Converting a Commercial TV Transmitter's Driver Amp for Ham Use

By John Sortor, KB3XG

This month we present part 1 of KB3XG's article on how to use the driver amplifier from an NTSC (analog) TV transmitter on 6 meters. Several club members were able to get these drivers when they were scrapped by WCBS-TV after the conversion to digital broadcast was completed. For members who have a driver, the article is directly applicable. Everyone, however, can learn quite a bit from it. It is also a great example of superb engineering writing that we all can use as an example.

A quick point of perspective: each driver makes well in excess of 1000 watts; a formidable amount of vhf power to any ham. Many of these were required to drive WCBS's output stage which made approximately 100,000 watts. --Ed.

Introduction:

The recent transition from analog to digital TV made some of the analog TV transmitters obsolete. Obsolete hardware usually ends up as scrap or in the hands of surplus dealers. In this case several hams with professional contacts were able to keep the modules out of the dumpster and into the hands of appreciative VHFers. This article describes how to put the Harris channel 2 transmitter into amateur service on the 6 meter band.

Circuit description: (see 1/4 module schematic on p. 5).

The channel 2 amplifier consists of four 1/4 modules. Each module consists of 2 push pull pairs with an on board 2-way splitter and 2-way combiner.

T1/T8 is a 2-way zero degree hybrid used to split or combine two 100 Ohm sources. The shields and center conductors are split at the center point to keep the port to port amplitude balanced.

T2/T3 and T4/T5 are two 4:1 transformers in series transforming 100 Ohms unbalanced to 6.25 Ohms balanced or 3.125 Ohms at each gate.

T6/T7 is a single 4:1 transforming 100 Ohms unbalanced to 25 Ohms balanced or 12.5 Ohms at each drain.

A regulated +15 VDC is applied to pin 1 of J1 (red wire) to provide gate voltage. The gate voltage of each MOSFET is biased to draw a drain current of approximately 0.5 Amps for class A-B operation. It was not necessary to readjust the gate bias pots.

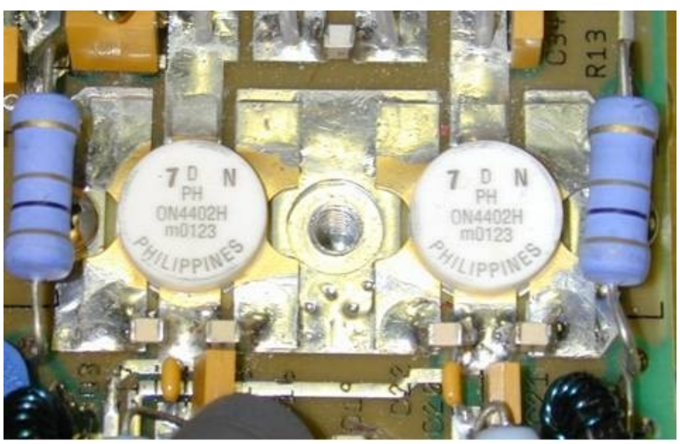
A balance transformer (T9) is connected across the isolation resistor (R15) of the output hybrid (T8). If both push pull pairs have the same Pout, the output voltage at the detector (CR1) is zero. If there is a fault with one or more devices, the detector sends an alarm to the control board. (pin 2 of J1 blue wire).

A thermistor (R1) attached to a solder tab is mounted directly to the hearsink between the devices. A bypass cap (C1) is mounted on top of the thermistor. If a fan fails or the airflow becomes impaired the current through the thermistor increases, the gate bias voltage decreases, the devices are biased off, and an alarm is sent to the control board (pin 3 of J1 yellow wire) .

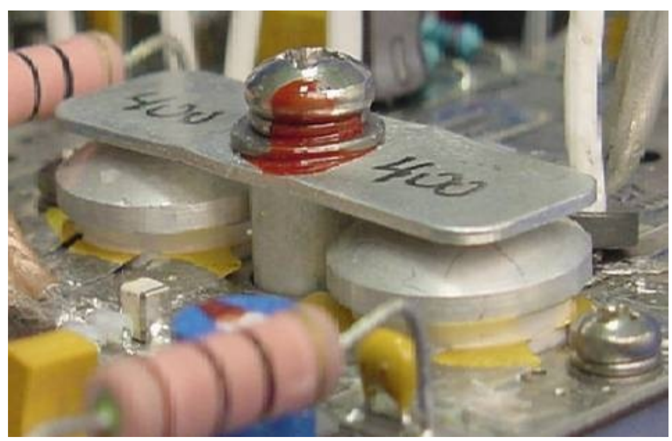
Gate bias/alarm connector & over temp

RF balance transformer and alarm

RF devices:
Very little information is available for the RF power MOSFET's (on4402h) used in this design. I believe the devices were manufactured by Phillips Semiconductor but I could not find an equivalent in any of the old Phillips data books. The transistor looks like a standard 0.500 6L (6 lead) package but it does not have mounting ears. The transistor is held tightly to the heat sink with a spring clamp and 2 aluminum cone shaped caps. The omission of the mounting ears allows the devices to be placed closer together. This reduces the inductance between the devices and makes it easier to match down to the low impedance of the gates. Harris must have spent a lot of money developing this device for this design.

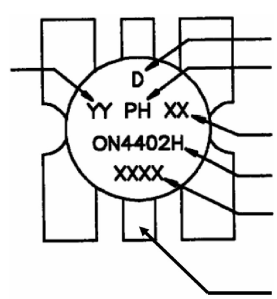


Phillips custom 0.500 6L transistor package

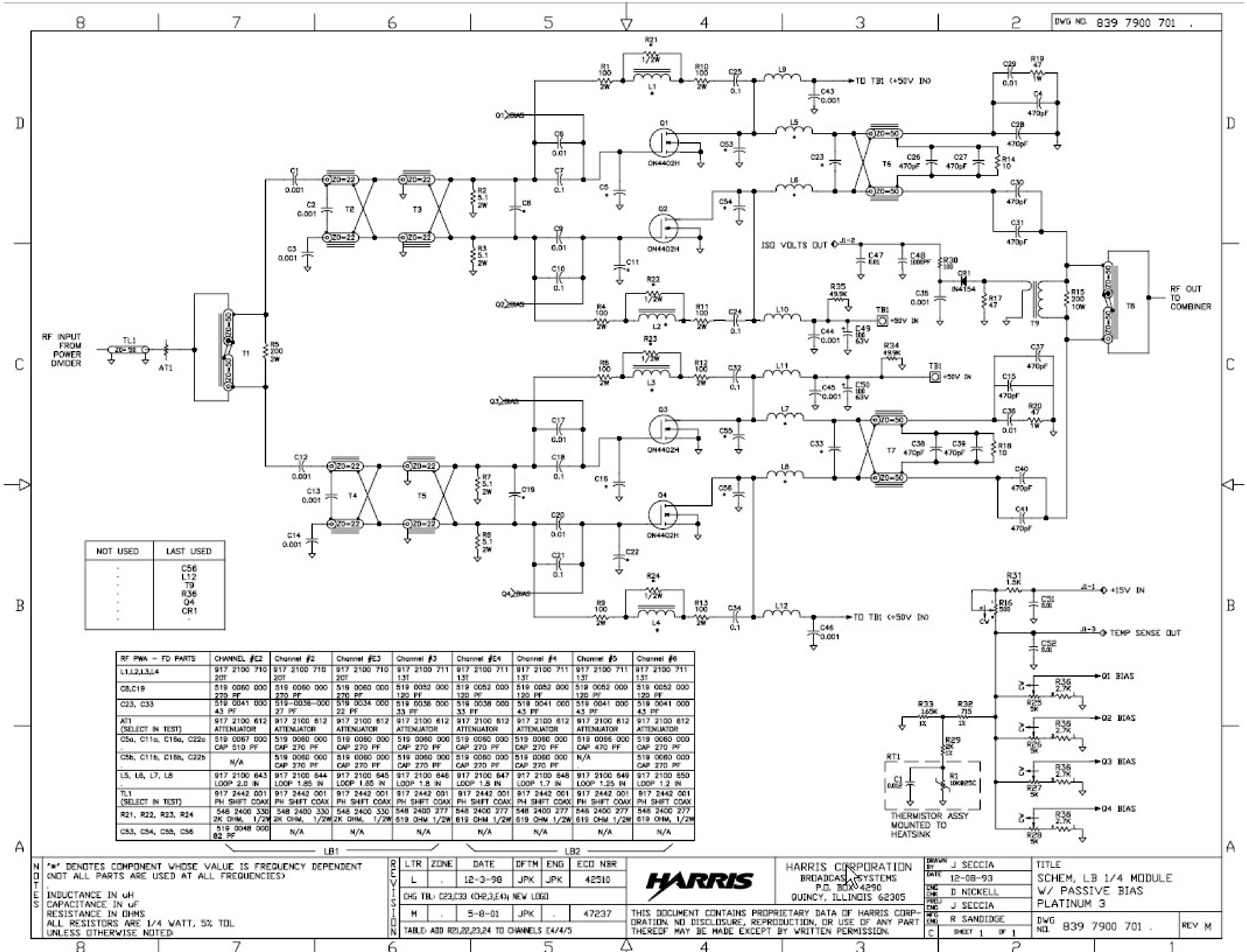


Device clamp to insure good thermal

I was able to locate the following device information from Harris online:
on4402h N-channel enhancement D-MOS
Drain to source voltage max 110V
Gate to source voltage max 20V
Drain current 9A
Total device dissipation 150W
Max junction temperature 200C
Four devices are used with power output of 275 watts peak power

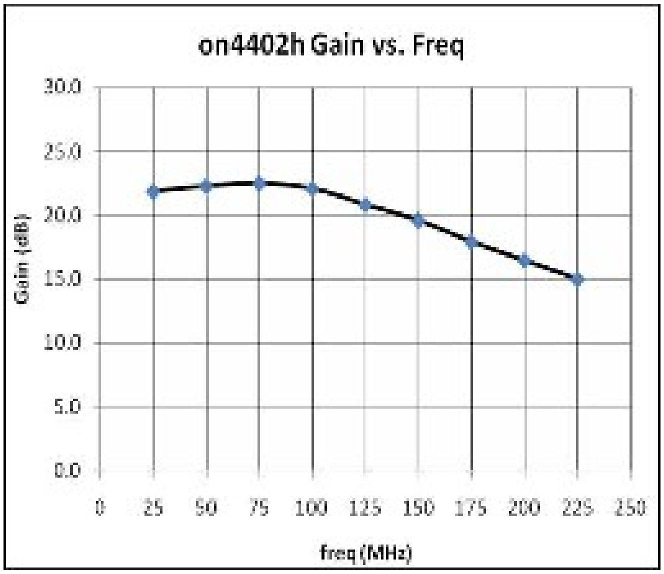


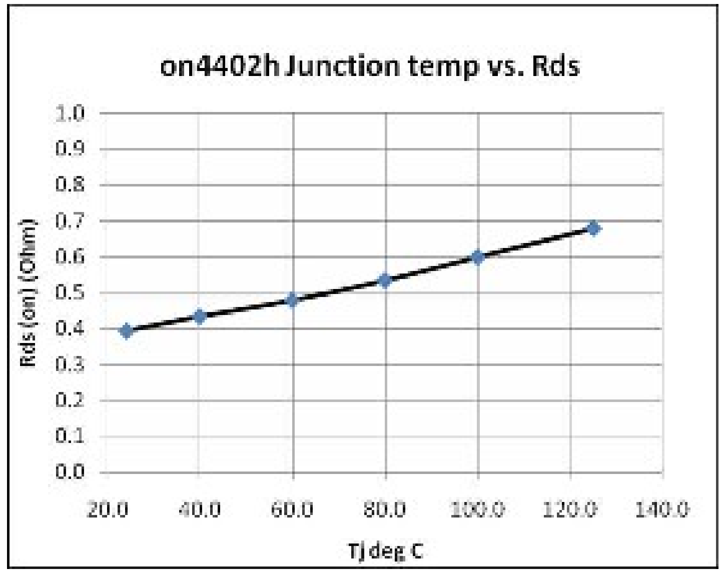
Legend:
"D"= Drain
"YY" = Gain Code
"PH" = Mfr (Phillips)
"XX"= Gate threshold code
"ON4402H" =Device type (part nr)
"XXXX"= Date code
Tab directly below drain is Gate



RF PWA – FD PARTS	CHANNEL #E2	Channel #2	Channel #E3	Channel #3	Channel #E4	Channel #4	Channel #5	Channel #6
L1,L2,L3,L4	917 2100 710 20T	917 2100 710 20T	917 2100 710 20T	917 2100 711 13T	917 2100 711 13T	917 2100 711 13T	917 2100 711 13T	917 2100 711 13T
C8,C19	519 0060 000 270 PF	519 0060 000 270 PF	519 0060 000 270 PF	519 0052 000 120 PF	519 0052 000 120 PF	519 0052 000 120 PF	519 0052 000 120 PF	519 0052 000 120 PF
C23, C33	519 0041 000 43 PF	~~519 0036 000~~ 27 PF	519 0034 000 22 PF	519 0038 000 33 PF	519 0038 000 33 PF	519 0041 000 43 PF	519 0041 000 43 PF	519 0041 000 43 PF
AT1 (SELECT IN TEST)	917 2100 612 ATTENUATOR	917 2100 612 ATTENUATOR	917 2100 612 ATTENUATOR	917 2100 612 ATTENUATOR	917 2100 612 ATTENUATOR	917 2100 612 ATTENUATOR	917 2100 612 ATTENUATOR	917 2100 612 ATTENUATOR
C5a, C11a, C16a, C22a	519 0067 000 CAP 510 PF	519 0060 000 CAP 270 PF	519 0060 000 CAP 270 PF	519 0060 000 CAP 270 PF	519 0060 000 CAP 270 PF	519 0060 000 CAP 270 PF	519 0066 000 CAP 470 PF	519 0060 000 CAP 270 PF
C5b, C11b, C16b, C22b	N/A	519 0060 000 CAP 270 PF	519 0060 000 CAP 270 PF	519 0060 000 CAP 270 PF	519 0060 000 CAP 270 PF	519 0060 000 CAP 270 PF	N/A	519 0060 000 CAP 270 PF
L5, L6, L7, L8	917 2100 643 LOOP 2.0 IN	917 2100 644 LOOP 1.85 IN	917 2100 645 LOOP 1.85 IN	917 2100 646 LOOP 1.8 IN	917 2100 647 LOOP 1.8 IN	917 2100 648 LOOP 1.7 IN	917 2100 649 LOOP 1.25 IN	917 2100 650 LOOP 1.2 IN
TL1 (SELECT IN TEST)	917 2442 001 PH SHIFT COAX	917 2442 001 PH SHIFT COAX	917 2442 001 PH SHIFT COAX	917 2442 001 PH SHIFT COAX	917 2442 001 PH SHIFT COAX	917 2442 001 PH SHIFT COAX	917 2442 001 PH SHIFT COAX	917 2442 001 PH SHIFT COAX
R21, R22, R23, R24	548 2400 330 2K OHM, 1/2W	548 2400 330 2K OHM, 1/2W	548 2400 330 2K OHM, 1/2W	548 2400 277 619 OHM 1/2W	548 2400 277 619 OHM 1/2W	548 2400 277 619 OHM 1/2W	548 2400 277 619 OHM 1/2W	548 2400 277 619 OHM, 1/2W
C53, C54, C55, C56	519 0048 000 82 PF	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Figure 1 Schematic of 1/4 Module . For a higher resolution picture, email the Editor



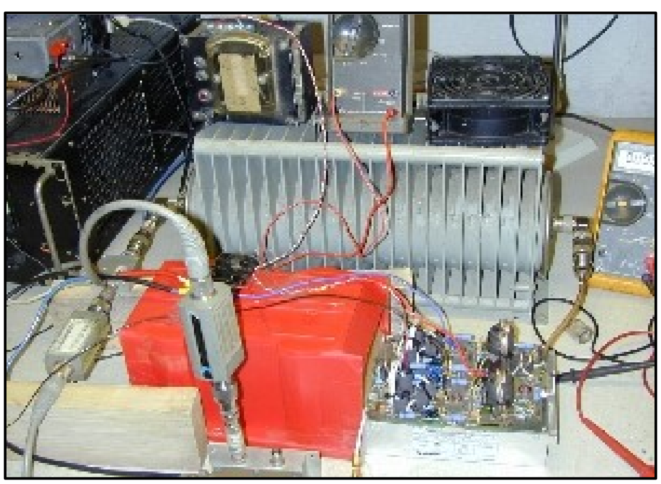


Pout = 100 Watts idq = 50 mAmps
Vds = 50 Volts ZdL = 9.1 Ohms

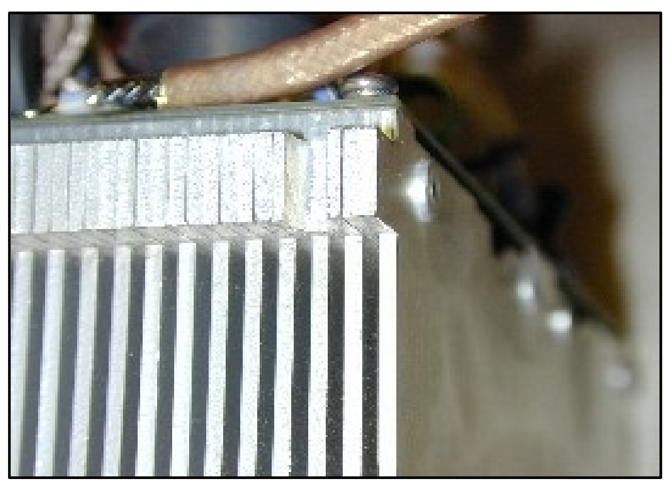
On resistance vs. Temperature

Cooling:
I have used plastic parts bins as air plenums to test various modules and amplifiers. I cut the back off of the bin and the opening is a perfect fit for a 4.5" fan. I use a piece of foam to keep the air from escaping around the top of the heat sink. This allows the fan to build up pressure and force all of the air through the heat sink fins. The flange temperature did not exceed 43 deg C under any test condition. The rule of thumb that my friends at ST use is to add +100 deg C to the flange temperature. So the die temperature is only +143 deg C which is very conservative.

I found the Harris heatsink design interesting. Harris took several plates of 0.100" aluminum, riveted them together, and machined the top surface. I'm sure this is much more expensive than an extruded aluminum heatsink but there is a thermal advantage. Heat exits a power device straight down in a 45 degree cone into the heatsink. Most extruded heatsinks have wide fin spacing so the fin under the device gets very hot while the other fins become ineffective heat radiators. The device package is 0.5" wide so at least 3 fins are illuminated by the heat cone in the Harris design. The fins run parallel to the devices so there is not more than 1 heat source on any single fin.



1/4 Module Test Setup



Harris Stacked Aluminum Heatsink

CW testing:
A single ¼ module from the channel 2 TV transmitter was tested under CW conditions. I tested the amp over the design bandwidth (54-60 MHz) to establish a benchmark and then recorded data at 50 MHz. I applied +50 VDC to the single terminal block at the center of the board, (thick red wire) and ground to the device clamp. (thick blue wire) The thermocouple (thin brown wire) was placed under the clamp between the devices and the gate bias (+15 VDC) was connected to pin 1 of J1. (thin red wire).

1/4 Module
Under Test .

Pout @ 3 dB
Compression
= 390 Watts

freq = 50 MHz

Pin W	Prev W	Pout W	Ids Amp	Vds volt	Flange degC	Rtn dB	Gain dB	Eff %	Pdiss W/dev	2nd -dBc	3rd -dBc
0.48	0.017	50	4.22	48.4	38.2	-14.6	20.2	24.5	38.6	-44.0	-33.0
1.06	0.039	100	5.87	48.3	40.8	-14.3	19.7	35.3	45.9	-40.0	-29.0
2.24	0.095	200	8.10	48.1	43.0	-13.7	19.5	51.3	47.4	-32.0	-25.0
4.20	0.197	300	10.12	48.0	41.8	-13.3	18.5	61.8	46.4	-31.0	-21.0
8.00	0.390	390	11.70	48.1	40.6	-13.1	16.9	69.3	43.2	-29.0	-18.0

freq = 54 MHz

Pin W	Prev W	Pout W	Ids Amp	Vds volt	Flange degC	Rtn dB	Gain dB	Eff %	Pdiss W/dev	2nd -dBc	3rd -dBc
0.56	0.050	50	4.18	48.1	37.0	-10.5	19.5	24.9	37.8	-40.0	-31.0
1.24	0.115	100	5.77	48.0	38.6	-10.3	19.1	36.1	44.2	-44.0	-29.0
2.60	0.250	200	8.00	48.1	41.2	-10.2	18.9	52.0	46.2	-35.0	-24.0
4.60	0.440	300	9.75	48.0	40.2	-10.2	18.1	64.1	42.0	-34.0	-21.0

freq = 60 MHz

Pin W	Prev W	Pout W	Ids Amp	Vds volt	Flange degC	Rtn dB	Gain dB	Eff %	Pdiss W/dev	2nd -dBc	3rd -dBc
0.66	0.102	50	3.96	48.4	36.6	-8.1	18.8	26.1	35.4	-39.0	-34.0
1.45	0.225	100	5.46	48.3	39.4	-8.1	18.4	37.9	40.9	-37.0	-30.0
2.95	0.450	200	7.47	48.2	39.4	-8.2	18.3	55.5	40.0	-36.0	-27.0
4.70	0.730	300	9.04	48.1	37.6	-8.1	18.1	69.0	33.7	-36.0	-24.0

Return Loss:
The return loss was poor (-8 dB) at 60 MHz. This caused RF to get into the thermocouple giving erratic temperature readings. There is a fixed power attenuator (AT1) at the input of each quarter module. This pad varies from -2.75 to -3.25 dB on the 4 quarter modules in the transmitter plugin that I have. Each ¼ module must be adjusted at the factory to meet a gain and phase window so the modules can be efficiently combined. In general the output of an amplifier is tuned for efficiency and linearity and the input is tuned for return loss and gain. Phase tuning is accomplished by tweaking the input for the required phase angle at the expense of input return loss. The fixed attenuator improves the input return loss and can be used to tweak the amplitude with no further change in phase. The good news is that the return loss looks good (-14 dB) at 50 MHz so no tuning or tweaking is necessary.

Power Output:
The module was first tested at the Harris Pout specification of 275 Watts for 4 devices. At 50 MHz and 300 Watts the efficiency was still increasing and the power dissipation per device (45 Watts) was well below the Phillips spec of 150 Watts out so I felt comfortable increasing the drive. The amplifier is about 3 dB into compression at 400 Watts out which agrees with the data the Maryland group published and the Phillips Gain vs. Frequency data (on4402h Pout = 100 Watts/device).

Harmonics:
The combined amplifier will require a high power, low loss, low pass filter if it is to be used at 1500 Watts out. The 2nd harmonic is suppressed (-30 dBc) due to the push pull configuration. (Splitting and combining at 180deg suppresses even harmonics). The circuit does not provide any suppression for the 3rd harmonic. The 3rd harmonic of a single module is only -18 dBc at 400 Watts out so 1500 Watts - 18 dB = 25 Watts out at 150 MHz.

2-tone testing:
The test setup was reconfigured to measure linearity or 2-tone (PEP) performance. A 2-tone test is equivalent to operating an amplifier at 50% duty cycle. The power dissipation of the active RF devices and transformers is half. The drain current is also half.

freq 1 50.05 MHz
freq 2 50.15 MHz

Two Tone Test Results

Pin W	Pout W	Ids	Vds	Flange	Gain	Eff (pk)	3rd order	5th order	7th order
Pk	Pk	Amp	Volt	degC	dB	%	-dBc	-dBc	-dBc
1.02	98.0	4.12	48.4	34.4	19.8	24.6	-40.0	-45.0	-60.0
2.20	200.0	5.60	48.3	39.8	19.6	37.0	-35.0	-48.0	-50.0
3.70	310.0	6.76	48.2	40.8	19.2	47.6	-28.0	-42.0	-47.0
5.64	410.0	7.87	48.1	42.8	18.6	54.2	-22.0	-39.0	-46.0

Conclusion on Two tone testing:
The Phillips devices are very linear. The commercial standard for 3rd order IMD products is -30 dBc. At 300 Watts peak the 3rd order IMD is -28 dBc. The ham standard for 3rd order intermod products is -20 dBc so this amplifier will sound great on SSB at 400 Watts peak for a single ¼ module.

1500 Watt testing:
Next month I will discuss the RF performance of 4 combined ¼ modules and show what mechanical and electrical modifications are needed to integrate this amplifier into your 6 meter system.

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Converting a Commercial TV Transmitter's Driver Amp for Ham Use --Part 2

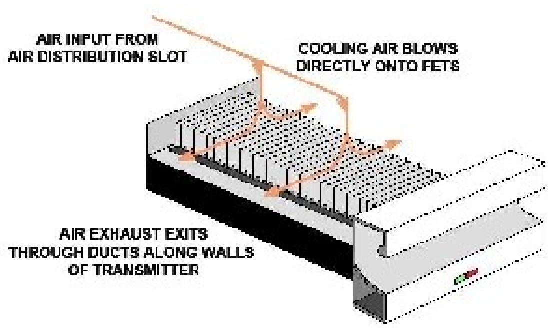
By John Sortor, KB3XG

Introduction:
Last month we discussed the performance of a single module to get an idea how much power we might expect out of 4 combined modules. Based on the single module data we should be able to see full legal limit power on 6 meters but first there is some mechanical work that must be done before testing the amplifier with RF.

Plug-In Module Circuit description
A single Harris plug-in module consists of four ¼ modules each conservatively rated at an output power of 275 Watts for a specified combined output power of 1000 Watts. The ¼ modules are split and combined using a network of 3 printed Wilkinson 2-way combiners. A high power output coupler provides protection against excessive reflected power. A high current FET switch also provides protection against over voltage, over drive, and high VSWR. A control circuit board determines if the amplifier operating conditions are safe based on all of the alarm outputs and status inputs .

Cooling:
Removing heat from high power semiconductor devices is always a technical challenge when designing a power amplifier. As power densities increase more exotic methods of cooling must be employed. I had to decide on a cooling method before recording any high power data.

Impingement Cooling:
I found a diagram from Harris that shows how the air passes from the distribution plenum through the heat sink fins. Another amateur channel 2 conversion article (sorry I do not know the source) shows a series of fans on top of the heat sink fins. (Impingement or jet cooling) This cooling method is commonly used on computer CPU's with a pin fin heat sink. The pin fins allow the air to flow in all directions. I did not see any thermal data attached to the photograph but it appears that the hub of the fan blades is blocking airflow to the 2 inside devices. Heat flows directly out of the device in a 45 degree cone into the heat sink. Lateral heat flow in a heat sink is highly inefficient. I do not have any thermal analysis tools to



Harris Airflow Diagram

Impingement / Jet Cooling

arrive at a calculated temperature, and impingement cooling may work well for this application, but the thermal data should be recorded on all devices to ensure a flat thermal profile across the heat sink.

Plenum / Forced Air Convection Cooling:

I decided to take the conservative approach and build an air plenum to cool the four ¼ modules. This cooling method was a little more work but it allows for an even laminar air flow through all of the heat sink fins. The fans were oriented to produce a negative pressure inside the plenum. I do not have the software to analyze the difference between negative and positive pressure but in general it is best to minimize the turbulence. I wanted to mount the unit in a 19” rack. I limited the width of the amplifier and plenum to 15” to give at least 2” on either side for intake and exhaust air. The fans blades are not designed like an airfoil so there is a large amount of “prop wash” introduced. There is also an abrupt angle on one side of the air plenum. Under positive pressure this creates unwanted turbulence before the air enters the heat sink. With negative pressure the heat sink fins come in contact with smooth air first. Turbulence on the exhaust side of the plenum is not a concern. I have seen this negative vs. positive pressure temperature difference in practice while testing extremely high power amplifiers at work. A negative aspect of negative pressure is dust and dirt accumulation.

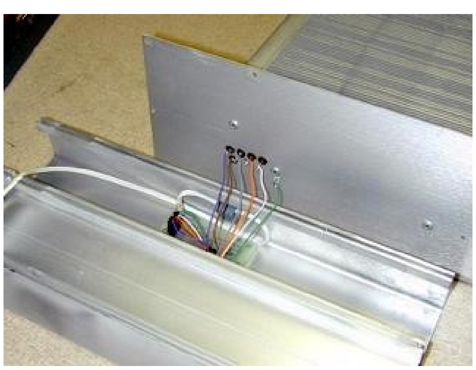
The plenum also cools the ¼ module components. There are 3 evenly spaced holes on either side of each ¼ module. The photograph shows the holes passing through the power combiner PC board. With no airflow the temperature of the ¼ module ferrite transformer cores exceeds +60degC after 10 minutes of full power CW operation. With the bottom cover in place the airflow through the cooling holes drops the core temperature to +40degC.

Completed Air Plenum

1/4 Module Component Cooling Holes

Front Panel Modifications:

The front panel was removed from the unit so the air plenum could be installed. The front panel has an interlock switch (2 white wires) to allow hot swapping of modules. When you grab the front panel handle the interlock switch closes which shuts down the amplifier. For ham use, the 2 white wires can be removed and the interlock switch discarded. The front panel also contains a small PC board with 2 LED’s. The LED’s provide operation status and error indication through a series of Fault Blink Codes . (More details on this later.) Document the wire colors and location and unsolder the wires. Use a drill to remove the pop rivets that hold the sub panel to the heat sink assembly.



Front panel & subpanel removal

Front Panel LED Blink Code Wires

Rear Panel Modifications:

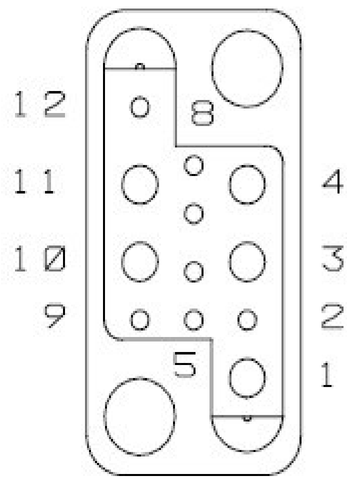
Cut the RF and DC wires leading into the black rear panel connector and remove the connector. Use 2 soldering irons to remove the ATC “B” size tuning cap at the output RF connector. Note the capacitor value in case the capacitor is damaged. The value of the cap in the unit I have is 2.4 pF. Remove the heavy duty buss wire between the connector center pin and the output coupler. Remove the quick disconnect output RF connector using a pair of needle nose pliers. Be careful not to damage the large solder tab soldered directly to the coupler board.

Original rear panel DC and RF input connector

Original RF output conn., tuning cap and coupler

Pin	Function	description
#1	RF input	RG-316 cable
#2	N/C	
#3	+50 VDC	red Teflon wire
#4	+50 VDC	red Teflon wire
#5	fault output	white Teflon wire
#6	enable/reset	purple wire (PTT)
#7	N/C	
#8	N/C	
#9	N/C	
#10	DC ground	black Teflon wire
#11	DC ground	black Teflon wire
#12	N/C	

DC / RF input connector (J2) signals



Front view of J2

<<< Special note on pin 5: If a fault in any of the four ¼ modules is detected, the white wire (Pin 5) is grounded through Q6. It is not necessary to use this error signal.

The hole in the rear panel for the original quick disconnect RF output connector is the perfect size for a standard “N” connector flange (the kind with 0.75” hole spacing). I drilled and tapped the top 2 holes for #4-40 screws since the output directional coupler leaves no room for nuts. On the bottom, I drilled through holes for the other 2 screws so I could use over sized washers to clamp the original ground solder tab. Once this was done I could re-install the buss wire between the new “N” connector and coupler. Be sure to re-install the ATC cap at the “N” connector pin.

New RF output connector on chassis

New RF output connector inside view. Note only 2 nuts used.

Note on FET Switch:
The FET switch is a pair of 60 Amp 100 volt switching power supply FET's mounted to a heavy duty buss bar located on the inside of the rear panel. This switch circuit is capable of passing the full load current (>40 Amps) of the +50 volt power supply. Turn on and turn off time is in the 100 nSec range which hopefully will prevent damage to the amplifier if an error or fault is detected. The FET switch is cycled every time you press the PTT switch. If a fault occurs it is reset by opening the PTT wire (opening the FET); thus removing the +50 volts for several seconds. This allows the storage caps on the control board to discharge.

FET DC Switch and Buss Bar

Rear Panel mods continued:
There is an unused 3/8" hole situated between the old DC connector and the FET switch which is the same diameter as a standard BNC connector. I soldered the center conductor of the RG-316 RF input cable directly to the new BNC connector and used a 3/8" solder tab to provide strain relief for the cable. This is now the amplifier input connector.

Replace the original black connector with a heavy duty Cinch-Jones type terminal block. Keep in mind that this connection will be carrying 40+ Amps at 50 volts. I removed the screws from one side of the terminal block and cut a piece of copper strap to further insure a good electrical connection. I fed the heavy duty black and red Teflon wires up through the back of the terminal block and soldered the wires directly to the copper strap. I soldered the PTT wires to the top 2 terminals.

RF input connector & Cinch Jones terminal block modified for heavy DC input

Internal wiring of Jones strip and new RF input connector

As a side note you may notice that the purple PTT wire which is bundled to other wires is covered in white heat shrink. All of my transverters have a sequenced +12 volt output to apply bias to my homebrew power amplifiers for the PTT function. The heat shrink contains a simple 2N2222 transistor switch which inverts the logic (just a transistor and base current limiting resistor) . If your system uses ground for PTT, connect the purple wire to the terminal block directly.

Control Board:
The control board is located near the rear of the unit under a shielded cover between the FET switch and the 1st quarter module.

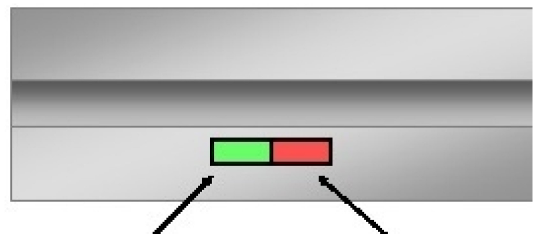
The control board monitors : 1) Temperature of each ¼ module, 2) Balance output power from each push pull pair, 3) Input DC voltage level, 4) Level of reflected power. (VSWR) and 5) Input RF power level

The control board controls: 1) the FET switch (amplifier shut down), 2) PTT command, 3) RF transistor bias sequencing, 4) LED fault blink codes

The control board contains relatively simple logic but it is implemented with 3 PAL's (Programmable Array Logic chips, U1, U2, U3) The control board is great if everything is working but if one of the PAL's is defective I'm not certain how to find a replacement. If there is a problem with the control board you can bypass the FET switch and all of the control and safety features and key the +15 volt bias line with your PTT line. Note: I had a self inflicted problem with the control board in my unit. There is a screw behind the 1 kOhm 1 Watt resistor (R39) in the upper left side of the control board (see picture). I used a screw that was a little too long when installing the plenum. The screw severed a trace on the board feeding 50 volts to the bias regulator (U10) and the control board would not allow the FET switch to turn on. The board was repaired with a short length of wire wrap wire.

A complete schematic of the control board is available from the author or from the editor. In addition, we hope to have the schematics available for download from the Packrat web site soon after this issue of Cheese Bits is delivered.

Control board, showing 3 PALs (center) and problem resistor R39 (upper left)



Power / RF input LED

Fault LED

STATUS and Fault LED's

Fault and Status LED's and their blink codes:

Here are the statuses and faults indicated by the LEDs with additional explanation of their meaning.

Status /Fault	Indicated by
Reflected Power Fault (VSWR)	1 Blink
Input Overdrive (>3 dB)	2 Blink
FET Amplifier Imbalance (ISO)	3 Blink
+50 VDC Over / Under Voltage	4 Blink
Over Temperature Fault	5 Blink
FET Switch Failure	6 Blink
No LED's illuminated	+50 Volts not reaching the modules
Steady red LED	+50 Volts is applied but module is not enabled
Dim Green LED	Module is enabled but there is no, or little rf drive
Full green LED	Normal operation

- Reflected Power Fault (VSWR):

There is a directional coupler connected directly to the RF output connector. The forward port is unused and is terminated with a 50 Ohm resistor. The reverse port uses a detector diode to measure the amplitude of the reflected power. With this configuration it is not possible to measure or calculate VSWR. But if the reflected power exceeds a predetermined level the control board will shut the unit down by turning the FET switch off. This fault level must be adjusted if operation at 1500 Watts is desired.

- Input Overdrive (>3 dB):

There is a printed coupler and detector diode at the sum port of the input splitter which is used to measure input power. If the input power exceeds the predetermined level, the control board will not allow the dc power FET switch to turn on. If the input power exceeds the predetermined level during operation the control board will turn the dc power FET switch off. This fault limit must be adjusted if operation at 1500 Watts is desired.

- FET Amplifier Imbalance (ISO):

There is a balance transformer on each ¼ module. (See photograph of RF balance transformer from last month's article.) During operation if the power output of one of the two push pull pairs decreases, the control board will turn the dc power FET switch off. For normal operation the output voltage of the balance transformer (Pin 2 of J1 on each ¼ module) should be +0.3 volts or less. The module will trip off between 1.7 and 2.1 volts .

- +50 VDC Over / Under Voltage:

If the input power supply voltage is not within the correct operating window (approximately 44 to 54 volts) the control board will not allow the dc power FET switch to turn on. If a voltage transient occurs during operation the control board will turn the dc power FET switch off.

- Over Temperature Fault:

During operation if the temperature of any of the four ¼ modules exceeds a predetermined limit the control board will turn the dc power FET switch off. The temperature sensor on each ¼ module is factory adjusted for 5.3 volts when the heat sink temperature is +25degC. A fault will occur if the temperature exceeds +80degC.

Conclusion:

I promised last month that I would discuss the performance of 4 combined modules. I have presented this information instead. High power testing will be discussed next month.

Based on the fact that the active devices are no longer available I felt it was important for you to understand how the amplifier works before applying power. In addition, next month I hope to have the settings for adjusting the reflected power fault trip point, and the input overdrive trip point for 1500 watt operation. --xg

Converting a Commercial TV Transmitter's Driver Amp for Ham Use -- Part 3

By John Sortor, KB3XG

Introduction :

I hope everyone has not been bored by technical details in the past 2 installments. This month we will cut to the chase and discuss how to bring the channel 2 / 6 meter power amplifier to life.

Preliminary Testing

Disconnect the 3 pin bias connectors on all 4 of the ¼ modules. (See photograph of gate bias/alarm connector from part 1) The entire unit can be checked functionally without turning on the bias to the devices. Connect a 50 volt power supply to the terminal block. It is recommended that a low power supply (<3 Amps) be used initially. If there is a problem with the amplifier the power supply will current limit and prevent damage. It is not necessary to terminate the amplifier during this phase of the testing. Reconnect the front panel LED board to the unit.

Over / Under Voltage :

Turn the 48 volt power supply on. Measure the drain voltage on any of the devices. Measure the gain bias voltage on one of the connectors. (Pin 1 of J1, red wire) Both voltages should be zero. Ground the thin purple wire from the rear panel connector. The voltage on the drains should now be +48 volts and the voltage at P1 of J1 should be +15 volts. While monitoring the drain voltage slowly decrease the power supply voltage. At approximately +44 volts the FET switch should shut the unit down and the drain voltage will drop to zero volts. Check the front panel LED board. It should indicate an over/under voltage error (blink code #4). Reset the unit by removing the purple PTT wire from ground and turning the power supply off for several seconds. Adjust the power supply for +48 volts. Turn the supply on, ground the PTT wire, and slowly increase the power supply voltage. At approximately +52 volts the unit will shut down.

Bias Current :

Use an ammeter to measure the 48 volt supply current. The power supply must have a current rating of >3 Amps. Turn the cooling fans on. Plug the gate bias connector into 1 of the 4 modules. Turn the 48 volt supply on. Ground the purple enable wire (PTT). You should measure 48 volts on the drain at about 1.5 to 2.5 Amps or 0.4 to 0.6 Amps per device. Open the enable (PTT) wire, connect the bias connector to the next module, and repeat the bias current test one module at a time.

One of the 1/4 modules in my plug-in unit had high bias current. (4.9 Amps or 1.2 Amps per device) I pinched 1 device off by connecting a 1 KOhm resistor between the gate and ground and the total current decreased by 1.2 Amps. I repeated this test for the other 4 devices. All 4 devices were drawing equal current. The 4 bias pots showed no sign of tampering and still had the drop of Loctite holding the pot in position. Maybe the factory adjusted this module for high bias current for a gain or phase adjustment. With no RF the flange temperature was more than 30 degrees hotter (+57degC vs +36degC) on the module with the high bias. At full RF power the difference in temperature was only 15 degrees C.

Note: This is another reason to treat your channel 2 amplifier with a little TLC. Some poor Harris technician spent considerable time tuning each 1/4 module for a predetermined gain and phase with an expensive array of calibrated test equipment. If you lose a device or worse yet an entire 1/4 module it will be necessary to measure each 1/4 module individually to make sure they all have the same gain and phase. Otherwise the modules will not combine efficiently.

Low Power Testing :
Configure the test setup with the appropriate attenuators and couplers so it is possible to measure the input and output power. Based on the single 1/4 module test data, the expected gain from the four combined 1/4 modules should be in the 20 dB range. Start by driving the amplifier with 1.0 Watt. You should measure 100 Watts out. If you do not see 20 dB of gain something is wrong. Shut the unit down and consider testing each individual module before proceeding.

High Power Testing :
Slowly increase the power and compare your results to the data in table #1. Periodically release the PTT line and check to make sure everything is running cool. (transistors, ferrite cores, power resistors) I found the efficiency continued to increase as the power was increased beyond 1000 Watts. The amplifier was 3 dB into compression at 1500 Watts out. There are a total of 16 devices rated at 100 Watts each so I did not feel comfortable driving the amplifier above 1500 Watts.

Pin (W)	PRev (W)	Pout (W)	Ids (A)	Vds (V)	Flange1 (deg C)	Rho (RL) dB	Gain dB	Eff %	2nd - dBc	3rd - dBc
2.1	0.047	222	19.0	49.3	36.6	-16.5	20.3	23.7	-31.8	-52.8
3.1	0.072	320	21.3	49.2	38.4	-16.4	20.1	30.5	-30.8	-50.8
5.2	0.122	509	25.8	49.1	41.2	-16.3	19.9	40.2	-30.8	-47.8
7.3	0.172	686	29.7	49.0	44.6	-16.3	19.7	47.1	-29.8	-45.8
10.4	0.238	914	34.2	48.9	45.0	-16.4	19.4	54.7	-29.8	-43.8
13.0	0.354	1091	37.5	48.8	45.2	-15.7	19.2	59.6	-29.8	-41.8
15.6	0.396	1205	39.3	48.7	46.0	-16.0	18.9	63.0	-29.8	-40.8
20.8	0.489	1371	42.4	48.7	46.4	-16.3	18.2	66.4	-28.8	-38.8
26.0	0.635	1496	44.6	48.6	46.6	-16.1	17.6	69.0	-28.8	-37.8

Table 1 Test Conditions

A. CW Data.

B. No low pass filter.

C. Test freq = 50.1 MHz.

D. Idq = 10.5A

Four combined 1/4 modules

Overdrive:

Control Board VSWR & Overdrive Adjustment Pots

A description of the input overdrive coupler and detector was included in part 2. The amplifier may shut down as the drive is increased for output beyond 1000 Watts. If this occurs refer to the front panel blink codes. Blink code #2 indicates that the input power has been exceeded. Reset the amplifier by releasing the PTT switch and turning the 48 volt power supply off for several seconds. Use a tweak stick to rotate the overdrive pot clockwise. I only had to turn the pot 1/4 turn for 1500 Watts out. Turn the amplifier on and resume the testing to verify that the input overdrive detector is set for 25 to 30 Watts.

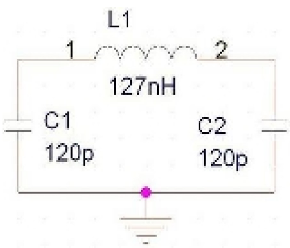
Reflected Power (VSWR):
A description of the output coupler and VSWR detector was included in part 2. This circuit only measures reflected power. As you increase the output power beyond 1000 Watts the amplifier may shut down (blink code #1) even though you have terminated the amplifier with 50 Ohms. My amplifier did not shut down when I had it connected to a 50 Ohm load but it did shut down when I connected it to my antenna. Before proceeding I checked the return loss of my antenna which was <-20 dB. Reset the amplifier and use a tweak stick to rotate the VSWR pot clockwise. I had to turn the pot 1 turn clockwise for 1500 Watts out into my antenna system. Turn the amplifier on and resume the testing to verify that the VSWR detector is set to work with your antenna.

Note: The best way to set the VSWR and Overdrive pots is to make adjustments while the unit is operating. Turn the pots clockwise so the unit does not trip off at full CW power. Slowly turn each pot counter clockwise until the unit trips off then turn the pot an 1/8 turn or so clockwise to give some margin.

The VSWR detector is designed to prevent damage to the amplifier. If your antenna does not have a good match and you rotate the VSWR pot so the amplifier does not trip off, you may cause device failures due to high reflected power. Your antenna may have a good match in the summer but you want the amplifier to trip off in the winter if your antenna is iced up. Do not re-adjust the pots to operate into the poor antenna match. Reset the amplifier and operate at reduced power .

Low Pass Filter:
The need for a low loss, high power, low pass filter was mentioned in part 1 of this article. The data in table #1 shows that the 2nd harmonic is only -29 dBc at 1500 Watts out, which is insufficient. Low loss is the most important factor to consider when working with high power RF. Most hams do not have the capability to measure output power with 0.25 dB accuracy. Consider this example: 1500 Watts – 0.25 dB = 1416 Watts out. i.e.: The filter will dissipate 84 Watts of heat. In general the number of elements you add to a filter is proportional to the loss. I used a linear analysis program to optimize the stop band of a 3 element low pass filter at 150 MHz. This is shown on the next page.

I used UT-141 silver plated semi rigid coax as my series inductor material and ATC "E" size porcelain caps as my shunt C elements. The inductor is suspended in air in a home brew box made of FR-4 material so as not to introduce any unwanted stray shunt capacitance. The low power test results show that the through loss of the filter is -0.05 dB but consider the dissipated power. 1500 Watts – 0.05 dB = 1483 Watts out. I.e.: The filter will dissipate 17 Watts of heat. The dominant loss element in the filter is the inductor. At 1500 Watts the inductor gets hot enough to remove skin from your finger. I had to vent the box and add a small fan to keep the inductor cool. Cooling high power filters is a common practice in the high power RF business. A high power amplifier company that I work for uses air conditioning tubing to wind inductors and runs water through the coils using fish tank hose.



High power low pass filter . Inductor is formed by 3 turns of UT141 coax, .72” dia, spaced as shown

Freq	s11	s21	s12	s22
50	-25.0	-0.02	-0.07	-28.0
100	-1.0	-23.0	-23.0	-1.0
150	-1.0	-38.0	-38.0	-1.0

Table 2: Low Pass Filter Data

High Power Testing / Low Pass Filter :

The amplifier was re-tested with the low pass filter inline. The FCC spurious emissions rule for amateur equipment is -40 dBc so the filter provides 8 dB of margin at full power. (1500 Watts – 48 dB = 24 mWatts @ 100 MHz)

Pin (W)	Prev (W)	Pout (W)	Ids (A)	Vds (V)	Flange3 (degC)	Rho (RL) dB	Gain dB	Eff %	2nd - dBc	3rd - dBc
2.1	0.036	218.1	19.0	47.6	55.6	-17.6	20.2	24.1	-52.8	-63.8
5.2	0.104	502.7	25.0	47.5	60.2	-17.0	19.8	42.3	-51.8	-63.8
10.4	0.229	903.6	33.2	47.4	57.8	-16.6	19.4	57.4	-49.8	-64.8
13.0	0.302	1090.6	36.9	47.4	57.8	-16.3	19.2	62.4	-49.8	-64.8
15.6	0.396	1194.4	38.3	47.3	59.4	-16.0	18.8	65.9	-48.8	-63.8
20.8	0.698	1319.1	40.9	47.3	60.1	-14.7	18.0	68.2	-48.8	-62.8
26.0	1.047	1474.9	43.7	47.3	61.2	-14.0	17.5	71.4	-47.8	-59.8

Table 3 Test Conditions: a) CW, b) With Lowpass filter, c) Freq = 50.1 MHz, d) Idq = 10.5A

High Power Testing / Two Tone :

The test equipment was reconfigured to measure 2-tone performance. An output power close to 2KW was measured. In this case I felt comfortable testing the amplifier beyond 1.5 kW since it was only 1.5 dB into compression and as mentioned in part 1, the average power each device must produce is half. At 2 KW out the 3rd order intermod products were only -17 dBc. This will make your SSB signal sound distorted. Operating at 1500 Watts with -22 dBc 3rd orders will give you “studio quality” audio.

Pin W(pk)	Pout W(pk)	Ids A (avg)	Vds volt	Flange3 degC	gain dB	3rd -dBc	5th -dBc
2.5	249.3	15.3	47.7	59.2	20.0	-32	-48
5.2	498.6	18.7	47.6	59.4	19.8	-30	-42
10.6	1038.7	24.4	47.5	60.0	19.9	-29	-40
13.3	1246.4	26.5	47.5	60.2	19.7	-27	-42
18.7	1537.2	29.5	47.4	61.0	19.1	-22	-45
24.2	1786.5	31.8	47.4	60.8	18.7	-19	-45
29.2	1994.2	33.7	47.4	60.8	18.4	-17	-37

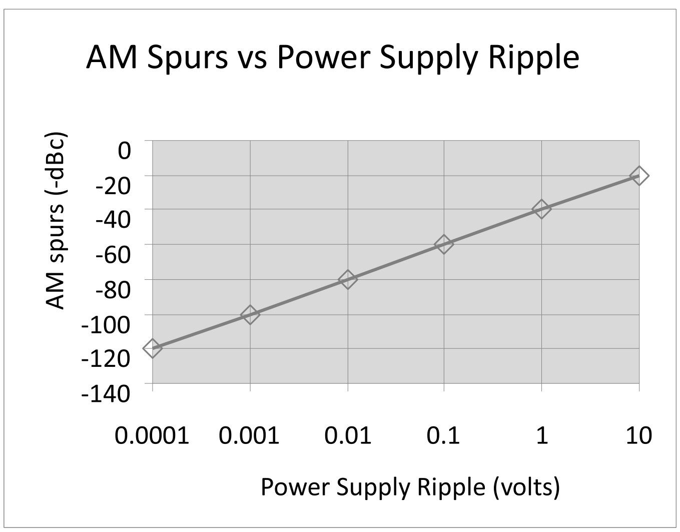
Table 4 (Two Tone) Test Conditions: a) Freq 1 = 50.05 MHz, b) Freq 2 = 50.15 MHz

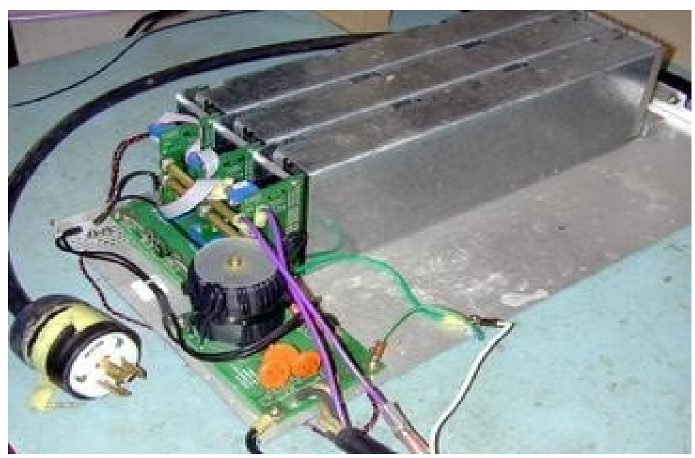
Power Supply:
I originally wanted to use 4 large gel cell batteries in series to provide pure DC to the amplifier. I thought this would be the cheapest way to get 48 volts at >70 Amps. I connected a 48 volt 5 Amp linear power supply to keep the batteries charged during the receive periods. The problem is that 4 batteries in series under a trickle charge have an output voltage of 56 volts and 3 batteries gives 42 volts. The over/under voltage alarm will not allow the amplifier to turn on unless the supply voltage is between 42 and 56 volts. I guess I need to look for a large 6 volt gel cell to fill in the gap.

For the January contest I used three 40 Amp switching power supplies slaved together. I use this +48 volt 120 Amp supply at home to test high power amplifier modules. I looked at the output voltage with an oscilloscope and measured <100 mVolts ripple with the amplifier at full RF power. I also looked for sidebands close to the carrier with a spectrum analyzer and did not see any AM spurs caused by the power supply. I have seen several surplus +48 volt switching power supplies that were originally designed for the telecommunications industry. Take the time to measure the ripple of your supply before you put it on the air. The closer you are to the maximum output of the power supply the higher the ripple. If you measure close to 1 volt of ripple at full RF power out your should consider designing a resonant filter to attenuate the switcher noise. The large switching power supplies operate in the low to mid kHz range so your power supply ripple may cause unwanted interference to other hams on 6 meters.

Use the following equation to calculate the amplitude of the AM spurs that are caused by the power supply ripple voltage.

-dBc spurs = 20 x log (%m /2) where %m (modulation index) = power supply ripple/output voltage.



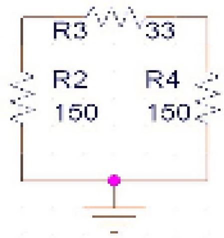


48 Volt 120 Amp Power Supply

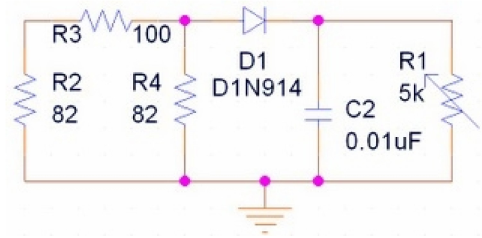
Directional Coupler:
I mentioned in part 2 that there is a dual directional coupler at the back end of the chassis connected directly to the output RF connector. Only the reverse port has been populated with components for the reflected power (VSWR) alarm. The forward port of the coupler is available as a power measurement point. I disconnected the amplifier from the coupler to tabulate the performance. This is an electrically short stripline design which has an increasing coupling factor as frequency increases but offers high power capability and excellent directivity in a small space.

Freq MHz	S11 dB	thru dB	coup dB	rev dB	iso dB
40.0	-38.0	-0.050	-36.20	-57.20	21.00
50.0	-39.0	-0.050	-34.30	-55.20	20.90
60.0	-38.0	-0.038	-32.75	-53.20	20.45

Table 5: Directional Coupler Data



-5.7 dB Pad



-13 dB Pad / Detector

Dual directional coupler

There are three approaches you can take to utilize the forward port of the coupler. 1) Remove the termination resistor (R2) from the coupler board, solder a coax cable directly to the coupler, and install a 2nd BNC connector to the rear panel. It will be difficult to gauge how much power you are putting out since the coupled value at 6 meters is an oddball number. (1500 Watts – 34.3 dB = 0.56 Watts) 2) Install a 5.7 dB pad using the existing connections on the PC board. (1500 Watts – 34.3 dB -5.7 dB = 150 mWatts). (Use 0.5 Watt resistors) 3) Populate the coupler board with a -13 dB pad and detector diode. Use the detected output signal to drive a meter movement. Install a pot to either the coupler board or the meter to calibrate the meter for 1500 Watts. I have future plans to add a font panel and a rail to the bottom plate so the amplifier can be installed in a standard 19" relay rack. The front panel will include a power meter and the LED board.

Conclusion:
I used this amplifier in my 6 meter system for the 2010 January contest and received many good comments about the quality of the signal. The broadcast industry adheres to high linearity specifications to meet the FCC rules on spectral purity. The broadcast customers demand conservative designs for a long trouble free service life. I don't have any of the price breakdowns but based on the cost of (16) 100 Watt power transistors I would guess that the cost of each of these 1 KW plug-in modules is >$8,000. We are very fortunate to be able to integrate this type of commercial quality equipment in our home ham stations. 73xg

NOTES:
1.Equipment used to measure the amplifier: HP8765A 3-1300 MHz network analyzer, HP141T spectrum analyzer with 8555A plug in, HP435 power meters with 8481A power heads, HP8640B 0.5-500 MHz signal generator, HP608 10-480 MHz signal generator for 2-tone tests, Mini Circuits ZFSC-2-1 power splitter for 2-tone tests, Textronix TDS220 oscilloscope, Narda 3020A 50-1000 MHz high power coupler, Bird 8895-300 2500 Watt 50 Ohm load, homebrew 1-150 MHz 25 Watt driver amplifier, homebrew 100 Amp current shunt, homebrew 10-500 MHz dual directional coupler.

2. The American Technical Ceramics (ATC) size "E" chip caps for the low pass filter can be obtained from Amplitude Technical Sales, 279 S. Main St., Suite 2A, Doylestown, PA 18901