Theory and Practice

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● A big area where theory and practice apparently differ occurs in feedback application. The deviations can take all forms, depending on the circumstances. We will content ourselves here with a couple of fairly simple ones, where the effect of feedback in reducing distortion isn't what calculations would predict.

Just to make it fair to that devious devil feedback, we'll take one case where he gives us more than we expect and one where he sells us short.

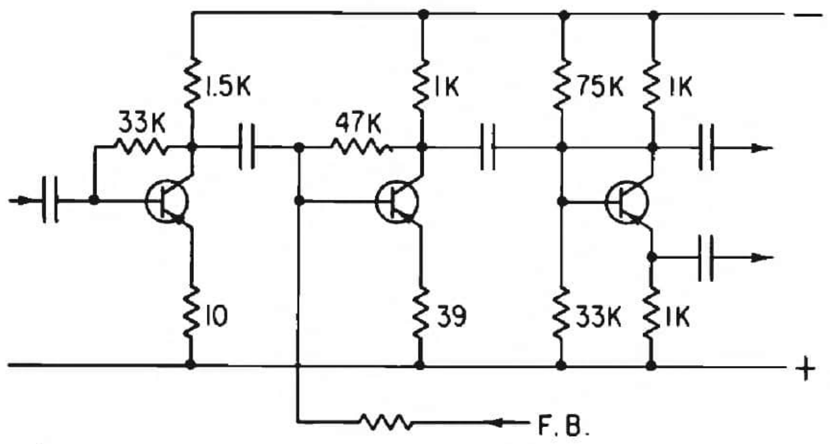
Many who have put together their own amplifiers must have experienced the first, with both tube and transistor circuits. You start with a circuit without feedback, that has a curvature giving say 3 per cent harmonic distortion at full output.

You are faced with a compromise problem, it appears, in that you don't have too much gain to spare. You can't really spare more than 6 dB feedback, from which you'd expect to reduce distortion only to 1.5 per cent, which isn't low enough. And you don't want to go to the trouble of adding another stage to get more gain. You feel it isn't worth that, with all the extra stability problems it could cause.

So you try 6 dB, as that is all you can spare, hoping for a miracle. And behold, a miracle happens. The distortion drops to about 0.4 per cent. How did that happen? It violates feedback theory, it seems.

Of course, it can't in fact. Somehow or other, you're getting more than 6 dB feedback, although it only *looks* like 6 dB. How can that be? Well, here's one example. FIGURE 1 shows the essential part of the schematic. This isn't the part where the main distortion comes in, which is the higher level output stages.

Each transistor shown has a nominal current gain of 100. The first stage operates with a collector voltage about 1/6th of supply. The 33K resistor provides about 15.6 dB of d.c. feedback, to



1. Over-all Feed-back AB	2. dB Distortion Reduction	3. Stage 2 Gain Reduc-tion	4. Stage 2 Gain	5. Base Input Ohms	6. Collector Load Ohms	7. Stage 1 Gain Reduc-tion	8. Stage 1 Gain	9. 2 Stage Gain	10. Effective fb. Gain change
0	0	3	33	1,330	700	3.1	32	1050	0
1	6 dB	4	25	975	590	2.8	36	900	1.4dB
2	9.5dB	5	20	780	515	2.56	39	780	2.6dB
3	12 dB	6	16.7	650	450	2.36	42.5	705	3.5dB
4	14 dB	7	14.3	560	410	2.24	45	640	4.3dB
5	15.6dB	8	12.5	490	370	2.12	47	590	5.0dB
6	16.9dB	9	11.1	433	336	2.02	49.5	550	5.6dB
7	18 dB	10	10	390	310	1.94	51.5	515	6.2dB

Figure 1. The circuit portion under discussion in the text. The column below illustrates the various degrees of over-all feedback in tabular form.

stabilize this operating point. The a.c. feedback over this stage depends on collector load, but is always less than 15.6 dB.

The middle stage operates with its collector at about ⅓rd of suppy voltage, stabilized by the 47K feedback resistor, which provides about 9.5 dB of feedback, both a.c. and d.c., because the third stage doesn't materially load the collector of this stage.

The third stage is a phase splitter. With 1K collector and emitter loads, it has a base input resistance of 100K, paralleling the 33K from base to ground. This makes 25K for the bottom part. Using 75K for the top sets the base voltage at ¼th of supply. So the third stage emitter voltage is ¼th of supply, and the collector voltage ¾th supply, giving maximum signal-handling capacity at this point.

Now let's figure what happens with various degrees of over-all feedback. If you add this by changing the value of the feedback resistor, you'll find it never gives quite as much gain reduction as you'd expect. We've tabulated the calculations for simplicity.

The first column is the AB factor for the over-all feedback, given as a multiple of the base input signal current at the middle stage, where it is injected. Column 2 gives the effect of this feedback *in reducing distortion* (from later stages), obtained by taking 20 times log to base 10 of 1 plus the factor in column 1.

This is the effective feedback from the viewpoint of distortion. But how do you measure it? You can't. What you measure is the change in over-all gain. So we'll figure that, to see how the effect we found happened.

Column 3 shows the factor by which current gain of the middle stage is reduced. With no over-all feedback connected, this is 3, because of the 47K resistor, which feeds back a signal current equal to twice the base input signal current, so that 3 times the input signal current is needed from the first stage.

Column 4 is the second stage gain, found simply by dividing the normal gain, 100, by the factor in column 3. Column 5 gives the base input impedance of the middle stage, found by multiplying the 39-ohm emitter resistor by the working current gain, which is the figure in column 4.

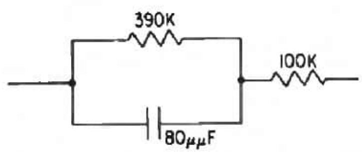


Figure 2. A commonly used feedback connection.

The collector load for the first stage is the parallel combination of the resistance calculated in column 5, with the collector resistance of 1.5K. This result is calculated in column 6.

The first stage feedback product (AB) is found by dividing 33K by the total collector load value (column 6) and then dividing this into the normal gain of 100. Adding 1 to this AB factor gives column 7, which is the factor by which first stage gain is reduced by the 33K feedback resistor.

Now divide 100 by the factor in column 7, and we have the working first stage gain, column 8. Finally, the over-all gain, from input to the phase splitter input, is found by multiplying columns 4 and 8, the individual working stage gains. This is entered in column 9.

Finally, the gain change, as measured externally, resulting from connecting the over-all feedback, is found by dividing the gain with feedback (column 9) into that without feedback (the top figure in column 9). Converting this to dB gives column 10.

From this, we see that 6 dB actual gain reduction corresponds with an effective over-all feedback somewhere between 16.9 and 18 dB. This is what reduces the distortion from 3 per cent to 0.4 per cent, although gain is only reduced 6 dB.

Now for the other case. This could be either a transistor or tube-type amplifier, and we'll only consider the type of feedback connection. It's shown in FIGURE 2. The response of the feedback connection shows a boost of about 14 dB, over a 5:1 frequency range.

Suppose the over-all externally measured frequency response of the amplifier is essentially flat up to 25 kHz, beyond which the fall-off is fairly sudden (FIGURE 3). As the loop gain adds the feedback connection response to this, the real, closed loop gain actually has a 14 dB peak before it finally falls off.

It is morally certain that when it does take its dive, the feedback is no longer negative, but goes through the 90-degree point somewhere near where it turns over. The amount of feedback at this point will be virtually nil.

This means that any spurious components at 25 kHz generated internally by the amplifier won't get reduced by feedback. They may get changed a little, but very little.

Now suppose the amplifier without feedback has distortion consisting of 3 per cent 3rd harmonic and 0.8 per cent 5th harmonic. The fundamental, of 5 kHz, will get about 14 dB feedback. So, compared to the final level of fundamental, after feedback, it will be 5 times what it was compared to the fundamental with no feedback (assuming the levels are readjusted to be the same). So we will have about 4 per cent 5th, with feedback.

The 3rd is in better shape. Probably the phase shift will be about 30 degrees. So it will produce about 86 per cent cancellation of 3rd, multiplied by the feedback factor for 3rd, which will be about 1.6 times its value for 5th. Feedback factor changes to about 1.4 on a 6 dB/octave slope, bringing the 3 per cent down to about 2.15 per cent.

Here is the net result, then. Without feedback, the distortion was 3 per cent 3rd and 0.8 per cent 5th. Feedback changes it to 2.15 per cent 3rd and 4 per cent 5th, which is scarcely an improvement. If the distortion reducing effect is measured at 1 kHz, there is probably in excess of 20 dB feedback to fundamental and at least 14 dB feedback of the 5th harmonic, which is now at 5 kHz.

So the results measured at 1 kHz would be changed to 0.4 per cent 3rd and 0.16 per cent 5th, which is more acceptable. As harmonic measurement is usually made at 1 kHz or not much higher, the amplifier may measure acceptably on harmonic distortion. But how about IM, the kind that the international method, using difference frequency should measure?

This measurement could also look satisfactory, if we take two frequencies 100 Hz apart, in the vicinity of 5 kHz. This is because the filter would only look for a 100 Hz component. But the 5th harmonics of the two waves would be in the vicinity of 25 kHz, where no feedback is operative. Any non-linearity would cause rectification, generating a spurious 500 Hz difference signal.

This could be found by exploring for frequencies other than 100 Hz. But, on music with difference tones and overtones in these regions, really nasty intermodulation might be audible, much worse than the measurements and specifications of the amplifier would lead you to believe.

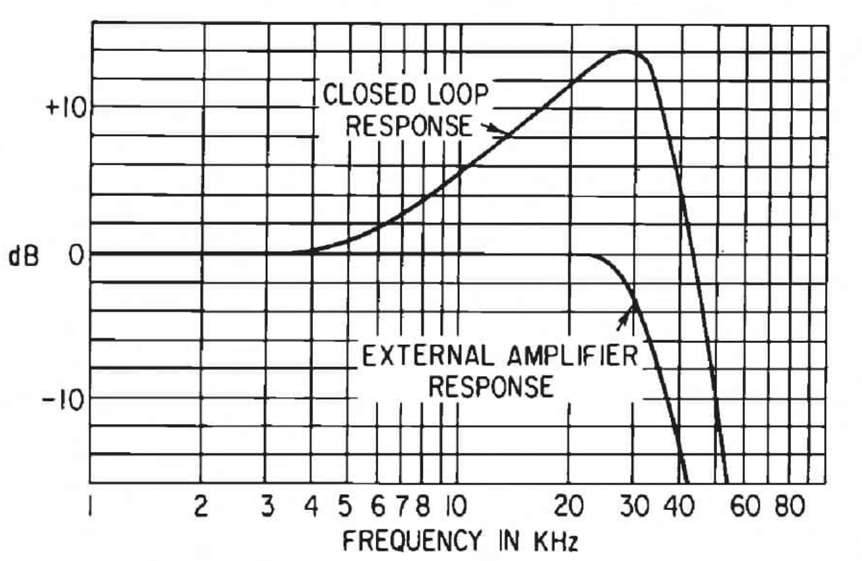


Figure 3. The loop gain necessary to provide a flat externally-measured response.