Theory and Practice

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● Picking up where I left off last month, I'm still thinking of the simple line amplifier, designed to use input and output impedances of 500 ohms. Now, let us examine what happens when they are cascaded so that they don't happen to match their nominal ratings.

In all modern circuits, after designing the circuit to use the amplifying elements (tubes or transistors) in as linear a mode as possible, over-all feedback is applied in lashings to bring down distortion to the lowest possible level. And we often trust the feedback when something we inadvertently did excuses it from doing its proper job!

If the output impedance is lower than the nominal load it is designed to load, it's safe bet that voltage feedback is used, because that is what will make source impedance lower. Let's take the same case where the internal output impedance is 100 ohms to feed a 500-ohm external load (FIGURE 1).

The combined parallel impedance, with the load connected, is 83.3 ohms, Let's assume it has 14 dB feedback. Without feedback, the combined impedance would be 5 times 83.3 ohms, or 417 ohms. But part of this combined impedance (as a parallel element of it) is the 500-ohm load. So the source-impedance part, without feedback, must b 2,500 ohms. (2,500 ohms parallel with 500 is 417 ohms).

With load connected, the feedback factor $(1 + AB)$ must be 5, or $AB=4$, to get 14 dB feedback. With the 500-ohm load, 1/6th of the open-circuit output voltage is fed back. With a 100-ohm load, this will drop to 1/26th. So this change will cut AB from 4 to 0.765 and the 14 dB feedback will become only 5 dB – quite a change!

Not only is there less feedback, but to produce the same output level, the input must be bigger (about 5 times). This will be allowed by the drastically reduced offset from the feedback signal. So distortion is likely to increase on two counts: higher internal operative level, and less feedback. So the specified performance becomes fictional!

Taking the other case, if the effective output internal source impedance is 2,500 ohms for a 500-ohm load (FIGURE 2) any feedback used must be of the current type, and the reverse situation applies. Working into a higher load, say 2,500 ohms, such as an amplifier input designed to work from 500 ohms, reduces current feedback by a similar factor also increasing distortion.

Using opposite deviations, for example a 2,500-ohm input impedance as a load for a 100-ohm output impedance (each designed to work *with* 500 ohms) the feedback will increase considerably. Take the same example we just calculated in FIGURE 1. If the voltage from 500 ohms that was fed from 2,500 ohms (actual source) yielded an AB factor of 4 (being 1/6th of the open-circuit voltage), changing the 500 ohms to 2,500 ohms will feedback half the open-circuit output voltage and raise the AB factor to 12, yielding about 22.25 dB feedback, instead of the design value of 14 dB.

That extra 8 dB feedback will reduce distortion more than intended, so there's no trouble about that, is there? Hold on a moment! Did you ever hear of instability?

Admittedly, no professional amplifier is likely to go unstable, using any loading from short-circuit to open-circuit, so it won't actually oscillate. But . . .

The amount of feedback, and the effect it produces, is probably optimized with correct or nominal loading. After all, that's when any self-respecting amplifier should do its best. And if, as many professional amplifiers do, it includes an input or output transformer, or both, there may be more reasons for difference when the actual load differs from the nominal. Whatever the change in loading and amount of feed-

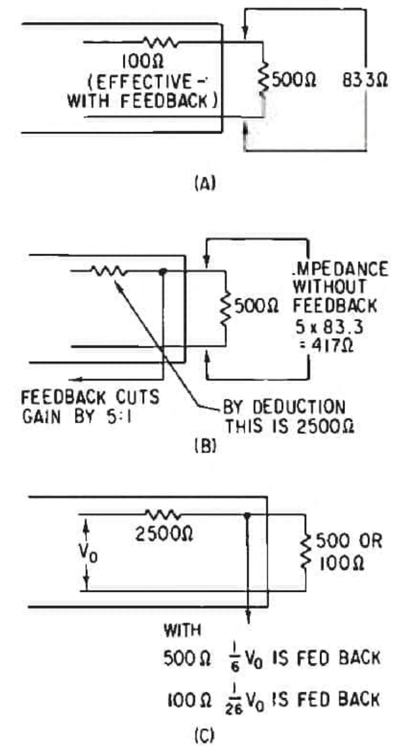


Figure 1. Deduction of the "innards" of a feedback amplifier output stage: (A) how it measures externally; (B) assuming 14 dB feedback with 500-ohm load, the actual internal impedance (before feedback) is deduced to be 2,500 ohms; (C) reduction of feedback by loading with 100 ohms instead of 500 ohms.

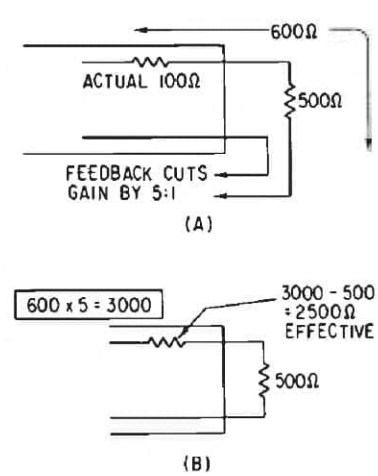


Figure 2. Similar deduction with current feedback: (A) what feedback works with; (B) the effect.

Figure 4. Tabulation of values and results of combination feedback designed to make internal impedance equal external nominal. The values are not calculated in the order shown, but as described in the text.

back, it will change response. The question is where and how much.

If the circuit is a simple one, optimized for maximal flatness response, 8 dB of extra feedback will produce about 4 dB peak at one or both ends of the frequency range. The effect could be worse than this, since I have assumed optimal design.

The low-frequency effect could run the amplifier into break-up, excited by any low-frequency transient. The high-frequency effect could produce an unnatural edginess, characteristic of an ultra-sonic peak.

In the example, we assumed 14 dB feedback. This was based on the effective internal impedance being either 1/5 or 5 times nominal value. If 20 dB feedback were used, the internal impedance would be about ten times, or 1/10 of nominal value, according to whether current or voltage feedback, respectively, was used. And using that much more feedback would aggravate possible changes in performance.

Transformers in the circuit, assuming they are excluded from the feedback loop (if they're included, the effects could be compounded) can change the response from maximal flatness to as much as an 8 or 9 dB peak, or to a similar loss at extreme frequencies, unless the circuit is skillfully designed to avoid such an effect.

If the input transformer is step-up or the output is step-down (the commonest arrangements used) then terminating externally with an actual impedance that is *lower* than nominal will be likely to cause *peaking*. Terminating externally with an actual impedance that is *higher* than nominal will cause a *loss* in response.

If the input transformer is step-down or the output is step-up (both of which are less common) then terminating externally with an actual impedance that is lower than nominal will be likely to cause a *loss* in response, while one higher than nominal will cause *peaking*.

Perhaps you now have the impression that no line amplifier can be as good as it ought to be. This isn't quite true. Its nominal performance can always be obtained by using its nominal loading, strictly. This may involve extra audio losses in the matching pads required to eliminate the inadvertent mismatch. But it is also possible to design an amplifier that is not susceptible to this problem.

Transformer-coupled circuits can be designed so that a change of external load value, within a likely range, does not materially change response. This only requires extra care in the design, which we won't go into here.

To ensure that an amplifier has an internal output impedance that matches the external impedance with which it is designed to work, dual feedback must be used to obtain adequate linearization; this should be both voltage and current, as related to the output stage.

Let's assume an output transistor or tube has an impedance 5 times the nominal load it is to work with (FIGURE 3). The parallel impedance will be 5/6th nominal. For source-to-equal load, the parallel value must be reduced to 1/2. This is a gain reduction of 5/3, or 4.4 dB. This much voltage feedback is not enough to do much good in reducing distortion. Now suppose the designer decides to use about 26 dB feedback, which means (1 + AB) must be 20.

First assume the current feedback with nominal load connected uses an AB factor of 9 (FIGURE 4). This is with a total output circuit impedance of 3,000 ohms, 2,500-ohms internal and 500-ohms external. A short circuit will reduce the total load to 2,500 ohms, increasing current feedback to an AB factor of 6/5 x 9=10.75. On short-circuit there can be no voltage feedback. So (1 + AB) at short circuit is 11.75.

With a nominal load (500 ohms) the output current should be half the short-circuit current, if source impedance equals load impedance. If the output-source voltage is unchanged, the rise in impedance from 2,500 ohms (short circuit) to 3,000 ohms (nominal load) will reduce output current by 5/6. So the voltage feedback, with nominal load, must reduce the source voltage by a factor of 3/5 (3/5 x 5/6=1/2). As the short-circuit factor is 11.75, the nominal load feedback factor (including voltage and current components) must be 5/3 x 11.75=19.56 (close to the desired 20, representing 26 dB).

Subtracting the 1 (of 1 + AB) and the AB=9 for current feedback (the figure we started with), the voltage feedback needs an AB of 9.56. Now as a check, let's see what happens if we change the external load to 2,500 ohms.

This will raise the voltage feedback AB product from 1/6 to 1/2 the open-circuit output voltage, a 3/1 ratio and cut the current feedback AB in the ratio 3/5. Thus voltage AB is 3 x 9.56 =28.6 and current AB is 3/5 x 9=5.4, making a total AB of 34. So (1 + AB) is now 35, making gain drop by 19.56/35.

Output voltage, before the effect of feedback is considered, rises 3 times, due to the change of loading, which delivers 1/2 instead of 1/6 the open-circuit voltage. So with feedback considered, output voltage rises by 3 divided by 35/19.56, which figures out to 1.675.

According to our calculation (last month) terminating a 500-ohm source with 2,500 instead of 500 ohms should cause the voltage to rise from 1 to 1.667, which is as close as we can expect such calculations to come.

That's about enough for one issue. We could pursue this much further. What would you like me to do? Do you want more details, so you could design your own line amplifiers? Let's know, and when I have enough answers to know which way you would like me to go, I'll write more on this subject. Meanwhile, in the next issue, I'll be guided by letters I've received already.

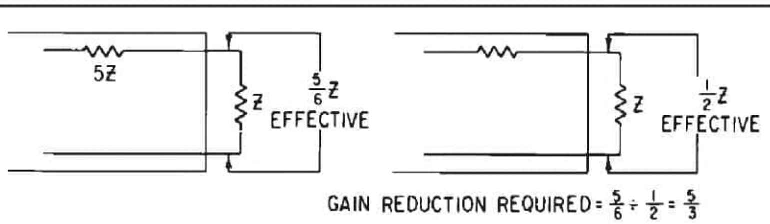
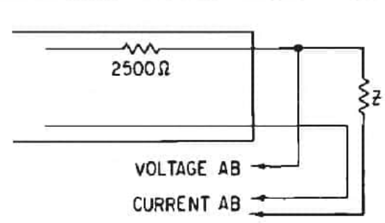


Figure 3. Deducing the voltage feedback needed to make internal equal nominal impedance: left, without feedback; right, with feedback (not shown).



Value of Z	Voltage AB	Current AB	Total 1+AB
0	0	10.75	11.75
500	9.56	9	19.56
2500	28.6	5.4	35

Value of Z	Output Without Feedback	Voltage With Feedback
500	19.56	1
2500	58.75	1.675

Figure 4