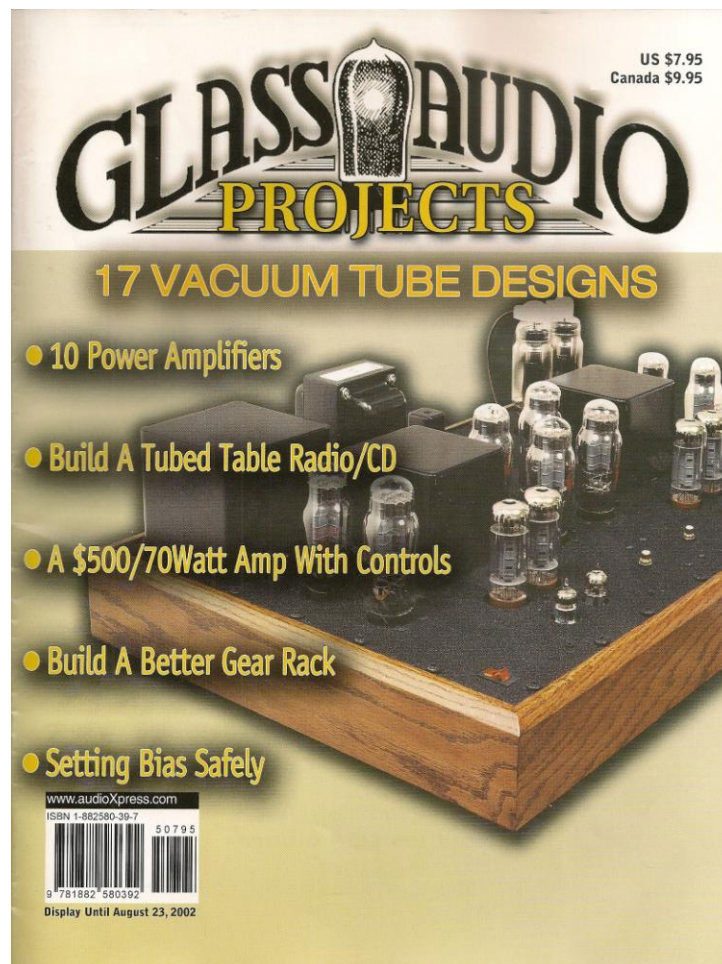


## The 33 Amplifier

This article was originally published in the Glass Audio Projects book in Summer 2002. It shows how an amplifier of reasonable power & fidelity can be built around 2 volt battery tubes. But this one runs off the power line.

John L Stewart PEng, March 2012





## **THE 33 POWER AMP**

A little background is in order. Many years ago as a child I became interested in electronics, like so many others. After a time, I moved from crystal radios on to vacuum tubes. These included the 201A, 264 & some WE globular triodes, the kind we would sell our soul for today. They managed to eat batteries rather quickly. I wasn't very kind to them either.

Later I became acquainted with tubes such as the 1H5GT & 1N5GT, which helped solve the battery problem. They needed only 70 milliwatts at the heater. I even managed to drive a loudspeaker by using a beam tetrode, the 1T5GT.

Soon after, my mother allowed me to connect to the power line & I never again had reason to use or experiment with tubes intended for battery operation. However, during all of the succeeding years I remained curious as to what could be done with battery operated tubes.

A sale flyer from Antique Electronics offering a Hammond 269EX Power Transformer at a good price pushed me over the edge. I just had to see what could be done.

This is it.

### **CIRCUIT FEATURES**

- 1) Operation in Triode or Ultralinear mode.
- 2) No external feedback.
- 3) Soft Start/Standby & Run modes.
- 4) Excellent performance.
- 5) Low cost.

### **TRIODE OR ULTRALINEAR?**

You can make this decision for yourself. Wiring of the output transformer can be easily changed to suit your personal preferences. In triode mode you can expect about 2.5 watts of power. Damping Factor measured 2. In the Ultralinear connection 4.5 watts output is possible. Damping Factor drops to one. This used to be called "Unity Damping".

Many articles were written & published covering the pros & cons of unity damping in the 50's & 60's. Some of the better amplifiers actually came with a control which allowed adjustment of the damping factor. This was achieved by a varying both the normal negative voltage & separate positive current feedback networks. Not recommended to be tried by amateurs.

Don't use a switch to compare triode to UL operation. When the output tube screen grids are unhooked from the power supply a large voltage transient occurs which can easily destroy an expensive output transformer, as well as the switch. All power sources should be unhooked & the wiring physically changed.

The amplifier & power supply are shown separately for clarity.

A performance summary is given in Table one. You should note in particular the very low levels of distortion higher than the 3<sup>rd</sup> harmonic. That is because the driver stage is not coupled by capacitors to the output stage. Clipping is avoided along with the higher order harmonics & blocking.

## **TUBE SELECTION**

I did a survey of tubes which would be suitable for this project. I rejected those which run in Class B since that type of circuit is notorious for generating distortion at low levels. The 33 was most promising for the output & driver stages because of its rather large filament. Gain from the grid of the driver stage to its plate is about 4.5. Other tubes which might be suitable for the driver stage are the 31 & 1H4G. However, they may not be able to fully drive the output stage into Class AB2 without generating distortion in the output grid circuits.

As far as I was able to tell there were no high mu triodes in the 2 volt series. As a result, I selected the medium mu triode 1B5/25S as the input voltage amplifier for this project. The input stage has a gain of about 15. I did not include a gain control on this amp, since I would normally include that in a preamp. If you like, you could replace R1 with a gain control. You will need 0.75 vrms at the input to get full output.

Table 2 gives a summary of the characteristics of the tubes I used in this project.

## **AMPLIFIER CIRCUIT DESCRIPTION**

At first look the circuit appears to be fairly ordinary. Refer to Figure one. The output stage is completely transformer coupled so that it can be driven into Class AB2. The output transformer I used is something I bought many years ago & didn't use at the time. A Hammond 1609 will work OK in this position. If you ever wondered about instability attributable to Ultralinear coupling a worthwhile read can be found in Norman Crowhurst's book "Audio Measurements"<sup>1</sup>. It is well worth the price of admission.

The interstage transformer shown in the photo is a Hammond 447 which is no longer available. Again you can assume I've had it for a long time. The 447 has a small stepdown ratio of 1.5:1 from the plate winding to each of the grid connections. It is meant to drive a Class B stage. It worked OK but I soon realized it was not optimum to drive the output 33 grids. Available plate swing from the triode connected 33 driver was insufficient to get full output when using the 447.

A Hammond 448 originally designed to drive a class AB stage with its small stepup ratio of 1:1.25 would be better. It too is no longer available. After several emails & telecons Hammond provided the answer. It is similar to their original 448 but with improved frequency response. Their part number is H300759. The plate impedance needs to be about 6K. It doesn't need to have response from DC to green light like you see in some of the stuff on the market today. That's because it is not inside a feedback loop. Again you could refer to Norman Crowhurst's<sup>2</sup> articles covering his Twin Coupled Amplifier design. See the parts list for recommendations.

If you are to avoid a rather complicated power supply, then the biasing network needs careful attention. Since these tubes do not have separate cathodes the use of cathode biasing resistors is inconvenient. If you did, you would need a separate DC supply for each of the 2 volt filaments.

The biasing network consists of the resistors R10, R11 & R12 along with the capacitor C3. Current from all of the tubes passes through this network, resulting in about 20 volts available for biasing. Connections to the network result in the output stage being biased for Class AB operation. Bias for the driver stage is tapped off at a lower voltage resulting in Class A. When the output stage is driven hard the change in bias results in a shift of the drivers operating point. This will partially compensate for output stage shift. A good description of this technique is covered in a reprint of the 1937 Sylvania Technical Manual<sup>3</sup>. You will find it on page 113 under Type 42 Power Amplifier.

Finally, the input amplifier is biased off the bottom end of the resistive network. The Capacitor C3 prevents instability which would result from interstage feedback in the bias network.

Resistors R8 & R9 have been included to help avoid parasitic oscillations & reception of your friendly local radio station. They are not used on the power tube grids since they need to draw considerable current on program peaks.

Since this amplifier needs to run in Class AB2 I was curious as to how much grid current would flow in the output tube grids. I connected a 10 ohm resistor (R13) in the grid return leads so that the grid current could be monitored at Test Point One (TP1). Refer to the resulting double oscilloscope trace labeled 33AMPU.

The one kHz output signal is set to maximum, about 4.5 watts in the ultralinear connection. Scaling on the left hand side refers to the output. A X10 probe was used. Scaling on the right hand side refers to the resulting grid current. In this instance I used a X1 probe. The grid current peaks are about 1.5 mA.

No adjustments are provided to set the amplifier for minimum distortion. However, you may want to try balancing the output stage by simply switching the 33's. I was surprised to find a worthwhile improvement in distortion readings at lower levels by using this technique. You will need something (distortion meter) to measure the results. My results are shown as part of Table One.

## **THE POWER SUPPLY**

Power requirements are modest so that a relatively simple power supply will do. Refer to Figure 2. The amplifier needs a total of about 200 volts in order to deliver full power. The plate circuit runs on 180 volts while the biasing network uses the remaining 20 volts. Voltage is kept down by using a rather small value (8  $\mu$ F) cap at input to the filter network. This also keeps the RMS current in the transformer down to prevent excess heating.



**You will need DC for the filaments of this tube series. The LM317 does a good job of filtering ripple at the output of the bridge rectifier. It also provides the 3.8 volts needed to run the soft start circuit.**

**During development of the amplifier I was concerned with the effect the turn on transient would have on filaments in these relatively fragile tubes. When I switched a 33 directly to a 2 volt, 25ah Gates Cell I measured turn on transients of more then one ampere. After about one second the current settled down to the specified 0.26 amp.**

**Ordinary VOM's & DMM's are not very accurate for the measurement of small resistances. That is partly because of lead & contact resistance. Accurate measurement of small resistances are best made by the 4-terminal method. A constant current is applied to the unknown R. Both current & voltage are measured on the leads of the R & then Ohm's law is applied.**

**Using this technique I found the 33 heater cold resistance to be 1.8 ohms. That result is consistent with the greater then one amp turn on transients measured above. By inserting a small resistance in series with each of the heater leads the turn on transient is greatly reduced. For the 33's I used 6.8ohms, made by paralleling a 10 ohm, 2 watt resistor with a 22 ohm, ½ watt resistor. Resistance in the 33 heater circuit now totals 8.6 ohms. The turn on transient now measured 0.44 amp. Again the heater current drops to the specified 0.26 amp in about one second. A 30 ohm, 2 watt resistor performs the same function for the 1B5/25S heater.**

## **CONSTRUCTION**

**The chassis I used for this project may appear to you to be large for the number & complexity of the components installed. That is because my version of the amplifier was built for development purposes. I wanted lots of room to try a number of ideas which usually come to mind during one of these exercises. I will describe two of these at the end of this article.**

**While reading articles devoted to the efforts of amateur constructors I've made some interesting observations. I hope my comments will help you build a successful project.**

**You should spend 90% of your time making sure that what is under the chassis is well done. Cosmetic appearance of the exterior will have little effect on the sound that you hear coming from your loudspeakers. Attention to detail under the chassis & in particular to soldering will make the difference between success & failure. A poor solder joint can make a very good semiconductor. I am aware of this from personal experience. A sine wave applied on one side shows up as a half-wave rectified waveform on the other. Does awful things to your sound.**

**Terminal strips are one of the best kept secrets of a successful project. They are inexpensive & will turn a rat's nest into a work of art.**

Most of the building & testing of your project requires access to the underside of the chassis. Use a simple wooden frame attached to each end of your chassis to lift it well off the work bench while inverted (see photo). This will help in avoiding damage to the tubes & scratching the finish on transformers & chokes. If you would like, leave them on. They make great handles. I use wood trim, available at your local lumber store.

Mount a 1½ inch X 6-32 machine screw so that it protrudes from the back of the chassis. This will be very handy as a ground connection when you are testing any box of electronics. It always seems we need far more ground connections when testing then there is space for. Problem solved.

Buy your fastening hardware such as screws, nuts & washers in quantity. They are cheap at the large building supply stores. This will help you avoid the frustration caused by running out when you most need them.

You should expect the unexpected. It happens all the time even to those of us who think we know what we are doing.

## **MORE**

There are several ways you can connect feedback to a single stage. The ultralinear connection is one of the most important & it is used in this amplifier to advantage.

I was interested in trying another method which shows up in some 1930's radios. Refer to Figures 3 & 4 (33AMPX & 33AMPY). You make a direct connection through an RC network between the plate & control grid of each tube. The resulting stage gain is controlled by the ratio of the feedback resistors. In each of the examples that would be 10. Both examples are unconditionally stable.

In a circuit using pentodes the gain is normally limited by the load impedance. Gain for a pentode is usually calculated as transconductance times load impedance. That works out to about 10 for the 33 when normally loaded. This is typical for pentodes & beam tubes.

However, gain can become very high when connected to a complex load such as a loudspeaker. At the loudspeakers resonant peak(s), gain could go up to 5 or 10 times the nominal. The result is usually poor sound. The amplifier has little control over the loudspeaker. You will have lots of overhang. The performance is typical of what some call the pentode sound.

You can control this condition by using one of the circuits illustrated. Gain is effectively controlled by the feedback resistors. The capacitor isolates the DC voltages on the plate & grid.

**Circuit 33AMPX is the series connection of this feedback.**

**The feedback voltage appearing at the junction of the 10K resistor, 1  $\mu$ F cap & interstage transformer secondary is in series with the voltage in the interstage secondary.**

**Circuit 33AMPY is the shunt connection of the feedback.**

**The feedback voltage in this mode is in opposition to that in the interstage secondary.**

**This connection is effective in loading the interstage secondary so as to reduce ringing.**

**The ringing results from stray capacities & leakage inductance in the transformer.**

**I did not use either of these connections in the final amplifier.**

**The output stage needs to operate in the Class AB2 mode in order to deliver full power.**

**The RC feedback networks would prevent necessary grid current from flowing.**

Notes	1	Audio Measurements	Norman Crowhurst
	2	Twin Coupled Amplifiers	Norman Crowhurst
		Radio Electronics	Nov 1957
		“	Oct 1960
		“	Jun 1960
	3	1937 Sylvania Technical Manual	

**Equipment used in the development of this amplifier-**

**HP 200CD Oscillator**

**HP 302A Wave Analyzer**

**GW GAG-810 Oscillator**

**Rohde & Schwarz BOL 4 Trace 100 MHz Scope**

**Radio Shack 22-168A DMM**

**Sanwa AX 303-TR Analogue Multimeter**

**PicoScope ADC-100 Virtual Instrument**

**Electronic Workbench Software**

**John Stewart is a Professional Engineer (Electrical) with experience in both power & communication systems. He developed his experience with vacuum tubes while working on various research projects at Ferranti Packard & U of T Physics from 1957 to 1965. Then began many years of hitech sales of test equipment, semiconductors & land survey equipment with Hewlett Packard, Rohde & Schwarz, Etc.**

**file- The 33 Amplifier**

**J Stewart**



# TABLE ONE SUMMARY

## 33 POWER AMP PERFORMANCE

### Percent Distortion at Watts Output

#### CONDITION

A)	Ultralinear Connection	1	2	3	4	4.85 max
	HARM 2 <sup>nd</sup>	~	0.05	0.20	0.45	0.53
	3rd	0.47	0.91	2.70	5.07	6.90
	4th	~	~	0.13	0.11	0.09
	5 <sup>th</sup>	~	~	0.32	0.40	0.10

Moves to Class AB2 at 2.35 Watts output

B)	Triode connection	1	2	2.5 max	
	HARMONIC	2nd	~	0.29	0.63
		3rd	0.06	1.64	2.56
		4th	~	0.12	0.18
		5 <sup>th</sup>	~	0.38	0.09

Moves to Class AB2 at 1.06 Watts output

C)	Distortion Comparison before & after output tubes were switched. Comparison taken at one watt output, Ultralinear connection.				
		Before	After		
	HARMONIC	2nd	0.30	~	
		3rd	0.48	0.47	

- D) Frequency response is 3db down from the one watt level at 30 hz & 30 khz.  
It is most dependant on the interstage & output transformers used.

# PARTS LIST

33AMP

AE indicates Antique Electronics

Some parts are available at Radio Shack

C1     0.22  $\mu$ F 400 vdc  
C2     1.0  $\mu$ F 400 vdc  
C3     2200  $\mu$ F 25 vdc  
C101,102     10 nF, Mallory UN102M  
C103     8  $\mu$ F 385 vdc  
C104     100  $\mu$ F 350 vdc  
C105     100  $\mu$ F 350 vdc  
C106     10000  $\mu$ F 10 vdc  
C107     220  $\mu$ F 25 vdc

R1     470K     1/2 watt  
R2     100K     2 watt  
R3     470K     2 watt  
R4     30 ohms, 2 watt  
R5,R6,R7     10 ohms, 2 watts  
             in parallel with 22 ohms, 1/2 watt  
R8,R9     1K     1/2 watt  
R10     220 ohms, 2 watt  
R11     47 ohms, 2 watts  
R12     30 ohms, 2 watts  
R13     10 ohms, 1/2 watt  
R101     120K     2 watts  
R102     10 ohms, 2 watts  
R103     470 ohms, 1/2 watt  
R104     220 ohms, 1/2 watt  
R105     270 ohms, 2 watts  
R106     150 ohms, 2 watts

T1     Hammond 269EX 190-0-190  
         @ 65 mdc & 6.3 vac @ 2.5 amps

T2     Hammond 1609 Output,  
         10K plate to plate  
         4, 8 & 16 ohm secondary taps

T3     Hammond H300759  
         6K plate to 9.6K  
         center tapped grid to grid

V1     1B5/25S  
V2,V3,V3     33

D1, D2     FR107 fast recovery,     AE p/n P-QFR107  
L1     Hammond 156L     5H, 75 mA

Bridge Rectifier BR-34, AE p/n P-QBR-34

S1     DPDT Center Off Switch

LM317 Regulator

#47 Pilot & Holder, AE p/n P-L114

Fuse 1/2 Amp & Holder, AE p/n S-H258

Aluminum Chassis 8" X 16" X 2"

Hammond 1444-26

If still available AE p/n P-H120

Aluminum Bottom Plate 8" X 16"

Hammond 1434-26

5 Pin Sockets, AE p/n P-ST5-216, need 3

6 Pin Socket, AE p/n P-ST6-207M, need one

Terminal Strips

AE p/n	lugs	quan
P-0201H	2	1
P-0301H	3	3
P-0401H	4	1
P-0501H	5	2
P-0701H	7	2
P-0901H	9	5
S-H317	6 screws	1

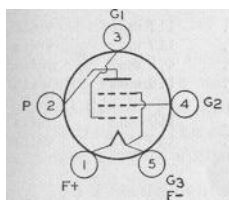
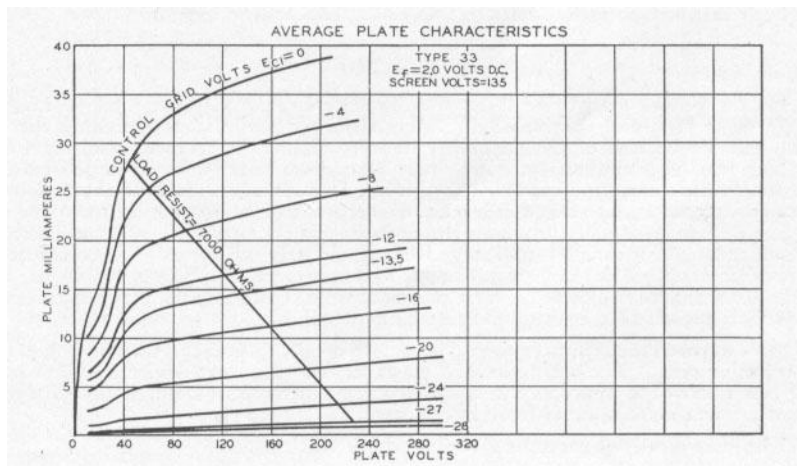
Double Phono Jack AE p/n S-H310

6 ft. Line Cord AE p/n S-W105

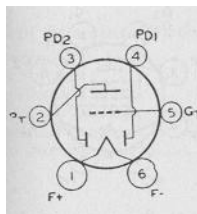
Rubber Grommets AE p/n P-G005, need

Rubber Feet AE p/n P-H253, need 4

Assorted machine screws, nuts & washers



33 Tube Base



1B5 Tube Base

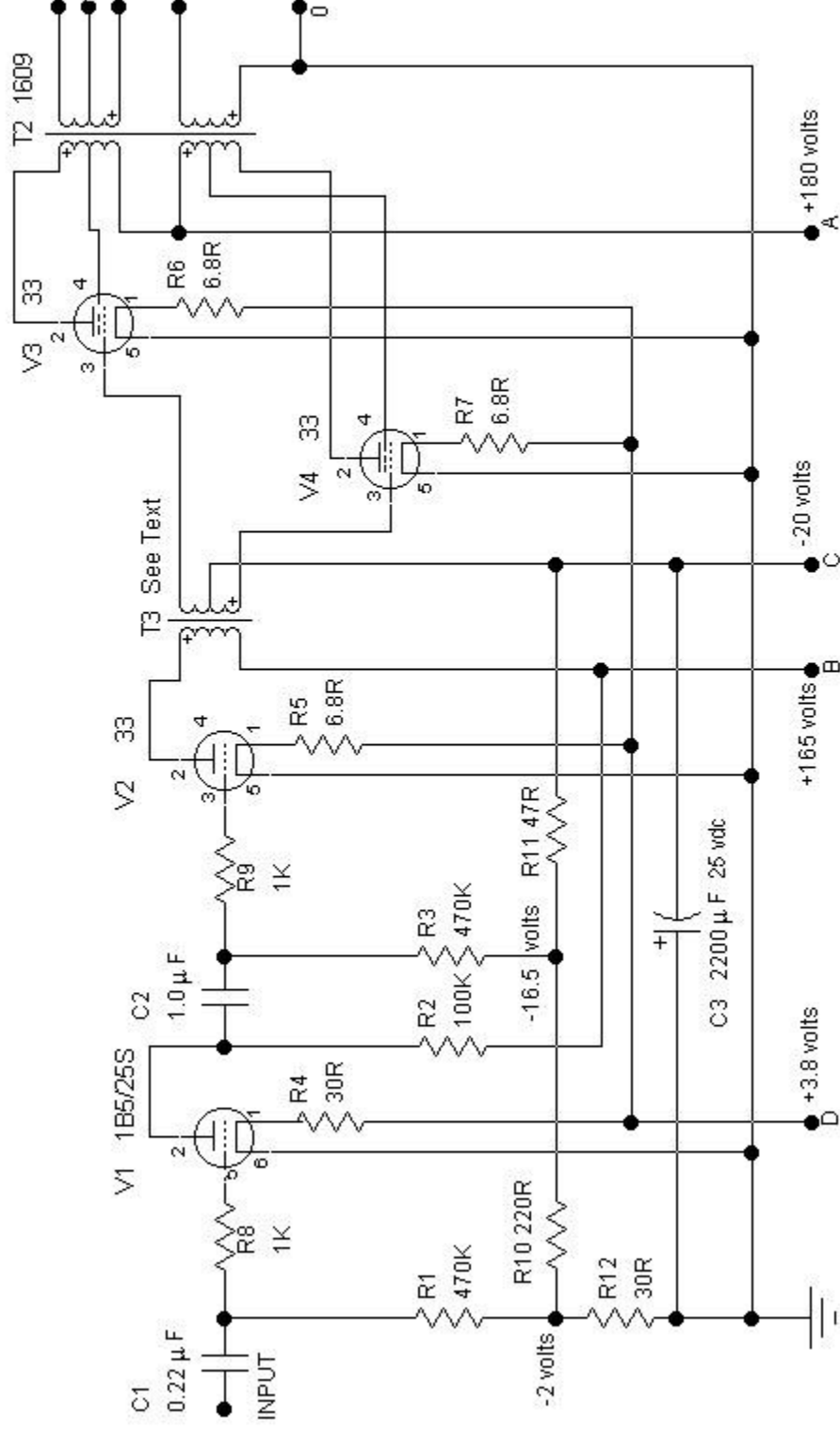
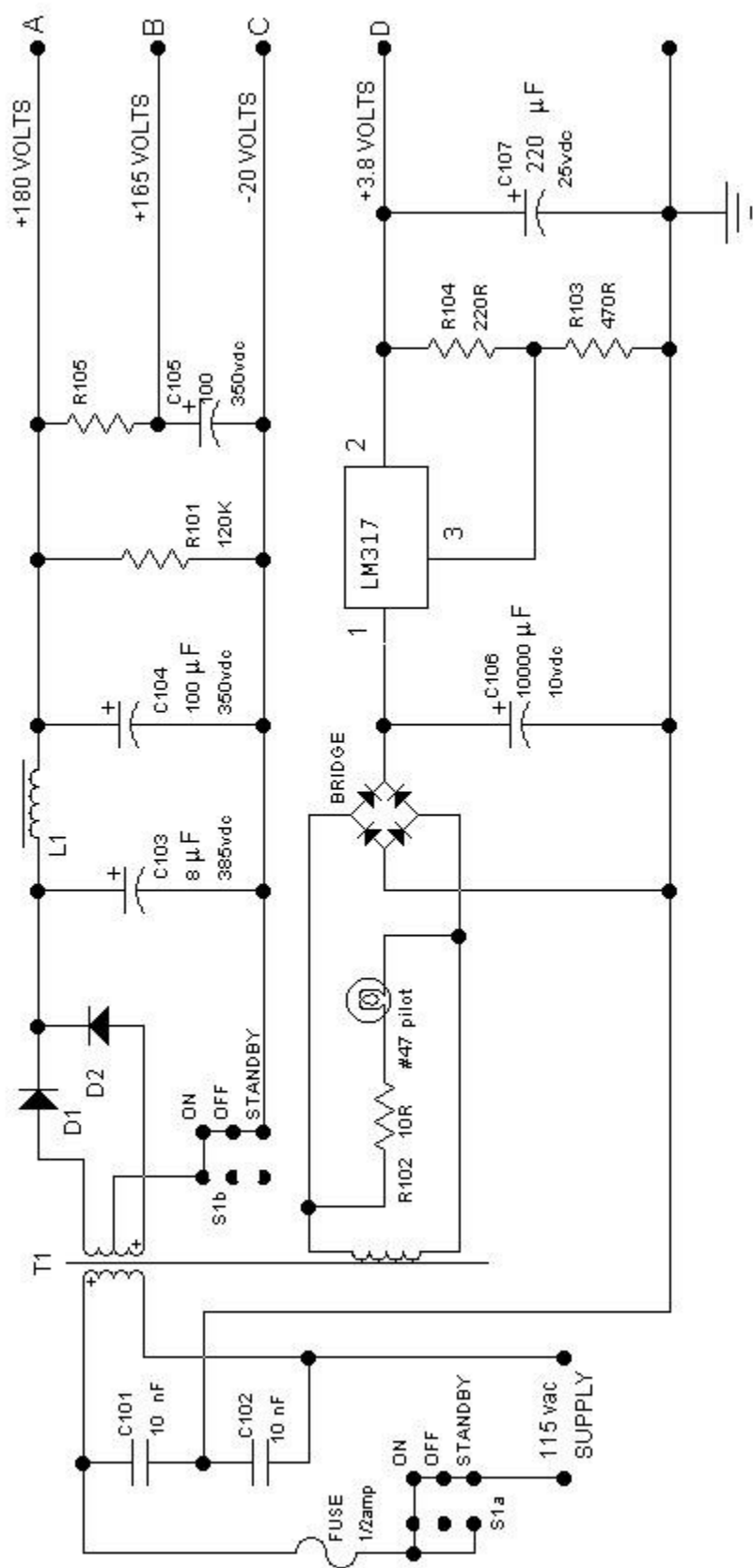
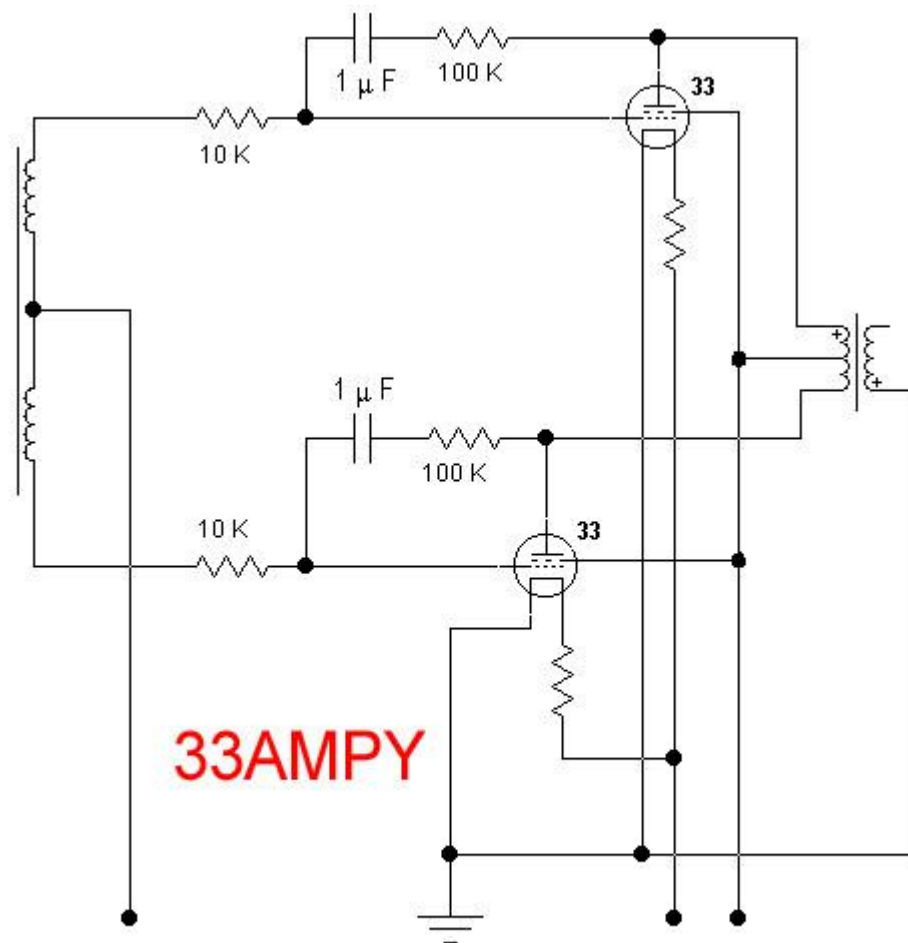
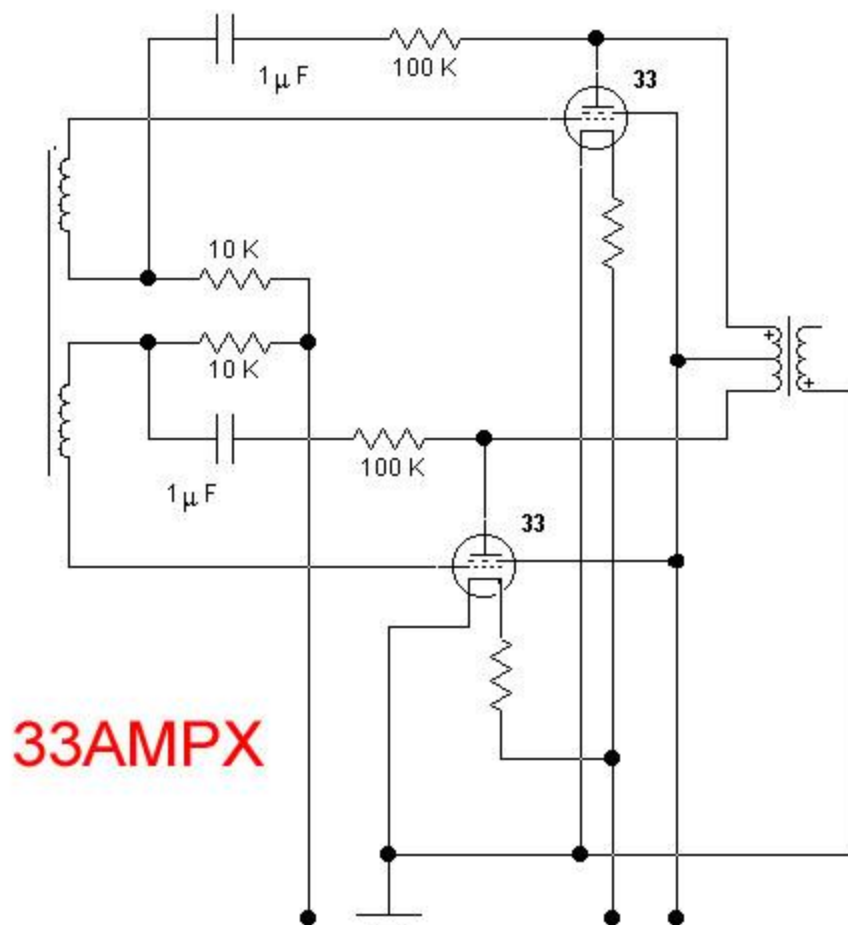


FIGURE ONE- POWER AMP

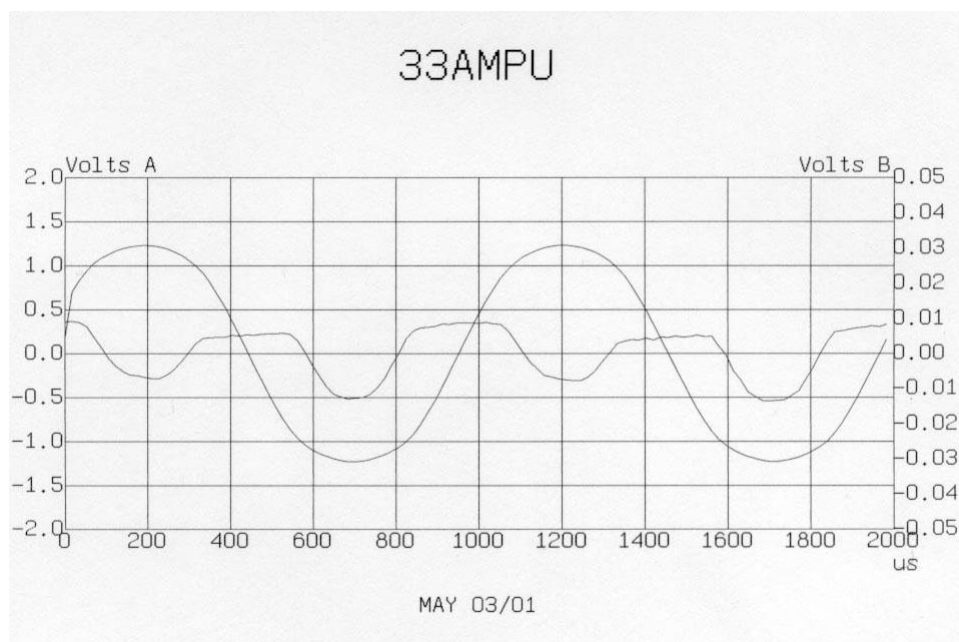
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33AMPB









## TABLE 2- TUBE CHARACTERISTICS

33 Pentode & 1B5/25S are as published.

33 UL & Triode specs are measured.

	33			1B5/25S
	Pentode	UL	Triode	
Plate Voltage	180	180	170	135
Screen Voltage	180	180	----	----
Grid Voltage	-18	-20	-16.5	-3
Plate Resistance	55 K	7.9 K	3.7 K	35 K
Mutual Conductance	1.7 ma/v	1.33 ma/v	1.33 ma/v	0.575 ma/v
Amplification Factor	93	10	5	20

