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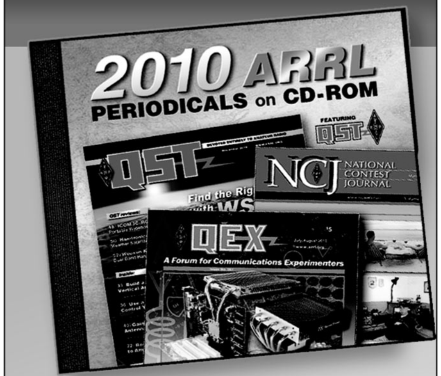

A Multiband 50 W Linear Amplifier

Give a bit of a kick to your homebrew challenge transceiver or other low power HF rig.

Jim Veatch, WA2EUJ

Here is a low cost linear power amplifier for the 40, 30, 20, 17 and 15 meter bands capable of 50 W output with as low as 2.5 W of drive. That's a gain of 13 dB, more than two S-units, a worthwhile increase if conditions are poor. The amplifier was designed specifically for the Second ARRL Homebrew Challenge and was designed to meet all the contest technical requirements.[1] This amplifier version

[1]Notes appear on page 38.

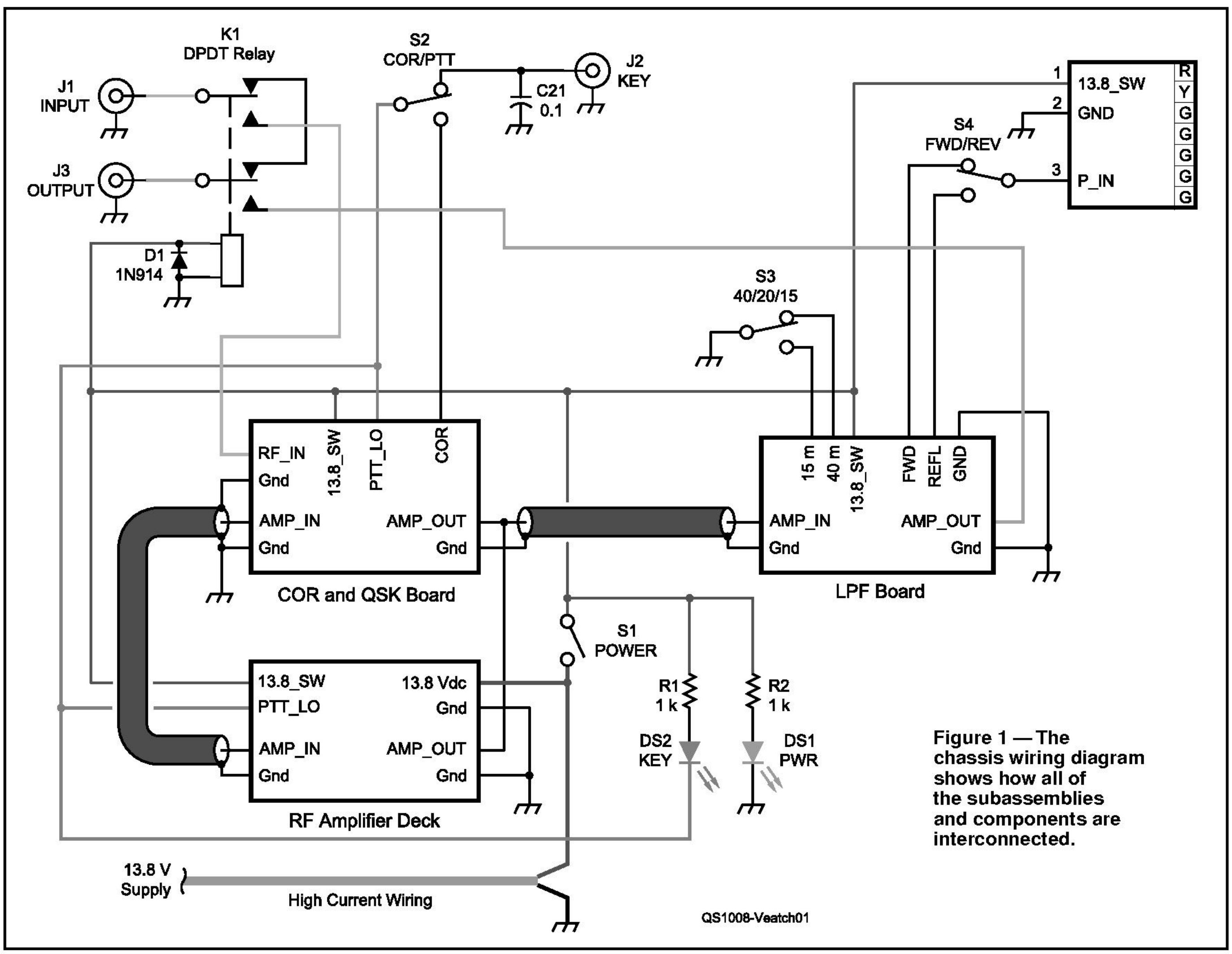

Figure 1 — The chassis wiring diagram shows how all of the subassemblies and components are interconnected.

was specifically designed to meet the special category of "most features in an amplifier that cost less than $125." In addition to the basic technical requirements, this amplifier features:

- Full output with an input of 2.5 W, to allow operation with other popular radios (the first HBC transceiver put out 5 W).
- Aluminum oxide power transistors were used to avoid safety issues of beryllium oxide devices.
- In addition to the required 40 meter operation, this amplifier operates on 30, 20, 17 and 15 meters.
- Transmit-receive switching supports full break-in (QSK) operation and, if selected, will switch over based on RF for radios without transmit-receive keying contacts. This is sometimes referred to as a carrier operated relay (COR), in spite of the fact that it also works with suppressed carrier modes.
- A directional wattmeter reads the forward and reflected power at the output of the amplifier with a display of seven LEDs serving as a bar graph.
- The amplifier also includes a mechanical bypass relay that connects the input and output connectors when the amplifier is powered off.

The total cost for the amplifier, as built, was under $95. A more basic one band version could be built for less than $50. The complete bill of materials including suppliers is available on the QST-In-Depth Web site.[2] The design is easy to modify, so only build the features you need and add more if you think that I've left out something important.

Transistors, Transistors, Transistors!

The first step in designing a power amplifier is selecting which active amplifying device to use. I decided to limit my search to RF power transistors that operate in the HF frequency range (3 to 30 MHz) and are designed to operate in Class A or Class AB modes. Using more exotic modes, or using devices that were not primarily designed for RF linear amplifier service seemed a bit ambitious for this competition and my design skills.

I evaluated every readily available 13.8 V, HF device to determine the cheapest way to get to 50 W. My answer was the RD16HHT1 power MOSFET available from RF Parts for $4.20.[3] Since the RD16HHT1 is only rated for 16 W, four devices are required to get to required output with a total transistor cost of less than $17.

I experimented with input and output combiners but quickly settled on the venerable and widely used parallel push-pull architecture. This allows the bias current of each transistor to be adjusted individually so matching of the devices is not required. The RD16HHT1 comes in a TO-220 package with the mounting tab internally connected to the source, which is grounded in this amplifier, so no electrical insulation is required between the heat sink and the transistors. Another advantage of using four devices is that the power in an individual device is still relatively low, which makes the job of removing heat a little easier. This amplifier uses an extruded aluminum heat sink that is bigger than necessary for this application so go ahead and run RTTY all night long.

The Circuit

The amplifier consists of four basic assemblies that are wired together and connected to the chassis mounted components to form a complete amplifier. The chassis wiring diagram (Figure 1) shows how all of these components are interconnected. Figure 2 shows the way the subassemblies are positioned on the bottom of the chassis.

The Amplifier Deck

The RF amplifier assembly schematic (Figure 3) shows the various components and connections of the amplifier deck. MOSFETs Q1 through Q4 form the RF amplifier. The parallel combination of Q1 and Q2 operate push-pull with the parallel combination of Q3 and Q4. The drain voltage is applied to all four MOSFETs via the primary winding of transformer T2. When the gate voltage is 0, the MOSFETs are in cutoff and very little drain current flows. This means that it is not necessary to switch the high current 13.8 V supply, but it also means that T2 and the drain connections are at 13.8 V even if the front panel POWER switch is set to OFF. So remember to disconnect the amplifier from the power supply before working on the amplifier.

Bias for each MOSFET is supplied via variable 1 kΩ resistors (R1 to R4), bypassed with 0.1 µF capacitors (C5 to C8) through 47 Ω resistors (R1 to R4). The 5.1 V Zener diode, D3, provides a regulated voltage to VR1-VR4 and even if inadvertently set to maximum voltage, the drain current, while excessive, will not destroy the MOSFET. The bias point changes very little with temperature so there is no need for temperature compensation on the bias voltage. Q5 is used as a switch to turn on the bias supply when the amplifier is keyed and the base of Q5 is pulled low via R7. R5 and R6 provide current limiting to correctly bias D3.

T1 couples the drive into the amplifier. The turns ratio is 1:1 and provides an input VSWR of better than 1.5:1. It would be possible to design an input matching network to improve the match if the transmitter driving the amplifier required a better match. An input attenuator would also improve the match for transmitters in the 5 to 10 W range. T2 has a 1:4 turns ratio to match the drain impedance to 50 Ω. R15, R16, C23 and C24 are used to supply a small amount of negative feedback, which helps to reduce intermodulation distortion.

The Low Pass Filter and Directional Coupler Board

The schematic of the low pass filter board (Figure 4 on the QST-In-Depth Web page) shows the components and connections of the output circuitry. Relays RY201-RY204 are DPDT relays wired with both poles in parallel to increase the power handling capability and reduce stray inductance. These relays select one of

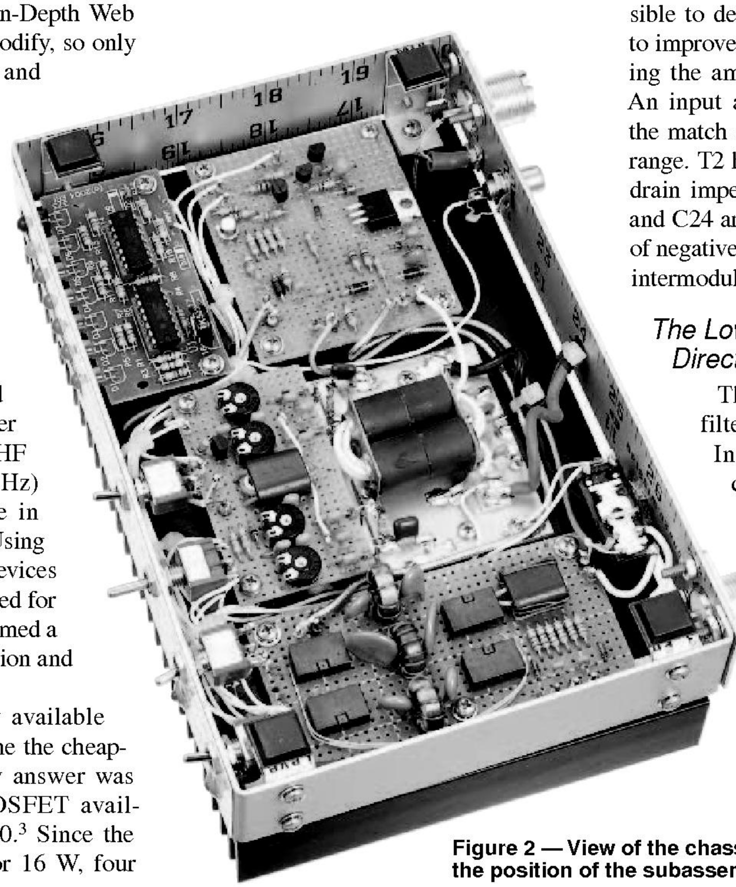

Figure 2 — View of the chassis bottom shows the position of the subassemblies.

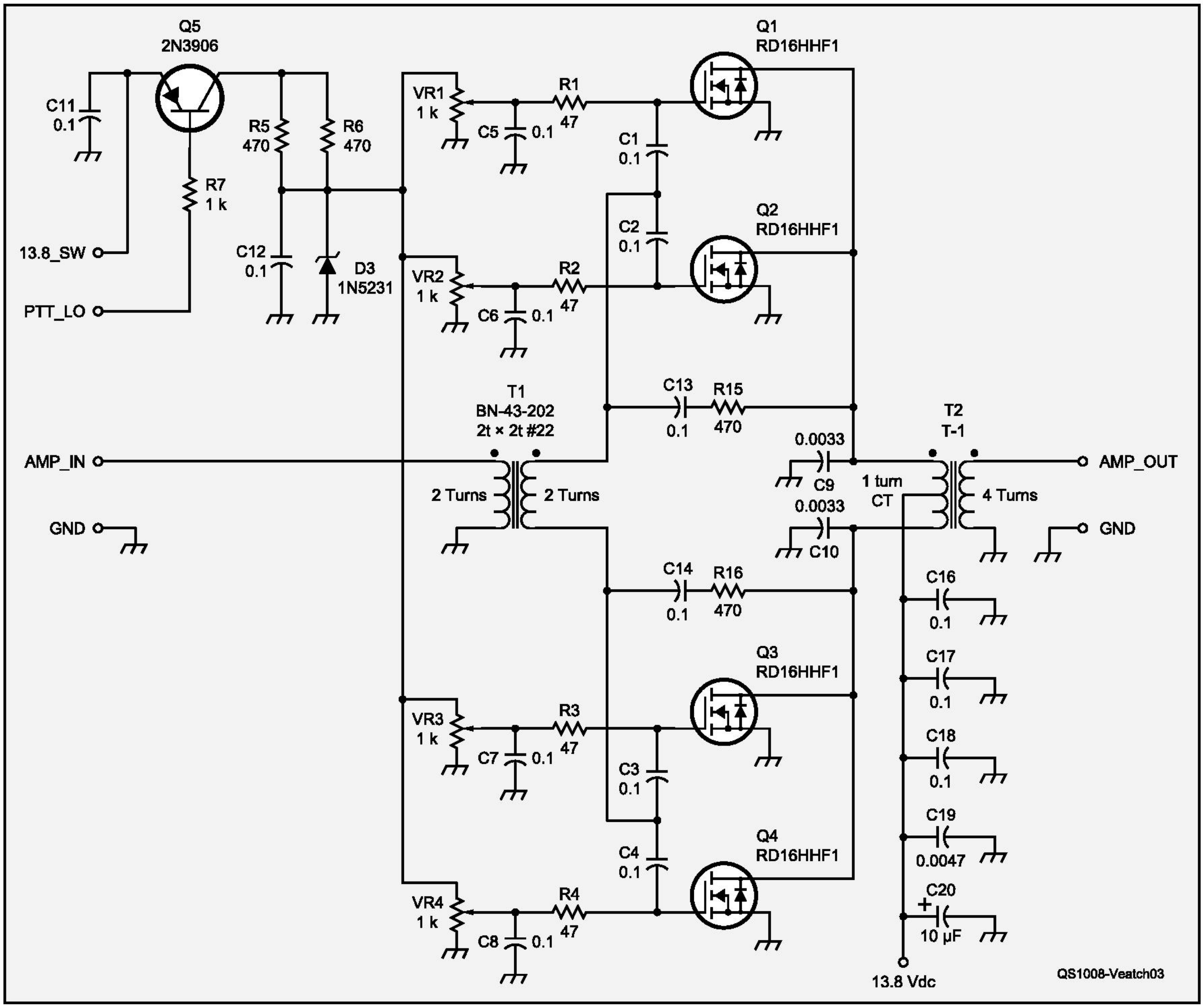

Figure 3 —The RF amplifier assembly schematic shows the various components and connections within the amplifier deck.

three low pass filters which, in turn, selects the band of operation. C107, C108, C109 and L103 are used on 40 meters. C104, C105, C106 and L102 are used on 30 and 20 meters, and C101, C102, C103 and L101 are used on 17 and 15 meters. There are only two control lines because with no relays activated, the 20/30 meter filter is selected. This allows the use of a center off toggle switch for band selection.

The directional coupler used to drive the power meter consists of a BN-43-202 binocular core with a total of four windings. Two of the windings consist of a single loop of #22 AWG Teflon insulated wire passed through each opening in the core. One is in line with the RF output and the other is terminated on each end by three 150 Ω resistors in parallel (50 Ω). Each opening also has a 10 turn winding of #30 AWG enameled wire, one end connected to ground, the other connected to the opposite 1 turn winding. The resulting RF across the terminating resistors is rectified to produce a dc voltage proportional to the forward or reflected power.

This is a fairly standard design and is easy to reproduce if the leads are kept short. I found the best way to build this directional coupler is to focus on neat layout and good RF practices, then figure out which one is forward and which is reverse after the fact.

The COR and QSK Board

The COR and QSK board (Figure 5 on the QST-In-Depth Web page) contains a single pole double throw RF switch, driving circuitry and an RF detector that can be used to key the amplifier when RF is applied to the input. D201 applies the RF to the input of the amplifier when biased on by Q202 and Q203. When Q202 and Q203 are off (unkeyed) a reverse bias is applied to D201 using R203 and R209. L201 and L202 isolate the RF lines from the DC bias voltages.

D202 and D203 are biased on by Q201 allowing the received signal to pass from the output of the amplifier to the input connector. During transmit, a small portion of the output voltage provided via C206 is converted to a large negative dc voltage by the voltage doubler circuit formed by D204, D205, C205 and C206. This negative voltage is applied to D202 and D203 via R212. L203 provides a dc return path for D202. The dc return for D203 is via the secondary winding of T2 on the amplifier deck.

The voltage produced at the output of the doubler can reach –100 V with 50 W of output power. Q201 is rated to handle –200 V so don't substitute just any P channel MOSFET here.

The Display Board

The display board consists of an off-the-shelf kit available from Jameco Electronics.[4] The kit is designed to be a voltage monitor and can be populated for a variety of different voltages and ranges. In this application we'd like to measure 0 to around 6.5 V, so we'll need to populate our board differently from any of the instructions included with the kit.

The LED dropping resistors, R3, R5, R7, R9, R11, R13 and R14, are 470 Ω. The voltage divider resistors, R1, R2, R4, R6, R8, R10, R12 and R18, are 1 kΩ. Put the 5.1 V Zener diode in the space for D8 *backwards* and bend the anode lead over to pick up the ground connection marked for D9's cathode. Do not populate D9 or R17. R15 is 1 kΩ and R16 is a 1 kΩ Trimpot. I put a 0.1 µF capacitor across the power leads of each IC (pins 4 and 11). 13.8 V is applied to the places marked INPUT + and INPUT – in the indicated polarity. The input voltage from the directional coupler is applied from the empty R17 leg that connects to R16 and ground.

I used D1-5 as green LEDs, D6 as yellow and D7 as red, but feel free to employ any color scheme that you feel appropriate. All of the required components are supplied with the kit except one green LED, which is included on the bill of materials on the QST-In-Depth Web site. I set my display so that the yellow LED comes on right around 50 W but if you don't have a wattmeter and can't borrow one set the yellow LED on at 6.5 V input and you'll be pretty close.

Construction

The amplifier case is made from an aluminum yardstick available from local hardware stores. An aluminum extruded heat sink forms the top of the case and the ruler is cut and bent into a rectangle that forms the back, front and sides of the case. Small L brackets are formed from small pieces of leftover ruler to attach the rectangle to the bottom of the heat sink. The individual boards and assemblies are mounted to the heat sink with standoffs secured in tapped holes. The COR/QSK and LPF/Directional coupler boards are built on small pieces of perforated project board and, as mentioned earlier, the display board is a PCB from a kit. The biasing components for the amplifier are assembled on perf board mounted above the RF MOSFETs so that the leads from R1 through R4 project off the perf board adjacent to the gate leads of the MOSFETs.

T2 and the high power dc components are mounted on a small piece of unetched PCB mounted in the chassis. Once the PCB is mounted to the heat sink and PA MOSFETs are mounted, use heat sink compound at the junction of the MOSFETs and the heat sink.

Use leftover PCB pieces to make insolated PCB lands for the MOSFET drains and V_{CC} connection points. T2 has metal tubes and PCBs on either end that form the primary winding. The drain side is the end that is split and the V_{CC} side is continuous. Solder T2 to the PCB lands before mounting T2 in the chassis. Form the leads of C8, C9, C16, C17, C18, C19 and C20 and solder one leg of each to the appropriate PC board land before this assembly is placed in the chassis.

Wind four turns for the secondary of T2 leaving the ends fairly long and free. Use Teflon coated #18 AWG wire for this winding. Trim the source (center) leads and solder to the PCB to make a ground connection at each MOSFET. Place the T2, land and capacitor assembly on the PCB and slide the drain lands under the drain (left hand lead) on each MOSFET and solder. Solder the ground (unconnected lead) for C8, C9, C16, C17, C18, C19 and C20 to the ground PCB. Solder one end of T2's secondary to a convenient spot on the ground plane. This is all that is needed to hold T2 in place but feel free to put a dab of RTV under T2 if you like.

The remainder of the chassis wiring can be completed at this point. This includes connections to the rear panel connectors and the front panel switches and LED as well as the module interconnections.

T1 is made from 2 turns of #22 AWG Teflon insulated wire for the primary and 2 turns for the secondary. Make the leads for each winding come out opposite ends of the core to simplify final connection. The core can be attached to the perf board by RTV adhesive for stability, if desired. Wherever an off-board connection is to be made, create a soldering loop with a component lead.

It may help to label these on the board with a single letter and mark them on the schematic as well. Mount all perf boards in the final position and make all off-board connections except the MOSFET gate connections. The front panel lettering is on a piece of glossy photo paper with the panel markings printed with an inkjet printer. There's a rectangular cutout for the LEDs and I blackened the rules with a marker to increase the display contrast.

Adjustments

After the amplifier is assembled, double check all wiring, check for shorts, then apply 13.8 V to the amplifier. Before connecting the gate leads to the bias resistors, check that the corresponding variable resistor causes the voltage at R1 through R4 to swing from 0 to 5 V dc and make sure that the voltage present at R1 to R4 goes to 0 V when the PPT line is not grounded. Then reset VR1-VR4 to 0 V at R-R4 respectively. Remove the 13.8 V supply and connect the MOSFET gates to the bias resistors R1-R4 as indicated.

My connections are arranged so that I can easily isolate the dc power going to the MOSFETs and that which goes to the bias and keying circuitry. If you can do this you'll set the bias closer because the bias circuitry seems to drift a little. In any case connect a milliammeter in line with the amplifier, note the idling current and adjust VR1 to VR4 in sequence looking for a 10 mA rise in the current. The distortion products will be lower if you take some time to balance these closely. Remove the milliammeter before applying the RF drive.

On the Air

Now you are ready to connect your favorite QRP transmitter, an antenna and work some stations. The drive level for 50 W output is just over 2 W. The amplifier is nice and linear at this power level. If running CW it's okay to drive it up to 70 or 75 W output but not for SSB. I tried this amplifier with my Elecraft K2, which does not have a PTT output so I ran the COR circuit. From Baltimore I was able to work Mississippi, Austria, France and Argentina with a GAP vertical on the roof of a row house.

Notes

[1]J. Hallas, W1ZR, "ARRL Homebrew Challenge," *QST*, Aug 2006, p 20.
[2]**www.arrl.org/qst-in-depth**
[3]**www.rfparts.com**
[4]**www.jameco.com**

ARRL member Jim Veatch, WA2EUJ, holds an Amateur Extra class license and has been a ham since 1976. Jim was a winner of the first ARRL Homebrew Challenge with his TAK-40 transceiver described in May 2008 QST. *He holds degrees in electronics technology and electrical engineering. Jim spent 12 years engineering long range HF and VHF sites for air-to-ground communications around the world. He is currently employed by L3 Communications developing RF direction finding systems. Jim is active on HF and 2 meters and is a volunteer in the Baltimore City RACES organization. He can be reached at 1704 Bolton St, Baltimore, MD 21217 or at* **wa2euj@arrl.net**.