The Low-Loading Self-Biased Amplifier

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Low loading has been suggested as a means of improving self-biased amplifiers. The author discusses the modification of conventional amplifiers to this mode of operation.

In a series of articles on amplifiers for high-quality sound reproduction published in *Wireless World* for May and June, 1955, W. A. Ferguson of Mullard of Britain presented some thoughts on what he called "low loading" as a means of improving the performance of a self-biased push-pull output stage.

In the booklet *"Philips Hi Fi Amplifier Circuits,"* published in 1958 in Holland, the same statements on low loading are covered, and are expanded into more concrete form.

The following is quoted from the Philips booklet: "The operating conditions for class AB normally recommended and published by the tube manufacturers are based on measurements with continuous sine-wave drive. The cathode resistor is so chosen that under zero-signal conditions the tubes are operated in class A, whilst at full drive the working point is shifted to class-B setting. The anode-to-anode load resistance is chosen for optimum performance in class-B setting at full drive. The shifting of the working point is due to the influence of the increased anode and screen-grid currents on the cathode bias. For a typical output stage with two EL84 pentodes on a supply voltage of 310 v. the increase in cathode current, and hence the control-grid bias, is about 40 per cent with a sinusoidal input voltage.

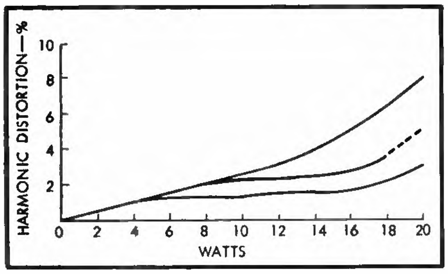

Fig. 1. Distortion of push-pull EL84's. (A), cathode-bias, 8000-ohm load; (B) fixed bias at same bias and load as (A); (C) fixed bias, 6600-ohm load, optimum bias. All measurements made with continuous sine-wave input.

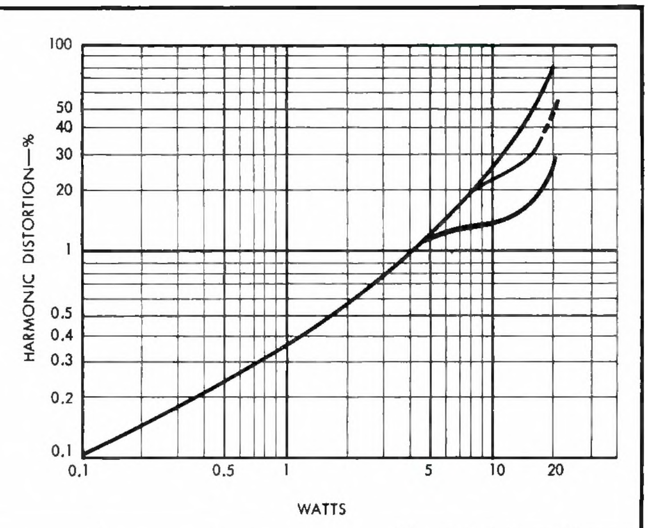

Fig. 2. Same curves as plotted in Fig. 1, but on logarithmic graph.

"When, however, such a power stage is used for the reproduction of speech and music, operating conditions are rather different. The mean-amplitude signal is now very small compared with the peak value which occurs from time to time, and the mean variations in cathode current are therefore also very small. Due to the relatively long time constant of the cathode resistor and its bypass capacitor, the shifting of the working point, even under peak-signal conditions, is small enough for the stage to be considered as working with a virtually fixed bias. If the normal class AB stage (cathode biased) is measured under the corresponding fixed-bias conditions with a sine-wave input, it is found that at high output levels the distortion is greater than when cathode bias is used. . . . In practice, a cathode-biased class-AB stage designed on a sinusoidal-drive basis will produce increased distortion when peak passages of speech or music are being reproduced."

The foregoing thoughts have presented a challenge to the author for some time, and so it was decided to attempt to verify or refute the low-loading idea through experiment. Mr. Ferguson presented a graph to illustrate his points, and tests were undertaken to verify the claims. Finally, similar results were obtained and are presented in *Fig.* 1. The conditions under which the measurements were made may be of some interest. The push-pull EL84's were resistance loaded and driven from an extremely pure dual-phase source. Adjustments were made at the zero-signal condition to maintain exactly 300 volts between the anodes and cathodes of the EL84's. Harmonic distortion was measured from anode to anode of the push-pull pair, as was the power level. There was no feedback. Curve A depicts the output stage distortion with a common 130-ohm bias resistor and an 80-µf bypass capacitor, with 8000 ohms anode-to-anode load. Curve B represents the same load, but with the bias fixed at the same point as zero signal for A. Curve C covers the optimum fixed bias condition with a 6600 ohm load. The voltages for the curves were:

	A	B	C
Anode voltage	310	300	300
Cathode voltage	10	0	0
Grid voltage	0	−10	−12
Screen voltage	300	290	290
A-A load, ohms	8000	8000	6600

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As logarithmic scales are usually used to illustrate power and distortion as the ear hears them, *Fig.* 2 is simply *Fig.* 1 redrawn on logarithmic form, which tends to reduce the apparent difference in the three modes of operation. Nevertheless there is a substantial difference in the curves above the 8 watt point, and as power peaks could fall in that area, it was considered worth pursuing the subject further.

The quotation continues, "One method of improving performance is to adjust the quiescent operating conditions in the output stage so that they are nearly optimum for fixed-bias working, although cathode bias is still used. This entails a smaller standing current and lower anode-to-anode load resistance."

Proof of the Theory

An amplifier using EL84 output tubes was constructed using a 8000-ohm Triad S142A output transformer in the circuit of *Fig.* 3. The IM distortion was under 0.6 per cent up to 14 watts. A KLH Six speaker was used, and a recording voltmeter was connected to the common output-tube cathodes. Music was then played at increasingly lounder levels until audible distortion was evident on extremely loud dynamic peak passages. It was found that the maximum deviation of bias was about 0.25 volts under these conditions, so that for practical purposes the bias was fixed. Audibly, distortion appeared at the same output level when either pentode or tapped screen output was used.

The amplifier was then converted to "low-loading" by substituting a 6600-ohm Triad S146A output transformer for the S142A. The self-bias network resistance was increased to 220 ohms to reduce the total cathode current in the EL84's to about 50 ma. Up to one watt output, IM distortion was under 0.1 per cent, and when tested with a steady input, distortion rose drastically as the drive was increased. At zero signal, bias was 11 volts. The same music as before was played over and over again at comparable and even higher levels, using the same speaker and input. A group of experienced listeners could detect no "break-up" or distortion. In this case the bias deviation was under 0.5 volt.

The amplifier was then arranged with both output transformers connected through a multicontact transfer relay that also changed the bias network when operated. This made possible almost instant switching between conventional and low-loading modes of operation. Listeners were allowed to switch back and forth at will, but with only the knowledge that they were trying two amplifiers. At low levels, there was no definite pattern of choice. At high-level listening, all 24 listeners chose the low-loading amplifier. Later, pentode and tapped screen "low-loading" modes were compared, with a fairly even split of choice. These trials were spread over a two-week interval.

A second amplifier, using EL34's and a 4000 ohm Triad S152A output transformer was built to check low-loading with more powerful tubes. The total EL34 cathode current was adjusted to 92 ma. See *Fig.* 3. At up to four watts this unit measures less than 0.1 per cent IM distortion, which rises quickly as steady sine wave input is increased, and as the bias increases. With music, the maximum bias deviation was 0.5 volts when driving the KLH Six, and 0.9 volts when driving an AR-1—again at levels near the testers' limit of tolerance.

This more powerful amplifier has been repeatedly A-B tested against the author's 60-watt fixed-bias amplifier, which was described in the March, 1959, issue. There is no detectable difference between the two in listening tests, although the author feels that the tapped screen connection improves the low-loading unit.

As a final series of tests, the AR-1 speaker was used with the conventionally loaded EL84 amplifier of *Fig.* 3. As the recording meter available was a two-trace device, the first channel was connected to monitor the power delivered by the amplifier, and the second channel was connected to a push button to act as a distortion-point indicator. Once again music was played at loud levels with the observers concentrating on operating the push button as they detected "break-up" or distortion. Even with this

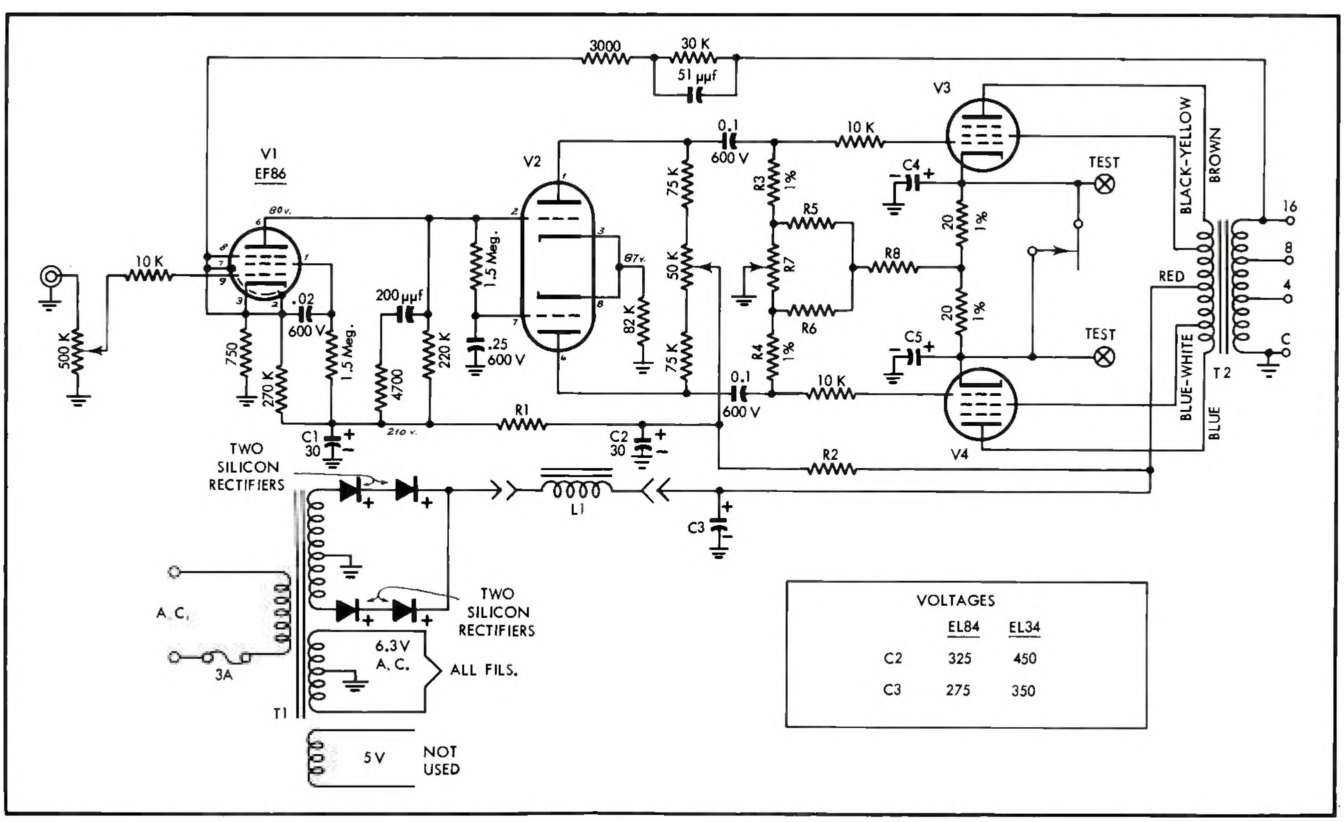

Fig. 3. Schematic of the amplifiers tested. See parts for values not on the schematic. The circuit is derived from the popular Mullard amplifier, and may be adapted for EL84 or EL34 output tubes.

very low efficiency speaker and moderate power amplifier, the average power required for music is quite low, running between two and four watts. Peaks where distortion occurred are a different ease however, for they could not be measured accurately, but apparently ran frequently into the upper thirty watt level. The duration of peaks, however, was extremely short, and to the author's disgust, was once again unmeasurable with the test equipment available. The evidence of the meter indicates that extended periods of distortion, up to a second, are actually a series of peaks and not continuous high power.

Summary

From this last series of tests it was concluded that an ideal amplifier is one that will coast along with average sound, yet reach effortlessly and successfully for the peaks. Thus far it must be concluded that a fixed-bias amplifier, or a comparable low-loading unit, best meets this requirement. Of course the amplifier should be matched to the speaker in potential power to efficiency, and a pair of EL84's is not quite enough for the AR-1 or AR-3, but they will handle almost everything else available today if properly loaded.

To recapitulate:

1. Self-biased class AB amplifiers require cathode bypass capacitors, hence have a bias time constant, and with music and voice are effectively operating with fixed bias.
2. If such amplifiers are loaded and the current adjusted as for fixed-bias conditions, they appear to sound clean, but they cannot be measured with steady-state signals except at low levels.
3. Low-loading reduces current through the output stage, hence the output tubes are at a low dissipation level.
4. The low current reduces power-supply requirements, and transformers run cool by comparison.
5. Low-loading retains the simplicity and safety features of self bias.

The author realizes full well that empirical data from listening tests are far from conclusive. It has not been possible to measure transient or high-level distortion in low-loading amplifiers thus far, and it could be argued that we need a new method of distortion measurement using random signals similar to music wave forms. It could also be said that the effects of feedback are neglected in comparing the value of low-loading with conventional operation, but in this area it is difficult to refute the practical demonstrations previously cited, and which can be readily duplicated by anyone so minded.

It would appear appropriate to close with a final quotation from the Philips booklet, "The low-loading adjustment provides reduced distortion at peak levels, although the improvement may be hard to detect until the ear is accustomed to high-quality reproduction, because it affects such short intervals of time."

Parts Differences Between EL84 and EL34 Amplifiers

Part	EL84	EL34
C_1, C_2	30 µf, 450 v	30 µf, 500 v, electrolytic
C_3	60 µf, 450 v	60 µf, 500 v, electrolytic
C_4, C_5	50 µf, 50 v	50 µf, 150 v, electrolytic
L_1	Triad C10X	Not used
R_1	39 k ohms, 2 watts	100 k ohms, 2 watts
R_2	15 k ohms, 2 watts	39 k ohms, 2 watts
R_3, R_4 (1 %)	500 k ohms, 2 watt	300 k ohms, ½ watt
R_5, R_6 (wirewound)	100 ohms, 3 watts	50 ohms, 3 watts
R_7 (wirewound pot)	100 ohms, 4 watts	200 ohms, 4 watts
R_8 (Low Loading)	160 ohms, 10 watts	300 ohms, 10 watts
R_8 (Conventional AB)	70 ohms, 5 watts	200 ohms, 10 watts
T_1 (Low Loading)	Triad S-146A 6600 ohms p-to-p	Triad S-152A 4000 ohms p-to-p
T_2 (Conventional AB)	Triad S-142A 8000 ohms p-to-p	Triad S-146A 6600 ohms p-to-p

Miscellaneous Data

T_1	350-0-350 v at 200 ma; Triad R-20A or B
Silicon Rectifiers	Four required with minimum P.I.V. of 400 v and minimum d.c. output current of 0.5 a.
V_2	ECC82/12AU7, 6CG7 (pins 8 and 9 strapped), 6SN7, or ECC83
V_3, V_4	EL84 or EL34; when EL34's are used, pins 1 and 8 should be strapped.

Notes on the Amplifiers

The two amplifiers used for low-loading experiments derive directly from the 60-watt unit described in the March, 1959, issue. While these amplifiers use a full-wave center-tapped power supply, the voltage-doubler supply described in the earlier article is recommended for the larger amplifier using EL34 output tubes.

The circuit derives from the "Mullard" 510 and 520 circuits, and borrows the Ampex front end. The d.c. balance network is a variation of Williamson's original, and appears to be the most satisfactory arrangement yet devised.

D.c. balance of both units is simply checked with a meter across the test points, the shunting key is opened, and the balancing potentiometer adjusted for zero indication.

A.c. balance is best set with a distortion meter. The shunt key is held open, signal is applied, and output distortion is adjusted to the minimum point with the 50,000-ohm potentiometer. Alternatively, the following method may be used:

1. Reduce the value of R_8 to the conventional value.
2. Load the output with a power resistor load.
3. Connect a voltmeter to the test points. Use a 3-volt scale or lower.
4. Drive with 50- or 60-cps input to near maximum power.
5. Open the cathode shunt key.
6. Adjust the 50,000-ohm potentiometer to zero the meter.

A third and least accurate method is to adjust the 50,000-ohm potentiometer to 105,000 ohms between pin 6 of the phase splitter and the arm of the potentiometer.

The smaller amplifier, *Fig.* 3, makes use of a full wave center-tapped power supply, with an inductive input filter for good regulation. It is interesting to note that the same power supply may be used for the larger EL34 amplifier by simply eliminating the choke and changing the 60-µf capacitor to a 500-volt unit, thus delivering 450 volts with capacitor-only filtration. It is the author's opinion that additional filtering is superfluous.

The units run cool because they are idling most of the time. Hum and noise cannot be measured on the 0.01-volt scale of the a.c. meter available, and no hum or noise is detectable in any speaker that has been connected.

Both units are designed on an extremely conservative basis, and if at least 100 per cent dissipation margin is used in selecting resistors, both low noise and long life can be expected. In the test amplifiers, 2-watt carbon resistors were used at all points unless wire wound or 1 per cent resistors are specified. The perfectionist will probably use low-noise deposited carbon or metal film resistors.

There is some difference in components between the large and small unit, and these are covered in the parts list. Æ