

Tubes

A Full Bridge Output Amp

By Monny Nisel

This author shows how you can use a four-tube bridge arrangement in amp design.

PHOTO 1: The completed amp.



This project started as a result of the circlotron amplifier I built several years ago. Although I liked the pleasant sound of the circlotron, I was annoyed by its major and well-known drawback, namely, the use of two independent power supplies for each channel. Thinking about a simplified solution, I tried to figure out what was different in the circlotron arrangement that makes it sound so good.

Apart from benefiting from the cathode-follower output loading and the low-impedance power stage, there is one more element that seems to go unnoticed but is quite significant, in my opinion: the total absence of DC through the primary winding of the output transformer (i.e., the DC supply of the output tubes is not flowing through the transformer winding). This is a completely different concept from most of the classic arrangements. I intended to reproduce those conditions in a simpler manner, and I first thought

about the single-ended push-pull schematics with the two tubes in series supplied from a single source.

Unfortunately, this arrangement needs a double power supply (although not two independent ones), or a series capacitor, or a capacitor divider to hook up the load. This idea did not look too appealing. At this point I figured I could try to use two single-ended push-pull circuits connected in parallel on the same DC supply with the load connected to both median points of the two branches. Well, it did not take me long to figure out I was not the first to have this idea.

I remembered seeing something similar in an old *Glass Audio* magazine. The article is called "Linear Output Stages," by Graeme J. Cohen (GA 6/95, p. 34).

A search on the Internet revealed a description of an amplifier using two 6AS7 tubes in the same arrangement and capable of 9W class-A out-

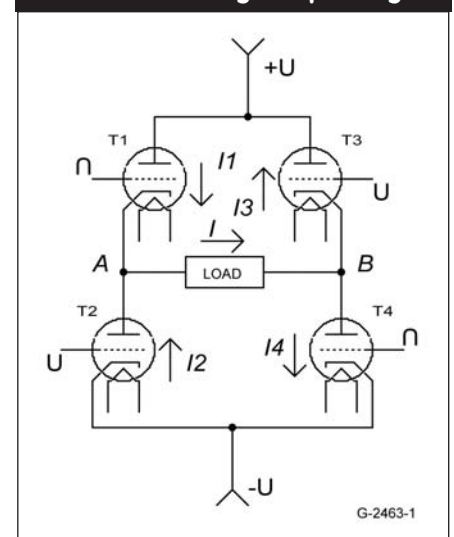
put power to be used with a 250W impedance speaker. This description by Kerim Onder was published in the October 1953 issue of *JAES*. As 250W speakers are history and 9W from two 6AS7 tubes seemed quite low, I figured that I should try a different approach in order to upgrade the initial concept to higher output power as well as to the use of regular 8W speakers.

FULL-BRIDGE OUTPUT-STAGE OPERATION

I called this arrangement full bridge to differentiate it from the circlotron, which is sometimes referred to as the circular bridge or simply bridge amplifier. It seems there was not much interest in any commercial audio amplifier using this arrangement, and for some good reasons: low plate efficiency, use of minimum four tubes in one channel output stage, and high supply voltage for the tubes in series.

However, most of these difficulties can be overcome by using a double triode such as the 6AS7. The configuration and operation of the full-bridge output stage is shown in *Fig. 1*. Two tubes are in series, on each branch, as

FIGURE 1: Full-bridge output stage.



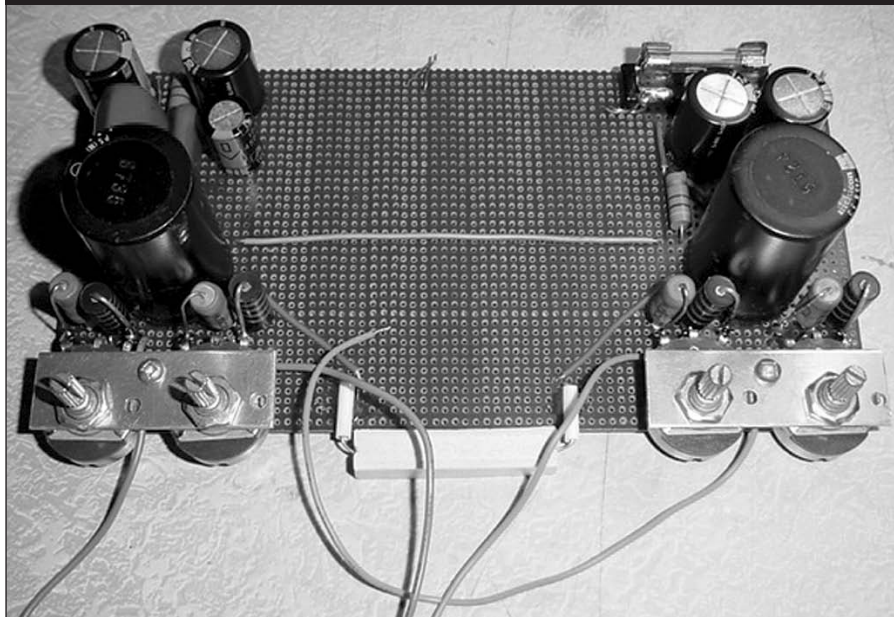
in a single-ended push-pull, with the two branches in parallel on the power supply. The load is connected between the midpoints of the two branches.

All conditions being equal (i.e., tubes matched and appropriately biased and with no signal at the grids), the DC voltages will be the same (approximately $U/2$) at the two middle points A and B. As a consequence, no DC current is flowing through the load.

Applying the signal to the stage is somewhat different from any previously known arrangement. Here is a simple explanation of the way the stage works. The bridge operates with so-called "diagonal phasing," meaning that you must apply one phase of the signal to tubes T1 and T4 and the opposite phase to tubes T2 and T3 as shown in Fig. 1. As the positive period of the signal is applied to the grid of T1, the current, as well as the voltage of the tube cathode (point A), increases (I1). The negative period applied to the grid of T2 decreases the tube's current (I2), keeping the potential of the tube's plate high (point A).

Practically, the effects of the opposite

PHOTO 2: Power supply assembly.



phase application are cumulating in point A, increasing the potential of this point. The same type of operation, but with reverse signal phasing applied to the right branch (T3 and T4), leads to the decrease of the voltage in point

B. As a consequence of the voltage unbalance of the two points (A and B), a current—I—following the signal flows through the load.

From the signal point of view, the two tubes on each branch supply the

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phase splitter drives the two second splitters using the two triodes of V3 in an unusual cathodyne configuration. These two splitters also act as driv-

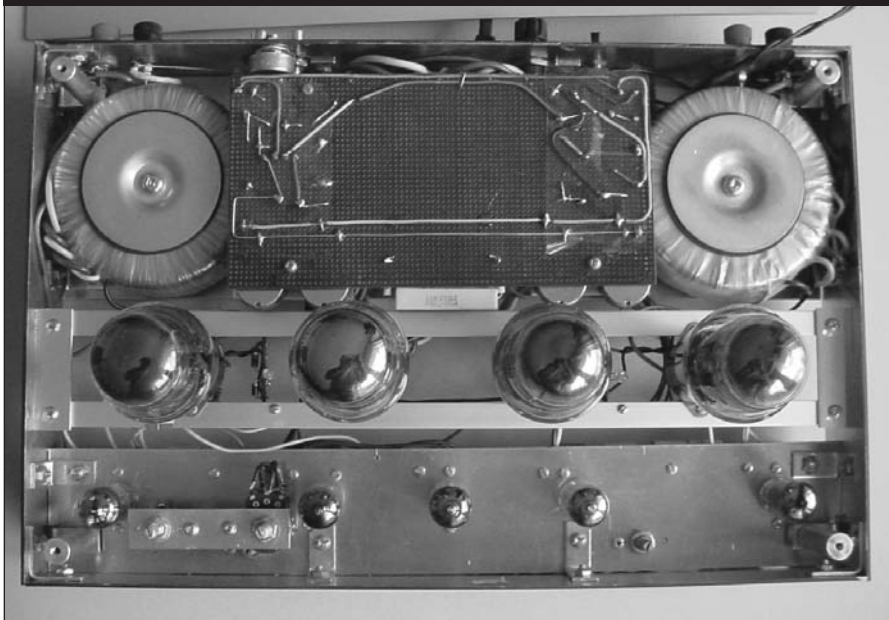
ers, each triode providing the signal with the right phasing and level to a pair of output tubes—V4-1, V4-2, and V5-1, V5-2, respectively. The bridge of the

[illegible]

A black and white photograph showing two circuit boards and a handheld device. On the left is a larger circuit board with various components, including a large integrated circuit, capacitors, and a multi-pin connector. To its right is a smaller circuit board with similar components. Below these two boards is a black, elongated handheld device with five white, oval-shaped buttons arranged in a pattern. The background is a plain, light-colored surface.

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PHOTO 4: Overhead view.



output tubes is redrawn to fit easier with the balance of the schematics. The use of the 6AS7 tube in the output stage came as a natural choice because it contains two completely separate tubes in the same envelope, has a low plate resistance and good sonic quality, and is easily available at a low cost.

I used the low-mu 12AU7 double triode in the two splitter stages. Apart

from getting higher drive current for the power stage, the 12AU7 is an inexpensive tube, which you can find even in a NOS version for a few dollars—this counts when you need four of them for the stereo version of the amplifier. I added an optional negative feedback circuit with two steps of 3 and 6dB between the output and input of the amplifier.

Though my personal preference was to listen to the amplifier without any feedback, some listeners preferred the sound with a certain degree of it. The three-position switch facilitates those preferences. I opted for a small amount of feedback, but I noticed quite a significant extension of the bandwidth and drop in distortion. Potentiometer P2 sets the balance between the two channels.

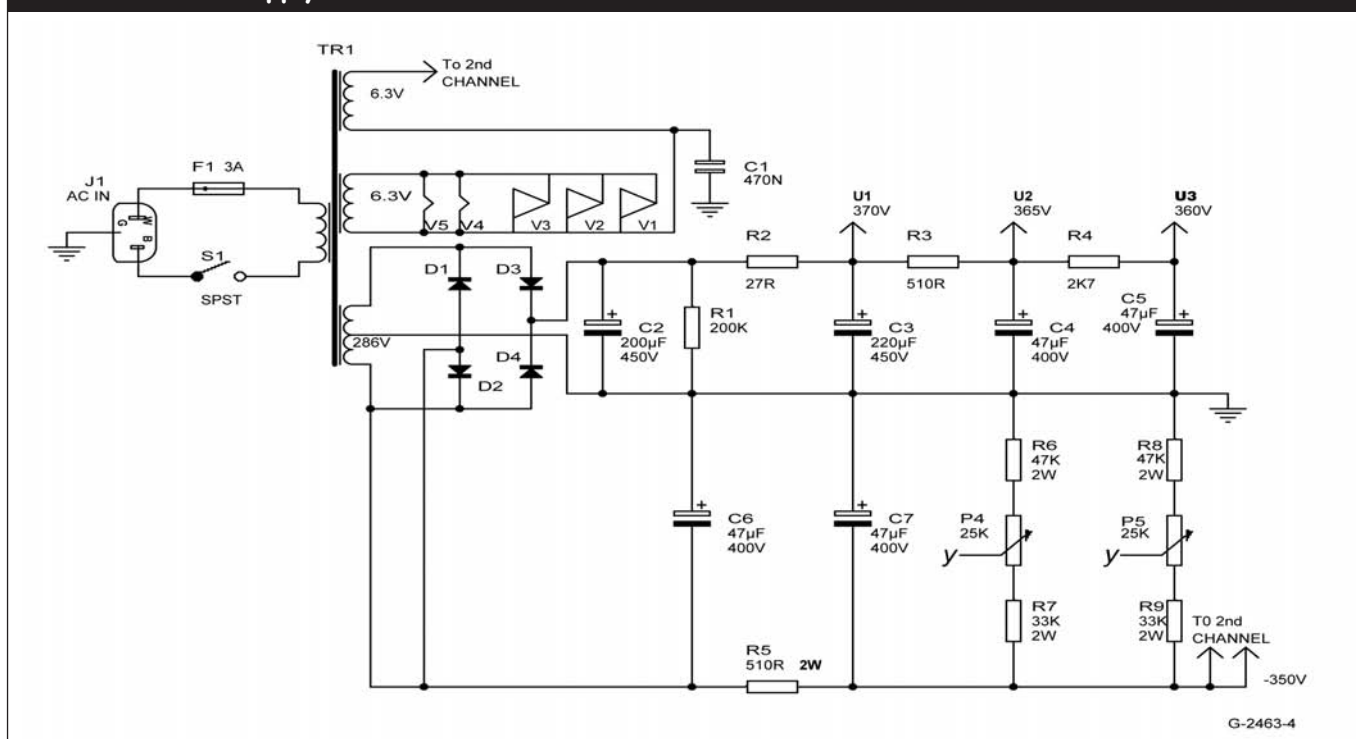
THE GAIN STAGES

The amplifier's total gain without feedback is 45dB, almost all of it achieved in the first two stages, the input stage, and the long-tail phase splitter. The coupling between these two stages is direct without any capacitors. There are practically only two coupling capacitors in the entire schematics of the amplifier. The voltage in the junction point should be around 80V DC. To drive the amplifier to full output power, you need 0.5V RMS; the first stage (V1) develops 14V RMS and the long-tail phase splitter 75V RMS on each output.

THE SECOND SPLITTER/DRIVER

Contrary to the regular cathodyne phase splitter, the one used to drive each of the output tubes has quite a different configuration. The load in the

FIGURE 4: Power supply—second version.



cathode is the 100k Ω resistor (R12 and R13), while in the plate it is the 270k Ω resistor (R14 and R15) connected directly to the positive rail. I initially started with the same load 100k Ω in the plate circuit connected to the middle point of the output power tubes (A and B). This arrangement was supposed to provide better stability through negative feedback from the output stage, as I found in some recommendations.

However, I could not reach more than 14 to 15W this way because the upper output tube operating as a cathode follower did not get enough drive, and after I tried several solutions I came up with the actual one. This way the drive voltage is higher with approximately 10%, and I could reach 18W of output power. I did not notice any instability or measurable increase of distortion.

The resistors (R14, R15) set up the initial bias of the upper output tube, bias which subsequently follows closely the adjustable bias of the lower output tube. The value of the bias resistor of the cathodyne (R9, R11) is critical in setting the right DC balance between

the two series output tubes. In case somebody wishes to try my initial arrangement by replacing R14, R15 with 100k Ω resistors connected to the median points A and B, the value of R9, R11 should be 12k Ω .

OUTPUT STAGE

When I began experimenting with the output stage, I started by using automatic bias as recommended for the 6AS7-type tube supplying the tubes through heavy cathode resistors. The results were disappointing: an important drop in the DC supply voltage, a lot of heat dissipated from the resistors, and, most important, the power output was less than 10W, all of which I did not like. Then I decided to try the automatic bias. While I was unaware of any example in the literature of the 6AS7 tube biased this way, I later found out that some designs used it despite the RCA warning against it.

I first tried this arrangement in my circlotron 6AS7 and, though it worked, the DC supply voltage of the tubes was much lower, and I tested it for only a short time. Being quite concerned with

what might happen with the tubes in series supplied at close to 400V DC and fixed bias, I prepared myself with a bunch of used but good 6080s meant to be sacrificed. Fortunately, things went smoothly: apart from a couple of tubes which I damaged by mistake, most escaped and seemed to work well with fixed bias. The two tubes in series on each branch are supplied with 370V, or approximately 185V per tube when all is balanced.

The average bias voltage of -85 to 90V applied to the grid of the lower tube allows for a quiescent current of 55mA and a power dissipation of just over 10W/tube. This power is quite close to the maximum dissipation power of 13W/tube. I like to run it this high because the sound quality is much better and the price to pay—the shortening of the tube's life—is not too high due to the low cost of the 6AS7. However, it is your choice to run the tube at lower current by adjusting the bias voltage accordingly. With this bias adjustment and an average drive signal of 55V RMS, the output stage operates in class AB and delivers an output



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power of 18W before clipping.

THE POWER SUPPLY

As Figs. 3 and 4 show, the high voltage DC power supply is straightforward. I used a toroidal power transformer, which I ordered at SumR for a very convenient price. Because I initially planned to use automatic bias, I did not provide for additional voltage to use for fixed bias; so when I switched to it, I needed something to avoid adding a new transformer. I came up with a simple voltage doubler, connected to the same high voltage AC winding on which I tapped the negative output to

get roughly -350V with respect to the negative rail of the DC high voltage supplying the tubes.

I later ordered another power transformer with a double high voltage winding from SumR, which I used on another sample of the amplifier. As you can see from the alternate schematics, the bias voltage is simply taken from the high voltage winding in a standard configuration. Both versions work well. The bias adjusting circuit provides between 70 and 100V, adjustable through potentiometers P4 and P5. The power transformer—in both versions—is capable of supplying the stereo configuration of the amplifier.

THE TRANSFORMERS

The transformers I used in this amplifier are all toroidal types, which I chose for several reasons. The most important was the opportunity to find a manufacturer called Sumner Technologies in Etobicoke, Ontario, who agreed to build me the transformers, without any preconditions and for a price that beat any of the well-known manufacturers. As it happened, Sumner Technologies is a manufacturer of toroidal transformers. The president of the company, Richard Sumner—a businessman with a busy schedule—found the time to listen to my requests and changes, and if the transformers came out right I must credit Richard.

The power transformer is a

straightforward type; the high voltage winding is either single for use with a bridge rectifier, or double for two separate rectifier diodes. Two 6.3V 7.5A heater windings each supply one-half of the tubes in the stereo version.

A second reason for using toroidal transformers was the output transformer's simple construction. The transformer has an impedance ratio of 450/8Ω. With one single interleaving—the secondary is wound between two halves of the primary—I received an almost flat response between 25Hz and 100kHz when I drove the primary from a generator with the secondary connected to an 8W load.

The low primary impedance helped a lot, but an important factor is the tight coupling specific to toroidal transformers. My main goal when choosing the transformers was to minimize the impact they have on the cost of the amplifier without significant compromises on the quality, thus making the amplifier more affordable to more people. With this output transformer the ±3dB frequency range of the amplifier extends between 20Hz and 50kHz at full 18W output power and without negative feedback. The sound is transparent and airy especially in the middle and higher range, voices and instruments showing an unusual presence. However, for those used to the sound of heavy damped pentode or beam tube output stages, the sound may be disappointing for the lack of heavy lower bass.

AMPLIFIER ASSEMBLY

I assembled the amplifier in a stereo version, on a somewhat unusual “mecano toys”-type chassis made from aluminum sheet strips, held together with metal angles and screws. I purposely did it this way so I could fit it with different face plates and change the look of the amplifier. The photos show a simple aluminum face plate, which I do not recommend because it was so time-consuming. Instead, you could use a Hammond type 17 × 10 × 3” chassis, on which you install the components in a classical way (i.e., transformers and tubes on top and all the smaller components under the chassis).

I installed the power supply and negative bias circuitry components on a vector board so I could fit them in the

PARTS LIST

1—AMPLIFIER

R1	1200R	1W	cc (carbon composite)
R2	270k	1W	cc
R3	1k	1W	cc
R4, R8, R10	1M	1W	cc
R5	22k	2W	cc
R6, R7	47k	2W	cc
R19, R11	10k	1W	cc
R12, R13	100k	1W	cc
R14, R15	270k	1W	cc
R16, R17	5.1R	0.5W	cc
R18	12k	1W	cc
R19	4.2k	1W	cc
R20	200R	1W	cc
C1, C2, C3	0.47μF	400V	polypropylene film
P1	100k		potentiometer log.
P2	250k		potentiometer log.
P3	25k		potentiometer lin.
V1	12AT7	tube	
V2, V3	12AU7	tube	
V4, V5	6AS7G (6AS7GA, 6080	tube	

TR1 – output transformer

Md. # Rx 01920302
450/8Ω from SumR

2 – POWER SUPPLY both versions

TR1 Power transformer: Md # RC0300 055 B, Make SumR

Primary: 2 × 115V
Secondary: 2 × 6.3V, 7A
286V, 0.55A

or Md. # RC0300 055 5, Make SumR
Primary: 2 × 115V
Secondary: 2 × 6.3V, 7A
2 × 286V, 280mA

D1-D6	1N 5408	103A	diode rectifier
R1	200k	2W	cc
R2	27R	10W	wire wound
R3, R5	510R	2W	cc
R4	27k	2W	cc
R6, R8	47k	2W	cc
R7, R9	33k	2W	cc
P4, P5	25k	1W	potentiometer lin.
C1	0.47μF	400V	polypropylene foil
C2, C3	200μF	450V	electrolytic
C4-C7	47μF	400V	
C8	10μF	450V	
C9	0.33μF	630V	polypropylene foil
C10	1μF	630V	polypropylene foil

small space around the power transformer. When using a standard type chassis, solder the components, both for the power supply/bias voltage and the rest of the circuitry, on terminal strips installed close to the main components they are related to (power transformer, tube sockets).

The stereo version of the amplifier includes eight potentiometers, which you must consider when planning a mechanical layout. Install balancing potentiometer P2 close to the main input potentiometer or close to the input RCA jacks. Mount potentiometers P3 (and P1 for the other channel not shown) in the proximity of the long-tail splitter. Place the bias potentiometers P5, P6, as well as adjacent resistors, next to the output tubes they supply.

The output tubes dissipate over 35W of power each—a lot of heat for the small envelope of 6AS7 GA or 6080. For this reason spread out the tubes and eventually drill ventilation holes around the sockets.

With the components installed, I wired the amplifier starting with the transformers, then the heaters of the

output tubes (which require at least #18 wire gauge) and advanced to the first stages. I wired small components using terminal strips.

AMPLIFIER ADJUSTMENTS

After wiring and with the right fuses in place—but without the tubes—I measured to make sure the voltages were right. In order to prevent the DC voltage from rising to dangerous peak levels on the power supply capacitors without the tubes, I connected a temporary load made up of a 5kΩ 20W resistor to the output of the power supply. When using this option of loading the high voltage, be aware that the resistor becomes extremely hot, so avoid touching it and isolate it from surrounding objects. A better way of powering the amplifier is through a Variac autotransformer and watching until DC voltage reaches 370 to 380V.

I strongly recommend measuring the voltages at the output power tube sockets and paying special attention to the presence of the negative bias voltage at the tube's grids. Before plugging in the tubes, turn the bias potentiometers so

you have the maximum negative voltage at the grids. To set the quiescent current of 55mA, you need to adjust the bias potentiometers P5, P6 until you measure 275mV on each of the cathode resistors R16, R17. You must perform the operation a few times, going back and forth from one tube to the other until you reach the right voltage drop on each of the two resistors.

The two 5W/0.5W, R16 and R17, resistors also act as fuses in case of a sudden and strong overloading or shorting of the tubes. After setting the quiescent current, it is important to check the balance of the output stage. You can start by measuring the bias voltage to check how the tubes match; a difference of 2–3V indicates a good match.

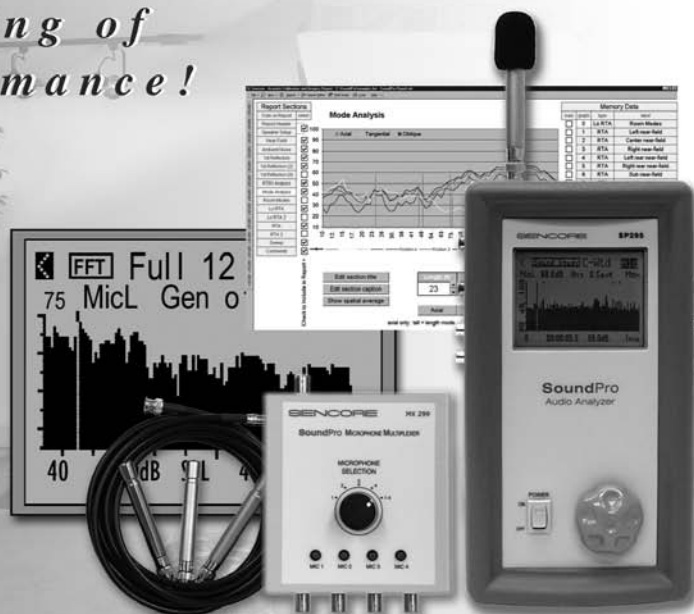
Next, disconnect one of the output transformer legs from the median point of the two tubes and measure the DC voltage across each of the output tubes. You should find half of the total DC supply voltage for a good balance. Again, a difference of 3–4V is acceptable.

If the difference is much higher, the culprit could be the lack of match-

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ing between the two halves of the output tubes or of the cathodyne splitter halves (V3). Even resistors R9, R11 and R14, R15 should be matched as closely as possible. The balancing of the output stage is more demanding in this type of amplifier if you plan to squeeze a few more watts of undistorted power. The last adjustment, which is straightforward, is the AC balance of the long-tail splitter through potentiometer P3.

THE DISTORTION PROBLEM

According to the articles previously mentioned, this type of output stage is one of the most linear with distortion below 1%. However, there is a difference between those amplifiers as per class of operation and power output. This amplifier is operating in class AB and outputs double the power of Kerim Onder's amp, which works in class A only.

Moreover, this design uses an output transformer, an additional source of distortion. With two well-matched tubes, the stage closely balanced, and no negative feedback applied, the distortion measured at 1kHz was 1.4% at full 18W output power; the distortion drops to 0.2% at 1W output power.

However, there are a few ways to decrease the distortion. The first (which I already mentioned) is by applying the negative feedback. With 6dB of negative feedback, the distortion drops almost a full percentage. Another method, suggested by Graeme J. Cohen, was to insert a small resistor into the positive DC rail supplying the two upper output tubes. According to the author, the resistor helps to balance the mutual conductance of the two tubes, thus contributing to reduce the second-order harmonics. The article does not indicate any value for the resistor so I tried a few myself.

A 100Ω resistor will reduce distortion by more than half a percentage point but will also drop close to 2W of output power. Another method I tried was to adjust P3 for the lowest distortion; the results were almost similar to the resistor method.

Because I worked hard for every watt of available power from this amplifier, I was reluctant to lose any of them, so I stayed with the negative feedback only. In one switch position

with the feedback network disconnected, there was no distortion reduction procedure applied. This was, according to my own taste, the position with the best sound.

A FEW MORE PRACTICAL NOTES

The following items, based on many hours of experimenting, will make it easier for you to build the amplifier.

- **The DC high voltage supply of the amplifier.** As previously mentioned, by using the SumR mains transformer, the DC high voltage in the stereo version will reach a maximum of 380V (or 190V per tube). I found that it is not safe to go over this voltage because of the thermal runaway tendency of the output tubes. This seems to be more evident with the 6080 version of the tube.

I mention this problem because of the existence on the market (or in hobbyist junk boxes) of over 300V AC winding transformers, which some may be tempted to use. If so, you need to lower the DC voltage to a safe level. My main voltage is a couple of volts lower than normal—the DC high voltage is 370V and the amp works well.

- **The DC voltage on V2-1 grid (point X).** Although most of the time the long-tail splitter will keep its cathode approximately 9V higher than the grid, I found that the voltage at the grid should be around 80V DC ($\pm 3-4V$) for the optimal operation of the stage. This voltage, being a function of the plate current of V1-1, may vary with different samples of the tube. To correct the problem you may need to change the tube or slightly alter the bias resistor. I could have solved this problem by using capacitive coupling between the stages, but I preferred to have one less capacitor in the signal path.

- **Matching the output tubes and balancing the output stage.** The 6AS7/6080—in many respects a beautiful tube—is particularly known for having quite a wide spread of parameters from one sample to another, even in tubes from the same batch. The problem of matching is further compounded in this amplifier by the need to match four tubes, two being located in the same envelope. The best

thing is to order two pairs of matched tubes from a supplier, but I imagine many hobbyists would like to use their own stock as I did. Because the test conditions were far apart from the operating conditions, and thus quite impossible to match the tubes in my tube testers, I resorted to matching directly in the amplifier.

When adjusting for the same quiescent current in the two tubes, I sometimes found differences of 10-15% in the bias voltage. In such cases I prefer to adjust for 3-5% difference in current, thus lowering the unbalance of the bias voltage. Also, you get an approximate idea of the mutual conductance by measuring the AC voltage on the cathode resistors of the output tubes when testing the amplifier for output power. Differences of 10% are not unusual. Even when you cannot match the tubes well, you can still expect 14-15W of output power before clipping.

- **Identical conditions for test.** The 6AS7/6080 tube takes quite a long time until it reaches thermal stability after you switch on the amplifier. I found it is best to wait 5-10 minutes before attempting any tests or adjustments.

Another factor to consider is the mains voltage. A drop of a couple of volts in the AC mains can translate to close to a 10V drop in the DC high voltage supplying the tubes, and this

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can mean quite a change in previously measured values. You must be aware of that factor so you don't become frustrated when you find that the output power is 1W less or the bias voltage is 5V higher than you measured a few days ago. I mention this because it happened to me all the time, and I would become frustrated even though I knew where it is coming from. My mains supply varies between 112 and 118V.

- **The amplifier test under full power.** When doing tests under full output power, the tubes overheat and the test should not last for more than 20 to 30 seconds at a time with appropriate cooling breaks.

- **The heater-induced hum problem.** Due to the configuration of the mains transformer, with its single heater winding per channel, as well as the amplifier arrangement, I preferred to leave the heater floating with respect to ground. To minimize hum I connected the heater winding to ground through a 0.47 μ F capacitor, which seemed to work well. I measured a barely audible 2mV at output with volume control at minimum hum. When experiencing hum from an electrically noisy mains, connect a 0.1 μ F/600V polypropylene dielectric capacitor between ground and each of the two 117V transformer primary wires.

- **Safety.** Voltages in the amplifier are lethal, so be very cautious when you work on it. Also beware of briefly turning the amplifier on or off; the heaters may not have the time to warm up while the capacitors have time to fully charge up. Modern electrolytic capacitors can keep the charge for many days.

A CONFESSION

I built my first version of the amplifier with low voltage power transformers in the output stage. Though I knew the output transformer should have a low primary impedance, I could not find anything available on the market, and I did not want to place a firm order before determining the optimal value of this impedance.

As I started experimenting with this project, I tried six different output impedances from 320 to 640 Ω and record-

ed the highest output power at 450 Ω . I decided to try a pair of 120/16V -150W toroidal transformers that I found in my junk box.

This transformer reflects the 8 Ω speaker impedance as a 450 Ω load seen by the amplifier. Though the measured results were somewhat at the limit of decency, the sound was good enough to encourage me to complete the amplifier in a stereo version using these transformers, as well as to order—not too long afterwards—the right transformers from SumR. I am still listening to this pleasant-sounding amplifier from time to time.

So why this confession? I know many amplifier hobbyists have well-garnished junk boxes and not much money, so there is a choice, though not the best one. *ax*

Monny Nisel is designing and building tube amplifiers as a hobby after retiring from the aerospace industry where he worked as an electrical and instrumentation engineer. He likes to try mostly projects which fall outside the beaten path.

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