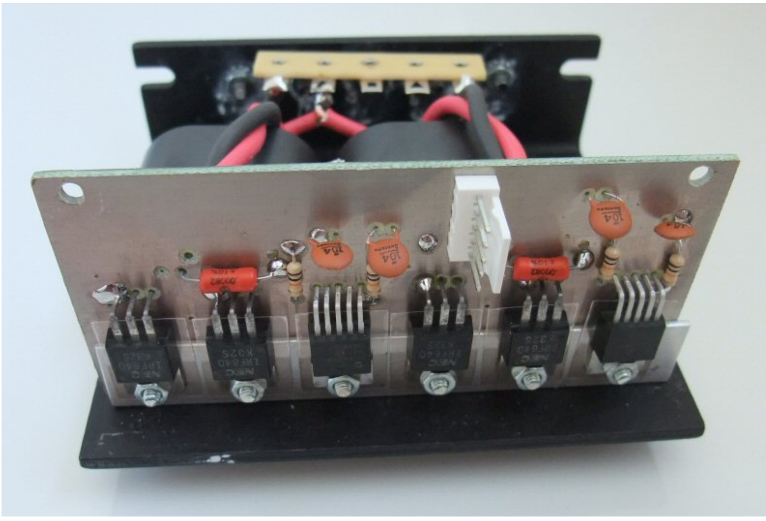
# FAT5 RF-PA Module
# Information Manual
# VERSION 1.0.0



**The FAT5 RF PA is part of the**
**FAT5 project, a Class E AM transmitter for 80m**

***This is a fully supported project.***
*Please contact the author at gw4gte@s9plus.com with any questions or problems before, during or after construction.*



**www.s9plus.com**

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# 1. Introduction

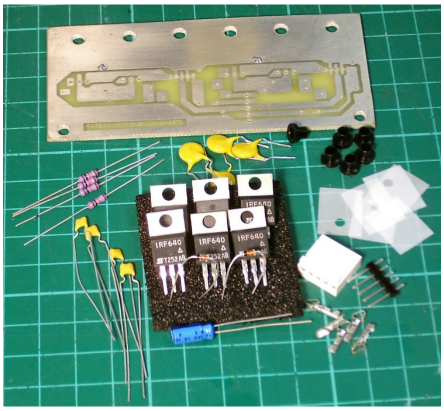


Figure 1.1 RF PA kit of parts

The FAT5 RF PA module is part of the FAT5 project, a Class E series modulated AM transmitter for 80m and other frequencies. It is based around a single PCB which contains components for accepting an anti-phase TTL drive signal and producing an output of at least 200W PEP. This power is tuned and matched to 50 ohms using external components not supplied in the RF-PA kit.

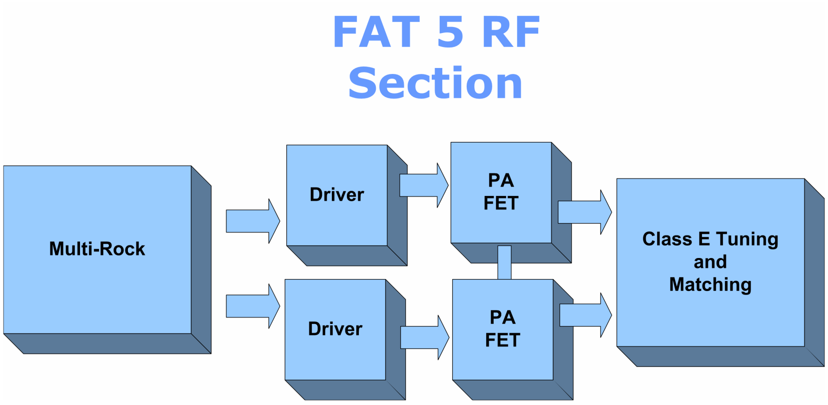



Figure 1.2 RF-PA block diagram

## Specification

**Frequency :** 80m amateur band (or 160m and elsewhere by changing tuning components)
[this version of the manual covers 80m operation]
**RF output:** 50W carrier, 200w PEP minimum
**Drive requirements :** 5V TTL level dual anti-phase inputs
**Power supply :** 8V @ 600mA for driver chips, up to 48V at 10A max for PA.

The RF PA module consists of a double sided PCB 100mm x 45mm

**What is supplied in the kit**
All components that are PCB mounted as shown in figure 1 below except the transorbs which are not needed at lower voltage levels where four FETs are used.

**Also needed**
Drive source, power supply, ferrite toroids, PA inductor and tuning capacitors, chassis/heatsink.

# 2. CIRCUIT DESCRIPTION

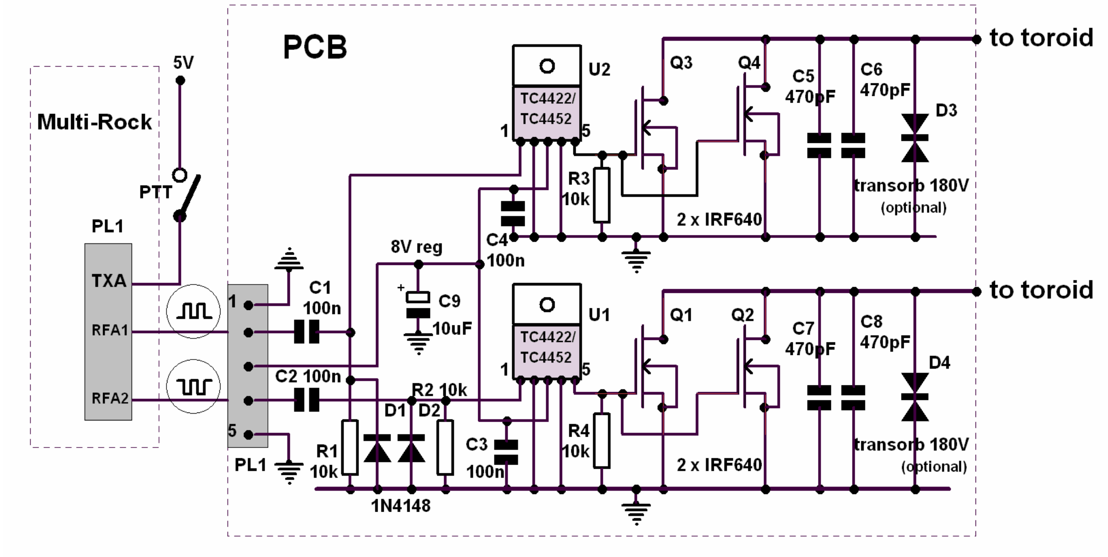



Figure 2.1 RF_PA circuit diagram (PCB only)

Anti-phase drive from Multi-Rock or another suitable source is fed via C1 and C2 to the inputs of U1 and U2. C1 and C2 provide DC isolation to keep the FET drive at zero volts when no drive is present. D1 and D2 are DC restoring diodes to clamp the 5V waveforms to a zero volt reference. U1 and U2 are non-inverting FET driver ICs that are capable of driving the input capacitance of Q1-Q4 at frequencies up to and above 3.8MHz. They are fed from a regulated 8V rail to ensure the output fully saturates the FETs and giving better modulation linearity. The drivers, and consequently the FET pairs are driven in antiphase. Using this sort of parallel push-pull arrangement gives a four-times increase in power over a single FET and reduces even-harmonics to negligible levels.

FETs in a saturated drive circuit can be successfully connected in parallel as they exhibit a positive on-resistance (RDS-on) temperature coefficient. Thus if one FET passes a greater current it will tend to heat up more, raising RDS-on and causing the other FET to pass more of the overall current thus restoring balance.

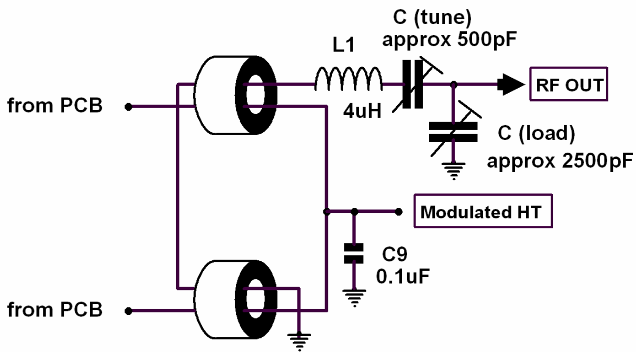



Figure 2.2 Transformer and PA tuning components

C5-C8, together with the output capacitance of the FETs form part of the PA tuning reactance. The capacitors also have the effect of reducing the voltage developed at the FET drains. C9 is an RF bypass capacitor. This is not on the PCB. **Don't forget to add it!**

Two ferrite transformers combine the output voltages in phase. L1, C(tune) and C(load) are external to the PCB as are the ferrite transformers. The PA tuned circuit is covered in more detail below.

# 3. CONSTRUCTION

**Before commencing construction**
Visually check the PCB for any etching or drilling errors. While all boards are carefully checked, as they are all made by hand a double-check is sensible. Providing they have not been used, any PCBs that are found defective in any way will be replaced free of charge on receipt of the defective board.

The FETs and drivers will require only modest heastsinking. Decide in advance how this will be achieved so the active devices can be correctly positioned.. As an example, using a length of right-angle aluminium strip (e.g. standard B&Q stock) sandwich the strip between the devices and the PCB carefully positioning the mica washers and collars appropriately. Attach the other edge of the strip to a suitable small heatsink or the side of the enclosure. Alternatively the FETs can be mounted vertically and attached to a heatsink without involving the PCB. An example is shown in figure 3. In still-air the heatsink will become quite warm, but with a modest airflow from a small fan the heatsink will feel cool to the touch. This was just a test setup and better passive cooling can easily be achieved.

**Assembly notes**
Solder all components using the component list in table 3.1 and the layout diagram in figure 3.1 below in any preferred order.

Several holes are countersunk. Where component leads pass through a <u>non</u>-countersunk earth plane hole to a pad on the other side, make sure you solder <u>both</u> sides as the leads act as wire links. The hole adjacent to PL1 pin 1 and the two holes shown between each pair of IRF640s have been riveted and soldered prior to dispatch

The companion header socket to PL1 will be supplied with crimping pins. These can easily be soldered instead if a suitable crimping tool is not available prior to fitting into the shell.

After construction the PCB will resemble that shown in figure 3.2 below. (Components supplied may vary)

| Component | Value | Quantity |
|---|---|---|
| | | |
| Resistors R1, R2, R3, R4 | 10k | 4 |
| | | |
| Capacitor C1, C2, C3, C4 | 100nF (104) | 4 |
| Capacitor C5, C6, C7, C8 | 470pF >500V | 4 |
| | | |
| U1, U2 | TC4422 FET drivers | 2 |
| Q1, Q2, Q3, Q4 | IRF640 TO220 FET | 4 |
| | | |
| Mounting kits | For U1,U2, Q1-Q4 | 6 sets |
| | | |
| D1, D2 | 1N4148 | 2 |
| D3, D4 | 180v Transorb (not supplied | 0 |
| | | |
| PL1 | 5 pin Header | 1 |
| SK1 | 5-pin header socket | 1 |
| | | |
| PCB | | 1 |

Table 3.1: Component list

**Inspect and Test**
Having completed the PCB assembly carefully inspect for solder bridges, especially around PL1, U1 and U2. Follow up the visual inspection with DC checks if in any doubt. It should be obvious from the circuit what readings are to be expected.

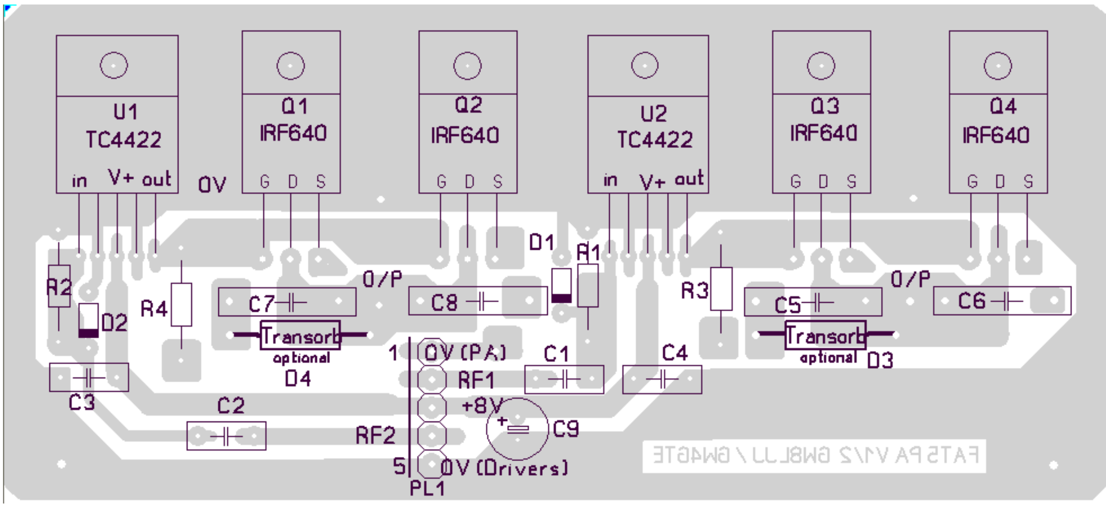



Figure 3.1. Layout diagram

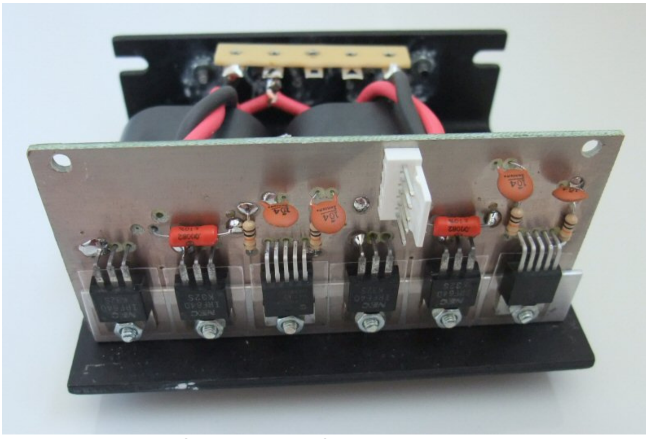


Figure 3.2 Completed PCB mounted via aluminium angle to small heatsink

# 4. RF TRANSFORMER

The RF transformer is actually two separate transformers. Each transformer primary is driven by one pair of FETs. As the FET-pairs are driven in anti-phase the primary windings are in anti-phase. The transformer secondaries are connected in series with one winding reversed so that the outputs combine in-phase.

## RF transformer – choice of ferrite

A ferrite transformer is used to phase the two push-pull PA halves into a single secondary in a space-efficient manner. Two types of ferrite core have been found to work satisfactorily (i.e. good linearity and low loss). Both are currently obtainable in the UK. The Type 43 oval core supplied by Farnell, part number 146-3420 is shown in figure 4 above. Maplin N90AB toroids also work well. These are circular cores of similar size to the oval ones. The type of mix is unknown. Builders are expected to source their own ferrites but these may be available along with the main kit (at extra charge) – please enquire.

## RF transformer – winding details

The two transformers are identical. They are wound separately then joined togther. Each consists of two turns bifilar wound. i.e. two passes through the core with primary and secondary wires twisted together to ensure good coupling.

Getting the transformers right is essential, and in order to avoid confusion a pictorial walk-through of their construction follows:

**1.**

Twist together two pairs of wire

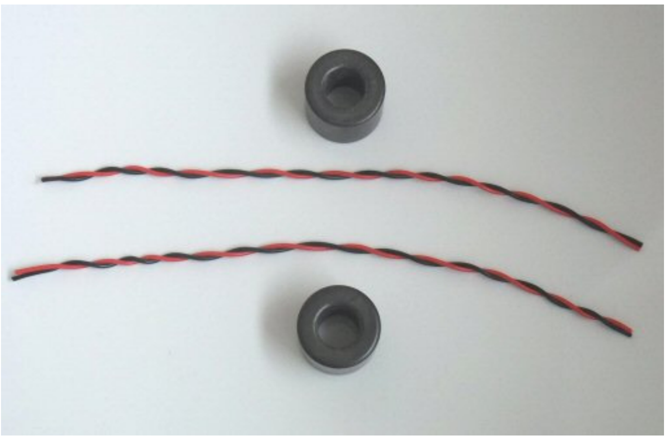


Figure 4.1

**2.**

Pass the wires through the cores making one turn i.e. one pass through the core

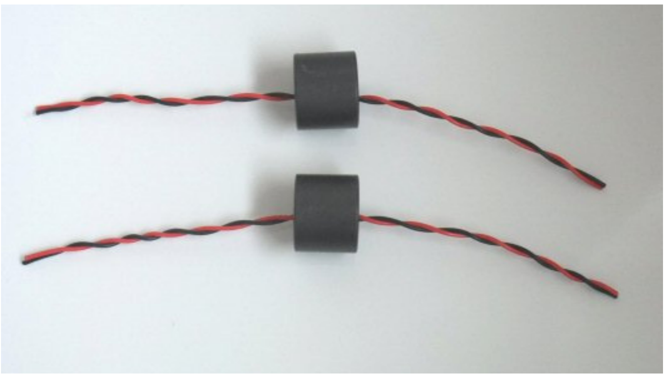
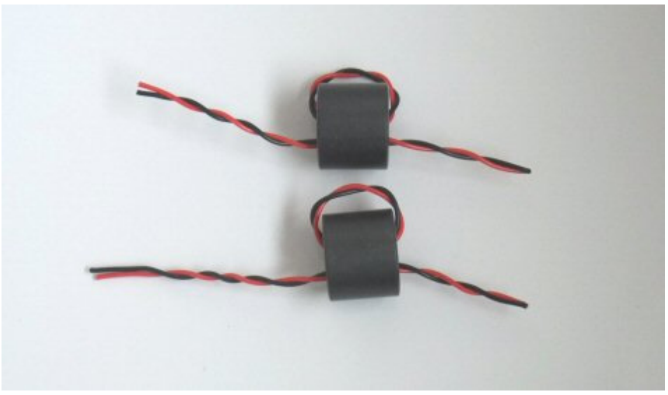


Figure 4.2

**3.**

Loop the wires through the core a second time making two turns i.e. two passes through the core

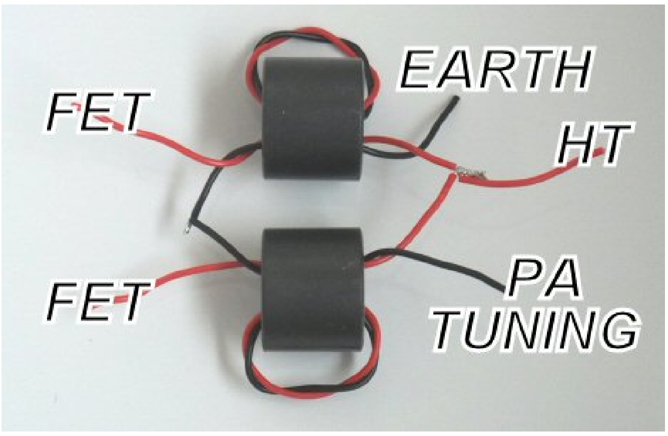
Figure 4.3



**4.**

Connect the wires as shown. The loops have been left loose for clarity.

Figure 4.4




| |
|---|
| Don't forget to decouple the HT feed point to earth with a 100n (0.1uF) capacitor |

## RF transformer – choice of wire

The usual rule of thumb for RF wires applies – the thicker the better. The same 2.5 mm sq mains cable recommended for the tuning coil is fine (this time with the insulation left in place). Twist the pairs as tightly together as possible to improve coupling. Use stranded or solid. Stranded is easier to handle.

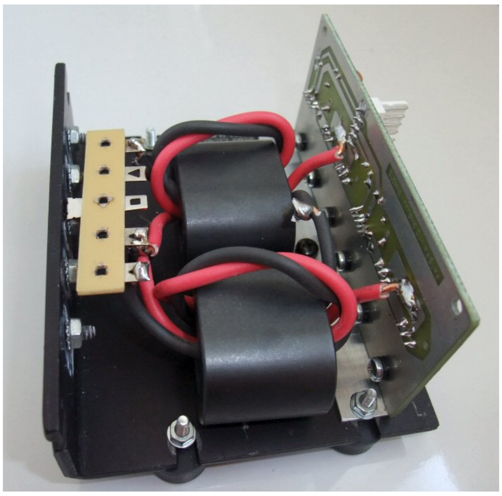


Figure 4.5 Completed PCB on a small heatsink, also showing a view of the toroid cores.

# 5. PA TUNED CIRCUIT

The PA tuned circuit is a conventional impedance matching arrangement. It has to work hard converting the low impedance output of the FETs up to 50 ohms. Additionally it is responsible for establishing the correct phase relationship between voltage and current around the PA tank. Class E achieves high efficiency by minimising FET switching loss. This is done by adjusting the tuning such that when the FETs switch, the voltage across them is close to zero. Because of this requirement a different tuning method must be adopted and monitoring the FET drain waveform shape is essential when initially setting up. More on this later.

## PA coil – winding details

The PA coil L1 has a measured out-of-circuit inductance of 4uH. Any reasonable sized coil exhibiting this inductance should work, with the usual comment that the greater the cross-sectional area the lower the resistive loss. For builders without the benefit of an inductance meter the following coil dimensions are suggested. The tuning description below was developed using this coil. Use a former slightly smaller in diameter as the coil will expand when released. Experiment on a short length of wire first.

**Material**: e.g. live or neutral of 2.5mm-sq mains cable with insulation stripped. (This equates to about 15/16 SWG. Thicker is even better, but avoid anything less than 18SWG or 1mm dia)
**Length of wire** : 1.9m to leave spare at each end.
**Number of turns**: 19
**Inside diameter of coil**: 30mm
**Overall coil length** : 75mm

Altering the value of L1 has an effect on the tuning characteristics. An inductance of 4uH gives a high power output with low DC voltages. Increasing the value of L1 will lower the drain current at the tuning point, hence more volts are required for the same power. With some experimentation one can set the power output to match the psu available.

Figure 5.1 below shows a less than perfect example of the 4uH coil described. It is just strong enough to be self supporting, although some extra support at the mid-position would improve rigidity greatly. Keep the coil air-spaced for best cooling.

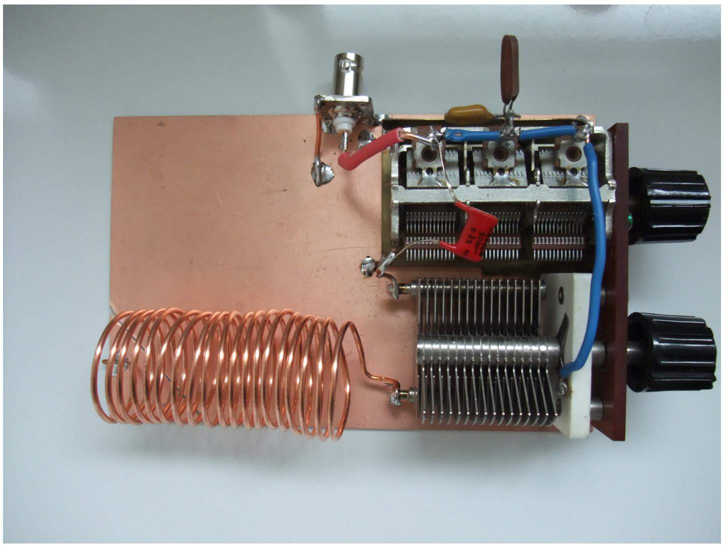


Figure 5.1 PA coil and capacitors

C(tune) and C(load) (also shown in the above photo) are air-spaced variable capacitors rescued from an old valve HF rig. C(tune) is padded with a 500pF mica capacitor. C(load) is padded with a 1n8 mica capacitor.

# 6. PA TUNING

## PA Tuning - introduction

Now on to the most important part of the whole thing, the Class E PA tuning.

To summarise, a Class E amplifier achieves high efficiency due to the fact that when ideally tuned there is no appreciable time overlap between the above-zero voltage applied to the FET drain and the above-zero current flowing through it. Obviously there must be volts for current to flow – the flywheel effect of the PA tuning produces this. The point is that when the FET changes state from on to off or vice versa, the source-drain voltage is almost zero, so no appreaciable power is lost as heat as the FET switches. To achieve this, the PA is tuned for the required phase relationship between Volts and current. There must be a reactive element present to achieve this, so conventional resonance tuning resulting in a purely resistive impedance transformation won't work.

The question then is how to establish the correct tuning point. The correct tuning point is reached when the circuit is working at its maximum efficiency for a given power level.

## PA Tuning - method

This section describes the PA tuning method and the author cannot over-emphasize the importance of following this procedure. Ignoring it is the sure way to a big shipment of replacement FETs!

The traces below are from the author's test transmitter and are typical of what can be expected.

**Equipment needed**

- Oscilloscope with Y response better than 20MHz
- Variable-voltage 5A power supply (0-14V), preferably current limited.
- Ammeter with 5A FSD if not integral with PSU
- In-line wattmeter e.g. Bird thruline with 50H or 100H slug
- 50 ohm dummy load
- General purpose Multi-meter
- Suitable signal from Multi-Rock or other anti-phase drive source

**Preparation**

(__) Supply power to the FETs via a variable voltage supply. We will be using no more than 6 volts at this stage. Place an ammeter in series with the supply (5A FSD would be ideal, but at least 2A FSD). Turn the voltage output to zero.

(__) Connect the TX output to a 50 ohm dummy load via a Bird thruline or other wattmeter. If using a Bird wattmeter the 50H 50W HF slug is ideal.

(__) Set C(tune) and C (load) to maximum capacitance.

(__) Apply an oscilloscope probe to the drain connection of one pair of FETs. It may help to solder a small off-cut of wire to a FET drain connection to act as a test pin for the 'scope probe. Set the Y input to AC, 5V per division and the timebase to 50ns.

**Tuning**

(__) Apply drive to the FETs, and slowly increase the drain voltage watching the current closely. Stop at 6 volts. The current should be quite low, well under 500mA. The wattmeter may read a few hundred milliwatts.

(__) Observe the oscilloscope trace, which should resemble the image opposite. Note the waveform is reasonably symmetrical and around 20V in amplitude. Any ringing especially on the baseline is of no consequence. You may observe a slight knee on the bottom of the trailing edge of the waveform.

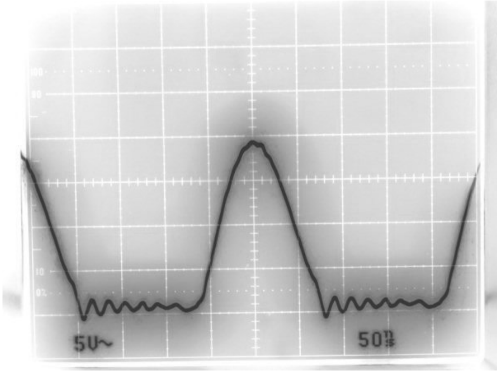



Figure 6.1

(__) With C(load) still at maximum C, slowly decrease C(tune) until the drain current increases to 1 A. The power output will increase along with the pulse amplitude. The pulse should start to narrow slightly.

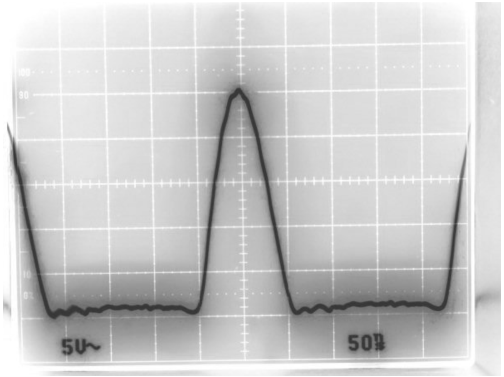



Figure 6.2

(__) Now decrease the value of C(load). The output power should increase, along with the drain current. Note also the waveform shape. The lower part of the trailing edge will start to round off as it approaches the baseline.. Note the drain current and power output which should typically be 1.5 A and 8 watts respectively. At this point the PA should be close to on-tune. *Note how the ringing has ‘settled down’.*

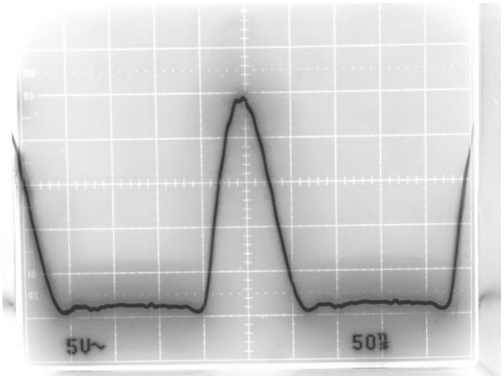



Figure 6.3

(__) Continue to slowly decrease C(load) watching the waveform. Observe the lower trailing edge start to form a sharp peak then increase C(load) again to just remove this condition.

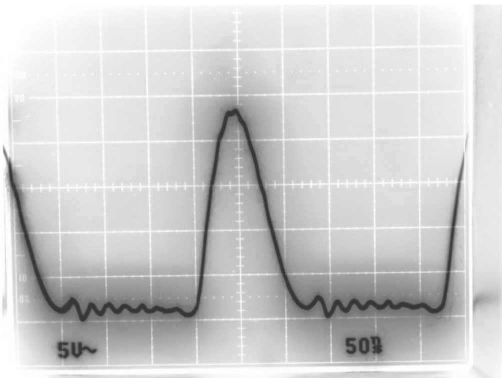



Figure 6.4

(__) As a further experiment to get a feel for the tuning, decrease C(tune) watching the waveform. Observe the lower trailing edge again start to form a sharp peak then increase C(tune) to remove this condition. The effect is more pronounced compared to varying the load capacitor in the previous test.

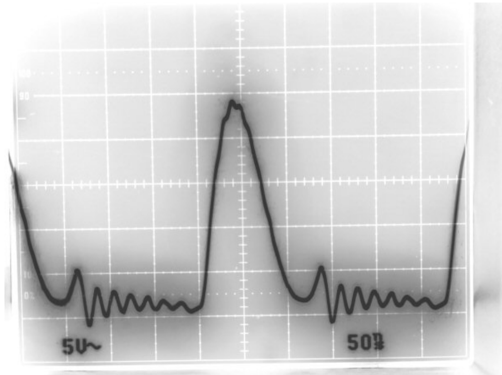


Figure 6.5

(__) Work out the PA efficiency by calculating the DC input watts and comparing with the RF output watts. For example 9 watts RF and 12 watts DC input gives an efficency of 9/12 x 100% = 75%.

(__) From this point a certain amount of trial and error will result in the best tuning point (best efficiency) being obtained. Vary C (tune) and C (load), all the time monitoring the current and RF output. There is no sudden 'sweet-spot' and quite a wide range of tuning will produce a similar efficiency. The circuit should be producing around 10 watts RF for around 6 V DC and 1.9A drain current, Efficiencies of 85% and greater are achievable.

(__) Now start to increase the power supply voltage leaving the capacitors in the same position. Stop at 9V and check the efficiency (it may have reduced slightly as the increase in voltage alters the FET characteristics a little). If all seems well increase the power supply voltage to around 13V. It should be possible to achieve 50W RF output at good efficency with no more than 14V.

The 'official' specification for this PA module is 50W carrier for <14 V drain voltage. At this level a fully modulated HT will give 200W PEP with excellent linearity. Experimenters may discover this is a conservative figure and significantly more power can be obtained by increasing the voltage.

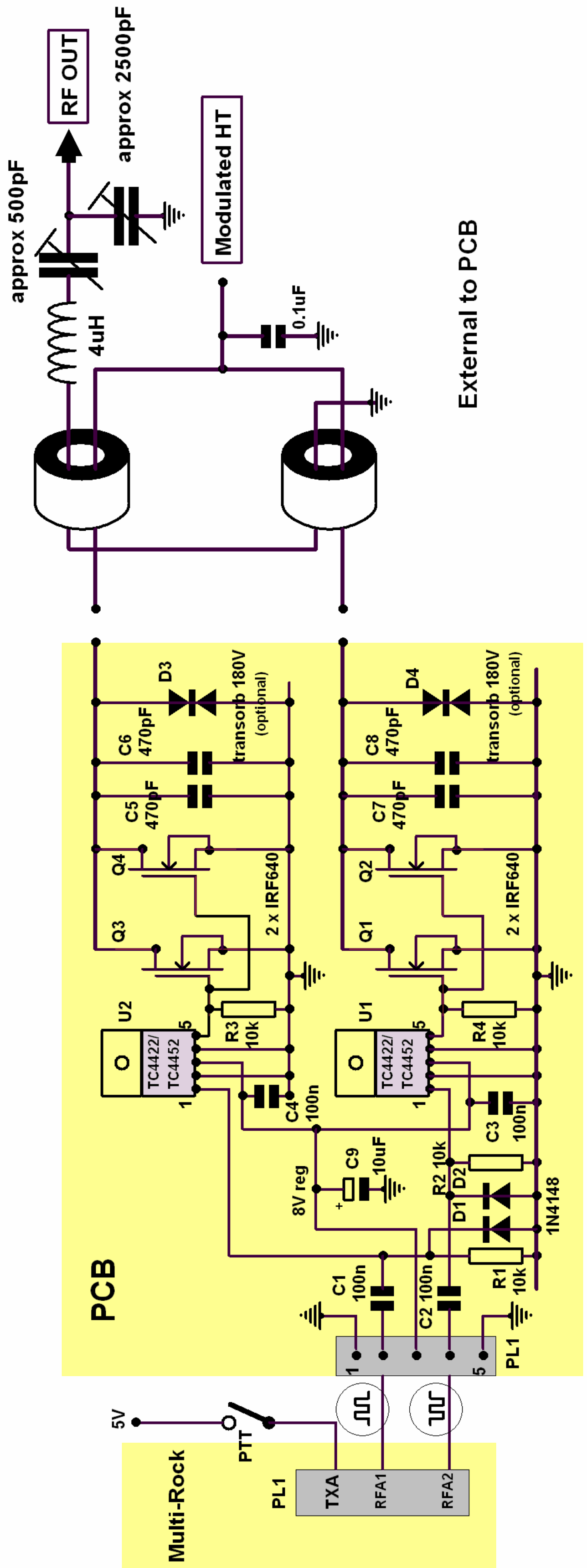
## PA Tuning – bandwidth

Once set up on say 3615, the circuit will require no retuing for small variations in frequency. The followng tests were performed with the PA hardware pictured in this document.

Conditions: Tuned for 25W carrier on 3615. No retuning.

3600 : 28W
3615 : 25W
3650 : 20W (or 25W -1dB)

That makes sense. The lower power on 3650 is due to the capacitor values being effectively too large at the higher frequency thus reducing the loading. The converse being true on 3600. No harm will be done letting the power reduce, but letting it rise obviously draws more drain current and may over-stress things depending on psu and heatsinking used. With larger changes of frequency the waveform shape will eventually fall apart with a rapid drop in efficiency, but that's not likely to happen within the AM band segment.


RF OUT
approx 500pF
approx 2500pF
4uH
Modulated HT
0.1uF
External to PCB
PCB
D3
D4
C6
470pF
C5
470pF
C8
470pF
C7
470pF
transorb 180V
(optional)
Q3
Q4
Q1
Q2
2 x IRF640
U2
U1
TC4422/
TC4452
R3
10k
R4
10k
C4
100n
C3
100n
C9
10uF
8V reg
R2 10k
D2
D1
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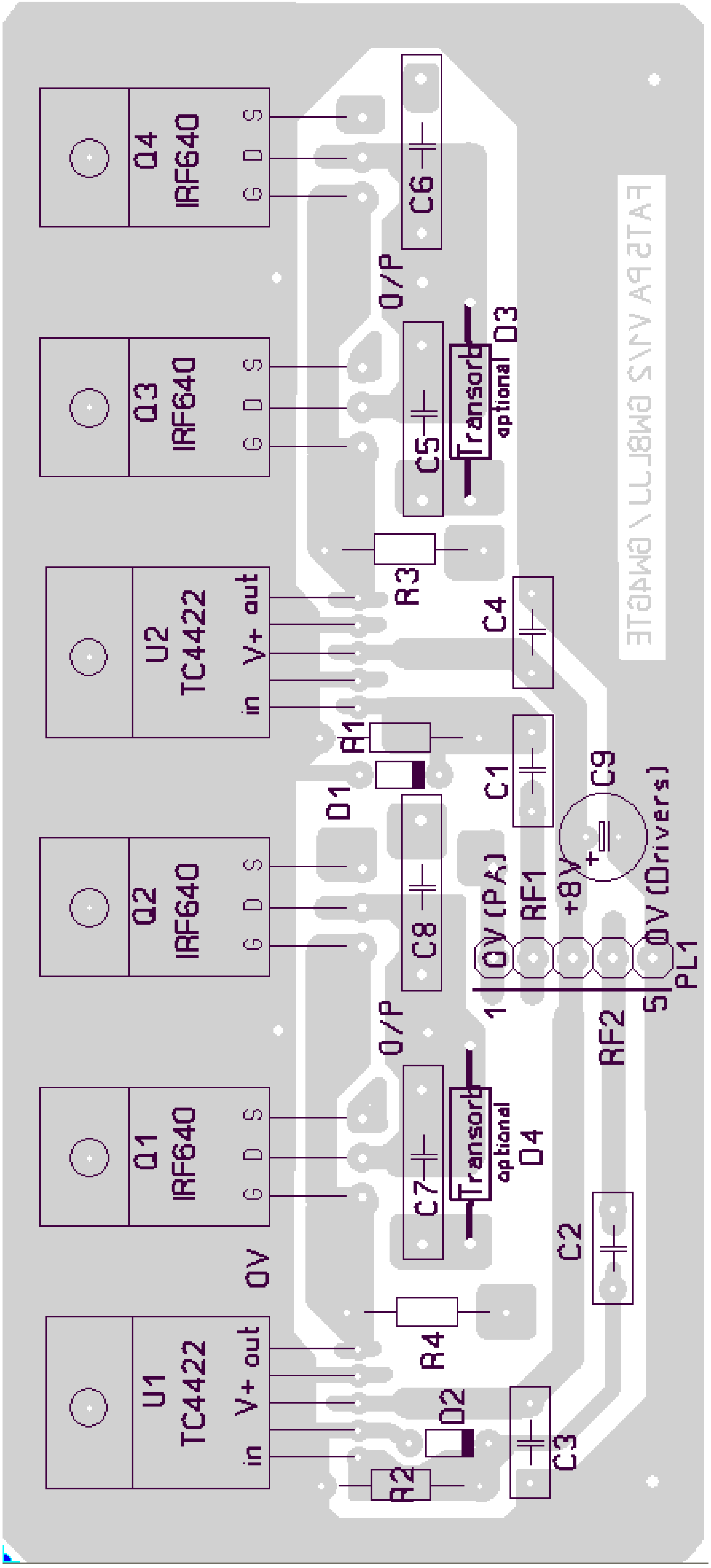
TXA
RFA1
RFA2


Q4
IRF640
G D S
C6
O/P
D3
Transorb
optional
Q3
IRF640
G D S
C5
R3
U2
TC4422
in V+ out
C4
R1
C1
C9
D1
Q2
IRF640
G D S
C8
0V (PA)
RF1
+8V
0V (Drivers)
PL1
1
5
O/P
RF2
Q1
IRF640
G D S
C7
Transorb
optional
D4
C2
0V
R4
U1
TC4422
in V+ out
D2
C3
R2