

Construction Of An Integrated 630-metre Power Amplifier

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1. Introduction

Space and financial constraints mean that radio amateurs wanting to use the relatively new LF and MF bands (2200 m and 630 m, respectively) often employ transmit antennas with efficiencies of order a few percent or less, meaning that transmit powers of more than a hundred watts may be required to reach the 5 W EIRP limit applicable in Australia and a number of other jurisdictions. As always though, much lower power sometimes produces remarkable results; for example, with occasional favourable propagation in winter 2019, I achieved respectable WSPR spots in New Zealand using only 5 W transmit power into an improvised T-antenna having an estimated efficiency of ~0.3 %. A later increase to 50 W transmit power using a homebrew single HEXFET amplifier opened up some two-way JT9 DX communications, a capability that will hopefully be enhanced with the amplifier described in these notes. This short summary is not a construction article as such but may, I hope, be useful to others looking for ideas on how to build and package a 630 m power stage.

The Kenwood TS-590S and TS-890S transceivers I use to generate 630 m (475 kHz) signals provide a 0 dBm (1mW) drive signal suitable for use with an external power amplifier (PA). No transverters are required, and all the expected transmit-receive switching – including that needed for a separate receive antenna – is implemented within the Kenwood radios, making for a neat system. One season of operating on 630 m, and the experience of building 5 and 50 W PAs, led me to set some top-level specifications for the new PA. These were:

1. Power output capability of at least 250 W, even if only to ensure a robust system when driven at lower legal outputs;
2. Class D or E operation for efficiency and to capitalize on the benign behaviour of cheap HEXFETs operating in fully saturated modes (meaning that most digital modes and CW, but no linear modes, are supported);
3. Fully integrated amplifier (RF module, all power supplies and other circuitry in one cabinet);
4. Good protection circuits, including shutdown on excessive RF reverse power;
5. Good RF power monitoring arrangements;
6. Switchable pass-through provision for an antenna analyser used to tune the antenna; and
7. Standard transmit-receive switching on command from the transceiver allowing, amongst other things, the transmit antenna to be used as a receive antenna when desired.

The choice to exclude linear modes such as SSB is no particular hardship although in Australia limited-bandwidth SSB can occasionally be used on the 7 kHz wide 630 m band, provided due courtesies to other band users are observed. My recommendation is that if a linear amplifier is needed, RF power devices and associated good linear amplifier design practice should be used; HEXFETs perform and behave much better in fully saturating power circuits. Australian operators should also note the maximum mean power limit of 120 W (in addition to the 5 W EIRP limit) for 630 m WSPR and similar emissions. Nevertheless, amplifiers such as the one described ensure a highly robust PA with great operational convenience.

My earlier 50 W PA used isolated pad style PCB construction but I was keen to use a commercial PCB for the new unit. Looking around, I found a promising design by David Bowman, GOMRF.

2. The GOMRF RF Module

The GOMRF amplifier design is a 300 W Class D module, and is an evolved version of David's earlier designs for 2200 and 630 m. The module uses two IRFP-250 HEXFETs in a transformer coupled push-pull topology. The amplifier schematic diagram (Figure 1), and associated PCB construction notes, are available on the GOMRF web site at <http://www.g0mrf.com/630m.htm>. Blank PCBs are available from David; his contact details and other information are at <http://www.g0mrf.com/>.

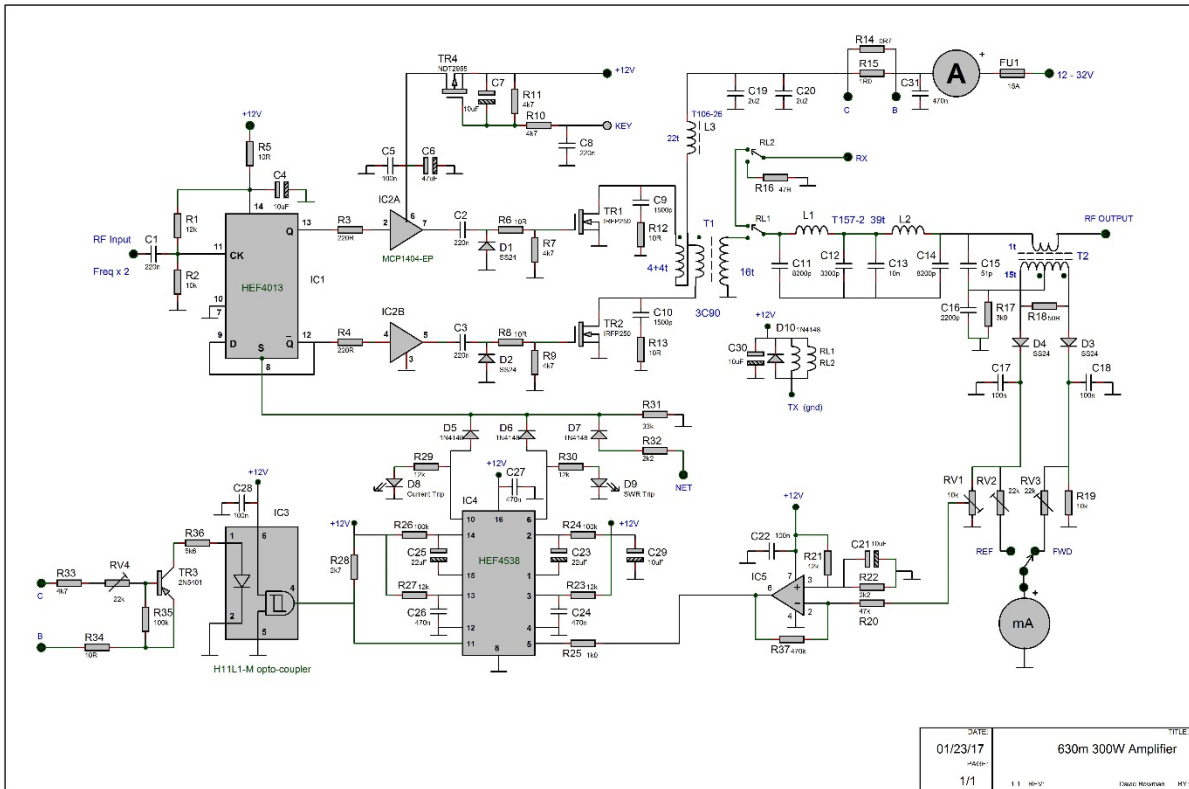


Figure 1. GOMRF 300 W amplifier PCB schematic (courtesy GOMRF).

The PA is well thought out, with an AC coupling and a DC-restored FET drive arrangement biasing the FETs off when no drive is present. On-board protection circuitry for power supply over-current and excessive reverse RF power is also used; this circuitry inhibits the amplifier drive by preventing an input flip-flop toggling for pre-determined lock-out periods (nominally 3 s). An on-board directional power sensor provides input to the reverse power protection circuit, and permits easy metering of the forward and reverse powers and SWR.

Perhaps the only downside of the highly symmetrical, flip-flop driven, push-pull design is the need to clock the amplifier input at twice the signal frequency (950 kHz for a 475 kHz transceiver output). Various frequency doubling approaches are possible but I used a slight variation on the analog, two-diode full-wave doubler circuit shown by GOMRF at <http://www.g0mrf.com/630m%20frequency%20doubler.htm>.

3. The VK6HP Power Amplifier

Figures 2 and 3 show exterior and interior views of my 630 m PA. The included sub-systems are:

1. The GOMRF RF module PCB (mounted horizontally);
2. A frequency doubler PCB (mounted vertically) containing a 10 dB gain, high-intercept buffer amplifier, followed by a doubler based on two Schottky diodes and a transistor 950 kHz tuned-output stage;
3. A +12 VDC, 1.7 A, linear general-purpose power supply for powering the small-signal section of the RF module, as well as other RF and control circuits in the amplifier enclosure;
4. A +30 VDC, 10 A, switching variable power supply for the RF module drain circuits, the variable supply voltage permitting easy setting of the Class D RF module output power;
5. A coaxial relay to switch the transmit antenna to either (a) the RF module output or (b) a front-panel BNC connector, to which an antenna analyser can be connected;
6. A MOSFET keying interface unit, allowing the PA to be keyed with only 1 mA keying current from a transceiver electronic keying line;
7. Various low-current LEDs (type HLMP – D105) indicating +12 V general purpose power present, over-current fault, excessive RF power fault, antenna analyser BNC selected (and PA drive inhibited), and amplifier keying line (PTT) unkeyed;
8. A crossed-pointer meter showing forward and reverse power, and antenna SWR;
9. An 80 mm diameter 12 V fan to blow air over the HEXFET heatsink, the warm air being exhausted via a 160 mm x 80 mm vent in the cabinet top panel;
10. Rear panel connectors for transceiver 475 kHz, 0 dBm drive input (BNC), PA RF output (BNC with permanent S0239 adapter), keying input (RCA) and receiver output (RCA).



Figure 2. Front panel of VK6HP power amplifier. Note the switch to control the coaxial relay which routes the antenna to the antenna analyser BNC connector. Labels are printed using the LetraTag system and clear adhesive tape.

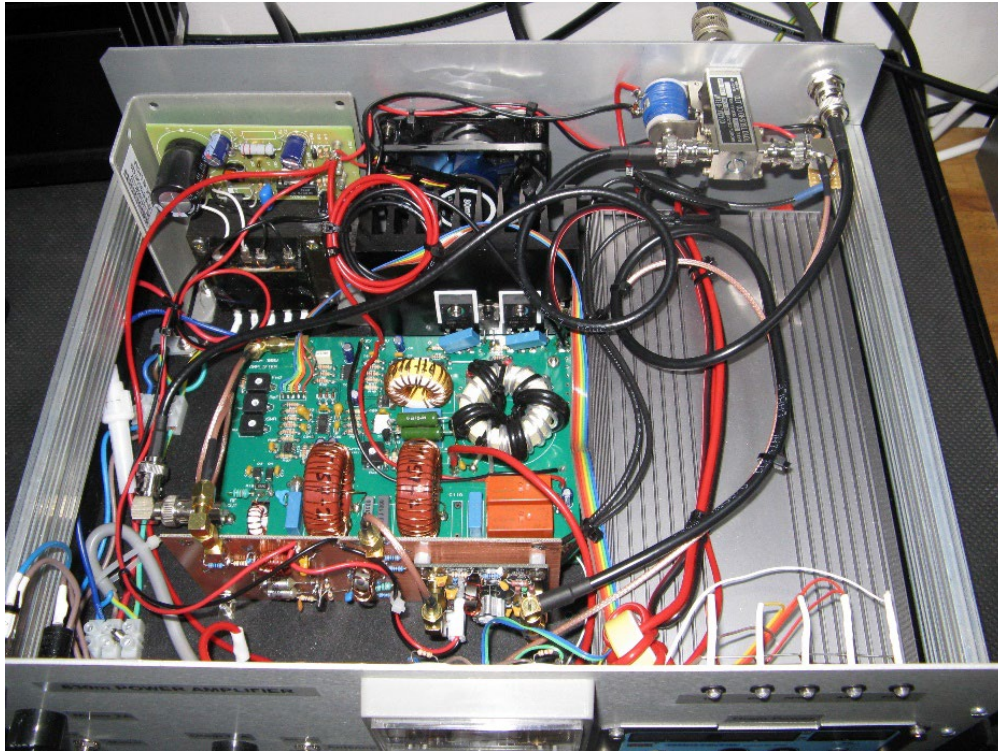


Figure 3. Interior view of the 630 m power amplifier. The GOMRF RF module is mounted horizontally and the doubler PCB is mounted vertically. The Toitsu coaxial relay and a small PCB containing the MOSFET solid state keying relay are visible in the upper right.

A few comments on the individual sub-systems may be useful. First, the cabinet is a Metcase aluminium enclosure with dimensions 367 (w) x 134 (h) x 300 (d) mm. Interestingly, it is the single most expensive component in the project! Australian constructors will find most components to be available from hobby stores, RS Components, Element 14 or Minikits. Rockby Electronic Components in Melbourne are also an economical source of toroid cores, including the harder-to-find T106-26 cores for the RF module L3.

The as-built RF module is very similar to that described by GOMRF. Minor changes include (a) the addition of a 1.5 mH RF choke across R17 to improve the directional coupler reverse power sensitivity in a two-meter system and (b) replacement of the current sense resistor R14 (0.07 ohm, 7 W wire-wound) with a parallel combination of 0.15 and 0.12 ohm Vishay 6 W, ceramic wire-wound, resistors (available from RS Components). The two resistors can be stacked vertically with suitable clearance between each other and the PCB. This keeps the heat away from the PCB and nearby components. The lower temperature coefficient Vishay resistors and cooler operation also makes the over-current trip point easier to set. Finally, depending on the PCB version, it may be necessary to add a couple of jumpers. On my board the ground tabs of the input SMA socket required a jumper to ground and a second jumper was needed to supply +12 V to pin 16 of IC4, the dual monostable IC. The IRFP250 FETs are loosely matched in my amplifier, the two devices being selected to have similar threshold gate-source voltages.

I used the “net” input of the RF module (Figure 1) as an inhibit line which is asserted high when the antenna is switched to the front-panel antenna analyser BNC. Not being a CW operator, the “key” input on my PA is permanently asserted low. GOMRF describes a construction sequence for the PCB

The low-noise switching power supply for the drain circuit is quite an important part of the PA functionality. It is a “Rek” 30 V, 10 A variable type (yet again sourced from eBay) and provides a digital readout of the drain voltage and current, and the resulting power product – the DC input to the PA. It also allows the drain supply to be isolated and the front panel controls to be locked. Physically, the supply is mounted by sandwiching the PA cabinet front panel between the power supply front panel and the body of the supply enclosure. Some careful mechanical alignment and paint marking of screw heads was needed to achieve this, while still having the power supply supported on the bottom of the PA cabinet. Importantly, the power supply output is clean and checks with a spectrum analyser and receiver show no artefacts on the PA output, save for a stable and very low level (just visible) TS-890S bandscope trace at 212 kHz during high sensitivity bench testing, perhaps corresponding to the power supply switching frequency. No WSPR multiple spots are observed and Appendix 1 contains examples of off-air spectra. Do not assume that other power supplies, especially switching supplies, can be substituted without careful selection and testing. Remember also to include a 15 A fuse in the drain DC line as a final defence against shorted FETs, RF module and drain power supply electronic protection notwithstanding.

After a period of testing and use I noticed that touching the voltage setting control, or encoder shaft, of the Rek PSU during transmit induced extra noise on the PSU output. Firmly grounding the shaft is the obvious solution but despite the encoder housing being connected to mains earth via a circuitous path, the unit objects to having a second DC ground at the shaft/front panel. I solved the issue by fitting a 22 nF disk ceramic capacitor between the encoder housing tab and chassis ground, at the corner of the PSU front panel PCB.

I prefer tuning the MF transmit antenna using a RigExpert AA-35 Zoom antenna analyser, and make good use of its graphical display and other features. To enable the antenna to be connected to either the GOMRF RF module output or the AA-35 Zoom, I use a front-panel switched Toitsu CX-230 coaxial relay, equipped with BNC connectors. While one pole of the front-panel switch activates the relay 12 V coil, the other inhibits the GOMRF module via its “net” input. Thus, switching the antenna to the antenna analyser front-panel BNC connector disables the drive to the amplifier module, just in case of operator finger trouble.

Keying circuitry for the GOMRF RF module is conventional, with a PTT connection to ground initiating the appropriate on-board relay transfers. Voltage and current keying requirements are 12 V and about 80 mA, which is quite reasonable. However, to improve the sensitivity and make the 630 m PA compatible with my other amplifiers’ electronic keying lines, a Matsushita AQV 254 photoMOS solid state relay IC is used as a buffer, resulting in a 12 V, 1 mA keying requirement. The associated postage-stamp sized piece of protoboard is mounted directly on the rear panel “key” RCA connector.

The crossed-pointer dual meter has 100 μ A, 1540 ohm movements, and 0-10 W (forward) and 0-2 W (reverse) scales; these read 0-1 kW and 0-200 W in the present application. The meter type is searchable on eBay as an SZ-70 dual SWR panel meter. I found that the dynamics of the movements are improved if each meter is shunted to \sim 500 μ A sensitivity using a parallel 390 ohm resistor; there is plenty of output available for the reduced-sensitivity meters from the GOMRF module’s directional coupler. With the Schottky diodes specified and the added 1.5 mH choke across R17, the intersection point of the pointers tracks the SWR locus curves quite accurately over at least a 20-300 W forward power range. The PCB-mounted coupler is a neat implementation but makes setting up a little more difficult as the RF input and output cannot be easily reversed. However, the forward power meter can be calibrated in several ways, most obviously by reference to an external power

meter with an accurate 630 m response. An oscilloscope and dummy load could also be used. To calibrate the reverse power and SWR indication in the most important display region (SWR < 2:1) I used some known impedance mismatches, including two 50 ohm dummy loads in parallel and a high power 75 ohm load.

The small fan is hardly necessary with the 90% efficient PA, although it and the cabinet top vents ensure that the amplifier and associated circuitry remain cool under all SWR and climatic conditions. The low-noise, 80 mm diameter fan blows over the HEXFET heatsink and the top vents are arranged such that they are directly above the output section (and current sensing resistors) of the GOMRF amplifier PCB.

4. Tuning and Results

On first bench testing of the GOMRF RF module I was pleased to see that it was able to deliver 300 W at 475 kHz into a dummy load, given a 32 V, 10.5 A drain supply. Things were getting noticeably warm when that output was sustained, principally because of the power dissipation in the original 0.07 ohm, 7 W current sense resistor. I also noted that the power bandwidth characteristic of the module was a little peaky, although 300 W was definitely possible over the whole 7 kHz of the 630 m band. Of course the integer turns effect on the output transformer and inductors, component tolerances and individual construction differences lead to some variation between units. In the end, I settled on a ± 1 dB 450-490 kHz power bandwidth with more than 250 W output, achieved by judicious adjustment of the turn spacing on L1 and the removal of one turn from L2. I set the over-current shutdown to a little over 10 A and the reverse power to 50 W, the latter done by simply open-circuiting the output according the GOMRF recommendation.

The PA is very clean, with the expected good even-order harmonic suppression of a push-pull design. Figure 5 shows output spectra at two power levels. In use, the amplifier is very robust and able to cope with wide and rapid antenna matching variations, such as those encountered using my wire T antenna (and its over-size top loading arrangement) in high winds. Just as importantly, the order brought by having the whole PA integrated into the one cabinet is a welcome change from my rather chaotic 2019 station, where the 50 W amplifier was operated "open plan" for much of the time, and power supply and other trailing interconnections abounded. I've had the new PA on the air for a few weeks now and I'm looking forward to using it seriously in the upcoming (southern winter) MF season.

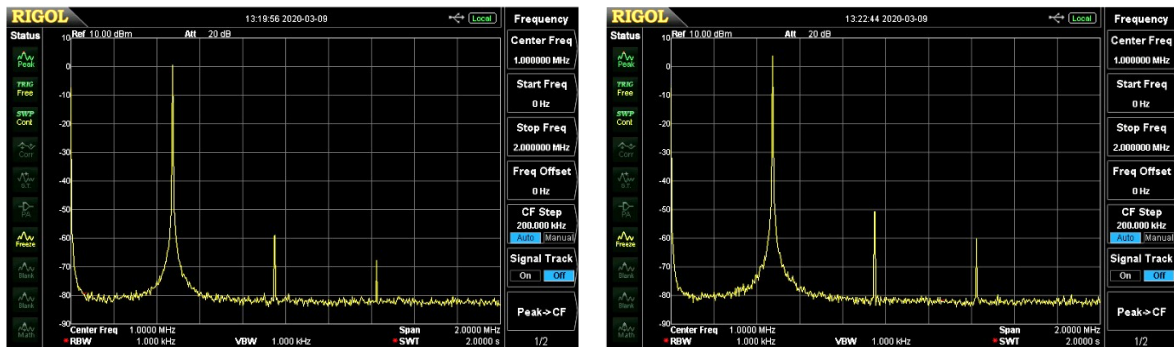


Figure 5. Output spectra of the 630 m power amplifier driving a 50 ohm dummy load with a 475 kHz CW input. The left and right traces show the output at 100 W and 250 W, respectively. Worst case second and third harmonics are at about -55 dB and -65 dB, respectively, relative to the fundamental output. No other harmonics are observed at significant level.

5. Acknowledgments

Thanks to David Bowman, G0MRF, for his work in making the original design available, encouragement in the present project and interest in the finished product. Thanks also to the many VK6 amateurs and others providing contacts and reception reports on 630 m.

Document Update History

Version 1 (original), 10 March 2020.

Version 2, 19 May 2020. Typos fixed; advice regarding bypassing of PSU encoder shaft incorporated; Appendix 1 added.

Appendix 1 – Power Amplifier Off-Air Measurements

To complement the bench tests of the PA a number of off-air tests have been done, particularly to verify that the switched mode drain power supply is adequately clean, the inherent power supply noise rejection properties of the push-pull topology notwithstanding. Robust tests are slightly challenging without a high-resolution FFT RF spectrum analyser, especially given arbitrary scaling and level control in software such as WSJT-X. Fortunately, the band and audio scope functions of the TS-890S receiver are sufficiently good to do the required calibrated checks although, as always, care is needed to avoid overloading the monitor receiver.

The narrowband tests reported here complement the wideband measurements shown in Figure 5. A TS-590S transceiver “drive” output (0 dBm) at 475.63 kHz was fed to the PA assembly, which was connected to a resonant Marconi “T” antenna. The very lightly coupled off-air signal was fed to a co-located TS-890S transceiver. Relative levels on the TS-890S bandscope were checked using switchable attenuators. Figure A1 show the results, in this case with a PA output of 120 W.

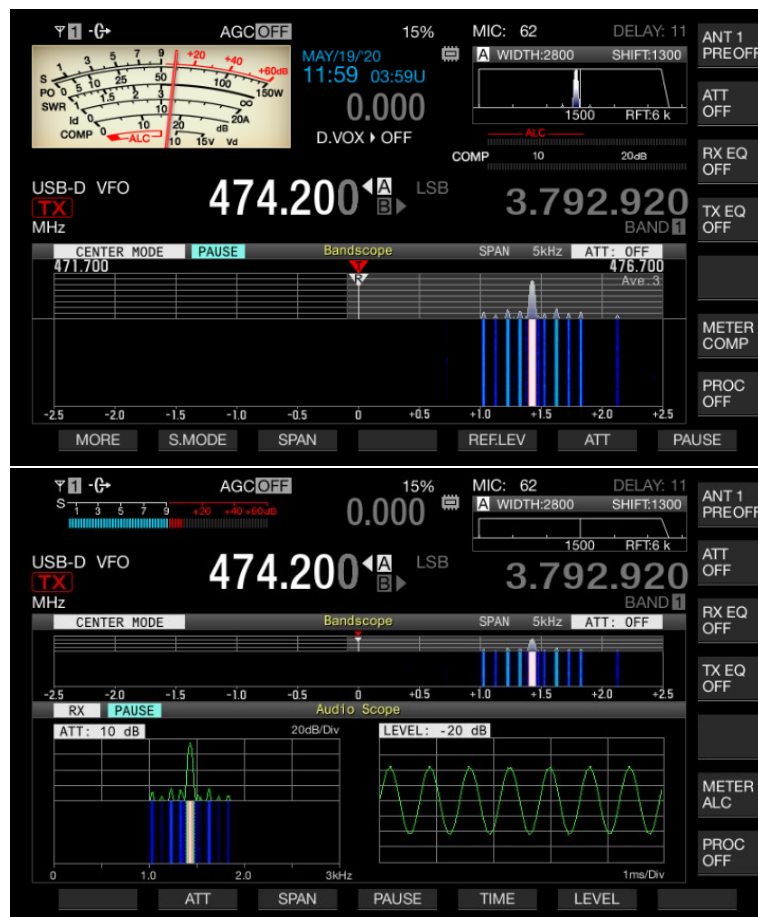


Figure A1. Off-air signals recorded at 475.63 kHz with the PA running 120 W output. The RF scope display is 10 dB/div, the audio scope is 20 dB/div, and the horizontal scales are 500 Hz per division. The data sets are similar, but not identical, in the two panels.

The results show that, while there is some power supply related noise in the form of multiples of 50 Hz offset from the carrier, these products are at a level of at least -55 dB relative to the wanted output. It is likely than a well-regulated, heavy duty, linear power supply would produce even better results but with the size, weight, cost and operational advantages of the Rek PSU, the trade-off is a reasonable one.