lost in a maze of ifs and buts. But let's take a look at a few practical circuits, and that might help to clear things up.

No doubt Fig. 5 looks, at first sight, like any innocent stage of amplification, and the un-bypassed screen and cathode resistors have a bearing on the subject.

With a positive going signal at the grid, the current through the valve increases. The voltage drop across the bias resistor also increases, and the cathode moves positive. The resultant change in voltage between the over this difficulty. It rather looks as though we shall have to put up with such a miserably small amount of feedback as to make it scarcely worth while bothering, anyway.

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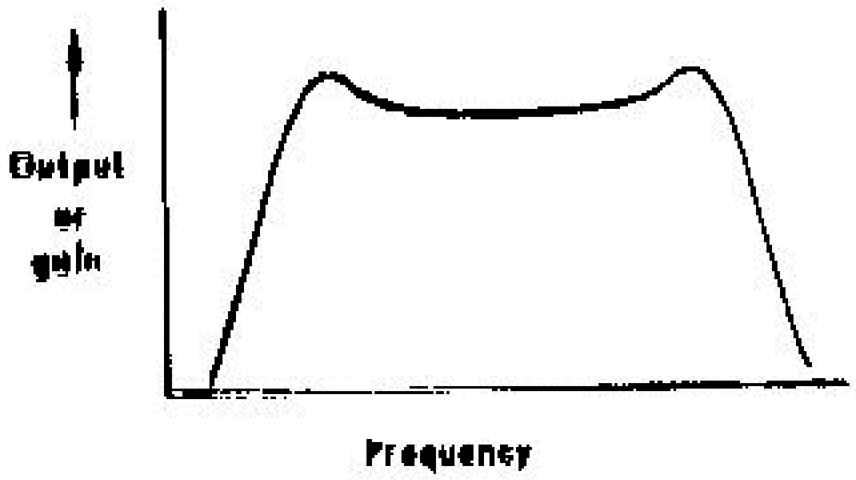

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The same action occurs at the screen. As the grid goes say, positive, the screen current will increase, the screen voltage will drop, and the current reaching the anode will be less than if the screen voltage had remained fixed. Once again, therefore, the anode voltage change will be less.

Fig. 6 shows a simple method for introducing feedback over one stage, in this case the output stage. If V1 is a pentode, and Rg is of the order mentioned above, the feedback factor β is, very approximately, $\frac{R2}{R1 + R2}$

A more accurate determination of β is

$$\frac{RaR2}{(Ra + Rf)(R1 + R2)}$$

where Ra is the AC anode impedance of V1.

Fig. 7 shows a similar method which only involves one resistor in the feed back circuit.

Here $\beta = \frac{Rf}{Rf + R}$, where R is the parallel combination of Rg, R1 and the Ra of V1.

There are innumerable examples of feedback circuit–too many in fact to deal with here.

I have not, of course, dealt with this subject in detail—that would not be possible in two articles—but I hope I have outlined it sufficiently clearly to enable you to at least avoid the major practical pitfalls and to give you a lead on further research if you find it helpful.