Solid State 1296 MHz Amplifier.

Using 8 x XRF286 devices to achieve 400W+

By: Charlie Kahwagi VK3NX

Preface:

I was searching for a legal limit (VK) amplifier for 23cm amateur band and the choices were to use solid state devices or a valve power amplifier. Many options exist for both methods. A number of commercial amplifiers are available for the 1296MHz band however their cost was found to be prohibitive for the power levels available. After much investigation it was decided to build a SSPA. Single devices delivering 100W + are available but many of these are not currently found on the surplus market. I stumbled across some designs utilizing the MRF286 device. These devices have been around for some time and whilst they were designed for commercial use in the 1-2.4 GHz range they see their main use at 2.3 GHz in "Base station" amplifiers. A number of amateurs have designed suitable input and output matching circuits to make use of them at 1296MHz. The MRF286 or XRF286 are capable of >10dB gain and >60 W at 1296MHz. These devices are available on the surplus market as "pulls" from "Spectrian" 2.3GHz amplifiers. Considering cost and availability it was decided to try to build an amplifier with these devices using 8 of them paralleled to deliver the VK legal limit of 400W.

The MRF286 is an N-Channel Enhancement –Mode Lateral MOSFET. The MRF286 and the XRF286 are electrically the same device and differ only by their mounting method. The MRF286 has a traditional flange that is screwed to a heatsink, whilst the XRF286 is flangeless and requires the base (Source) to be soldered to a heat spreader before mounting on a heatsink. Electrically both devices are identical.

The datasheet is available from several sources on the internet, but essentially the device will produce 60+ Watts at > 10dB gain. The device is in use (commercially) primarily at 2.3GHz, but it was found to behave similarly at 1296MHz with suitable input and output matching circuits.

Datasheet from Motorola at: http://www.motorola.com/semiconductors/
At 60W CW output with 26V on the Drain it will handle a 10:1 SWR.

In 2008 a search on the internet shows that several French amateurs and others have built amplifiers for 1296MHz using this device. These amplifiers used boards with 2 devices and input and output hybrid couplers etched on the same board to deliver >120W. These designs looked promising, however during an initial unsuccessful 1st attempt to build one of these boards I came across a project by the "Brisbane VHF Group" (BVHFG). Led by Doug (VK4OE) and Ron (VK4KDD), a board was prototyped and successfully built to produce a single device amplifier capable of >65 W. After much work, the BVHF group had these boards professionally fabricated and have made them available for experimenters. Rather then continue with optimizing the board I had constructed, I decided to acquire some of the BVHF groups' boards and attempt to build these up.

In this article I have tried to document my construction of:

1: A single XRF286 amplifier stage and

2: Combining multiple single stage amplifiers for high power output.

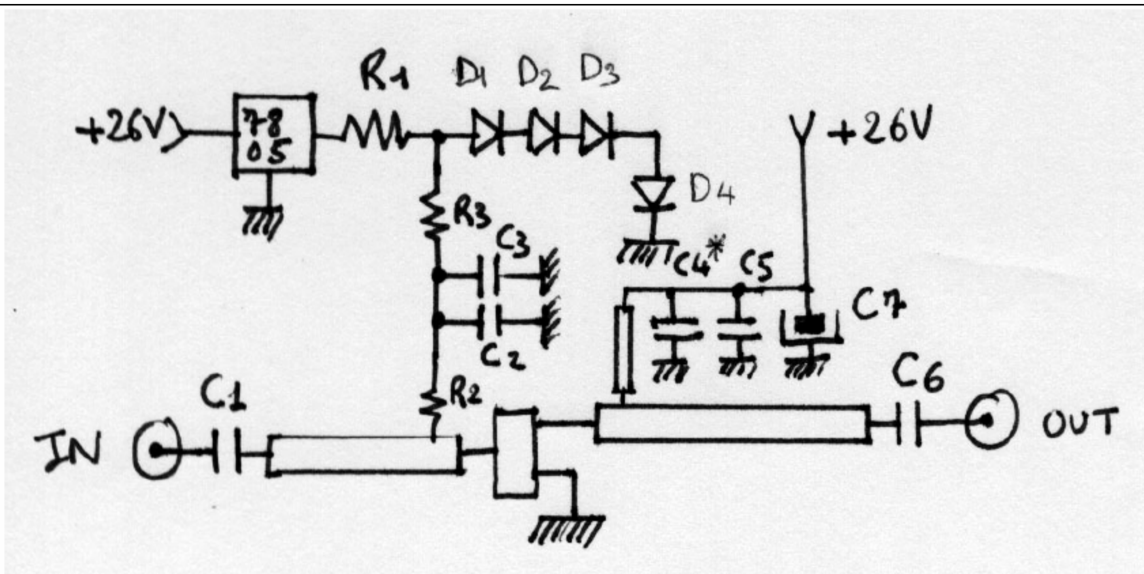
For anyone wishing to duplicate this amplifier please contact the Brisbane VHF group directly for the availability of boards. The XRF286 devices were acquired on the surplus market through "ebay".

Construction of a single stage XRF286 Amplifier using the BVHF group board.

The Brisbane VHF group modeled their input and output matching networks on those described in an article by F5EFD.

The amateur research on the use of the MRF286 on 1.3 GHz can be found at: http://f1chf.free.fr/MRF286/technique%20mrf286.htm

The schematic of the amplifier used in the development of the BVHF group boards' is as follows:



C1=2.2pF C2=C4=C6=22pF C3=C5=330pF C7=22uF/40V
R1= Between 220 and 1000 ohm adjusted for an ambient current of 300mA
R2=1.2K SMD R3=1.5K D1=D2=D3=Si diode D4= LED
C1 and C6 are ATC chip capacitors

Changes I made in my implementation:

I made some changes as such:

C3=C5=1000pF chip caps
R2=1000K chip res.
C7=100uF 50V

On the LM7805 regulator I used a 0.1uF monolithic capacitor on the input and the output. I also used a 10uF/25V electrolytic on the output and a 3.3uF /63V on the input.

For R1 I used a 500 ohm variable resistor trimpot.

When the boards arrived I was extremely impressed with their professional manufacture. They are double sided 0.8mm FR4 with plated through holes and silk screened. The board requires some preparation and there are some very important points to consider regarding their mounting:

Heat spreader: A 1mm thick brass plate is used as a heat spreader. The XRF286 device is soldered directly to it. The mounting holes for the board need to be drilled and the brass plate is "sandwiched" between the board and the heat sink in final assembly.

Heat Sink: A 200mm X 75mm heat sink is used for the cooling. (This was purchased from "Jaycar" electronics). The heat sink is drilled and tapped for 3mm screws to be used in attaching the board.

Connectors: Some PCB mount SMA connectors were purchased and these are soldered to the board for the RF connections. Direct connection with UT141 hardline is also possible and a substantial through-plated ground plane is provided for this.

ORDER OF CONSTRUCTION:

PREPERATION OF BOARD, BRASS PLATE, HEATSINK and MOSFET:

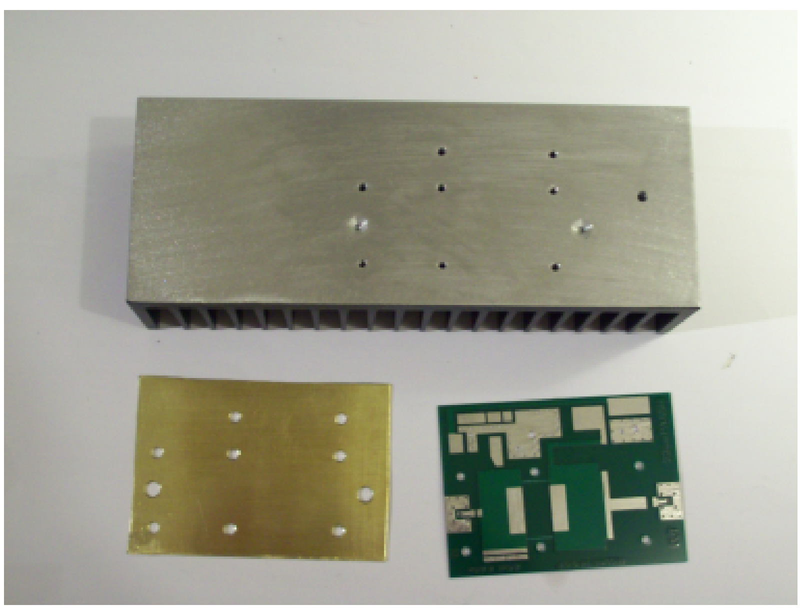
- Inspect the boards for errors (none were found!)
- Prepare the 1mm thick brass plate heat spreader. Drill all holes to align with the PCB mounting holes. Drill clearance holes to prevent shorting of the RF track at the SMA connector. De-Bur all holes.
- Prepare the heat sink by drilling and tapping for the mounting holes. The board is supplied for 2.5mm screws but I used 3mm.
- Cut out the MOSFET mounting hole in the PCB. Ensure no shorts from the input and output mounting pads, to the ground plane on the underside. It is important to make the hole larger so that when soldering the device, no solder flows up and shorts out the pads. But do not take away too much or it will not tune up correctly.
- Clean the brass plate thoroughly and affix the board to the brass plate with screws and nuts. Do not attach to the heat sink.
- Pre-tin the brass plate in the area of the transistor using a "flame" from the underside. Ensure a thin but even spread of solder.
- File flat the XRF286 flange and pre-tin.
- Heat the brass plate and position the device with firm downward pressure. When I did this the first time I was very hesitant about damaging the transistor. Remember to use a hot flame and work "quickly". No devices have so far been lost with this method.
- Allow the brass plate to cool slowly.
- Once it has cooled check for any shorts to ground. Solder can and does flow up to the input (gate) and output (drain) pads if there is excessive solder.
- Precut the SMA connectors so they sit very close to the board without shorting the RF tracks. A 1-2mm clearance is fine. Solder the connectors in place. The centre pin is soldered on the underside ensuring the pin doesn't extend past the 1mm brass plate. (To be sure of no shorts in the final assembly a hole of 5mm diam. was drilled into the heat sink in these areas.)
- Now remove the screws affixing the board to the brass plate and clean the underside of the brass plate.

- Place a small amount of heat transfer compound on the brass plate in the area around the MOSFET and screw the board and brass plate to the heat sink.

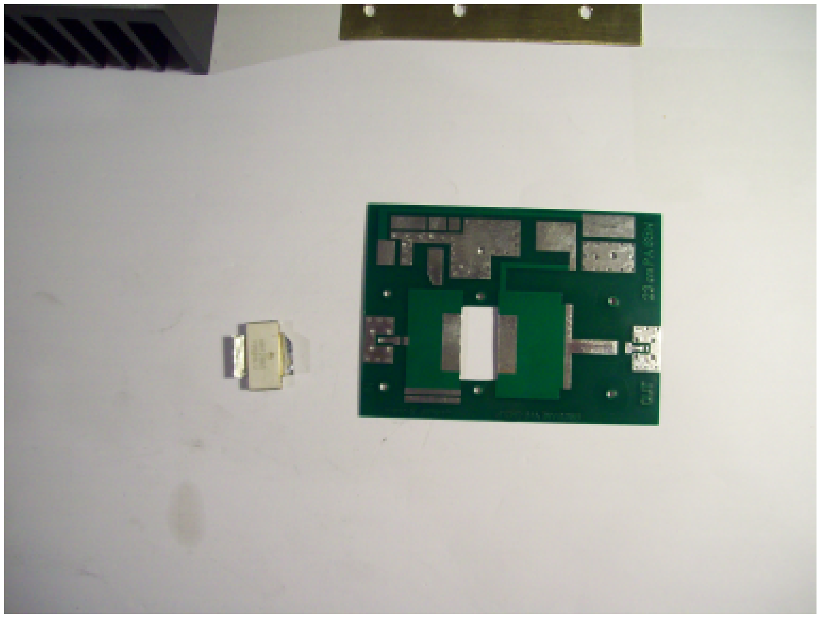
COMPONENT PLACEMENT:

Once the board is secured on to the heat sink the components can be placed. The assembly is now rigid enough that the SMD components can be placed without fear of fracture. There is no component overlay but by following the circuit diagram the placement of the minimal components used is quite intuitive

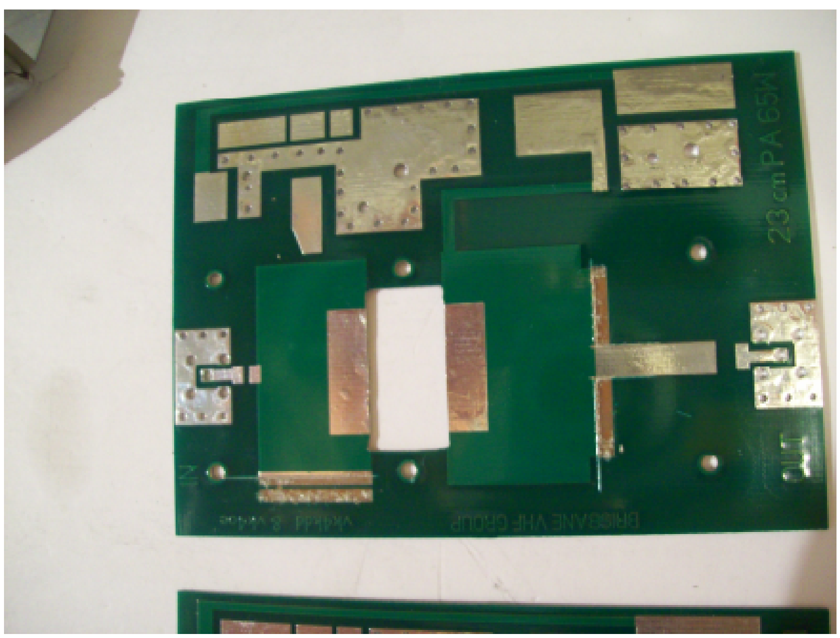
- Solder the Drain and Gate leads. Ensure and check no shorts exist.
- All SMD components can now be placed. Ensure the 22pF BYPASS chip caps are placed immediately at the cold end of the Drain printed circuit line choke and immediately after the 1.2 K gate resistor.
- Placement of the other components is fairly standard.



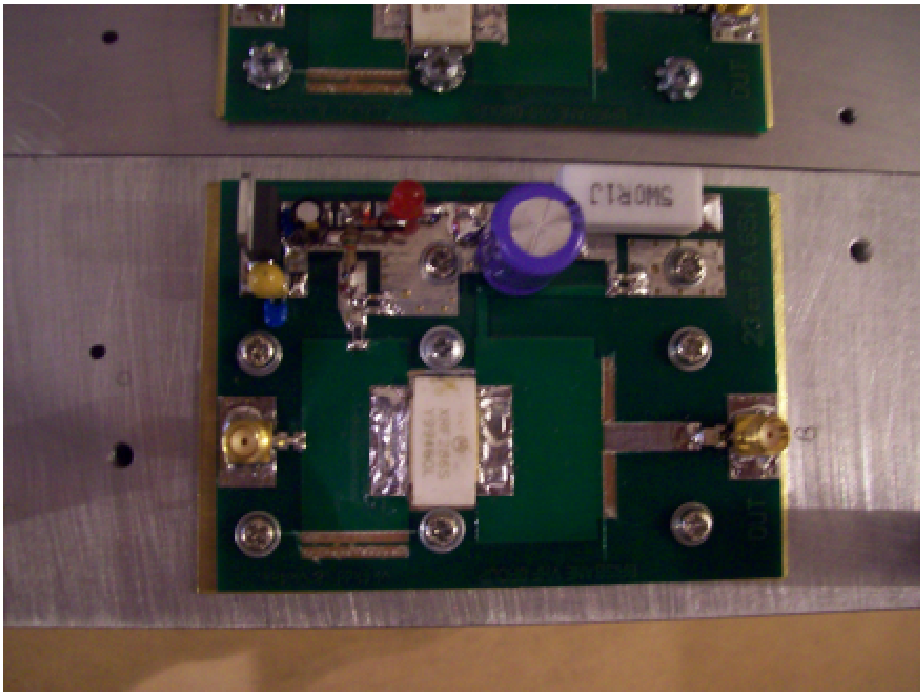
Heat sink, brass plate and board prepared. The Space for the XRF286 has not been cut out yet but the mounting holes have been widened for 3mm screws.



XRF286 device and space in board prepared.



After a few boards, I began removing the tinned exposed areas of copper on the Drain and Gate pads. The gate near the bottom of the board and the Drain near the output connector side of the pad. At 1296 MHz these units required no further “tuning”. Remember that copper “snowflakes” can always be added back. Compare this with the “untouched” board above.



Completely assembled board. This is one of the earlier units with a fixed resistor (SMD not visible) for R1

INITIAL TESTING:

Once built and checked place 50ohm loads on the input and output connectors and connect 26 – 28 VDC. Apply power and monitor for 30mV drop across the 0.1 ohm drain resistor. Also check for correct voltage from the bias circuit. We are aiming for 300mA Drain Current. I adjusted my 500 ohm trim-pot to achieve this. If a fixed resistor is used in the place of R1 then this will experimentally need to be changed to achieve as close as possible to 300mA quiescent or "resting" current.

Switch of DC power and connect a 5-6 W 1296 MHz source and a power meter and 50 ohm load (capable of handling 80 W +)

Switch on and check for initial power out. It should be 40W + as a starting point.

The input and output need tuning depending on whether 1250 MHz or 1296 MHz operation is required.

On all the boards I have built I found that the units peaked at ~1225MHz for max power output for best input Return Loss. Copper was removed and the boards were “Snowflake” tuned for best input Return Loss, Power out and efficiency at 1296 MHz.

On all 8 boards I found that for best 1296 MHz operation, all the tinned parts of the pads were removed on both the Drain and Gate. Some experimentation is required to achieve the best results. The areas of interest are the “exposed” areas near the output RF track as indicated below and on the input, the exposed area near the bottom of the board, was removed. Tuning will be slightly different for 1250 MHz operation, with LESS copper needing to be removed. Some of the tuning stubs may even need to be included.

TYPICAL PERFORMANCE RESULTS:

After building 8 boards, I found the following test data very typical:

V_d = 28 V
I_q = 300 mA
Pin = 7 W
Pout = 75 W
I = 5.2 A
Input SWR = 1.8 :1

Efficiency = 52%

Most units produced 70 W at ~ 5A and in long term use 5A Drain current should not be exceeded to maximize life of the devices by avoiding thermal overload.

Some units produced as much as 85 W out at 10dB gain. This however is pushing the transistors a little too hard and heat transfer is the problem.

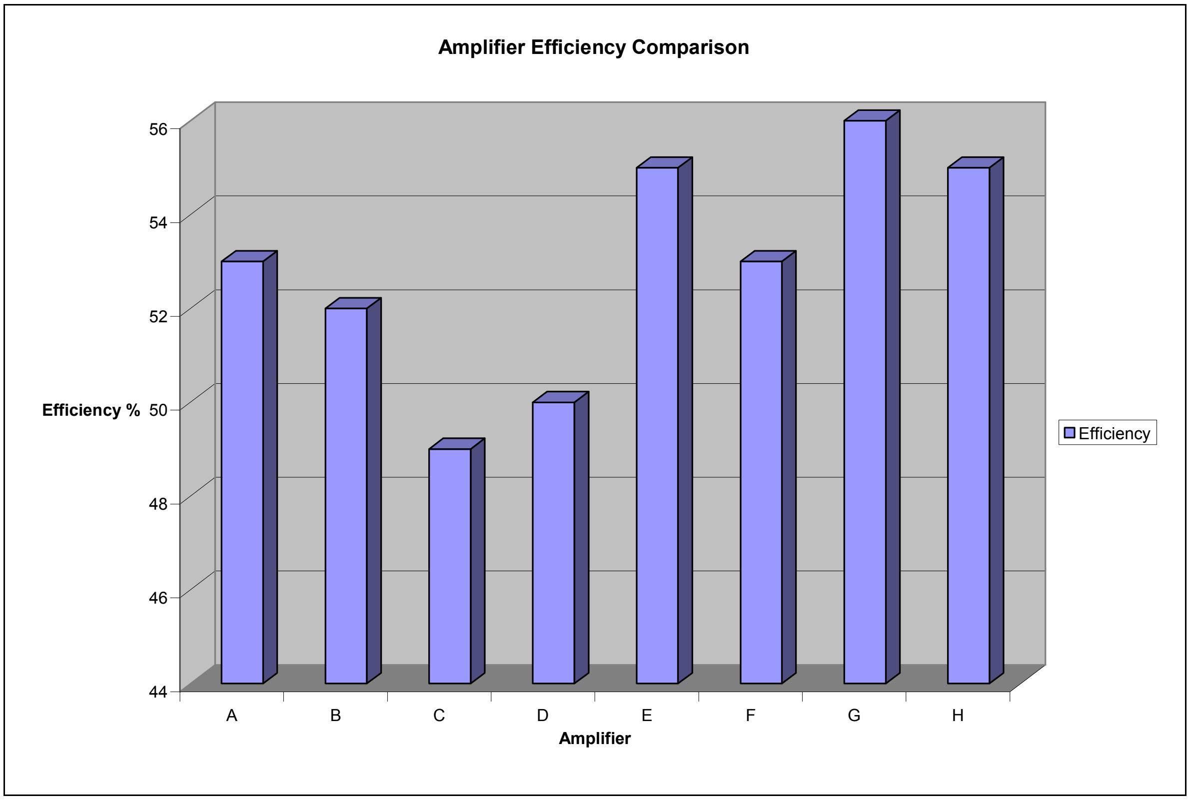
The heat sinks used seemed adequate (if not excessive) but for ATV or continuous carrier modes forced air cooling would be mandatory. As the devices heat up, power output does drop.

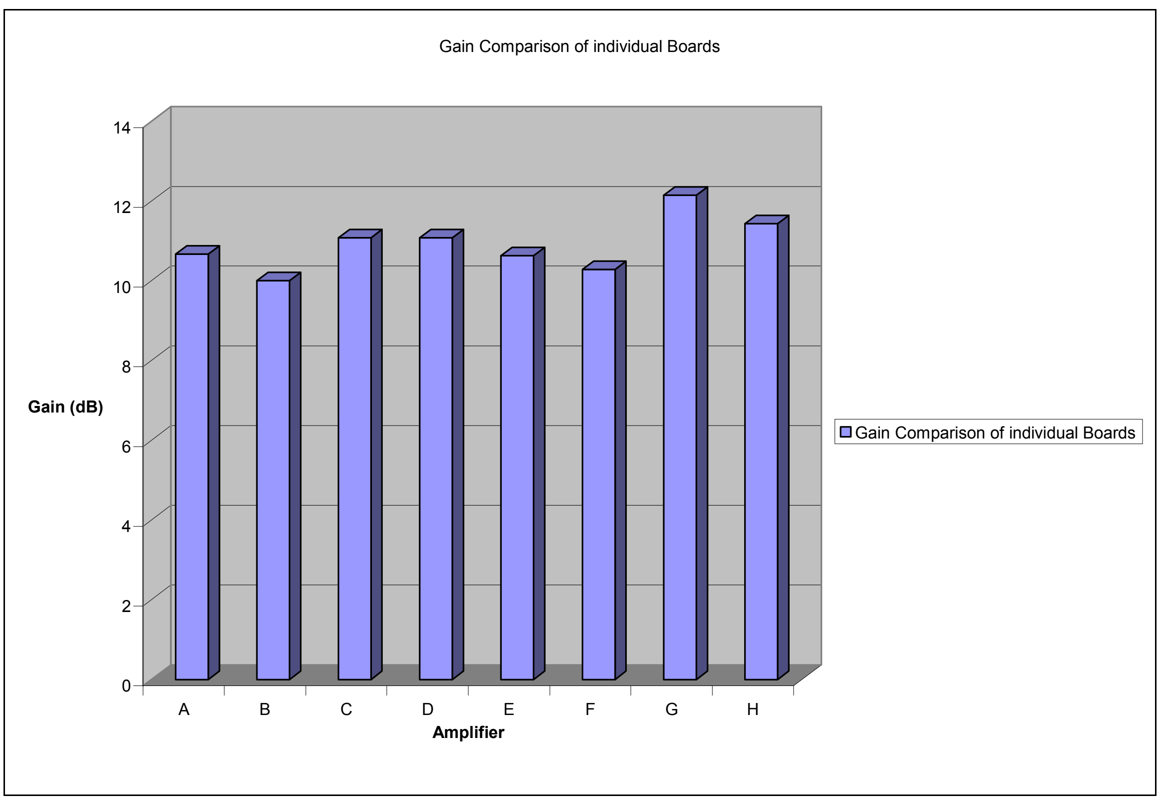
Test results achieved on 8 individual boards:

The following results are with Vd =28 V, Iq = 300mA and all tuning completed as described above:

AMP	P in W	P out W	I_A at full power	Input SWR	Eff. %
A	7.5	80	5.4	1.8:1	53
B	7.5	75	5.2	2.0:1	52
C	6.5	72	5.1	2.0:1	49
D	6.5	72	5.1	1.8:1	50
E	8 5	85 70	5.4 4.5	2.2:1	55 55
F	7	72	4.9	2.0:1	53
G	7	85	5.4	1.8:1	56
H	7	80	5.2	1.8:1	55

With further "tweaking" of the boards, the input SWR or Return Loss can be made better. For my combined application there was no need to achieve a better result.


Amplifier Efficiency Comparison
56
54
52
Efficiency %
50
48
46
44
A
B
C
D
E
F
G
H
Amplifier
Efficiency


Gain Comparison of individual Boards
14
12
10
8
Gain (dB)
6
4
2
0
A
B
C
D
E
F
G
H
Amplifier
Gain Comparison of individual Boards

Construction of 8 combined amplifiers.

The main goal of this project was to have a 400W amplifier unit. Having successfully created 8 identical single device amplifiers, the next task was to combine them together.

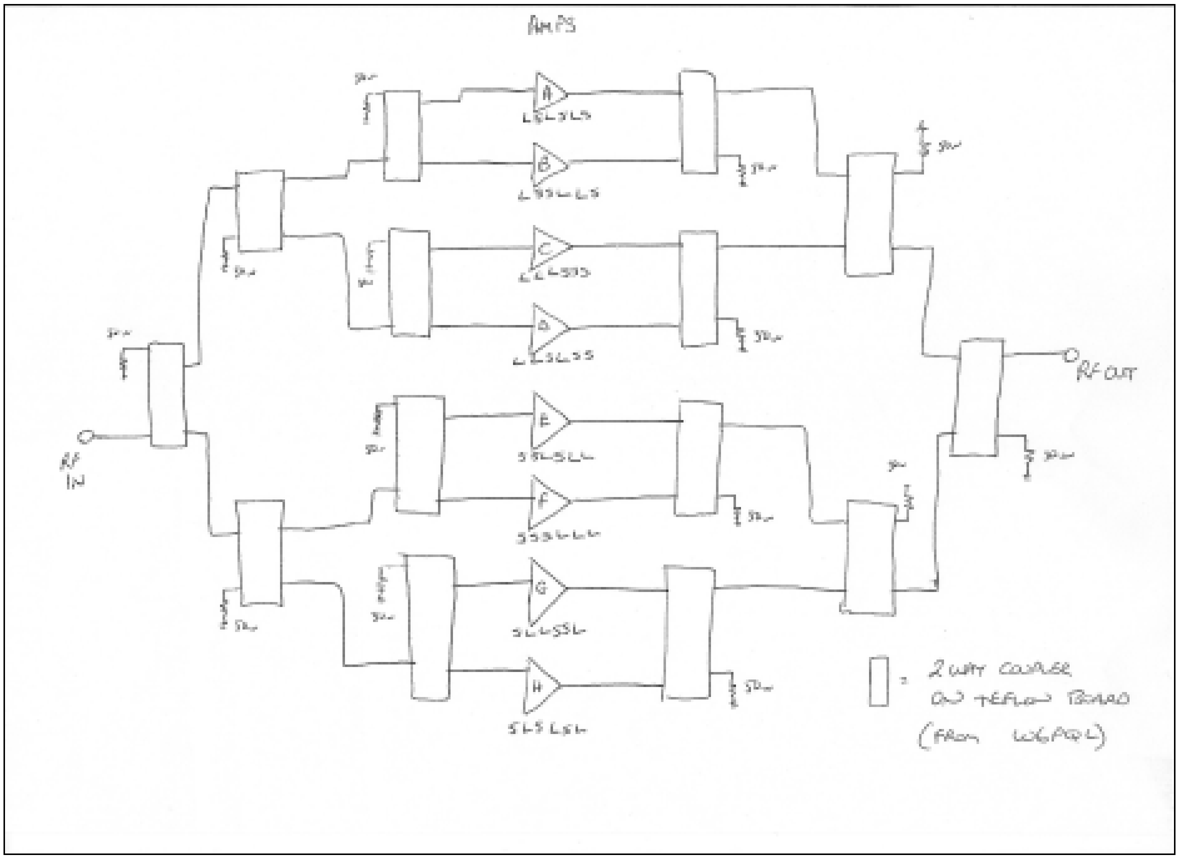
To achieve this HYBRID COUPLERS were going to be utilized for the splitters and combiner networks. These offer excellent port-port isolation and if built on low loss TEFLON board, very little would be lost in the splitters / combiners and they would be able to handle high power levels.

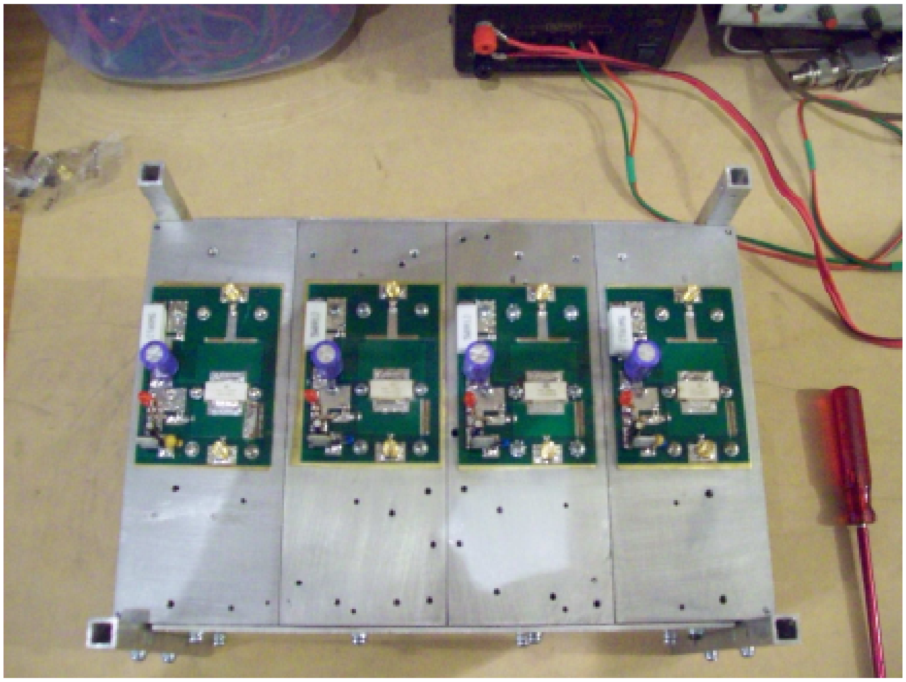
As I started to design these boards, I was alerted by a fellow amateur operator that I could purchase some individual units at a very reasonable price. Jim, W6PQL, provides some of these as well as suitably rated terminating resistors. Jim's website is at: www.w6pql.com. It seemed too good an offer to refuse and I purchased the 14 individual coupler units that would be required as well as the terminating resistors from him.

The 8 heat sinks were bolted together and as the pictures show, the splitters / combiners were placed symmetrically around the heat sink "cluster". Care must be taking in "phasing" the units together and identical lengths of flexible UT141 (known as "Quick Form") are used between the sections. When using combiners / splitters it is important to make sure that the electrical length of the entire path from input to output for each individual amplifier unit is identical to all the others.

For those that need further explanation then please consult any of the numerous textbooks on this subject. I found my copy of the "ARRL UHF Microwave experimental handbook" invaluable in learning how splitters /combiners work and how to use them.

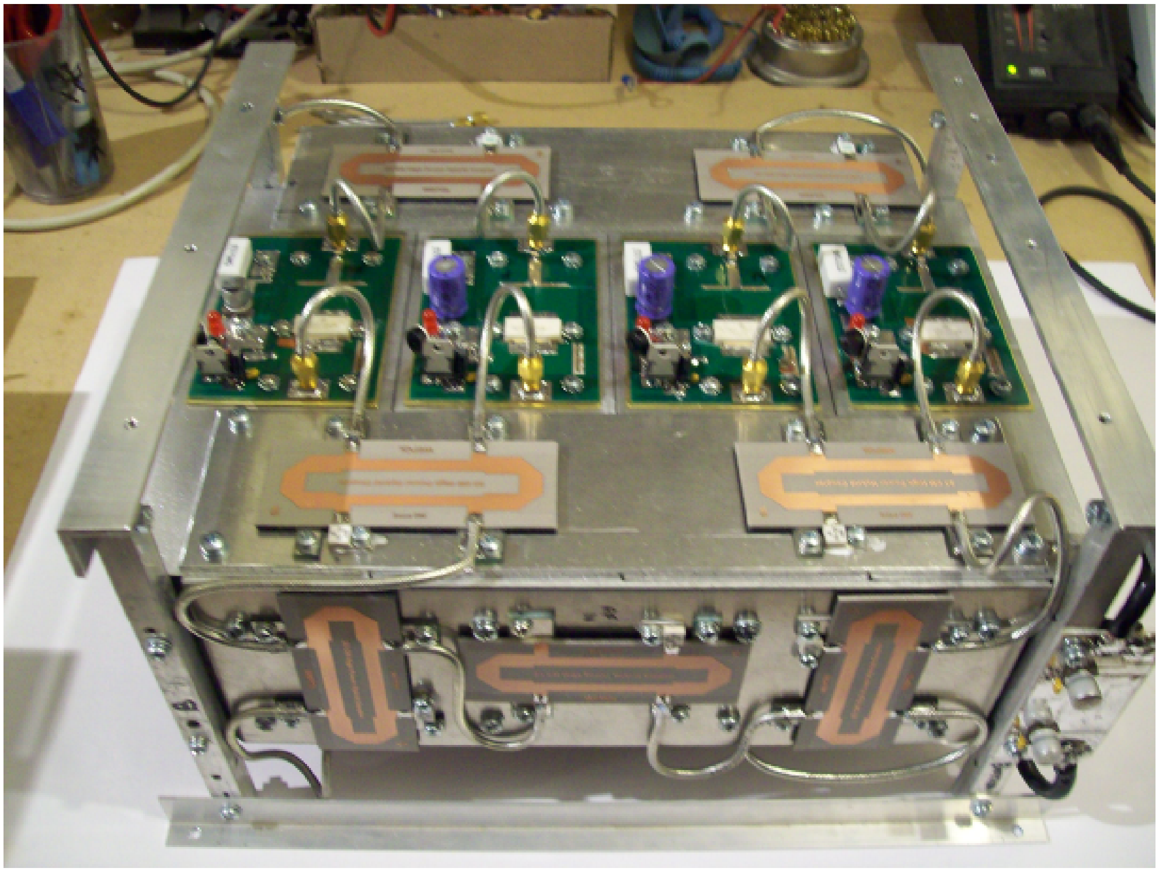
Splitter / Combiner Schematic:



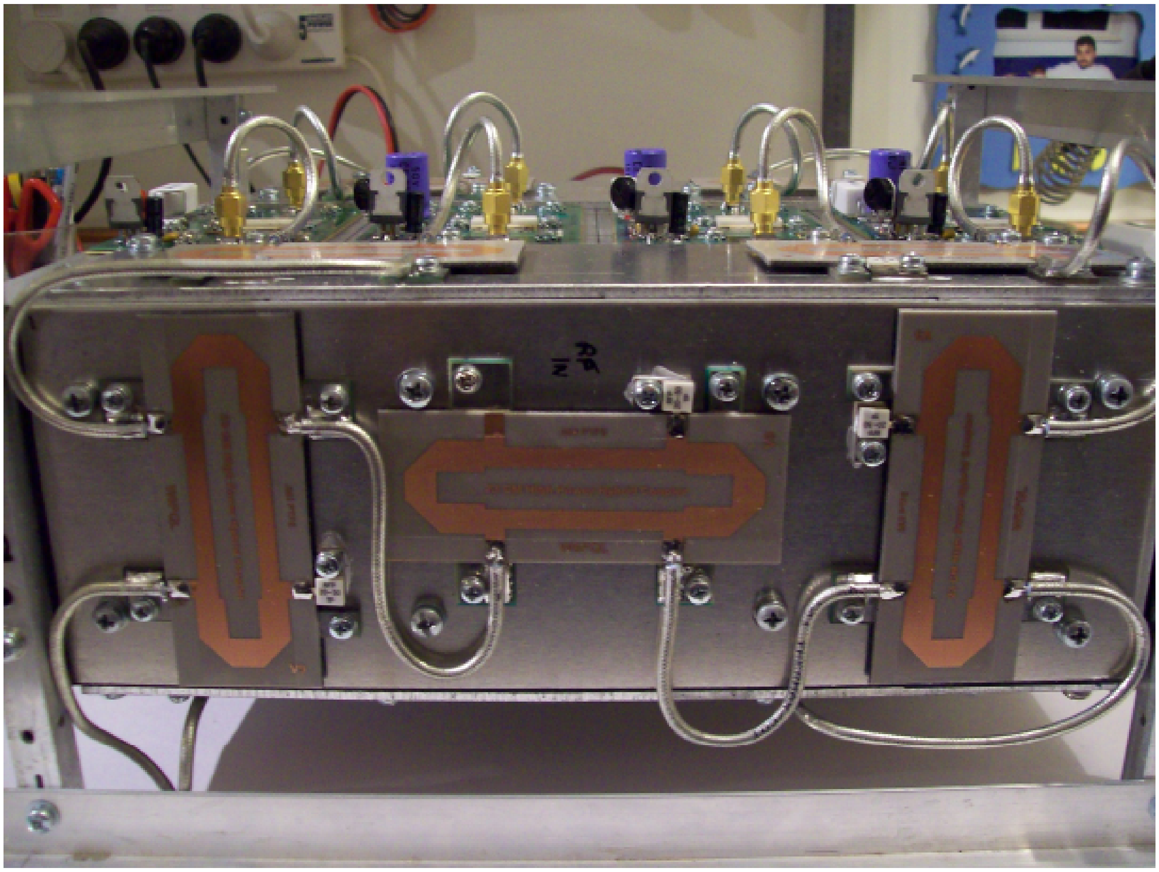


1 side of “Amplifier Cluster” without splitters or combiners in place showing 4 individual and identical amplifier units.

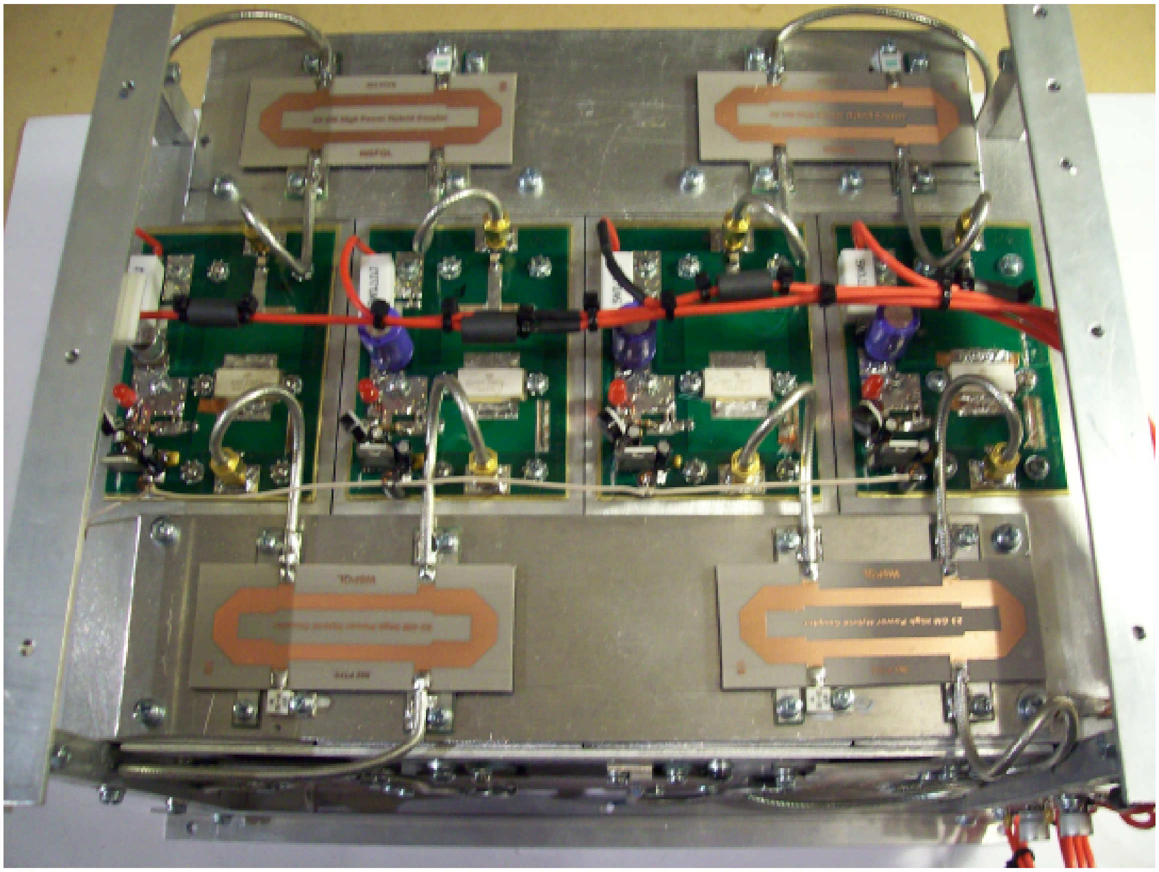
The heat sinks are placed fin to fin and the upright rails raise the “cluster” off the deck to protect the bottom 4 amplifier units.



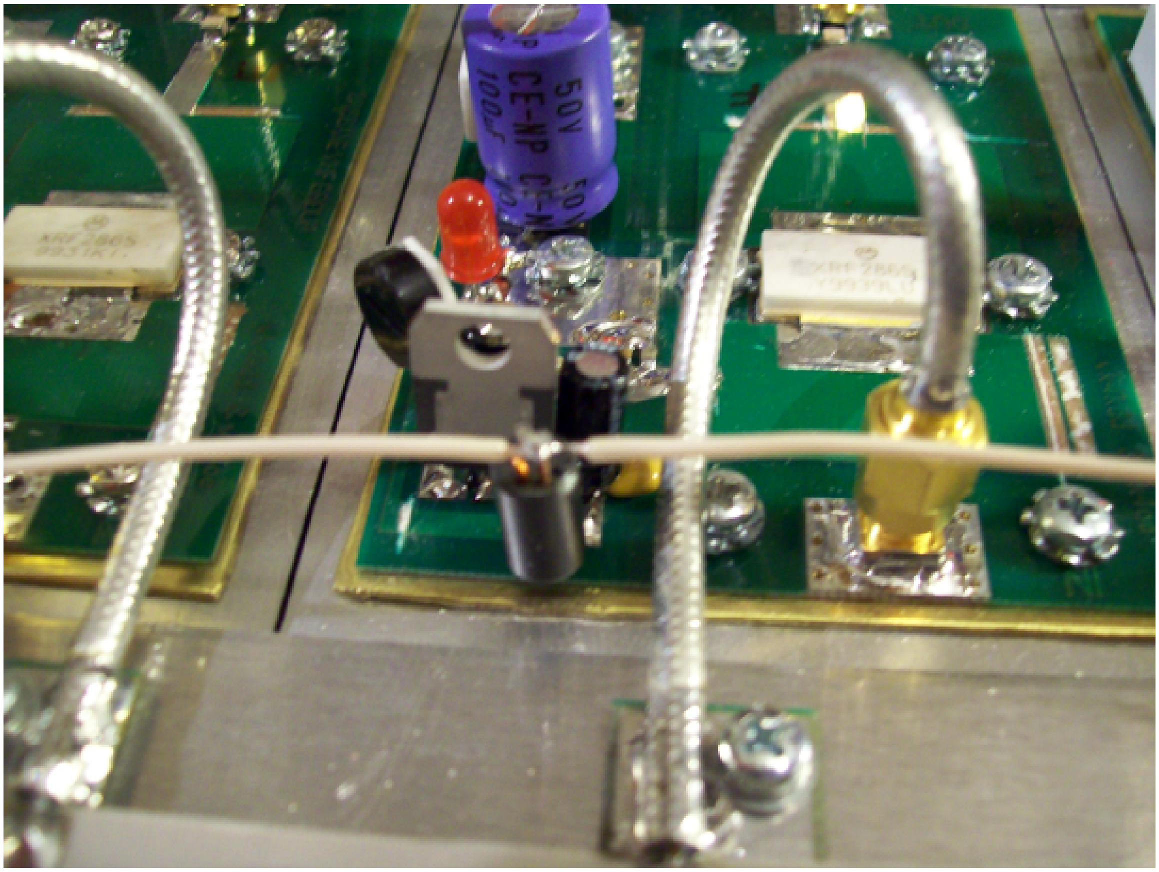
“Input side”: All couplers in place and all RF connections completed. Also noticeable are the Variable resistors now placed for setting the resting current. On the input, the terminating resistors for the couplers are 20 W 50 ohm. On the output 100 W 50 ohm resistors were used.



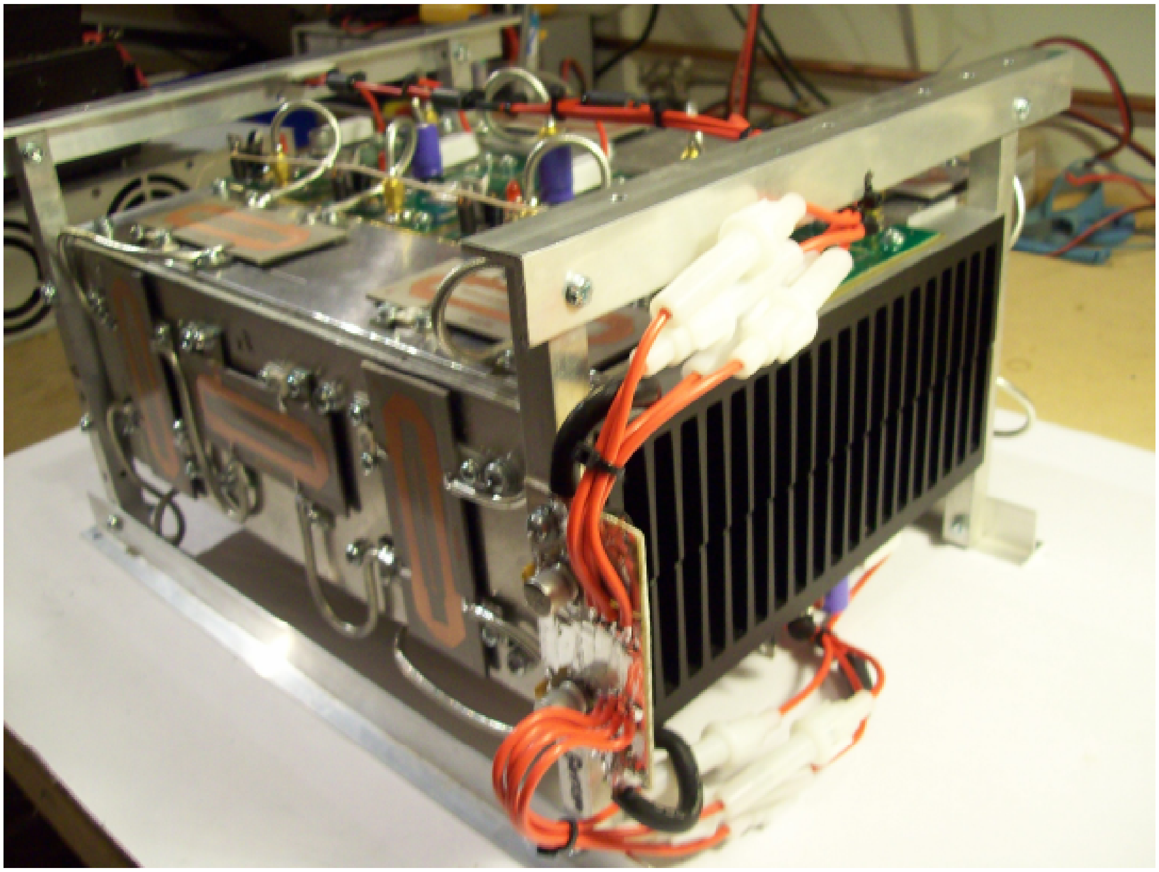
Input side (again)



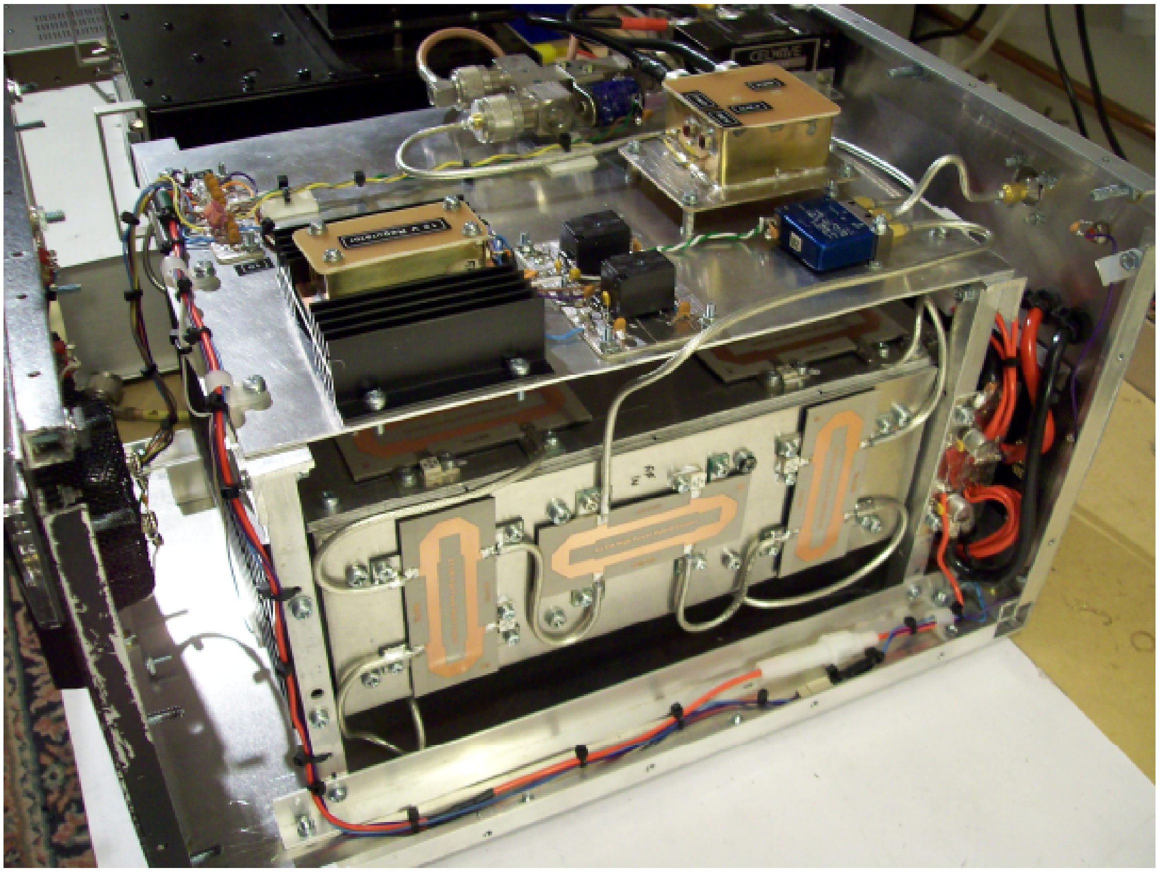
DC connections completed. The Bias line tracks were cut on the boards and these are fed with DC (via a Ferrite Bead) only on Transmit. Each Drain supply has a large FB slipped over the wire.



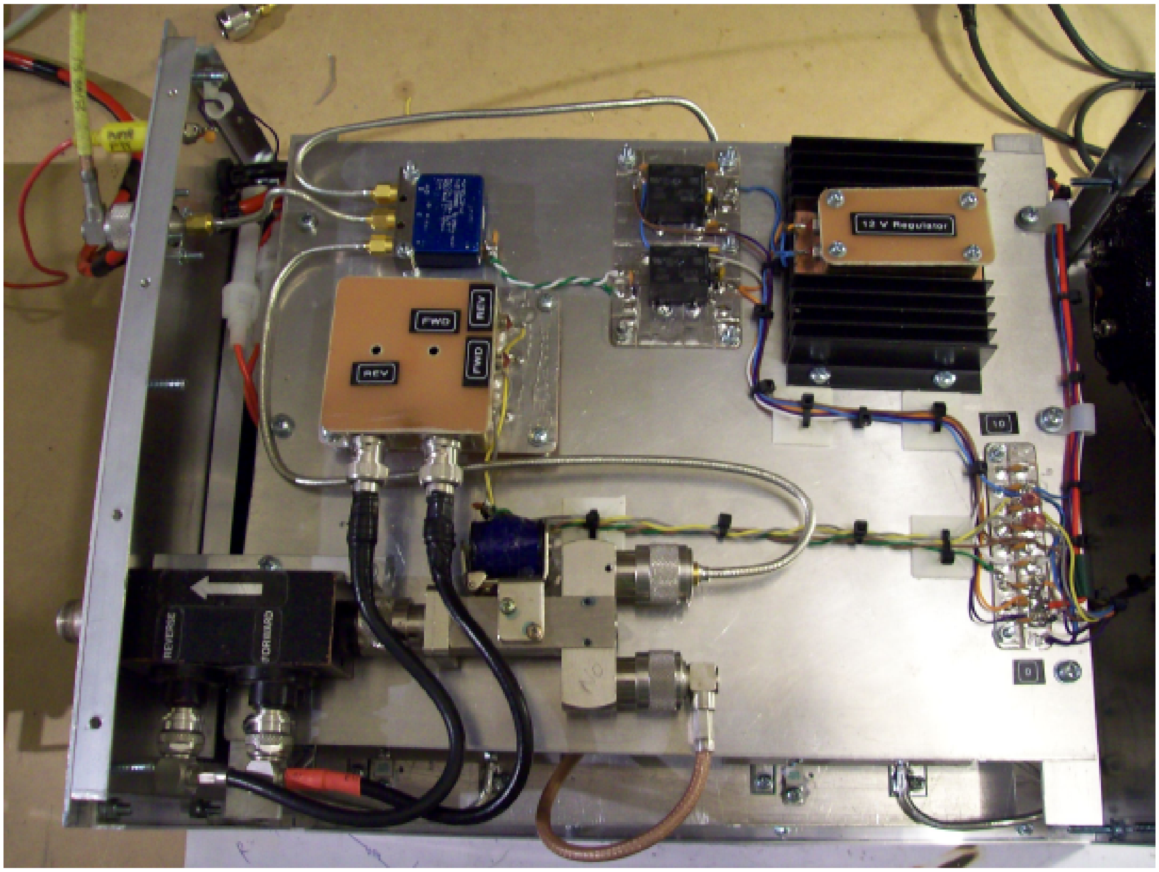
Picture of cut in Bias track and placement of a choke for feeding DC volts only during Transmit. The 28V stays on the Drain continuously. The choke is 5 turns 0.63mm ECW wound through a 6-Hole Ferrite Bead.



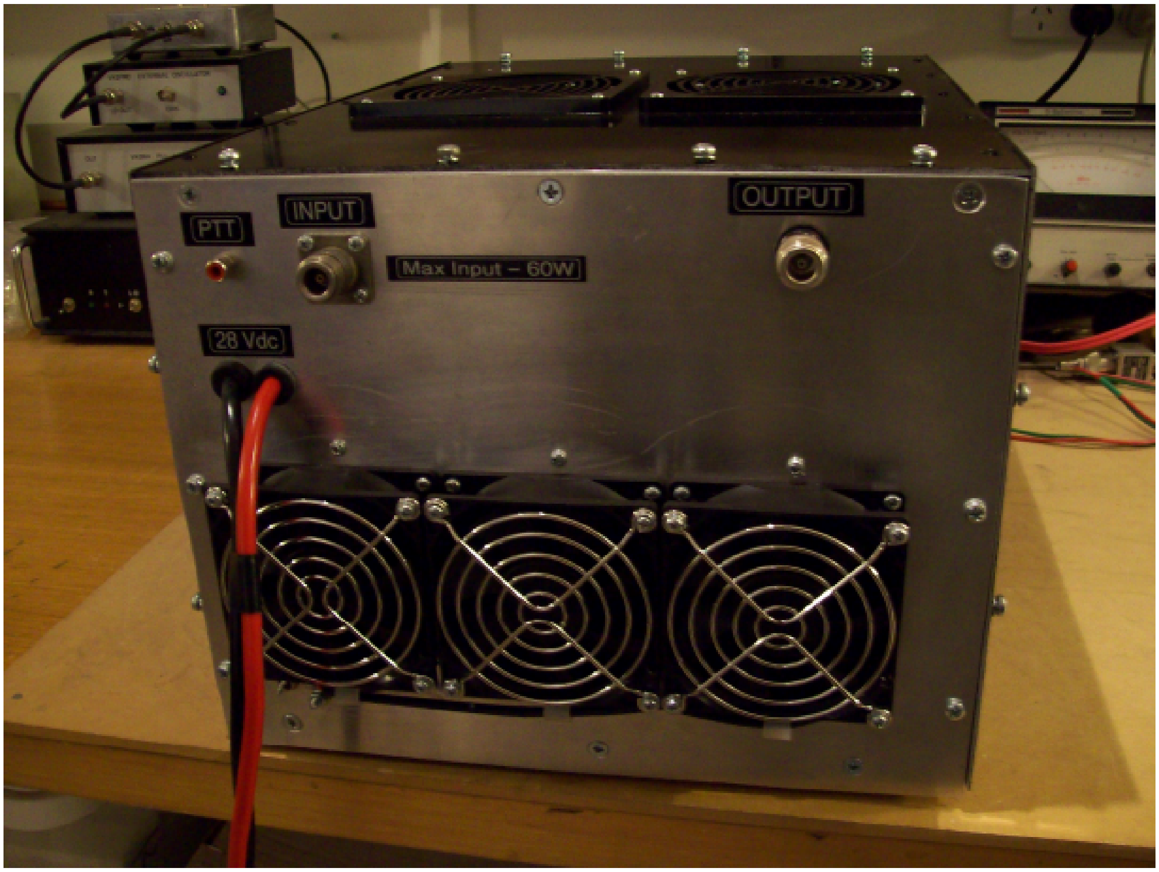
Each device is separately fused (7A fast Blow) and all lines are routed back to a "distribution board" upon which are 2 @ 100uF 50V and 2 @ 1000pF and 2 @ 22pF SMD capacitors for extra decoupling.



- Amplifier cluster in chassis with control circuitry in place.
- DC distribution board visible near the back right corner.



- “Control and Switching” circuitry
- Coax from output combiner to CX600N is RG142 Teflon coax, visible at the bottom of the picture.
- Input has an SMA relay
- Shielded 12 V regulator
- Output directional coupler
- Detector unit
- DC PTT Switching Relays. 28 V for the SMA and 12 V for the CX600N



Rear Panel View

- 3 @ 80mm Muffin fans used to force air through the heatsink cluster
- All Fan cutouts are shielded with wire for RF shielding. In addition a wire shield is place around the front panel meter to help achieve this.
- Input PTT is a “connect to ground” command
- Outlet vents are placed on the top of the cabinet

- Front Panel View.
- Bypass switch incorporated
- Front Panel meter Calibrated for Forward and Reverse Power indication.

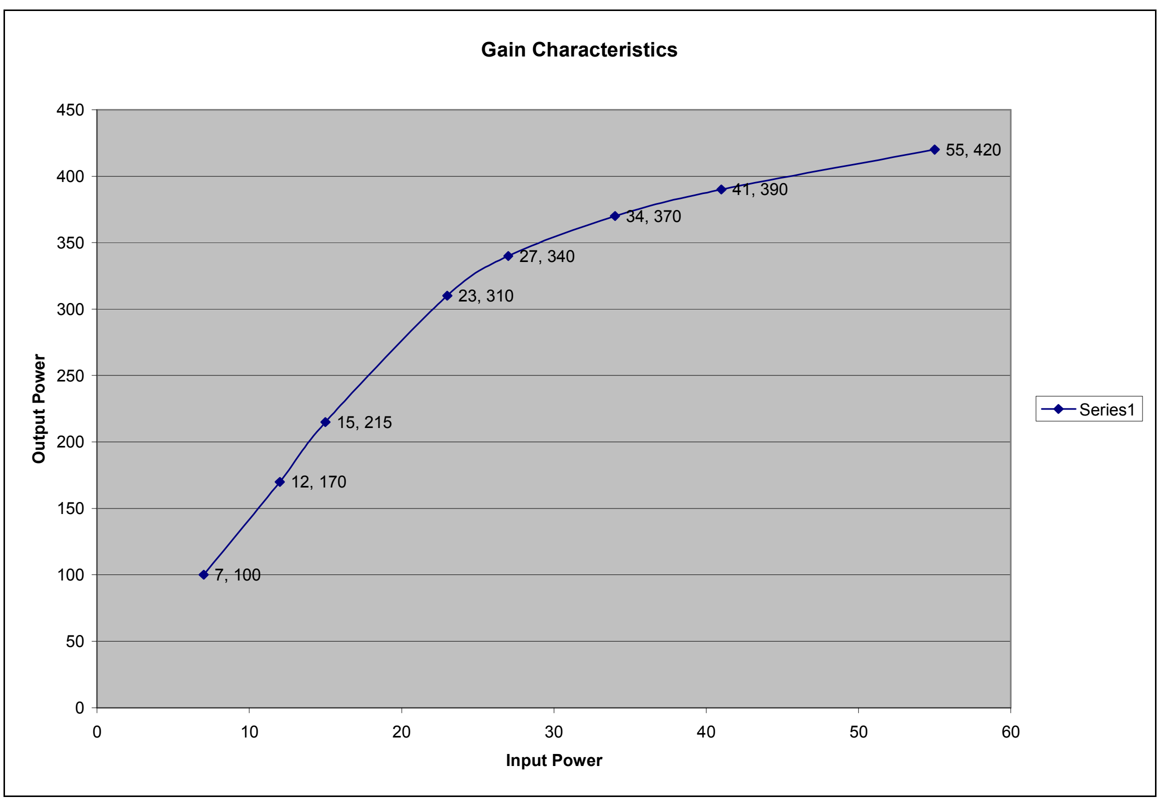
Final test results for completed amplifier:

SUMMARY:

Input Power (Back Panel) = 55 W
Input SWR 1.1:1
Output Power (Back Panel) = 420 W

Actual Test Results:

Power Input Watts	Power Output Watts
7	100
12	170
15	215
23	310
27	340
34	370
41	390
55	420



An interesting observation is that these devices don't seem to show the typical linear increase and then into gain compression type curve. There is a "knee" in the gain characteristics but the amplifier seems to stay fairly linear after this, at least to the levels shown, with a somewhat reduced gain factor (~7dB). W6PQL reported similar characteristics in an amplifier of similar output power level that he constructed. (See Jim's website below.) I will soon test at higher power levels if possible to see where the gain starts to taper off as it goes further into compression.

Whilst each amplifier unit showed 10.0 – 10.5 dB gain the resultant overall gain is less then this due to the losses in the associated wiring, relays and coupler boards.

2-Tone IMD testing was crudely performed using a down-converter on a low level coupled signal. The 3rd order IMD of the amplifier was no worse than the ~34 dB obtained from the 1296 MHz driver alone. The amplifier may yet be "cleaner" than this (already acceptable level). These tests were done on a "Clifton Labs" Panadapter at a down converted signal of 28MHz. As such the accuracy will not be sufficient to draw an absolute figure of merit. One day when I have a spectrum scope able to perform the 2 tone test at the 1296 MHz level I will repeat the tests.

Additional information on XRF286 amplifiers for 1296 MHz:

Of interest to those reading this is that Jim, W6PQL, now has a 2 device board available in kit form. (At the time of writing this article August 2008) Jim's website is at www.w6pql.com . The boards have 2 devices plus the input splitter and output combiner all etched on the 1 Teflon board.

Acknowledgements:

Thanks to Ron VK4KDD and Doug VK4OE for, firstly, making these professionally made boards available to the wider amateur community and secondly, for their assistance in replying to my numerous questions during the initial construction phase. The project undertaken at the expense of the Brisbane VHF group has produced a wonderful single device amplifier that is VERY easy to get going and produces a "serious" low cost alternative for increasing power on the 23cm band for many operators whom have 5-10 W transverters and or commercial 23cm equipment. For others like myself this small single device amplifier is a dependable building block for a more powerful amplifier as it allows multiple units to be combined.