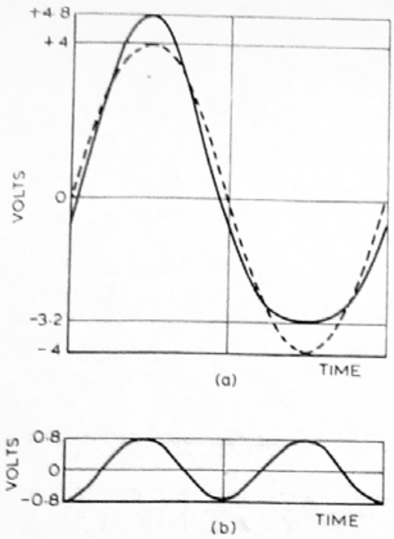

Fig. 5. *The full line in (a) shows the output waveform of an amplifier with the characteristic shown in Fig. 4, when the input is a pure sine wave. The broken line is the fundamental part, corresponding again to Fig. 4. The difference between the two, shown by itself at (b), is the second harmonic.*

positive peak it is 100 + 80 = 180 and at the negative peak it is 100 − 80 = 20. So 20% distortion, which is not as horrible as you might expect, if it is all second harmonic, is associated here with a no less than 9 to 1 variation in amplification over each cycle of signal. We can hardly be surprised, then, if we find that negative feedback doesn't work entirely according to plan.

Perhaps the best way of seeing how it does work is to plot a with-feedback curve to compare with Fig. 4, which can be done by making a table to calculate some points. Remember, the voltage fed back at any point is equal to Bv_o, and this added to v_i gives v'_i, the with-feedback input needed.

To make it easy to compare the two curves, the v' scale of the new one should be the v_i scale of the old multiplied by as many times as v'_i must be greater than v_i to maintain the same output. A convenient figure for this, which is also reasonable for feedback practice, is 10. (1 + *AB*) being 10, *AB* is 9 and *B* is 0.09.

(1) v_i	(2) v_o	(3) $0.09v_o$	(4) v'_i
0.01	1.1	0.099	0.109
0.014	1.596	0.1436	0.1576
0.02	2.4	0.216	0.236
0.03	3.9	0.351	0.381
0.04	5.6	0.504	0.544
−0.01	−0.9	−0.081	−0.091
−0.02	−1.6	−0.144	−0.164
−0.03	−2.1	−0.189	−0.219
−0.04	−2.4	−0.216	−0.256

Column (1) contains a selection of points covering the peak-to-peak swing of v_i. Column (2) contains the corresponding output voltages calculated from the equation, which were needed for plotting Fig. 4. Column (3) shows the voltages fed back, equal to $0.09v_o$. Lastly column (4), which is got by adding (3) to (1), shows the input required at XX in Fig. 1(b) to maintain the same output (2) as before.

Plotting Fig. 6 from columns (2) and (4) we are at once impressed by the success of negative feedback in straightening out the amplifier curve. It is now hardly distinguishable from a straight line, especially on the positive side.

Becoming a little more critical, we note that we need considerably more than 10 times the former peak input; to be exact, 13.6 times. But 10 was calculated on the basis of *A* = 100, whereas we have already noted on Fig. 4 that *A* varies from 100 to 180 during the positive half-cycle, and if we calculate the average multiplier for this range of values of *A* we find that it is 13.6. Rather than find fault here we might thank feedback for raising the positive fundamental peak output from 4V with 20% distortion to 5.5V with about 1½% distortion.

On the other hand any satisfaction that might at first be derived from seeing that the input needed for the negative peak has been increased only 6.4 times is damped by the unfortunate accompanying fact that the fundamental negative peak has been reduced from 4V to about 2.5V. And of course a 5.5V positive peak is no good with a 2.5V negative peak – unless use of the amplifier is confined to rather unusual waveforms.

It seems, then, that if at least our original 4V peak sine-wave output is to be maintained it will be necessary to bring up the negative input, as we would be able to do, seeing that we were prepared to find at least ±0.4V. To see what we get we shall have to extend our plots in the negative direction. If we proceed to calculate column (2) we find that beyond $v_i = -0.05$V a complication sets in; increasing $-v_i$ reduces $-v_o$, making the curve bend up. This is because the curve is derived from the equation for *A*, which makes *A* negative if v_i is more negative than −0.05V.

In a real amplifier, however, the decline of its gain to zero during the signal cycle is normally due to the cutting off of one or more transistors. In the usual push-pull configuration – in which distortion is largely third-order – the gain recovers as the signal goes more negative; indeed, if the biasing is correct it shouldn't fall off in the first place. But we are considering a square-law amplifier, to which the nearest practical approximation is a single-ended type, which cuts off altogether if the signal goes too negative. So a realistic procedure will be to continue the curve horizontally to the left:

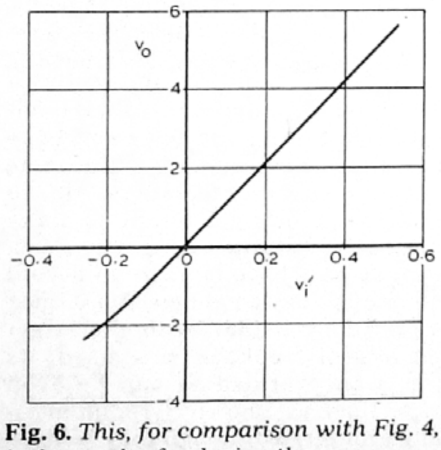

Fig. 6. *This, for comparison with Fig. 4, is the result of reducing the small-signal gain A-fold by negative feedback and correspondingly increasing the external input (v') to yield the same net input (v_i) as before.*

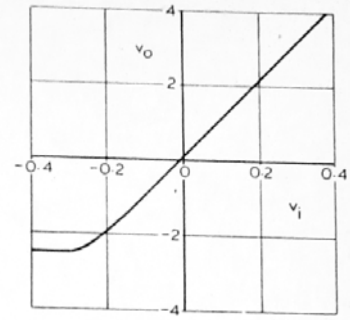

Fig. 7. *The result of further adjusting the input v_i to ±0.4V. Audibly, the result would be worse than without feedback (Fig. 4), and the output less.*

v_i	v_o	$0.09v_o$	v_i
−0.05	−2.5	−0.225	−0.275
−0.06	−2.5	−0.225	−0.285
−0.07	−2.5	−0.225	−0.295

At this rate it is obviously going to take us a long time to reach $v'_i = -0.4$, but we now have enough information to omit the intermediate stages and boldly write

$$v'_i = -0.4;\ v_0 = 2.5$$

Continuing beyond our original ±0.4V (to match the ±0.04V in Fig. 4) is clearly not going to make the picture any prettier, so in Fig. 7 I have kept within those limits. Now we see the truth about negative feedback, and it doesn't look as good as we may have supposed. And if anyone is thinking I've fiddled it by arbitrarily departing from the simple quadratic equation at the negative end, I invite him to stick to the equation. The result will be even more ghastly than Fig. 7.

That is quite bad enough, for on analysing Fig. 7* I find that the fundamental output is only just over 3V peak, compared with 4V in Fig. 4 (a power reduction of 44%) and in exchange for our 20% second-harmonic distortion we have received the following mixed bag:

Harmonic	Percentage
2	13.2
3	7.4
4	3.3
5	1.24
6	0.16
7	0.83

*By the method described in M. G. Scroggie's *Radio & Electronic Laboratory Handbook*, 8th edition, Sec. 11.10.