This is a contribution from Steve Bench, a friendly
and helpful tube-fan from the US.

He evaluated 841 triodes in a rather unusual configuration for
Audio: with grid current at positive bias.

I asked him for permission to publish this here and he agreed.

If you have questions to him, please mail to

S[delete_this_string]Bench@aol.com

Thank you, Steve

Jan

www.askjanfirst.com

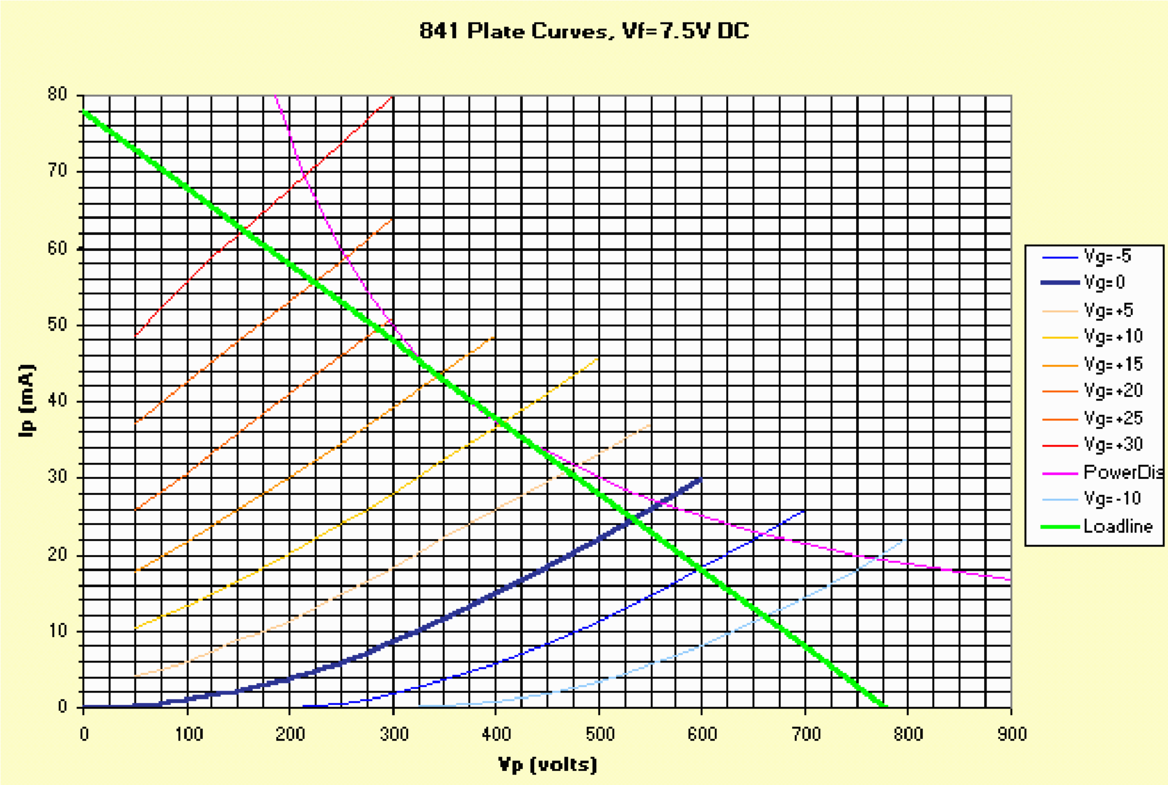
Introduction

In this series of articles, we will talk about various aspects of A2 operation. This is the purposeful biasing of a tube so that its grid is positively biased. We will discuss why one might do this, what the advantages and disadvantages are, and various aspects of design that are somewhat unique to this kind of operation.

For this series, we will use the 841 directly heated triode as an operating example.

The 841

The 841 is somewhat similar to the 10 or 801, except it has a mu of 30 instead of 8. Here is a set of tube curves for the 841. The 841 has a maximum plate (anode) dissipation of 15 watts, and 450 volts maximum ratings. The filament, like a 10 or 801 is 7.5 volts at 1.25 amps. Base is 4 pin "4D" connection. It is a W-Th filament DHT device.



I have already drawn a (green line) load line that we will use in this series. This is not to indicate that this is the only or even best operating point for this tube. However, for our example, the operating point chosen is 450 plate volts and 33 mA. We will provide +/-30 volts (60VP-P) swing into the grid, causing it to vary from +7 volts (quiescent) to +37 volts and to -23 volts. This will provide a 700 volt swing on the plate into a 10k loadline, which means the power output can be about 6 watts.

What A2 Allows Us To Do

When you operate the grid in the positive region, it draws some current. The amount of current it draws is a function of both the grid voltage and the plate (anode) voltage.The lower the plate voltage, the higher the grid current for a given grid voltage, and the higher the grid voltage, the higher the grid current for a given plate voltage. Sometimes you can find a set of grid current curves for a given tube. For the 841, assuming an instantaneous plate voltage of at least 2.5 times the grid voltage, the grid looks like a slightly non-linear resistor of about 2.5k ohms or greater. For instance, at a positive grid bias of 40 volts, the grid draws about 16mA, at 20 volts it draws about 8mA, at 10 volts, about 3.5mA.

The reason for considering this kind of operation is actually twofold:

1. The plate resistance curves in the positive bias region are very linear instead of following the 3/2 law. This can be noticed by inspecting the curves shown above. In principle, this means you can get some pretty good sound!
2. You can gain a LOT of additional power output over A1 operation. Notice, for instance, that with +30 volts bias on the grid, I "only" drop 150 volts across the tube at 62mA of plate current. In the example we will be

using, I will bias the tube at +7 volts quiescent at 450 plate volts (for a plate current of 33 mA. Then, by applying a signal of "only" +/- 30 volts from that point (to +37volts and -23 volts) I can achieve a 700 volt peak to peak swing into a 10k transformer, achieving about 6 watts. In A1 operation, I could only obtain perhaps 150V peak to peak from the same tube, producing much less than one watt of power.

The disadvantage of this kind of operation is, as mentioned, that the grid draws current, so you have to supply some power to the tube. This can be done in a number of ways, as we will discuss in the section below. One definite thing to notice, is that the driving circuit has to be low impedance, since the grid impedance does change over the operating range. Said another way, in order to "swamp out" the effect of the varying grid resistance, the driving impedance has to be much lower than the grid impedance. There is another subtle disadvantage. Since the grid is often driven in positive and negative region, only the positive region draws current. This means that you can't effectively use any form of RC coupling, since the "rectification" will change the bias point depending on the signal condition.

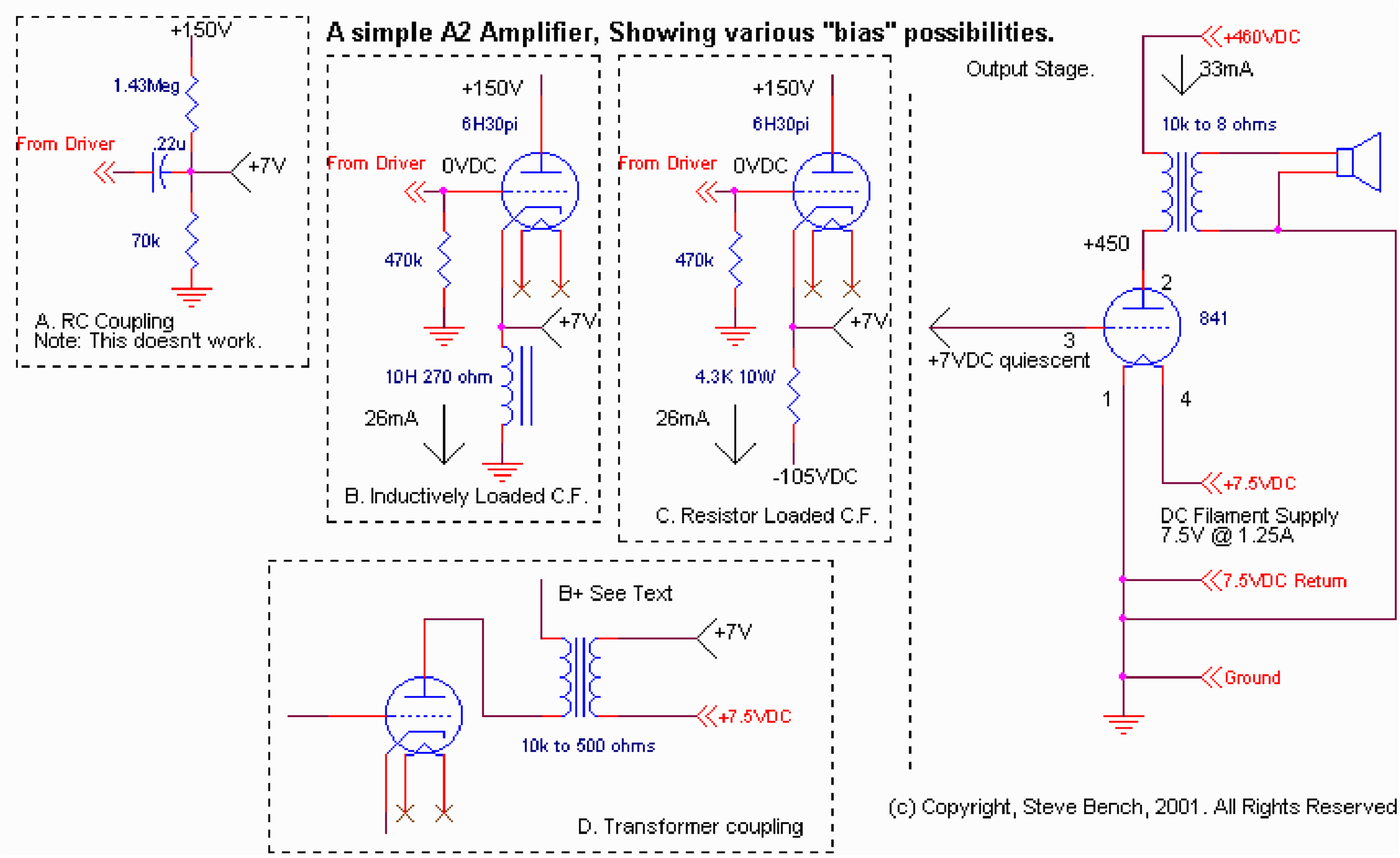
There is another subtle advantage to be gained in A2 operation. Usually the tubes that operate best in A2 operation are relatively high mu devices. In A1 operation, one problem with high mu devices is the relatively high input capacitance that you have to deal with (Miller Effect). Since A2 operation already pre-supposes a low impedance driver, the input capacitance is of little or no consequence, and there is no problem getting extended high frequency response.

Lets see if we can list these advantages/disadvantages:

A2 ADVANTAGES	A2 DISADVANTAGES
greater power output	grid draws power
can use high mu parts	more complex bias/driver
linear plate resistance curves	driver must be low impedance
hi mu=lower amplification needed	can't "capacitively couple" output stage
can get good frequency response	

Driver / Bias Circuits

Here is a circuit of a very simple amplifier. As indicated above, the biggest "issue" is how to bias the tube, and how to provide a low impedance drive. I've shown the output circuit and 4 potential "drive" circuits.



The output section is relatively common. Note however, that I have chosen to use DC heating for the filament. When you're traversing through the "0 volt" bias point, this is often the best thing to do in order to avoid hum modulation. For A2 operation, there does not appear to be any sonic penalty for DC filaments that seems to occur in A1.

The first "attempt" at biasing and driving is shown in the "A" box in the schematic. There are several things wrong with this approach. First, since the grid is actually drawing substantial current at +7 volts bias, the voltage divider shown won't actually produce 7 volts on the grid. Also, since the current changes with applied signal level, it is only the "average" current that will cause bias. This means the bias shifts all over the place with applied signal. Bottom line: Nope-won't work. What we need to "learn" from this attempt is that we need a stable "DC" operating bias point; implying a low DC source resistance. The next three possibilities do just that.

In "B", I've used an inductively loaded cathode follower. For a 6H30pi, with 143 volts plate to cathode, a 270 ohn resistance in the cathode circuit provides about 26 mA, and therefore +7 volts quiescent. This is just perfect for biasing our 841, even considering the couple mA the grid of the 841 consumes at 7V bias. The very low impedance of the cathode follower allows us to drive a very clean signal to the grid of the 841. The disadvantage is a relatively large choke. In the next part of this series, we'll also talk about what to do with the grid of the 6H30pi.

"C" uses a very similar approach, except the choke has been replaced with a "large" resistor connected to a high negative voltage instead of the choke. Operation is substantially the same as "B", with the cathode follower providing a low source impedance to the grid of the 841. This, of course, trades the choke for a power supply. This may or may not be easier to do, depending on what you happen to have on hand, and whether you have "other" uses for a negative supply voltage.

Notice that B and C both rely on the low source impedance of a cathode follower to provide the "power" to the grid of the 841. Notice that the cathode follower has to have the capability of "sourcing" over 40 mA in our application. The 6H30pi chosen can easily do that.

The other approach we can take for bias and drive is shown in the "D" box. This is a transformer drive circuit. Since we have a good source of "stiff" 7.5VDC (and requiring it to be well filtered), the transformer secondary can be driven from the +7.5V "filament" voltage. The IR loss in the transformer secondary then delivers the proper +7VDC. The impedance transformation indicated then delivers a low source impedance AC drive to the grid. To provide the needed 60V peak to peak AC signal, you would need 270V peak to peak at the driver plate. This is achievable using a number of different driver tubes, but it does increase the overall voltage amplification needed in the system. The 270V peak to peak into a 10k load would pobably mean you would need a 250V B+ voltage on the driver tube (or even 300V). If you chose this approach, you would need to draw a load line on your intended driver components just like you would for an output stage.

What's Next

In the next article, we'll put together an A2 amplifier based on the 841, just to see what can be done with this kind of operation. The approach I will take is an entirely "DC coupled" amplifier, up to the output transformer. THAT will be further expanded upon in part 3.

goto part 2

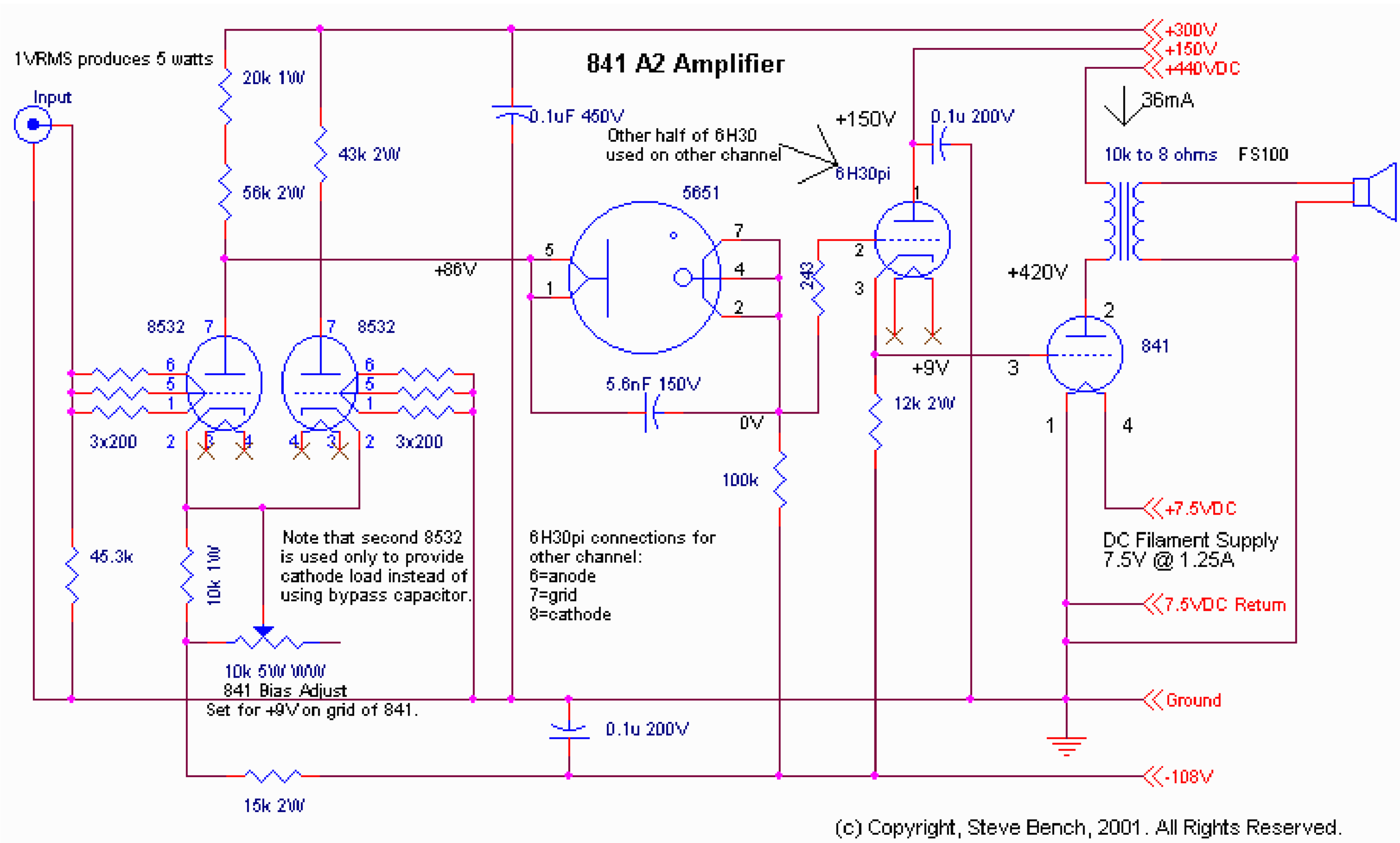
-Steve

Introduction

In this report, I will describe a practical A2 amplifier based on the 841 introduced last time. Actually, the goal of this amplifier design is to evaluate two distinctly different A2 amplifiers; the first is a simple 841 delivering slightly over 5 watts. However, I designed the circuit topology so that with some very simple circuit mods, I could change it into a SV572-160 amplifier providing about 8 to 10 watts.

The power supply used in the initial amp is designed to be capable of more current than the 841 needs. Also, I used a 5R4 rectifier. By replacing it with a 5AR4, about 40 additional volts is available from the high voltage supply, allowing more power from the bigger tube. The input and driver are run from regulated supplies. Merely changing the dropping resistor to the driver supply suffices for the 572 version. Then the other change is to change the filament source. For the 841, I developed a 7.5V DC source using a 6.3VAC 10A transformer. Then, with the 572-160s, I have the option of using 6.3VAC bypassing the DC circuit, or with some luck, the supply will deliver enough DC voltage at the higher current requirement of the 572s.

The Amplifier Schematic



Amplifier Description

There are a number of novel features in this amplifier. The input stage is a differential 8532 stage. However, if you notice, only the "input side" of the differential amplifier is actually used. The "right hand" 8532 merely provides a cathode load on the "left hand" 8532, avoiding the need for a cathode bypass capacitor, and its attendant sonic signature.

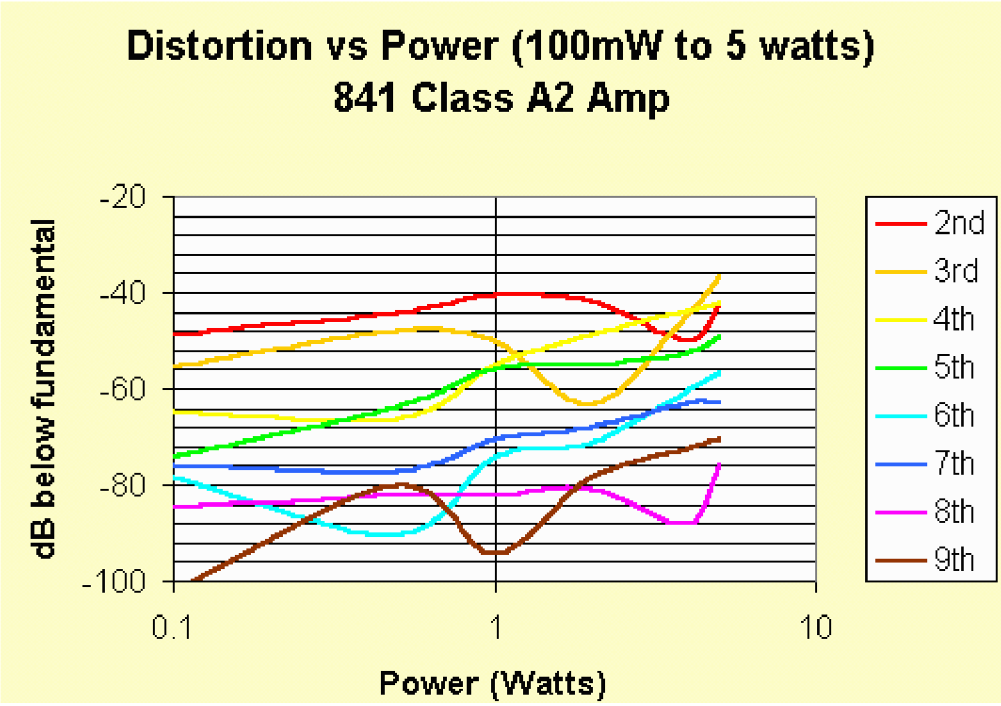
The amplifier is totally DC coupled. The only low frequency rolloff is due to the output transformer.

Incidentally, notice that the voltage at the grid of the cathode follower driving the 841 is near zero volts. One could then ask why the complication of adding the DC coupling, and the reference tube. Well, indeed I tried that, and the amp measured OK, but sounded VASTLY inferior to the DC coupled circuit. Distortion cancellation anyone?

Performance is actually pretty good. Darned good, in fact. As the circuit is drawn, sensitivity is about 1 volt for slightly over 5 watts output. Combined hum noise and crosstalk (measuring one channel with no input on it while the other is being driven to full output) is 0.5mV for a signal to noise ratio of 84 dB. See the power supply details for how that trick was pulled off!

Frequency response is essentially strictly controlled by the transformer. As shown it measures 0.9 dB down at 20Hz and 20kHz. I did add an additional circuit, shown in the next section that improves this to 0.1 dB from 20Hz to 25 kHz. (I happen to like wide range, and didn't need all the gain!)

Distortion is primary second order, but you can see the effects of distortion cancellation occurring. Here's the plot:



Notice the distortion remains below 1% for any component up to about 5 watts, where clip starts to drive up the third order.

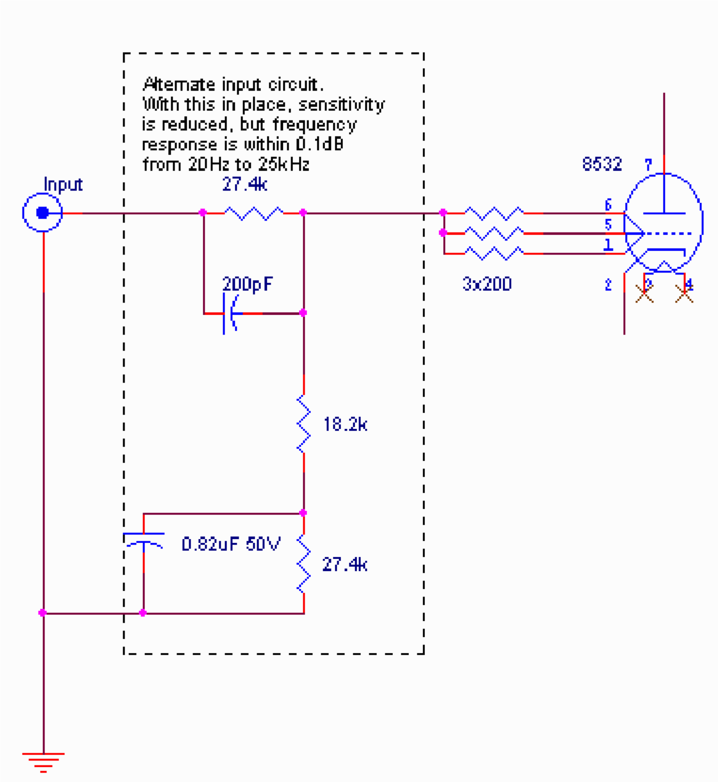
What's it sound like? (I'm listening to it as I type this). Wonderfully quiet, as expected from that S/N measurement. Unlike some amplifiers, this one LIKES to be played LOUD. Clipping is invisible until well into clip. The "likes to be played loud" seems to be a characteristic of A2 amplifiers. It's not that it sounds bad soft, but it seems to come into its own at higher volume levels. (Command Classics vinyl version of Capriccio Espagnol playing and it sounds marvelous).

I'll take this to work for an audition next chance I get.

In terms of construction, if you decide to build something like this thing, get the supply working with the driver stages first, then set the idle before plugging in the output tubes. I did have one "fault" show up that actually placed +56 volts on the grid of the 841s. (Interestingly, at 400 volts and lots of current, hum was still low, but the 841 DID start to glow!)

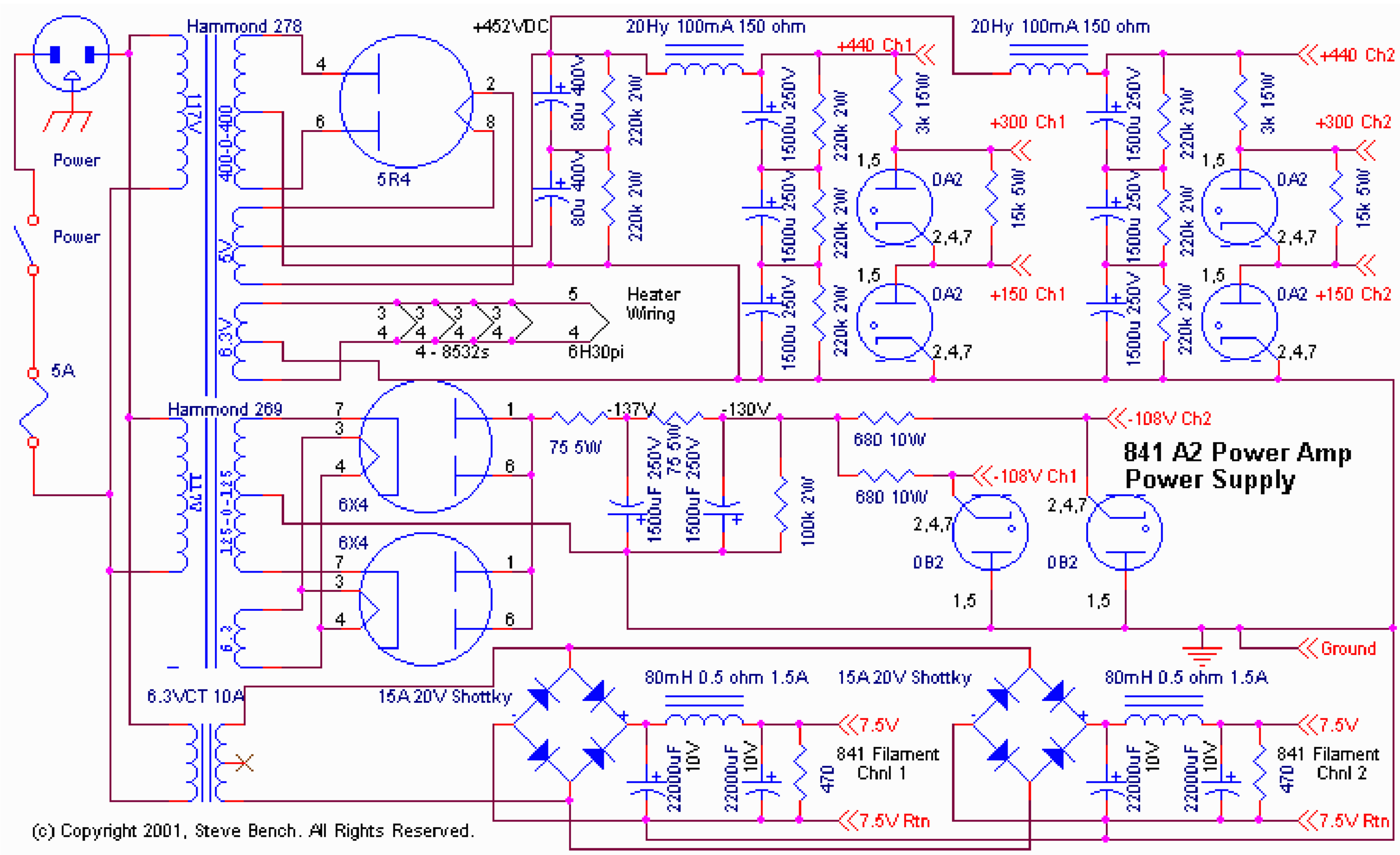
Input Circuit Mod

As I mentioned, I like wide band. Sooooo, here's a simple modification to the input circuit to compensate for the output transformer response. This extends the response from 0.9 dB down at 20Hz and 20 kHz to 0.1 dB from 20 Hz to 25 kHz:



Power Supply

There are a number of things I did that are a little unusual, but absolutely improve the performance of the amp due to power supply. Notice that each channel has its own high voltage filter and regulator. As you might remember from the "regulator series", the shunt regulators also tend to keep the unregulated supply a bit more constant by placing a minimum load on the circuit. Also note that the filament supplies are separate through the rectification as well.



Some additional things I also wanted to mention about this supply. The 3k resistors that feed the VR tube regulators are actually made up of a 5.1k 10 watt in parallel with 2 - 15k 3 watt resistors. The reason for this is that it allows me to easily re-set the current thru the regulators when I change to 5AR4 rectifier and up the voltage for the 572-160s. Also the 6.3V 10A filament transformer has a currently unused center tap. This allows me to supply 6.3VAC CT on the 572-160s if I like.

What's Next

There's a lot of additional things that can be done with these relatively simple circuits. I'll audition this amplifier, then ultimately convert it into a 572-160 version. I'm curious how it performs with respect to this one. In the next part of this series, I'll describe the results of the audition, and the conversion to 572.

-Steve

[go to part 3]

A2 Part 3 - Converting the 841 amp into a 572-160 A2 amplifier

Background

The 841 amp was auditioned by several people in one of my lunchtime sessions. General consensus: very very quiet, very dynamic. Also quick with absolutely defined transients. Also confirmed my own observations that this amp LIKES to be played loud.

As noted in the previous installment, I had planned on being able to easily modify the amplifier to 572-160, and this article will describe that modification and the expected results.

I will note up front that this amplifier shares some of the sonic capabilities of its 841 progenitor, but has its own sonic character.

Specifications

Maximum power at clip : 8 watts. (a bit more power than the 841)

Maximum sensitivity: 0.45 volts produces 8 watts. (considerably higher sensitivity)

Noise level: 800 microvolts. (80dB below 8 watts. This is slightly noisier, but still remarkably quiet. The added noise can be accounted for by the increased sensitivity).

Frequency Response: -2dB at 20Hz, and -0.9dB at 20kHz with no compensation. With modification to the input compensator described last time, response was within 0.1dB from 20Hz to 26kHz, which is similar to the 841 amp. The worse LF response is due to the higher plate resistance of the 572-160s.

Distortion. (see section below). In this amp, distortion is essentially all second order: the distortion spectrum is totally different than the 841 amp version.

Output impedance: 16 ohms on the 8 ohm tap. (higher Z out due to higher plate resistance).

The Modifications

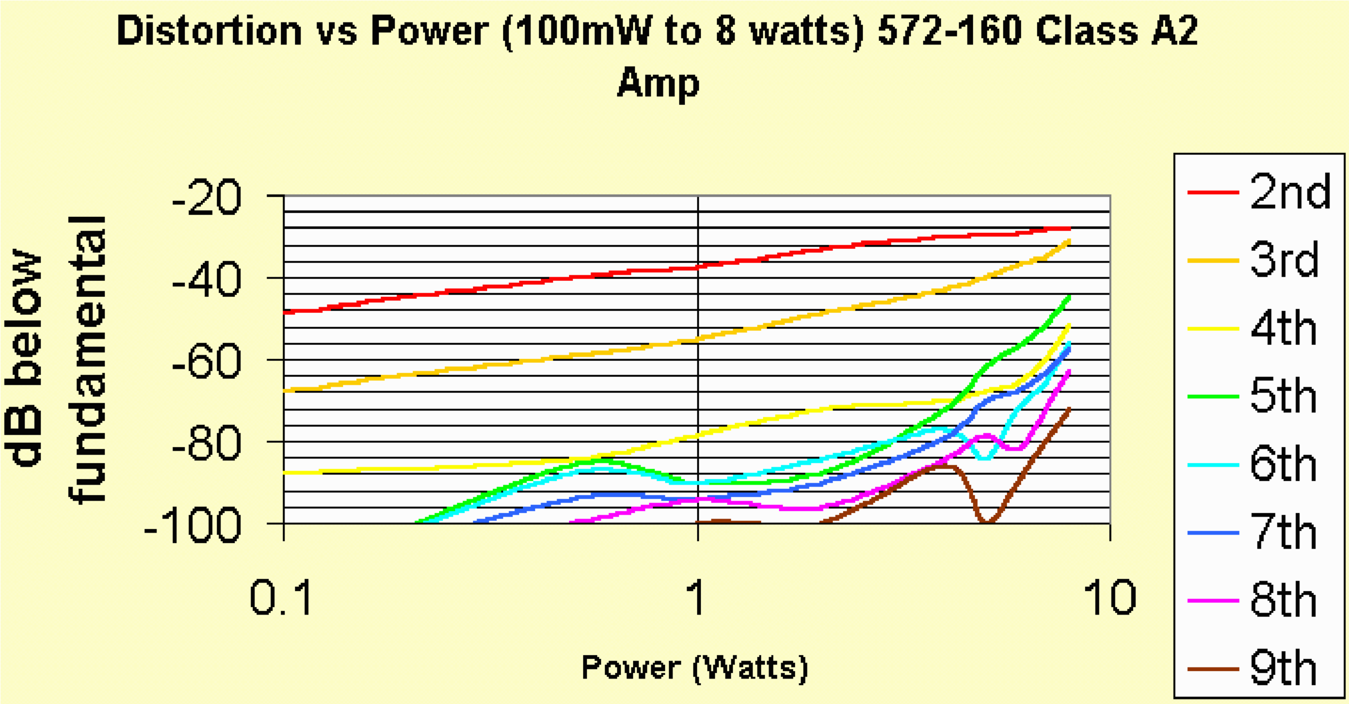
There are some really easy modifications used, but otherwise, the "schematic" remains unchanged. These are:

1. Unplug the 841s, replace with 572-160s.
2. Change the 5R4 rectifier to a 5AR4. This provides about +490 volts.
3. Change the 3k 15 watt resistors going to the 0A2 regulators to 3.75k. (Since I used 5k in parallel with 2 15k paralleled resistors, I simply removed one of the 15k resistors in each channel).
4. Bias set to about +13 volts instead of +9 volts. (causes about 40mA idle current in the 572-160s).
5. Filament chokes changed from 80mH to 4mH, 4A, 0.15 ohm and the capacitors changed to 44000uF on either side of the choke instead of 22000uF. I actually paralleled additional 22000uF capacitors. If I thought more about this up front, I would have initially gone with these values, since the "final" combination provides about 7.6 volts at 1.25 amps and about 5.9 volts at 4 amps, so would have accomodated either tube with no changes.
6. If you use the "optional" frequency response compensation, changing the 18.2k resistor to 12.1k produces flat response from 20Hz to 26kHz.

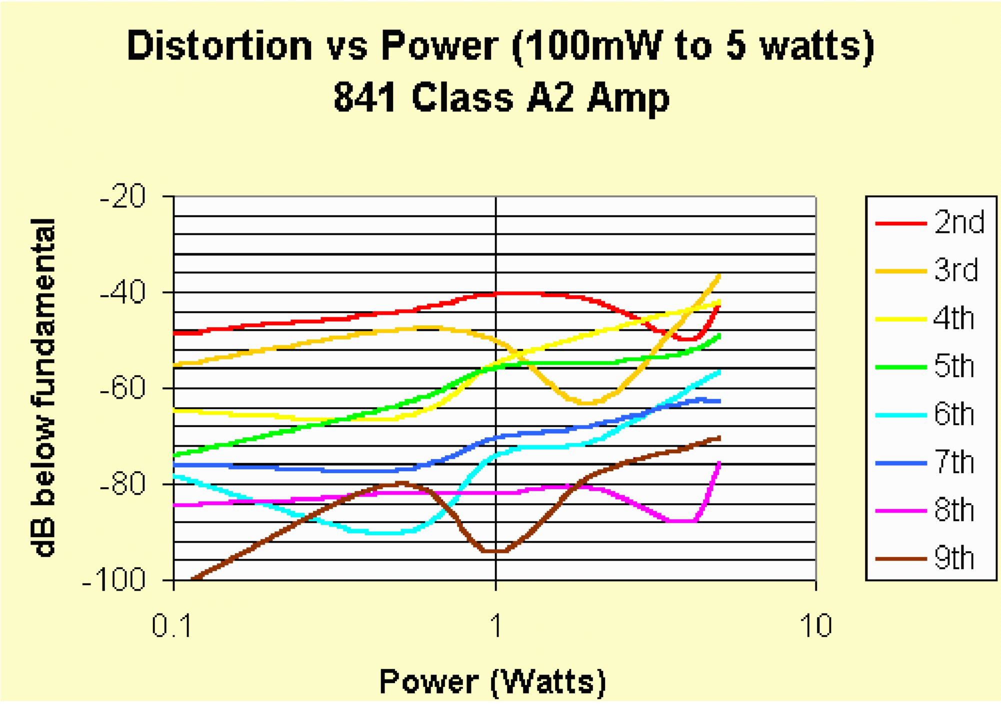
There are no other required changes.

Distortion

This amp produces a completely different distortion spectrum than the 841 amp. It consists primarily of second order and a little third order, with very little higher order components. This is essentially similar to A1 amplifiers.



For comparison, here was the 841 distortion characteristics:



Listening Tests / Discussion

This amp shares the 841 amps "like" to be played loud as well as it's dynamics, and almost invisible clip characteristics. In addition, you get a feeling of more "reserve" that isn't apparent from the less than 3dB increase in available power output. The higher output impedance may possibly be an issue with some speakers, but may actually aid other speakers. On my transmission line speakers, there is no evidence of bass muddiness.

This series is intended to present a useable form of A2 amplifier. There is some thoughts that A2 cannot be made to be as clean as A1. Noting the characteristics described above, this does no appear to be the case, if properly driven. (This may be one of those cases where a cathode follower does not harm the sound quality.).

This version of A2 amplifier also shows that in A2, at least, DC heated filament is no impediment to sound quality, and it remains a QUIET amplifier.

-Steve

841

841
R-F POWER AMPLIFIER, OSCILLATOR, A-F VOLTAGE AMPLIFIER

Filament	Thoriated Tungsten	
Voltage	7.5	a-c or d-c volts
Current	1.25	amp.
Amplification Factor	30	
Direct Interelectrode Capacitances:		
Grid to Plate	7	μμf
Grid to Filament	4	μμf
Plate to Filament	3	μμf
Maximum Overall Length		5-5/8"
Maximum Diameter		2-3/16"
Bulb		S-17
Base		Medium 4-Pin Bayonet

MAXIMUM RATINGS and TYPICAL OPERATING CONDITIONS

A-F VOLTAGE AMPLIFIER (Resistance-coupled)-Class A

D-C Plate Voltage	425 max.		volts
D-C Plate-Supply Voltage*	1250 max.		volts
Plate Dissipation	12 max.		watts
Typical Operation and Characteristics:			
Filament Voltage	7.5	7.5	d-c volts
D-C Plate-Supply Voltage*	425	1000	volts
D-C Grid Voltage	-6	-9	volts
Peak A-F Grid Voltage	6	9	volts
D-C Plate Current	0.7	2.2	ma.
Plate Resistance	63000	40000	ohms
Transconductance	450	750	μmhos
Load Resistance	250000	250000	ohms
Voltage Output (5% second harmonic)	126	225	volts

* Voltage effective at plate is less than the plate-supply voltage by an amount equal to the voltage drop in the load resistance caused by the plate current.

A-F POWER AMPLIFIER & MODULATOR - Class B

D-C Plate Voltage	425 max.		volts
Max-Signal D-C Plate Current*	60 max.		ma.
Max-Signal Plate Input*	25 max.		watts
Plate Dissipation*	15 max.		watts
Typical Operation - 2 tubes:			
Unless otherwise specified, values are for 2 tubes.			
Filament Voltage	7.5	7.5	d-c volts ←
D-C Plate Voltage	350	425	volts
D-C Grid Voltage	-5	-5	volts
Peak A-F Grid-to-Grid Voltage	176	180	volts
Zero-Signal D-C Plate Cur.	7	13	ma.
Max-Signal D-C Plate Cur.	114	120	ma.
Load Resistance (per tube)	1300	1750	ohms
Effective Load Res. (plate to plate)	5200	7000	ohms
Max-Signal Driving Power	3.2	3.6	approx. watts
Max-Signal Power Output	21	28	approx. watts

* Averaged over any audio frequency cycle of sine-wave form. ←

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APRIL 5, 1937 DATA

RCA RADIOTRON DIVISION
RCA MANUFACTURING COMPANY, INC.

RCA

841

R-F POWER AMPLIFIER, OSCILLATOR, A-F VOLTAGE AMPLIFIER

(continued from preceding page)

R-F POWER AMPLIFIER – Class B Telephony

Carrier conditions per tube for use with a max. modulation fact. of 1.0

D-C Plate Voltage		450	max.	volts
D-C Plate Current		50	max.	ma.
R-F Grid Current		4	max.	amp.
Plate Input		22.5	max.	watts
Plate Dissipation		15	max.	watts
Typical Operation:				
Filament Voltage	7.5	7.5		a-c volts
D-C Plate Voltage	350	450		volts
D-C Grid Voltage	-12	-15		volts
Peak R-F Grid Voltage	60	60		volts
D-C Plate Current	45	45		ma.
D-C Grid Current**	4	4	approx.	ma
Driving Power**°	3.5	3.5	approx.	watts
Power Output	4.25	6	approx.	watts

→ ° At crest of a-f cycle with modulation factor of 1.0.

PLATE-MODULATED R-F POWER AMPLIFIER – Class C Telephony

Carrier conditions per tube for use with a max. modulation fact. of 1.0

D-C Plate Voltage		350	max.	volts
→ D-C Grid Voltage		-200	max.	volts
D-C Plate Current		60	max.	ma.
D-C Grid Current		20	max.	ma.
R-F Grid Current		4	max.	amp.
Plate Input		21	max.	watts
Plate Dissipation		10	max.	watts
Typical Operation:				
Filament	7.5	7.5		a-c volts
D-C Plate Voltage	250	350		volts
D-C Grid Voltage	-40	-47		volts
Peak R-F Grid Voltage	125	130		volts
D-C Plate Current	50	50		ma.
D-C Grid Current**	15	15	approx.	ma.
Driving Power**	2	2	approx.	watts
Power Output	7	11	approx.	watts

R-F POWER AMPLIFIER & MODULATOR – Class C Telegraphy

Key-down conditions per tube without modulation ##

D-C Plate Voltage		450	max.	volts
→ D-C Grid Voltage		-200	max.	volts
D-C Plate Current		60	max.	ma.
D-C Grid Current		20	max.	ma.
R-F Grid Current		5	max.	amp.
Plate Input		27	max.	watts
Plate Dissipation		15	max.	watts
Typical Operation:				
Filament Voltage	7.5	7.5		a-c volts
D-C Plate Voltage	350	450		volts
D-C Grid Voltage	-30	-34		volts
Peak R-F Grid Voltage	115	120		volts
D-C Plate Current	50	50		ma.

##, ** See next page

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841
R-F POWER AMPLIFIER
A-F VOLTAGE AMPLIFIER

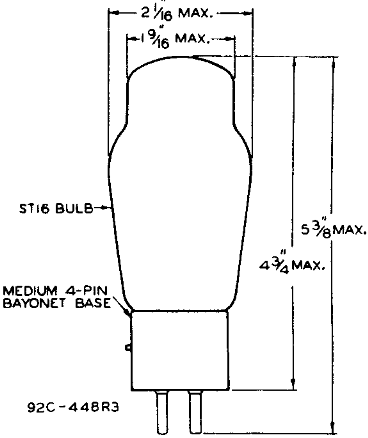
(continued from preceding page)

D-C Grid Current**	15	15	approx.ma.
Driving Power**	1.8	1.8	approx.watts
Power Output	11	15	approx.watts

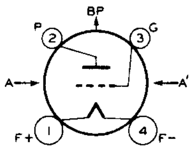
Modulation essentially negative may be used if the positive peak of the audio-frequency envelope does not exceed 115% of the carrier conditions.

** Subject to wide variations as explained on sheet TRANS.TUBE RATINGS.

For the use of the 841 at the higher frequencies refer to sheet TRANS. TUBE RATINGS vs FREQUENCY.



BOTTOM VIEW OF SOCKET CONNECTIONS



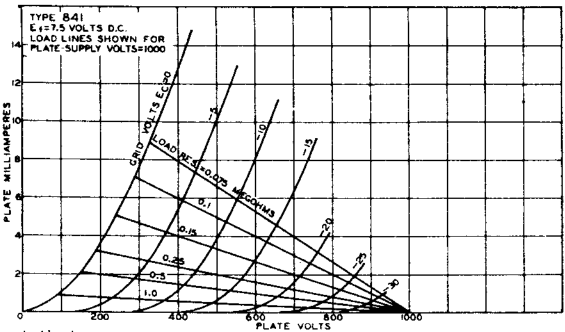
AA'=PLANE OF ELECTRODES

Pin 1 - Filament +
Pin 2 - Plate
Pin 3 - Grid
Pin 4 - Filament -
BP - Bayonet Pin

TUBE MOUNTING POSITION

VERTICAL: Base down
HORIZONTAL: Plate in vertical plane (on edge)

AVERAGE PLATE CHARACTERISTICS



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841

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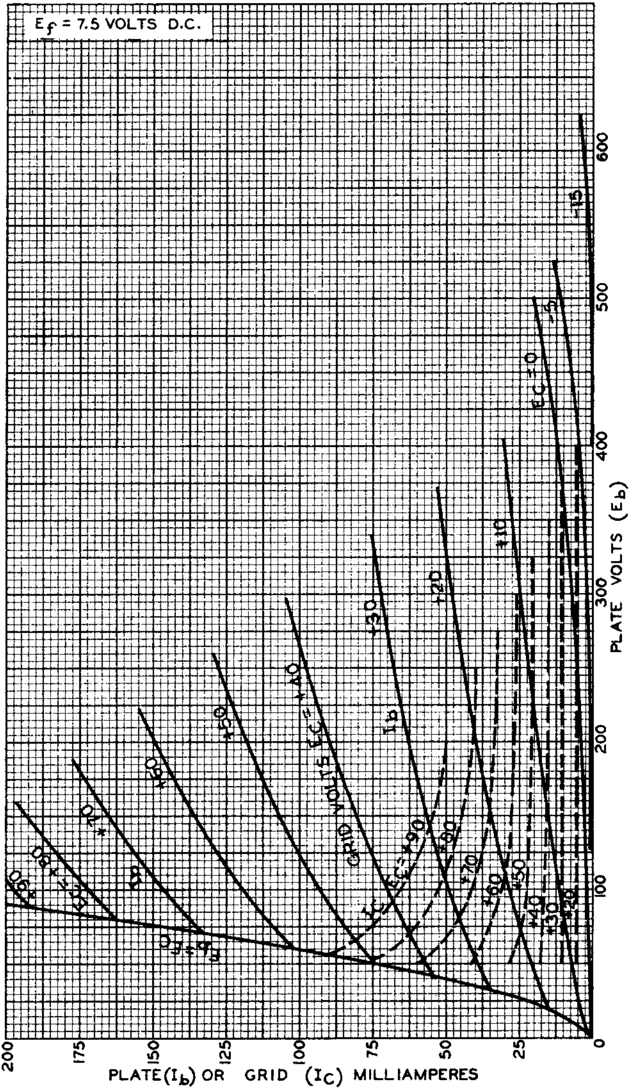
AVERAGE PLATE CHARACTERISTICS



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