

Self Inverting Push Pull Power Amplifiers

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This paper covers a group of circuits intended to accomplish Push Pull (PP) operation in the output stage of a power amplifier without any phase inversion in an earlier stage, as is customary. The benefit of such a circuit is reduced cost & the ability to call the completed circuit PP, a marketing advantage.

The basic circuit goes back to at least the 1940s & perhaps earlier. For example, the schematic covering the Sparton 8549 is dated 1947.

A rigorous study of various versions of the basic circuit indicate this topology has some problems. It does not deliver the kind of performance often claimed by its proponents. The tests shewed that no version of the circuit delivered more than one half the audio power that would be available in the ordinary hookup.

Referring to the spreadsheet of the distortion vs power output, the distortion increase rapidly as power output is increased. Higher order distortion products appear in the spectrums at higher power levels.

Self Inverting PP Stage Distortion		Percent Distortion Measured by HP 334A Analyzer					
Version	/	One Watt	3.75 Watts	4.5 Watts	5 Watts	5.4 Watts	6 Watts
Sparton 8549 540R to Common		3.9	9.2		7.5		
Popular Electronics 250R Tail to Common		4.3	10.5			14.0	15.5
5H 255R to Common		2.0	7.2			12.0	14.5
5H 505R to -22.4 Volts		2.8	8.0			14.0	18.0
NFET to -22.4 Volts		2.4	11.0			26.0	
500R to -22.4 Volts		2.7	8.0			11.5	
LM317 to Common (Oddwatt)		2.7	10.6		18.0		
~~~~~							
Philco 37-640 Screen Drive			7.8	12.5			
6AD7G		An attempt to do it without the extra tube					

The formatting has altered the vertical alignment in the Distortion table.



Most but not all of the tests were performed on the cathode coupled version of the self inverting PP stage.

One test of the screen driven version is included. The initial results of a plate driven inverter were so inferior the test was terminated.

A summary of the circuits was published in the Radio Designers Handbook, Vers 4 & reproduced here.

### (vi) Cathode bias

See Sect. 5(vi) as for push-pull triodes, except that the screen dissipation must also be checked.

### (vii) Parasitics

See Sect. 5(vii) as for push-pull triodes, also Sect. 3(iii)H.

### (viii) Phase inversion in the power stage

In the interests of economy, push-pull is sometimes used in the output stage without a prior phase inverter. All such methods—except the Cathamplifier—have inherently high distortion, and some have serious unbalance between the two input voltages.

#### (A) Phase inverter principle (Fig. 13.44)

The grid of  $V_2$  is excited from the voltage divider  $R_3R_4$  across the output of  $V_1$ .  $R_3 + R_4$  must be very much greater than the load resistance (say 50 000 ohms).  $R_5$  and  $R_6$  are grid stoppers. All other components are normal.  $R_k$  may be bypassed if desired.

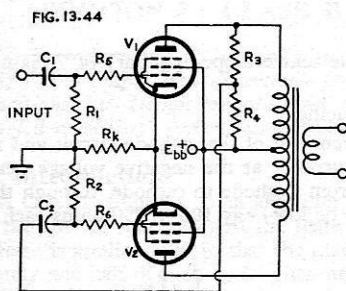


FIG. 13.44

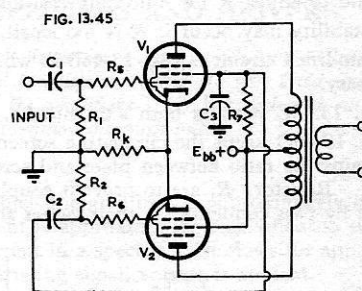


FIG. 13.45

Fig. 13.44. Push-pull circuit using phase inversion in the power stage.

Fig. 13.45. Push-pull circuit using screen resistance coupling from  $V_1$  to the grid of  $V_2$ .

The signal voltage on the grid of  $V_2$  must first pass through  $V_1$  where it is distorted, then through  $V_2$  where it will be distorted again. Thus the second harmonic will be the same as for a single valve, and the third harmonic will be approximately twice the value with balanced push-pull. The balance, if adjusted for maximum signal, will not be correct for low volume, owing to the third harmonic "flattening."

#### (B) Screen resistance coupling (Fig. 13.45)

This is a modification of (A) being an attempt to obtain from the screen a more linear relationship than from the plate. No comparative measurements have been published.  $R_7$  may be about 1500 ohms for type 6V6-GT or 2500 for type 6F6-G, with  $E_s = E_{c2} = 250$  volts—the exact value should be found experimentally;  $C_2$  may be 0.002  $\mu$ F. For better balance an equal screen resistor might be added for  $V_2$ . Ref. E10.

#### (C) Common cathode impedance (Fig. 13.46)

$R_1$  and  $R_2$  in series provide a common cathode coupling impedance [see Chapter 12 Sect. 6(vi)].  $R_2$  may have a value of, say, 1000 ohms to give an approach towards balance, but necessarily must carry the plate currents of both valves—say, 70 or 80 mA—and will have a voltage of, say, 70 to 80 with a dissipation around 6 watts. Care should be taken to avoid exceeding the maximum heater-cathode voltage rating.

See Reference E23.

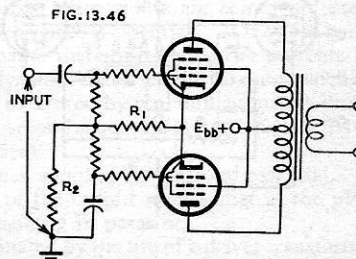


FIG. 13.46

Fig. 13.46. Push-pull circuit with common cathode impedance coupling.



While doing simulations of this circuit about 10-15 years ago I noticed the circuit performance did improve as the cathode tail resistor was increased in value. That could be expected. PP balance depends on a large resistance in the cathode tail. For good balance the cct needs to satisfy the relation

$$R_k (\mu + 1) \gg r_p + R_l$$

That translates to the cathode resistor times  $(\mu + 1)$  should be much greater than plate resistance plus plate load.

But there is a practical limit on how far that could be taken with resistors.

Here is an example of what does not work well, for fidelity anyway. A typical stage is PP 6V6s, loaded by 8K, p-p. So each  $R_l$  is 4K. Refer to the simplified schematic.

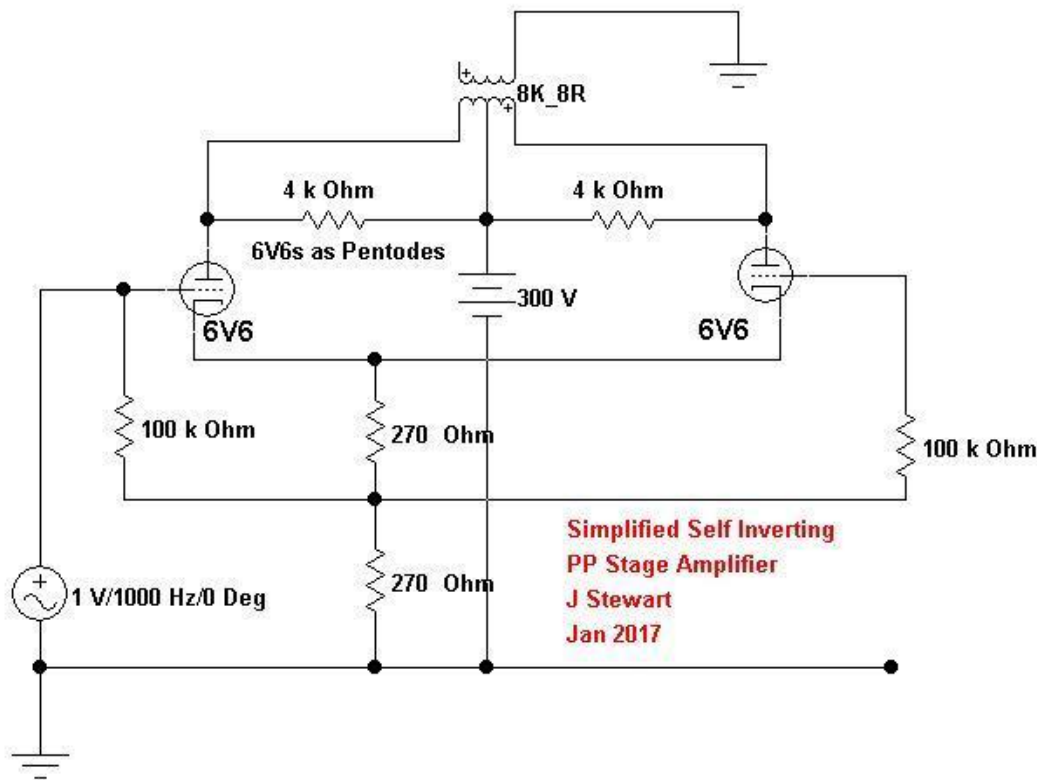
The longtail in one of these circuits ( Sparton 8549) is a series connexion of two resistors of 0.27 K each. The grid bias is taken off at their midpoint. The Class A operating point of the 6V6 results in  $r_p$  of 50K &  $g_m$  of 4.1 ma/v, so  $\mu$  is 205.

Plugging the numbers into the relationship we get-

$$R_k (\mu + 1) \gg r_p + R_l$$

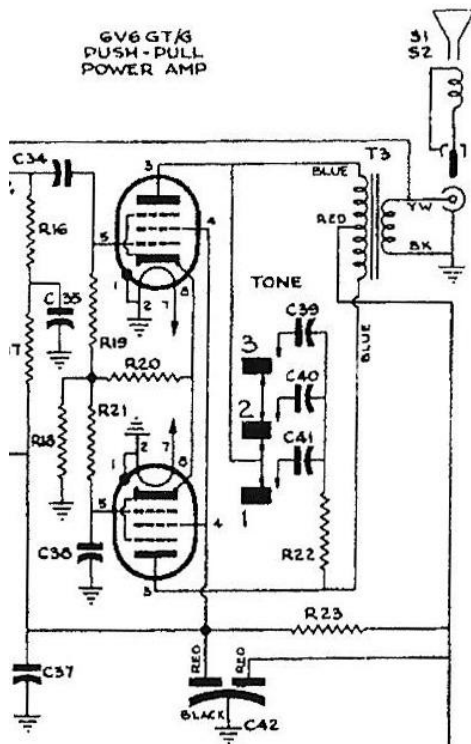
$$0.54 ( 206 ) \gg 50 + 4$$

111.24  $\gg$  54 Ouch! The relationship fails. Dismally.

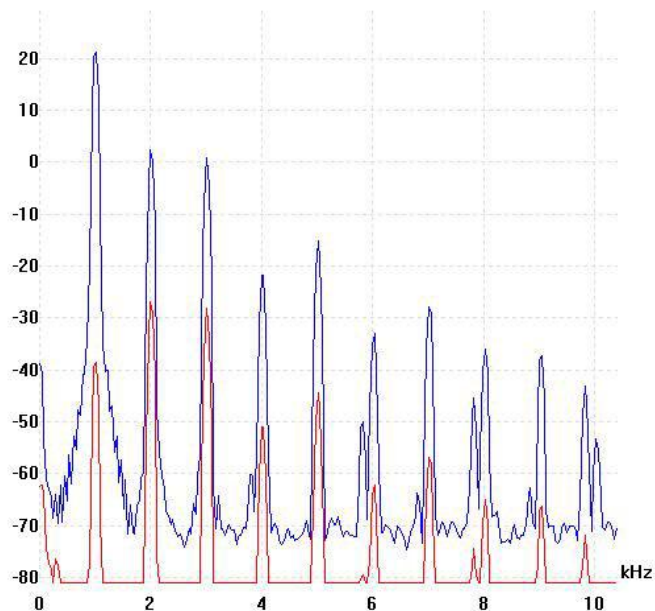




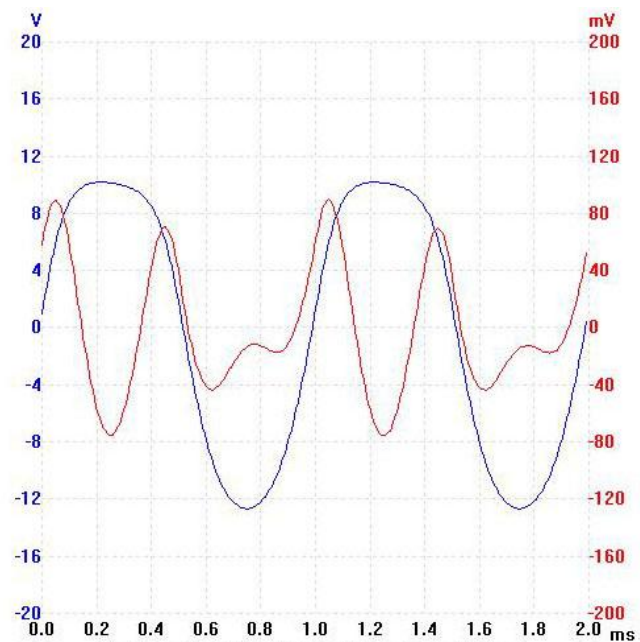
## SPARTON 8549 Schematic, Output Section



R18 & R20 are 270R each



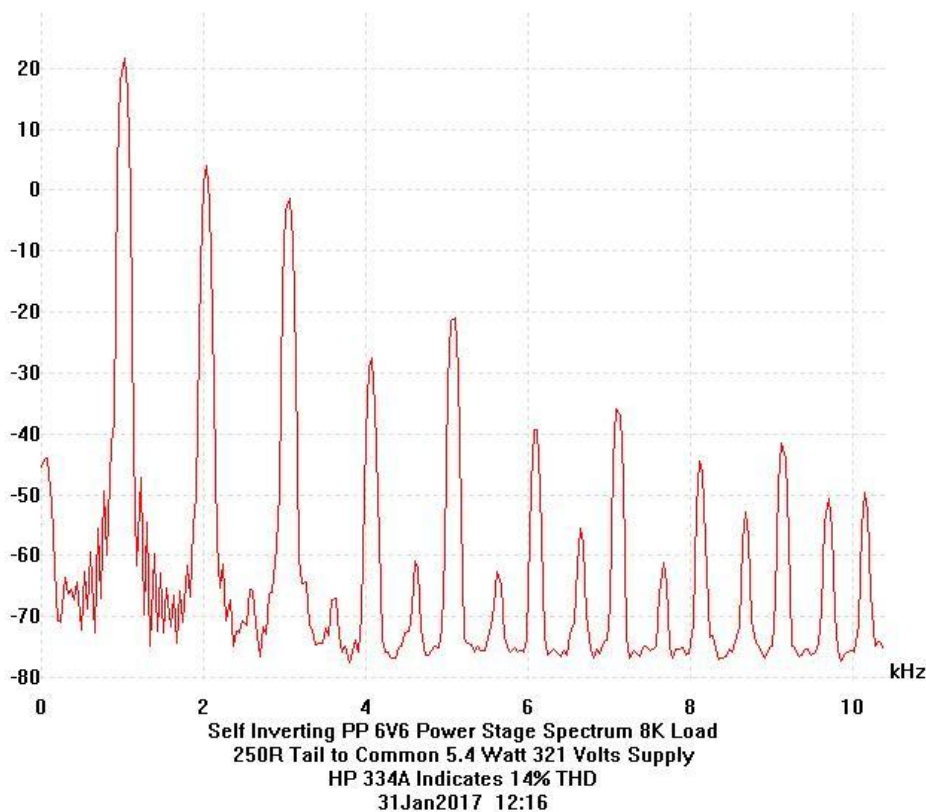
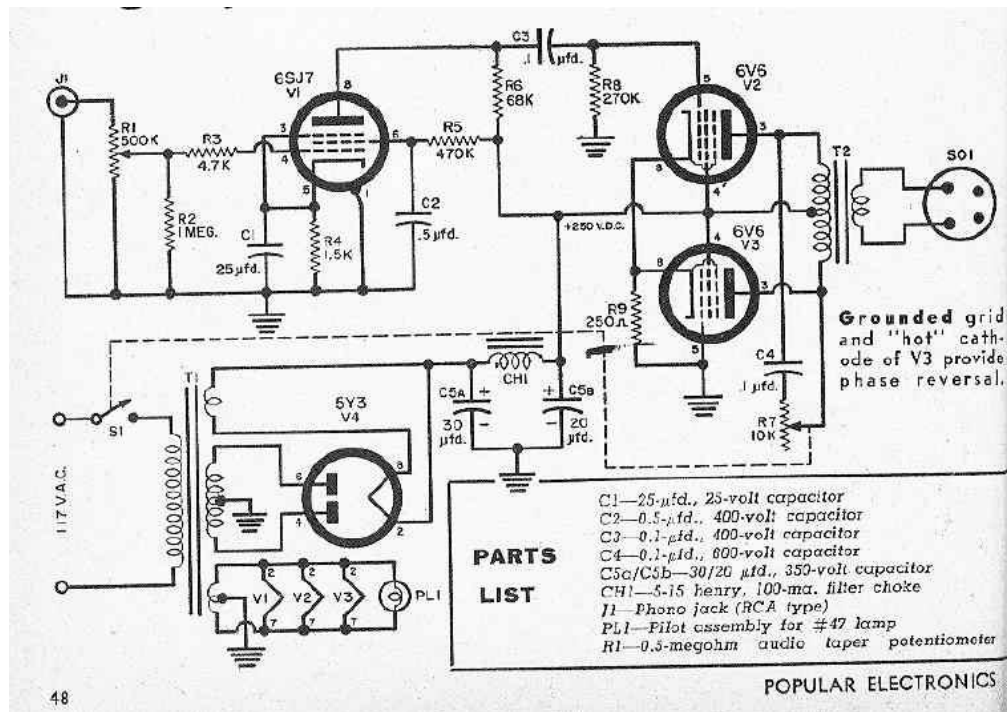
Self Inverting PP 6V6 Power Stage Spectrum 8K Load  
Ebb 335 Volts Cathode Return 270R & 270R 5 Watts no FB  
HP 334A Indicates 13% THD Red Trace is Distortion Products  
Sparton 8549  
26Nov2016 14:57



Self Inverting PP 6V6 Power Stage Scope 8K Load  
Ebb 335 Volts Cathode Return 270R & 270R 5 Watts no FB  
HP 334A Indicates 13% THD Red Trace is Distortion Products  
Sparton 8549  
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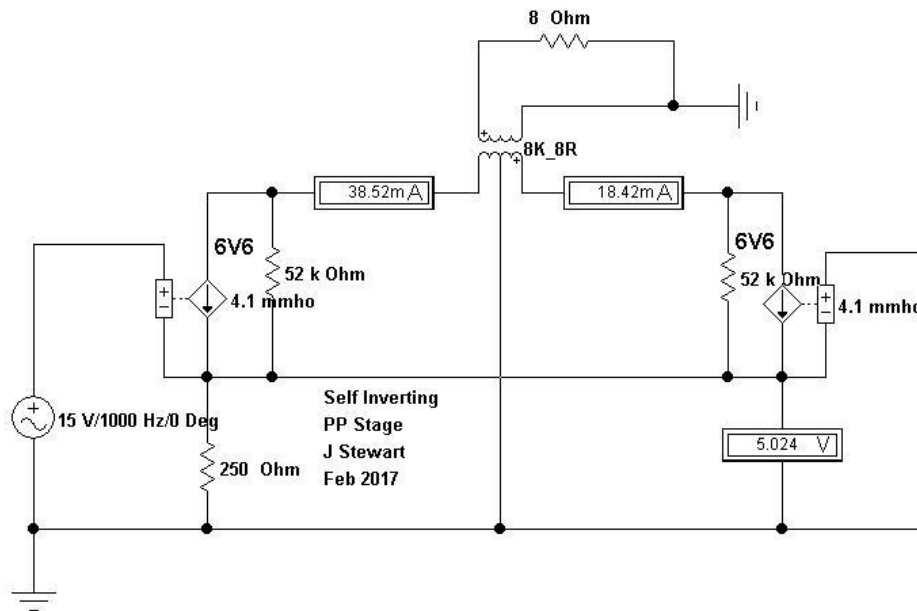
One of these circuits that had quite a bit of interest appeared in Audio Magazine, a respected HIFI publication of the 50s & 60s, in 1961. The author of the article Melvin Liebowitz claimed good performance. He most probably did not subject his circuit to any objective measurements. A similar circuit appeared in Popular Electronics later. The performance at best is only marginal. Refer to the spreadsheet under 250R to Common.



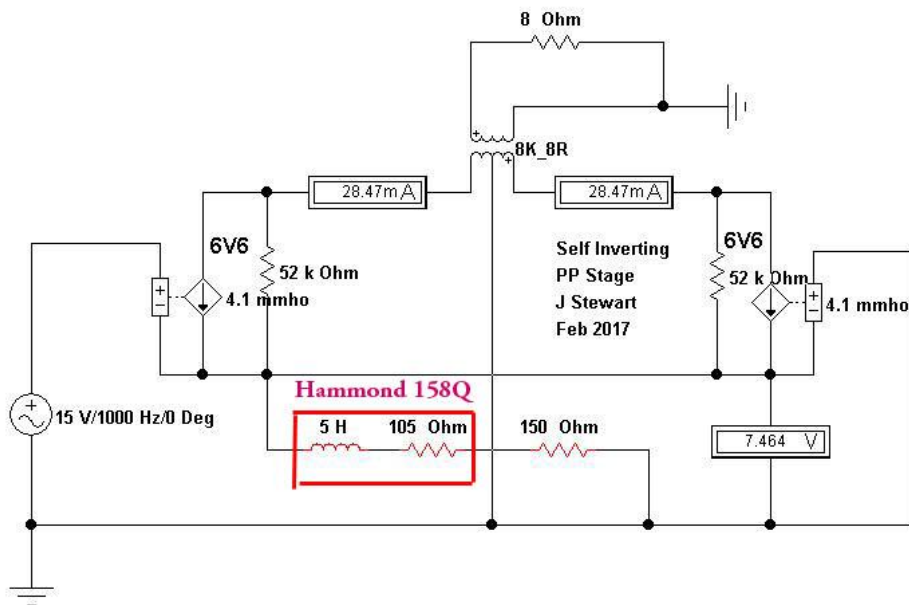
There are some extra responses at the high frequency end appearing on this trace. This is aliasing, a result of digital sampling used by the spectrum analyzer. The subject for another paper.



Simulations of the circuits shewed that current in the two halves of the output transformer were not equal.

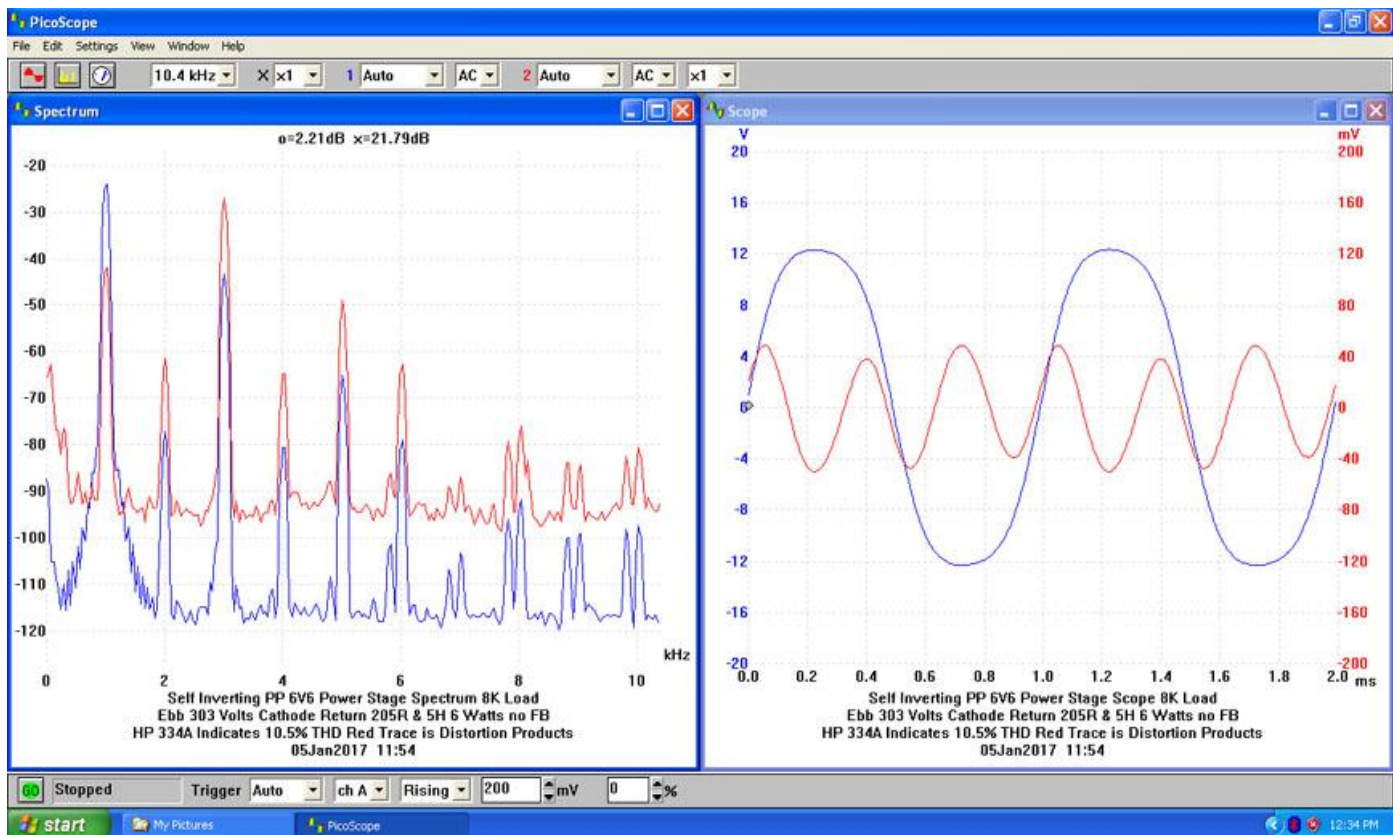


Simple simulations are often based on small signals. The component models do not work well for large signals. But here was an indication the circuit needed some help. The voltmeter is indicating the AC voltage on the cathode, which is driving the 6V6 on the RHS. A modification that might work is to insert a choke into the cathode tail. That way the much higher impedance in the cathode circuit would better drive the output to balance. For example a 5H choke looks like ~32K @ One KHz.



That looks better! The next step was to test this circuit under large signal conditions.





That looks better but THD is 10.5% at just 6 watts, almost at overload. In later tests with the cathode resistance increased to 255R in order to limit 6V6 plate dissipation THD was 14.5%. A PP pair of 6V6s under similar conditions in an ordinary PP configuration is capable of 12-14 Watts audio. What was causing the problem?

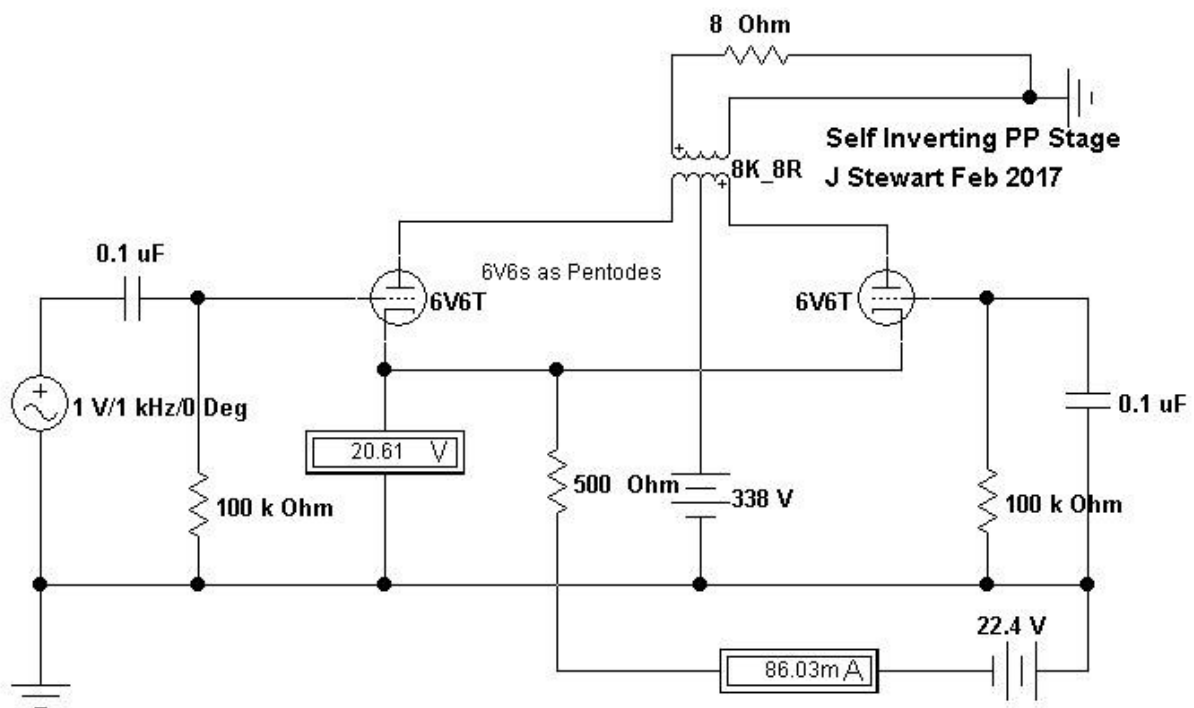
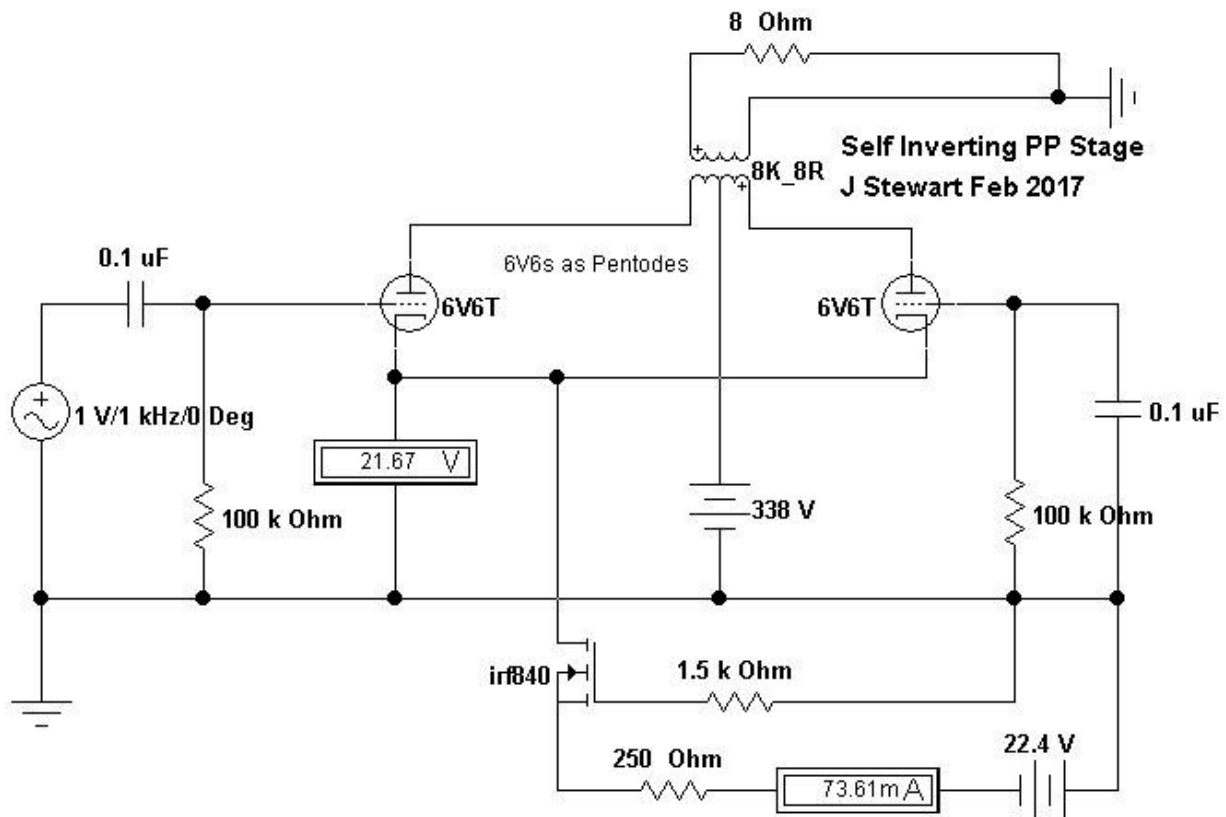
The cathodes are pulled up by a positive going signal on the LHS 6V6 grid. That would bias the RHS 6V6 so that if enough that tube would be pulled out of conduction. But it was not even close to that. It looked like the cathodes were not being pulled down enough in order to drive the RHS 6V6. A negative 22.4 Volt Power Supply was added as a better pull down for the cathode tail.

Then various cathode tail circuits were tried as follows-

NFET	IFR840
500R	Just a plain old resistor
5H 505R	Hammond 158Q Choke

Results for all were poor. THD increased rapidly at 4-5 Watts audio.

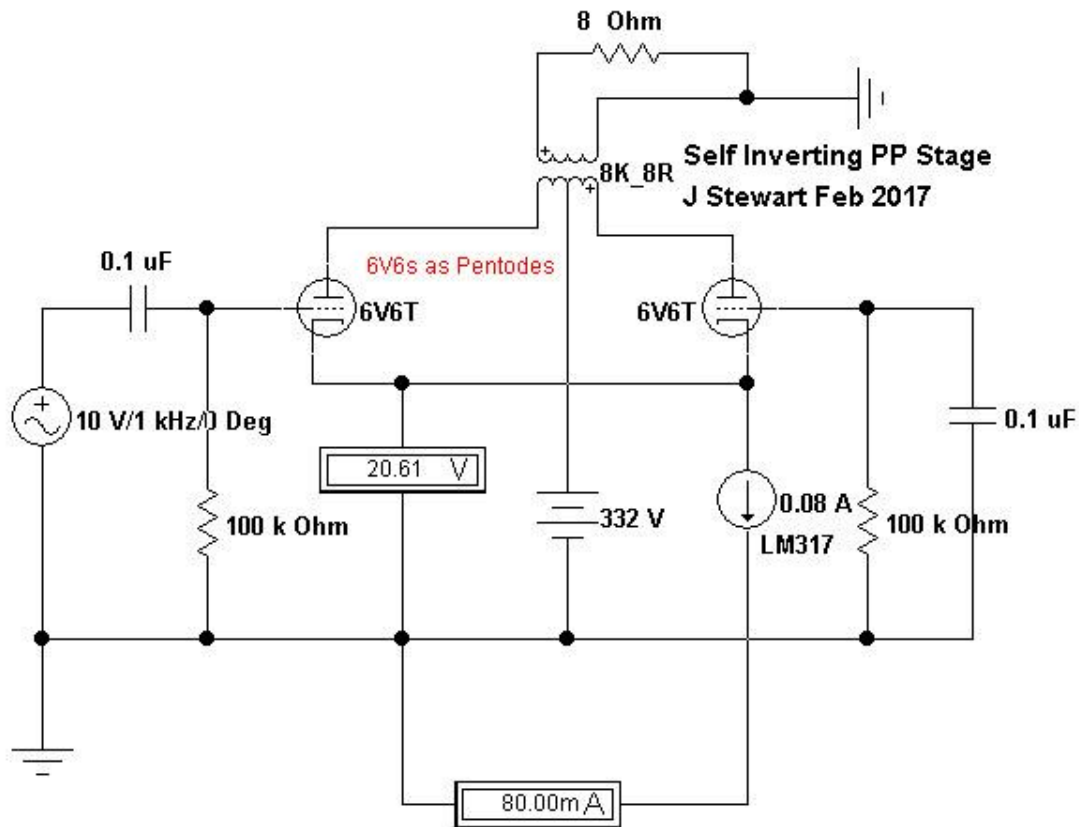




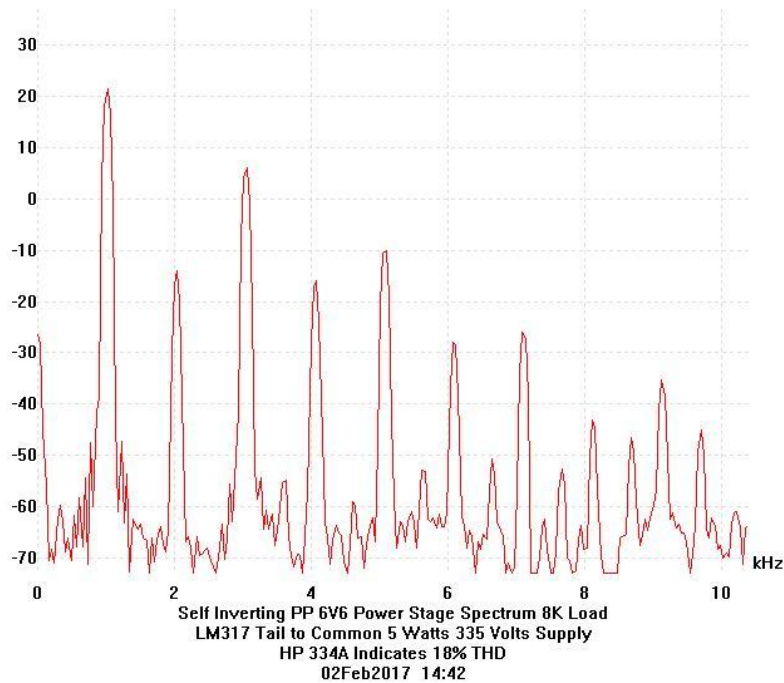








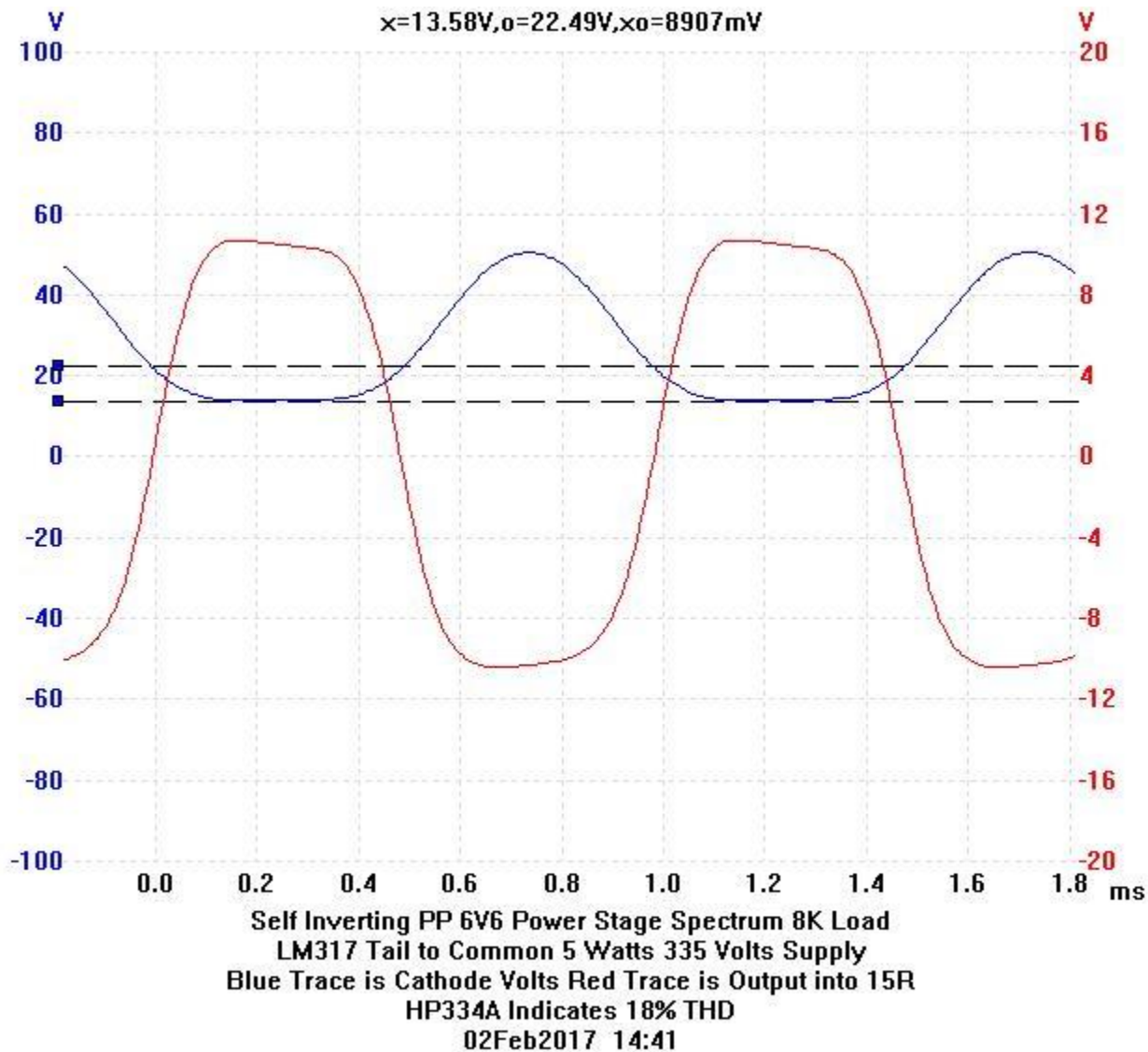
## Test Circuit for LM317 3-Terminal Regulator Sink



This one performed no better than any of the others. It was time to look at what was limiting in the cathode circuit.



The tests showed that no matter what cathode tail was used the cathodes were never pulled down to less than about 13 Volts. Under that circumstance it was impossible for the RHS 6V6 to be ever driven to full power. So that is the flaw in the circuit. See below.

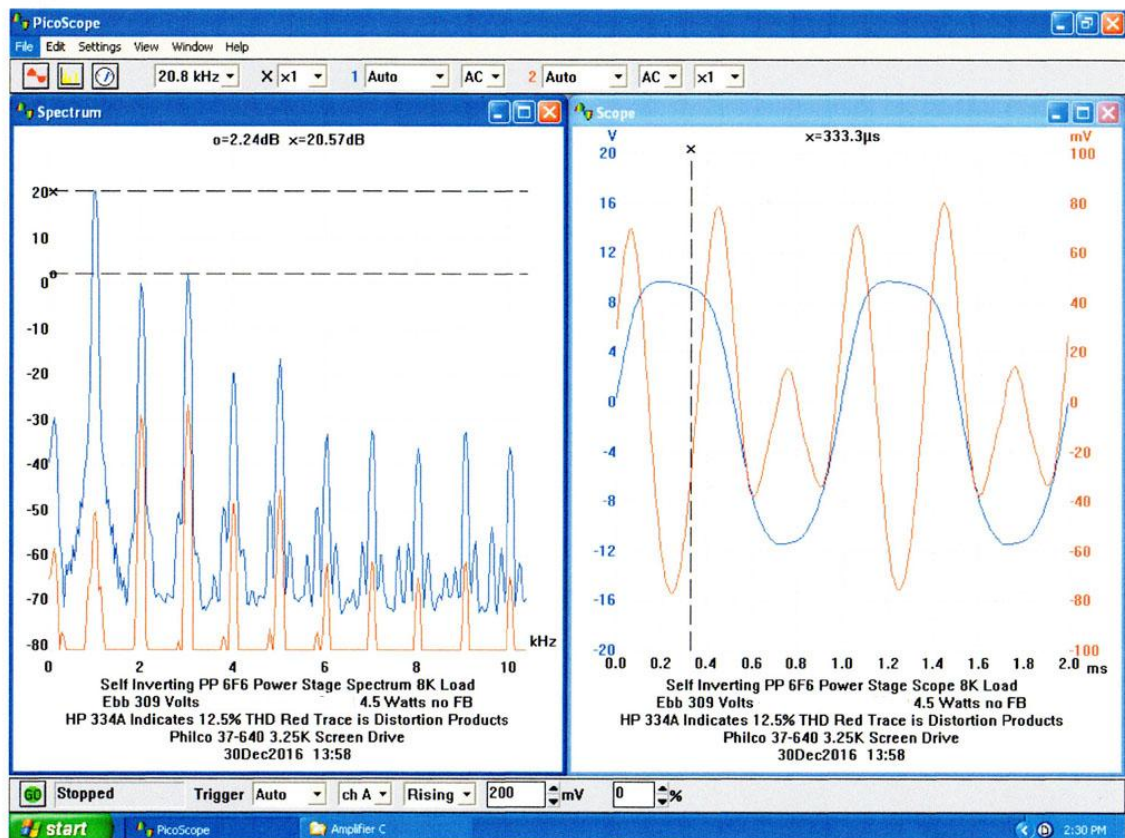
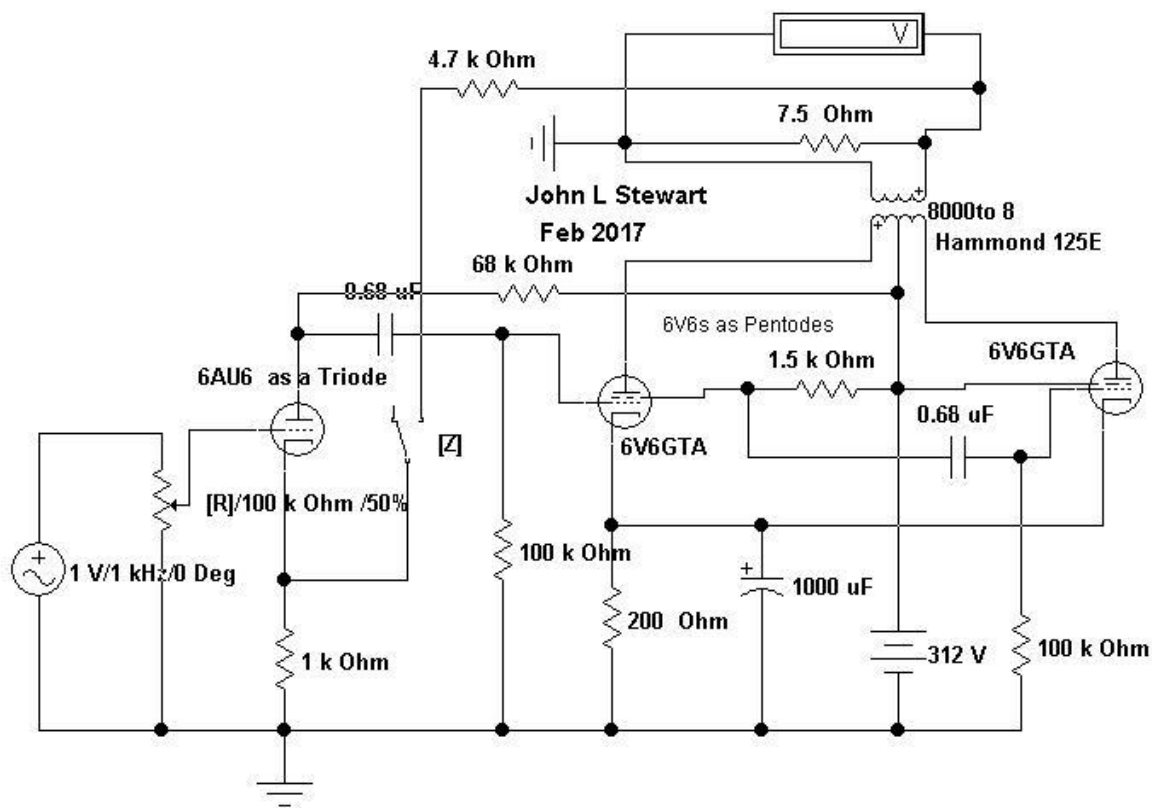


The blue trace shews the cathodes are pulled down only to 13.58 Volts. But the positive going part gets way up to >46 Volts. The result is very unsymmetrical & causes much even order distortion in the output signal.

The measurement system shewed 5 Watts ..... but 18% of that was harmonics. Something to think about.



Here is the screen drive test circuit, based on the Philco 37-640.





The 6AD7G combines the functions of two tubes into one envelope. In combination with a 6F6G in a PP circuit all the problems encountered in the previous circuits are solved. The 6F6G has two unused pins. These are used to connect the plate & grid of an included parasitic triode to the PP circuit, in a normal phase inverter mode. The triode has a very long grid base so that the normal 6F6G bias is useable. The triode has quite low Gm. But it has only to invert the signal so that low Gm is not a problem at all.

Care needs to be taken, the 6AD7G will not work in the socket of metal 6F6 where the pin one is used as a connexion to the metal shell. I did not have a 6AD7G in my stash, so there are no test results here. But the specifications indicate very good results can be expected. There is no similar tube for the 6V6 or any other.

6AD7-G



6AD7-G

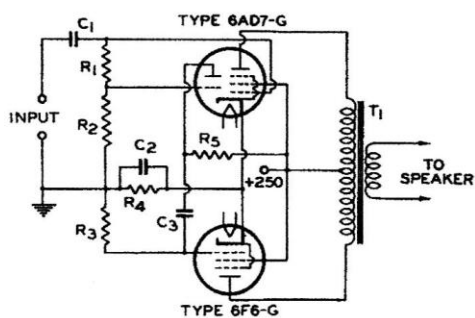
### TRIODE-POWER AMPLIFIER PENTODE

(continued from preceding page)

Screen Voltage	285	max.	volts
Plate Dissipation	8.5	max.	watts
Screen Dissipation	2.7	max.	watts
Typical Operation with Cathode Bias - Class AB ₁ Amplifier:			
Values are for pentode unit of 6AD7-G and 6F6-G together			
Plate Voltage	250	285	375
Screen Voltage	250	285	250
Cathode Resistor	560	470	470
Peak A-F Grid to Grid Volt.	59	64	55
Zero-Sig. Plate Current	36	47.5	41
Max.-Sig. Plate Current	41	54.5	50
Zero-Sig. Screen Current	6.7	8.2	6.7
Max.-Sig. Screen Current	11.7	13.7	9.2
Effec. Load Resistance (plate to plate)	14000	12000	16000
Total Harmonic Dist.	4	4	2
Max.-Sig. Power Output	6	8.5	9
			ohms
			%
			watts

For curves of the pentode unit, refer to Type 6F6.

#### TYPICAL PUSH-PULL CIRCUIT WITH PHASE INVERTER USING 6AD7-G AND 6F6-G



R₁ = 330000 OHMS  
R₂ = 120000 OHMS  
R₃ = 470000 OHMS  
R₄ = 560 OHMS  
R₅ = 150000 OHMS

C₁ = 0.01 μf  
C₂ = 25 μf  
C₃ = 0.01 μf

T₁ = OUTPUT TRANSFORMER:  
PLATE-TO-PLATE LOAD, 18000 OHMS

← Indicates a change.

The license extended to the purchaser of tubes appears in the License Notice accompanying them. Information contained herein is furnished without assuming any obligations.

Sept. 2, 1941

RCA RADIOTRON DIVISION  
RCA MANUFACTURING COMPANY, INC.

DATA



## Test Equipment used as follows

Pico Technology ADC216 16 bit Virtual Scope/Spectrum Analyzer running on XP

Pico Technology Differential Probe X10/X100

Probe X10

HP 334A THD Analyzer

GW GAG-810 Audio Generator

Two MetraHit 29S Precision DMM & Wattmeters

Mastercraft DMM