The Design of a High Fidelity Amplifier

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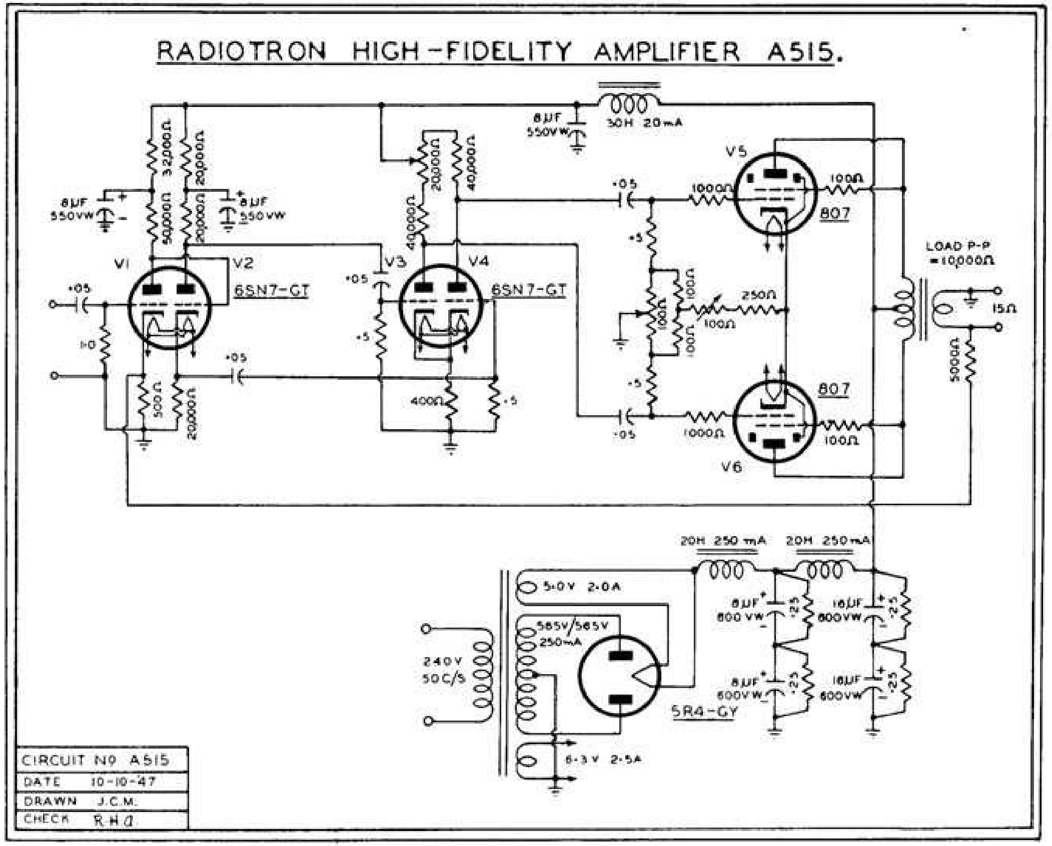
(3) A Design using Push-pull Triodes with Negative Feedback.

If it is desired to reduce distortion to the absolute minimum, there appear to be two possible approaches. The first of these has received the greater amount of publicity during recent years, and is the application of push-pull pentodes (or beam power valves) with a high degree of negative feedback. Although this is capable of providing extremely good results, the design is complicated owing to the extremely high degree of feedback and the precautions which require to be taken to avoid instability.

The second approach is through the application of push-pull triodes with negative feedback. In this case the initial distortion is considerably less, and the degree of feedback necessary to provide the required fidelity is not so great as to require abnormal precautions in the feedback loop.

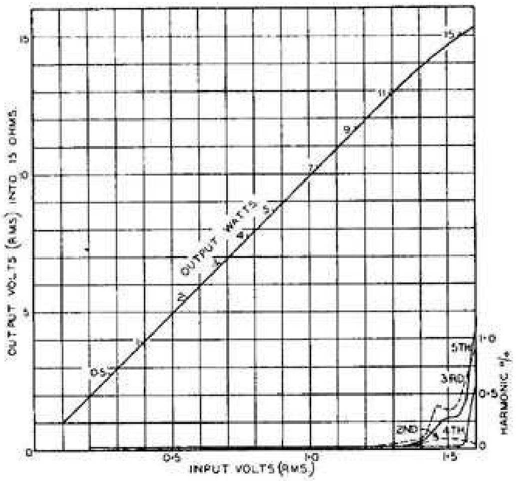
We were interested to read an article by D. T. N. Williamson, "Design of a High Quality Amplifier" in the Wireless World, April and May 1947, using push-pull triodes with negative feedback. We therefore adapted it to suit our own valve types and then carried out tests to see whether the claimed low distortion limit of less than 0.1% total could be reproduced.

The original amplifier used one triode valve as a resistance coupled amplifier with its plate directly coupled to the grid of a second triode operated as a phase splitter with equal plate and cathode loads.



The plate and cathode of the second valve were capacitance coupled to the grids of the push-pull triodes, which in turn were capacitance coupled to the grids of the power valves. The latter were the English type KT66 which is somewhat close in characteristics to types 6L6 and 807. The KT66's were operated with plate to cathode voltages of about 400 volts which were in excess of the maximum triode ratings for either type 6L6 or 807.

In order to attempt to duplicate the results obtained in the English amplifier, tests were carried out on type 807 to see whether it could be used with the higher screen voltage in triode operation. During these tests we had no valve failures and subsequently arranged for a number of 807 valves to be placed on life test with triode connection and a combined plate and screen voltage of 400 volts to cathode. The



results of these tests will not be known for some months, but in the meantime there does not seem to be any reason why the valves should not be used under these conditions for individual amplifiers at the risk of the user, since the risk appears to be quite small. The screen dissipation is considerably below its maximum value and the only possible breakdown is through the increased screen voltage causing electrolysis or breakdown in the stem-press between adjacent leads. It would, of course, be possible for the output valves to be used within their maximum ratings by reducing the voltage from 400 to 300 but the power output would then be considerably smaller.

The valves used in the original voltage amplifier stages were type L63, which has characteristics resembling those of type 6J5-GT or one half of type 6SN7-GT. It was therefore decided to use two 6SN7-GT valves, one in place of each pair of L63 valves. This gave a valve complement of two type 6SN7-GT,* two type 807 and one type 5R4-GY rectifier. Special attention was given in the original design to the avoidance of phase shift. The direct coupling from the plate of the first valve to the grid of the second valve eliminated one possible cause of phase shift at low frequencies, while the cathode return circuit was purely resistive. All the cathode resistors are unbypassed so as to avoid any phase shift at low frequencies, leaving only the coupling condensers to the third and fourth stages, and the output transformer. The latter was required to have a primary inductance of at least 100 henrys, measured at 50c/s with 5 volts rms on the primary, a leakage inductance of not more than 30mH measured at 1000 c/s and a primary resistance of the order of 250 ohms. In order to avoid the delay in having a special transformer made for the job, we substituted various transformers which were on hand. It was found that the transformer supplied with the Goodmans 12" loud speaker would give quite satisfactory results, and this was therefore adopted for the initial tests. An order has been placed for a transformer specially designed for this amplifier, which should be available at a later date. The amplifier was then wired up in accordance with the circuit diagram given herewith (A515).

The static plate currents in the final stage were balanced, and the drive to each valve was adjusted to give equal outputs at the plates when the valves were supplied with d.c. through separate chokes with individual loads of 5000 ohms each. The cathode bias resistors on the final stage were adjusted to keep the total plate dissipation less than 25 watts per valve. Without feedback, the amplifier was perfectly linear up to an output of 7.3 watts on a resistive load. With feedback, the amplifier was perfectly linear up to an output of 11.12 watts and it gave a smooth overload so that an output of 15 or 16 watts could be achieved without serious distortion.

The harmonic distortion for a power output of 11 watts was 0.01% 2nd harmonic, 0.04% 3rd harmonic, 0.01% 4th harmonic and 0.015% 5th harmonic. Even with an output of 17 watts as for an overload condition the distortion only reached the values of 0.46% 2nd harmonic, 0.31% 3rd harmonic, 0.53% 4th harmonic and 1.25% 5th harmonic. When tested on a speaker load it was found that for fairly large outputs at low frequencies a high frequency oscillation (about 60 Kc/s) would commence and be accompanied by a pulsed output of some other frequency. Both these incipient oscillations were cured by the addition of a 0.0005µF capacitor from earth to the screen of the 807 valve which tends to provide positive feedback to the cathode of the input stage. It was found that the by-pass was slightly more effective when connected to the screen than to the plate.

**If this type is not available, each 6SN7-GT may be replaced by two type 6J5-GT, or 6SJ7-GT (triode connected), 7193, 2C22, 9072, CV6 or any general purpose triode with a plate resistance of about 7000 to 8000 ohms and amplification factor about 20.*

The following tests were carried out with this addition. It was found practicable to apply sufficient feedback from the voice coil to the cathode of the input stage to provide 20db reduction in output with complete stability under all conditions. The phase shift between the input and output was quite small over a frequency range of 20c/s to 13 Kc/s.

The frequency response on a resistive load was constant from 20 to 10,000c/s and rose only 0.42db at 13,000c/s. On a speaker load the output was practically constant from 20 to 13,000c/s, using a Goodmans 12" speaker, although the speaker was showing signs of frequency doubling with an input of 20c/s, as would be expected. As a matter of interest the resonant frequency of the speaker, when used in a vented baffle, was 45c/s.

It was found that harmonic distortion on the speaker load was very similar to that on a resistive load except at low frequencies, and the detailed values are tabulated at the end of the article. The distortion is extremely low down to a frequency of 40c/s.

At the time when these tests were carried out it was not possible to perform intermodulation distortion tests, but these will be carried out and published at the earliest opportunity. It is obvious that the total intermodulation distortion will be very low, and the tests are only intended to form a basis of comparison with other amplifiers.

SUMMING UP

This amplifier is by far the best which we have ever tested and we wish to give full credit to the original designer. It not only gives extraordinary linearity and lack of harmonic or intermodulation distortion but is comparatively simple and involves no special problems except the choice of output transformer. Unless the latter is specially designed for this circuit, or is one having extraordinarily low leakage inductance and exceptionally high primary inductance (such as the Goodmans transformer referred to in the article), the best results cannot be achieved.

TEST RESULTS

Static Measurements

(with Avo model 7).

	No output	11W. output	15W. output
Ground to plate of V1	82V		
Ground to cathode of V1	1.78V		
Ground to plate of V2	222.0V		
Ground to cathode of V2	90.0V		
Ground to plate of V3	148.0V		
Ground to cathode of V3	4.1V		
Ground to plate of V4	152.0V		
Ground to cathode of V4	4.1V		
Ground to cathode of V5 and V6	39.0V	39.2V	28.8V
Cathode to plates of V5 and V6	400.0V	401.0V	425.0V
Screen dissipation of V5 and V6	2.16W	1.7W	1.8W
Plate dissipation of V5 and V6	47.4W	37.3W	36.4W

	No output	11W. output	15W. output
Total B+ voltage	440.0V	441.0V	452.0V
Total B+ current	142.0mA	140.0mA	112.0mA
Ground to filament of 5R4-GY	465.0V	565.0V	565.0V
Input voltage to V1 (rms)		1.34V	1.55V
Input voltage (rms) to V1 with no feedback		0.125V	
Input voltage (rms) to V2		1.95V	2.83V
Input voltage (rms) to V3		3.3V	4.4V
Input voltage (rms) to V5 and V6 (grid-to-grid)		59.0V	85.0V
Output resistance		0.3 ohms	
Damping factor (R_L/R_o)		50.0	
Hum output (across 15)	0.34mV at 50 c/s 0.06mV at 100 c/s		

Performance Measurements On A515

Linearity with *no* feedback. Constant B+ supply. Plate-to-plate resistive load of 10,000 ohms.

input volts 400 c/s	output volts	gain	watts
0.01	30.0	3000	
0.02	60.0	3000	
0.03	90.0	3000	
0.04	120.0	3000	
0.05	150.0	3000	
0.06	180.0	3000	
0.07	210.0	3000	
0.08	240.0	3000	
0.09	270.0	3000	7.3
0.1	295.0	2950	8.7
0.11	324.0	2945	10.5
0.12	335	2790	11.2
0.13	358	2750	12.8

Linearity with feedback. Resistive load (15 ohms).

input volts 400 c/s	output volts	gain	watts
0.1	1.0	9.95	
0.2	1.95	9.95	
0.3	2.96	9.95	
0.4	3.95	9.95	
0.5	4.95	9.95	
0.6	5.94	9.95	
0.7	6.95	9.95	
0.8	7.97	9.95	
0.9	8.95	9.95	
1.0	9.95	9.95	
1.1	10.9	9.95	
1.2	11.95	9.95	
1.3	12.95	9.95	11.12
1.4	13.8	9.86	12.65
1.5	14.7	9.8	14.3
1.6	15.3	9.57	15.6

Frequency Response

Constant input of 0.05V without feedback and 0.5V with feedback.

c/s	Output volts: speaker load		Output volts: 15 ohms resistive load	
	no feedback	feedback	no feedback	feedback
20	4.8	5.05	4.65	4.95
30	5.62	5.0	4.88	4.95
40	6.3	4.95	4.95	4.95
50	6.3	4.9	5.0	4.95
60	5.8	4.9	5.05	4.95
70	5.75	4.9	5.06	4.95
80	6.15	4.9	5.08	4.95
90	6.3	4.9	5.1	4.95
100	6.12	4.9	5.1	4.95
1000	5.55	4.9	5.1	4.95
3000	5.9	4.9	4.98	4.95
4000	5.95	4.92	4.92	4.95
5000	5.95	4.92	4.88	4.95
6000	5.95	4.95	4.72	4.95
7000	5.95	4.95	4.65	4.95
8000	5.95	4.95	4.5	4.95
9000	5.95	4.95	4.4	4.95
10,000	5.95	5.0	4.3	4.95
11,000	5.95	5.0	4.2	4.96
12,000	5.95	5.0	4.08	4.97
13,000	5.95	5.0	4.02	4.98

Bass resonant frequency of Goodmans 12" speaker in vented enclosure was 45 c/s.

Harmonic Analysis

Resistive load of 15 ohms at frequency 400 c/s.

Output volts	Watts	Harmonics per cent. H_2	H_3	H_4	H_5
2.74	0.5	0.025			
3.88	1.0	0.02			
5.49	2.0	0.02			
6.72	3.0	0.02			
7.76	4.0	0.025	0.01		
9.5	6.0	0.025	0.01		
10.98	8.0	0.025	0.01		
12.28	10.0	0.01	0.015		
12.88	11.0	0.01	0.04	0.01	0.015
13.42	12.0	0.01	0.08	0.01	0.06
13.98	13.0	0.03	0.38	0.01	0.21
14.5	14.0	0.075	0.35	0.01	0.26
15.0	15.0	0.07	0.54	0.01	0.28
15.5	16.0	0.04	0.92	0.11	0.45
16.0	17.0	0.046	0.31	0.53	1.2
Oscillator distortion (approximate)		0.06	0.035		

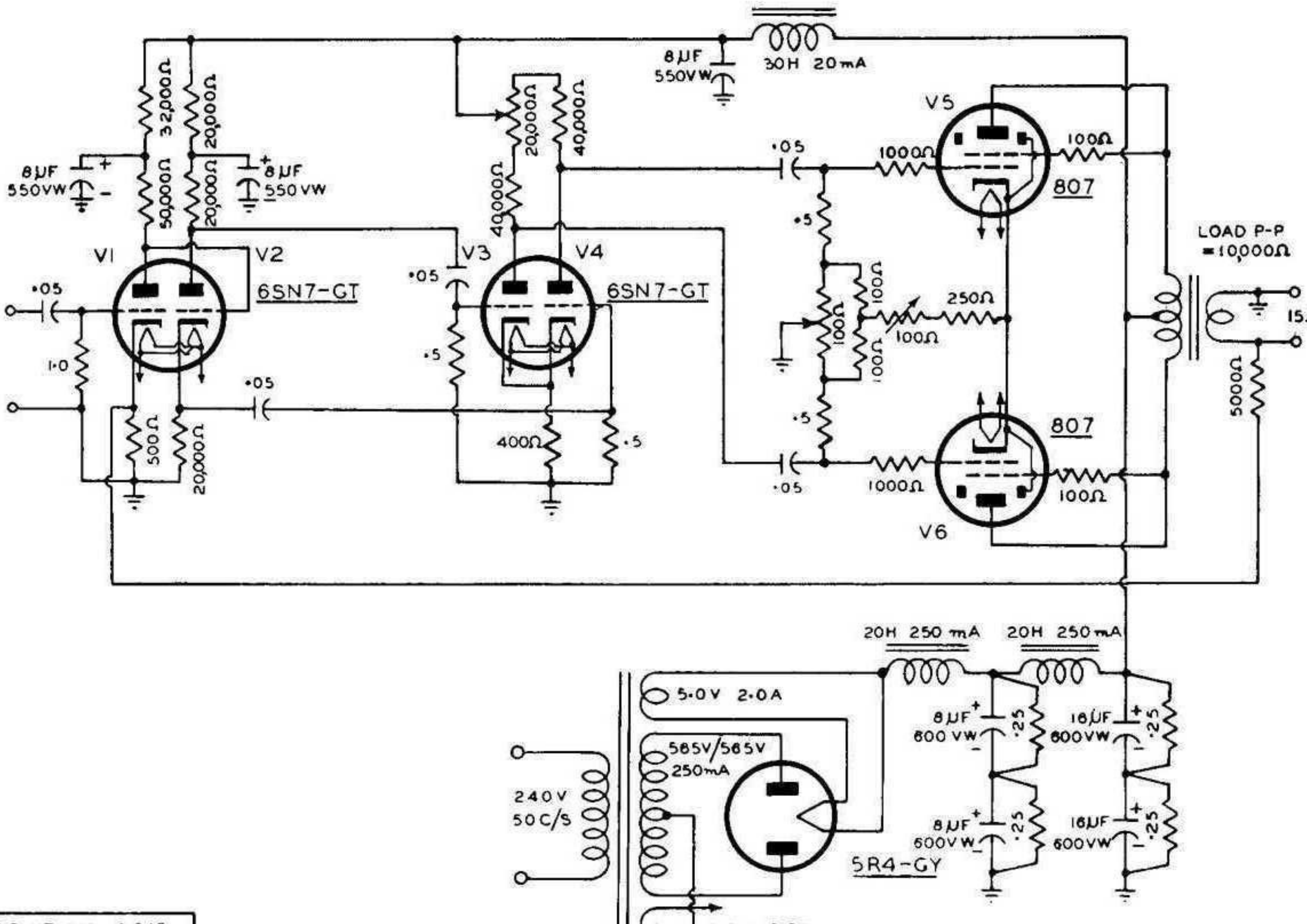
Harmonic Analysis

Speaker load, with power output of 11 watts, measured across the voice coil.

Frequency c/s	Harmonics per cent. H_2	H_3	H_4	H_5
40	0.18	0.98	0.14	0.23
50	0.32	0.4	0.05	0.05
60	0.22	0.14		
75	0.18	0.07	0.02	0.075
100	0.18	0.07		
300		0.02		
1000	0.05	0.03		0.02
3000	0.04	0.07	0.01	0.09
5000	0.04	0.08		
7500	0.07			

Further harmonics were beyond the range of the analyzer.

RADIOTRON HIGH-FIDELITY AMPLIFIER A515.



CIRCUIT Nº	A515
DATE	10-10-47
DRAWN	J.C.M.
CHECK	R.H.A.

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