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LABORATORY REPORT ON LEAK TL12 MAIN AMPLIFIERS

WITH A DISCUSSION ON STABILITY, OVERSHOOT AND RINGING

by F. Langford-Smith and A. R. Chesterman

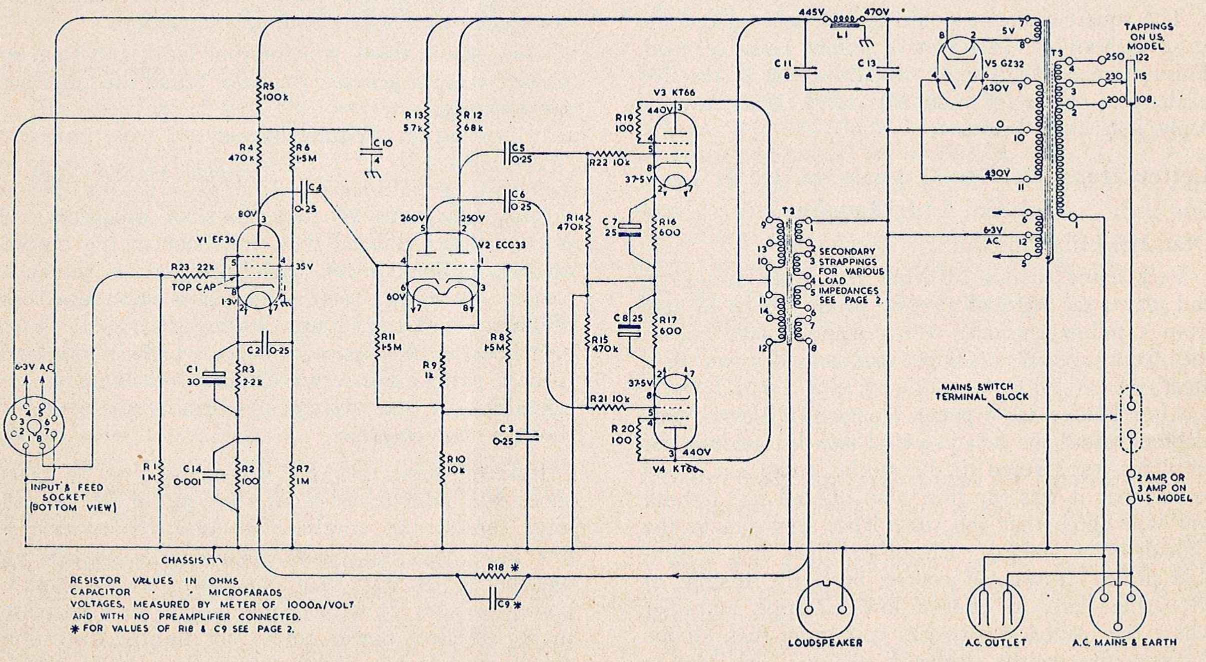
This amplifier has for many years been regarded by the authors as one of the world's best. It has a triode output stage with all the advantages which this confers when driving a loudspeaker load. It has extremely low non-linear distortion — the measured value at 12 watts output was less than the specified figure of 0.1% total harmonic distortion at 1000 c/s.

At low frequencies the performance is very good indeed, the rated output of 12 watts being obtained down to 30 c/s with THD not greater than 0.2%. At 10,000 c/s the total harmonic distortion reaches 3.7% at 12 watts output but, since music would never provide full power at such a high frequency, the THD at half power output, about 0.6% at 6 watts, provides a more realistic figure.

The effect of unbalanced direct currents on the total harmonic distortion was not measurable up to 20 mA at 1000 c/s but it increased the THD from 0.12 to 0.42% at 30 c/s. This performance is good.

The linearity characteristic is almost perfectly straight up to the rated power output, thanks largely to the triode output stage, and the full amount of feedback is therefore sustained up to this level at middle frequencies.

The negative feedback at 1000 c/s is 26 db, and this is maintained very well down to 30 c/s (25 db), but falls of appreciably at 15,000 c/s (17 db). This



Circuit diagram of Leak TL12 Main Amplifier.

is one of the factors responsible for the increased distortion at high frequencies.

At lower levels the distortion can be expected to fall off in the conventional Class A triode manner. In this, it differs from "Ultra-Linear" amplifiers in which the distortion usually rises somewhat from full power output to some value of reduced output.

The frequency response with and without feedback indicate that, on a purely resistive load, the feedback is negative all the way from 1 c/s to the highest frequencies. The minimum negative feedback at low frequencies is 6 db about 3 c/s, and at high frequencies about 0.5 db at 65,000 c/s. This is a very creditable performance indeed, since the great majority of amplifiers have positive feedback at one or other or both of the extreme frequencies.

However, the amplifier was unstable with our admittedly very severe condition of inductive loading (dummy loudspeaker load). It was also unstable with a shunt capacitance of 0.15 μF across 15 ohms or 0.1 μF when shock excited. Very few amplifiers are absolutely stable, that is, stable under any possible load conditions. The fact that some are absolutely stable indicates that this is an ideal capable of achievement. It is too early for us to attempt to lay down any specific performance on reactive loads; at some later date we hope to publish the measured reactive components of loudspeakers with various types of cross-over networks and from these results to derive a criterion for testing amplifiers for stability. It is also desirable to take into account the capacitive loading of an electrostatic loudspeaker.

With any capacitance shunted across the load resistance, the feedback at very high frequencies becomes positive in this amplifier.

The square wave response is excellent except for an overshoot of 34% on a purely resistive load. This point, and also the instability on a reactive load, were taken up with Mr. H. J. Leak and his reply is printed below.

Letter from Mr. H. J. Leak, of H. J. Leak and Co. Ltd., London

Dear Mr. Langford-Smith,

Very many thanks for your letter of June 27th, and may I say right away how pleasant it is to hear from a fellow engineer whose name I have known for twenty years? I hope that one day we shall meet.

After Black's 1934 paper a period of eleven years elapsed before the first practical low-distortion audio amplifier was offered to the public, and I am proud to say that it was my firm who offered it. I think you will agree that the time lapse was due to the difficulties of making such an amplifier at a reasonable price. It was, of course, perfectly feasible, at an earlier date, to offer a low-distortion amplifier where the feedback networks cost more than all the components in the forward chain! Any design which I have offered has had to fulfil three criteria:—

(1) That it sounds excellent under commonly found working conditions, i.e., with conventional loudspeaker systems connected to the amplifier by short leads.

(2) That it stays that way.

(3) That the amplifier will, on test, meet its published performance figures.

It is quite certain that tests can be applied which the amplifier will not meet perfectly when the gauge of perfection is a theoretical one.

I agree with you that there is some overshoot in the amplifier, but we have been quite unable to detect any difference, on an immediate change-over, between an amplifier with overshoot and one with a flat top, and, in practice, on reasonably-priced amplifiers it appears difficult to get a flat top whilst still maintaining stability in the high frequency region.

I also agree with you that oscillation will occur when a 15 ohm resistive load is shunted by a capacitance of 0.1 mfd. or over. I do not consider this of practical importance for the reason given above, that is, a loudspeaker is normally connected by short leads of low capacitance. I do agree that some dual loudspeakers with quarter-section cross-over networks do not look like a pleasant load to some feedback amplifiers! Though we have not had instances of instability with such loudspeaker systems (and we have sold thousands of amplifiers in the States, where there are such loudspeakers), we do actually, in our service sheets, advise people to use constant-resistance half-section dividing networks. Incidentally, have you ever made any voltage/frequency tests on such networks when they have loudspeaker windings connected to them? Resonance commonly occurs within the pass bands unless damping resistors are fitted. This can be done with but slight effect on the rate of attenuation.

Once again, thank you for your letter and I am so pleased that, in general, you have found the amplifier not wanting.

Yours sincerely,

(Signed) Harold Leak.

This brings us to the effects of overshoot. It is not always realized that overshoot in the output of an amplifier is fed back through the feedback loop to an earlier stage where it is combined, out of phase, with the input voltage. Since there is no overshoot in the input voltage, which is assumed to be a perfect square wave, there is nothing which can eliminate the overshoot, which is passed right through the amplifier.

It seems inevitable that a large amount of overshoot will tend to cause overloading in the output stage, unless the amplifier is operated at such a low level that the peak input voltage (including overshoot) is less than the amplifier maximum power output. Thus overshoot results in a decrease in the effective power output for limited distortion when reproducing sharp transients, and is therefore undesirable.

There seems to be no doubt that, with amplifiers having no positive feedback at any frequency, there are only two possible causes of overshoot.

1. The time delay between the application of a pulse to the input terminals and the time when the fed-back voltage reaches the same point. This time delay will vary from almost zero at mid-frequencies to that occurring with the highest significant frequency component of the pulse which completes the feedback loop.

2. The output transformer, which we are inclined to blame for most of the overshoot.

On the other hand there is no doubt whatever that all of the ringing in an amplifier, with no positive feedback at any frequency, is due to the transformer. We stress the importance of distinguishing between overshoot and ringing. If there is no overshoot there is normally no ringing (although we have known cases where the overshoot was suppressed by some network in the amplifier, leaving an irregular "wiggle"). However, there is no direct connection between the amount of the overshoot and the amount of the ringing — for example, with different output transformers having approximately the same overshoot there may be quite marked differences in the amount of ringing. It appears that both overshoot and ringing can be reduced to a considerable extent by careful transformer design. Of course, with any one transformer and fixed arrangement of the windings, reducing the overshoot must result in some increase in rise time*, and the designer in this case is forced to adopt some compromise. However, it appears to be possible, by suitable internal arrangement of the windings, to achieve the optimum condition for both small and overshoot and rapid rise time. This is a point which would repay careful investigation by transformer designers.

We would be pleased to receive comments from our readers on this subject, which has not been adequately treated in the literature.

The mechanical design and finish of the Leak TL12 amplifier are quite outstanding.

* See Ruben Lee "Electronic Transformers and Circuits", John Wiley and Sons, New York, 1947.

Details of electrical performance are given in our standard test manner, and comments on these tests are given below.

See June '56 issue, P.69 for results with a loud speaker load.

COMMENTS ON TESTS USED IN THE RADIOTRONICS LABORATORY ON MAIN AMPLIFIERS

By F. Langford-Smith and A. R. Chesterman

The following remarks refer to the amplifier test form used elsewhere in this issue for the Leak Model TL12 Amplifier.

1. Square wave tests

The usual tests of rise time, overshoot and transient recovery time are made at 5 Kc/s because this frequency has been found to be the most satisfactory over a wide range of amplifiers. Top and bottom tilt are measured at 50 c/s for a similar reason.

An article entitled "Square Wave Testing" appears in Radiotronics 20.6 (June, 1955), page 65, giving detailed information on this test. The generator used for these tests is noteworthy because it has a very rapid rise time (0.05 μ sec.).

This test is carried out first because, in our circuit development, we adjust the feedback network and some other circuit constants for optimum square wave response at 5 Kc/s before proceeding with the other tests.

1.2. Shunt capacitance to cause oscillation

This test is first carried out without shock excitation. The largest capacitor used for this test is 1 μF shunted across 12-16 ohms, or inversely proportional to this value for lower impedances. This gives, in our opinion, the highest phase angle ever likely to be reached under any condition of load. The fact that a particular amplifier is unstable with a specified shunt capacitance does not mean that the amplifier is necessarily defective. It is hoped to investigate the input impedance of cross-over networks, supplying a loudspeaker load, and to publish the findings in some future issue, and from this to develop a criterion for the test.

1.3. Stability when shock excited by a 5 Kc/s square wave

This is a more severe test than 1.2 above. Stability is noted under three conditions — short-circuited and open-circuited load, and capacitance shunted across the normal resistive load to cause oscillation.

1.4. Partially capacitive load for further tests

If instability occurs in 1.3 above with a stated value of shunt capacitance, 80% of this capacitance is used for a measurement of the overshoot and recovery time, and later (2 below) for a frequency response curve.

If instability does not occur in 1.3 above, then the shunt capacitance giving the greatest overshoot is selected for these same tests.