A High Gain 5.76 GHz Power Amplifier.

The traditional approach to building a 5.7 GHz transverter is to use a commercial transverter that generates about 200 mW (23 dbm) power, followed by a power amp with a couple of transistors to bring the power up to the level of 4W, or 8-10W, or even higher. In the authors’ case, a different approach to the design was decided on. This was to take the direct output of a mixer (heavily filtered to ensure that no out-of-band products were present) and build a high-gain PA to generate in the region of 4 to 10 W (36 to 40 dbm). In this case the required gain was of the order of 45 db (mixer output at onset of compression is expected to be about -3 dbm). The design and implementation of this amplifier are described in this article.

1. Selection of Transistor and MMIC types.

A spreadsheet was built up to allow rapid comparison of several transistor and MMIC types in the line-up of a complete amplifier. Using GaAs FET devices alone, either 4 or 5 stages were needed to obtain the required gain. By using a high-gain, 1W MMIC as the driver, the number of stages could be reduced to 3.

The final transistor should be selected first, and it is most likely to be a matched device such as a TIM xxxx, FLM xxxx -04 or -08 or MGFC36 or 40 xxxx device where xxxx = 5359 or similar. In the authors case an MGFC36V7177 device was used (36 dbm or 4 watts, for use between 7.1 and 7.7 GHz). The -5359 devices can likely be used without extra tuning, but others will require tuning by adding copper snowflakes. This type of transistor has about 9 to 10 db of gain, so needs between 0.4 to 1.0 watt of drive. The author has found that these transistors generally give about the specified gain and power at a lower frequency than they are specified for, if they are re-tuned by external means.

A Transcom TC3531 1W MMIC was chosen as the driver. It has 22 to 24 db gain, and much simplified bias arrangements compared to discrete solutions. The operating range is 5.7 to 5.9 GHz minimum. The only complication for home construction is the mounting / heatsinking arrangement. The pre-driver that was chosen was an RFMD NLB400 device, which has about 10 db gain and can easily supply the needed few mW to drive the TC3531 device. Other similar devices could be used.

The PA GaAs FET devices can often be found on e-Bay for attractive prices, or can be bought new from suppliers such as RF-Elettronica in Italy. Often they can be re-claimed from microwave links that have been taken out of service. The Transcom TC3531 and RFMD NLB400 devices can be purchased over the net from Minikits in Australia. In the authors’ case, the devices were delivered by post exactly 1 week after purchase.

2. Circuit topology.

The RF parts of the circuit are in principal very simple – the active devices, coupling capacitors and 50 ohm transmission lines, with plenty of space for adding “snowflakes” of copper for tuning the amplifier in the vicinity of the final PA transistor. As the final device is often not specified for use at 5.7 GHz and there are no S-parameters or similar data available covering this frequency range, there seemed little point in adding matching sections to the original PCB artwork. The power supply, protection and bias are very much as have been used in a large number of 2 stage amps by DB6NT, F1JGP and others. In this design, an additional LM7808 regulator is added after the LT1085 10.5 V regulator to reduce the power dissipated in the series resistor for the TC3531 MMIC. The regulator only has 2.5 V between the input and output, but this is just within its rating. About the only critical components are the interstage coupling capacitors, they should be special microwave porcelain types such as ATC type 100. The values specified have their series resonant frequency above the 5.7 GHz operating frequency.
The schematic was captured using the Eagle CAD tool, which has been used by the author for several conventional and microwave board designs for some years. The tool can be obtained either free (for small sized boards up to 100 mm by 80 mm), low cost for boards up to 160 mm by 100 mm, and private use or higher costs with unlimited board size and unlimited use. Several PCB manufacturers accept the files from the tool directly or conventional Gerber and Drill files can be output. You can also print up the files yourself and make the boards (e.g. by using direct laser toner transfer to the PCB) at home. Using the laser toner transfer process and home etching for a small board such as this power amplifier takes about 1 hour total.

Of course the tool has no microwave layout design aids. But you can make components easily. For example if you choose the PCB material (The author uses Rogers 7880 material, 15 mil (.015 inches) thickness), you can design simple objects such as 50 ohm input and output pads, transistor packages with 50 ohm pads for Gate and Drain, 5.7 GHz quarter wave bypass shorts, mitered bends and a modified 0805 capacitor package where the pad widths match the 50 ohm transmission line width. You don’t need much else for this kind of amplifier, apart from the conventional parts which are generally found in the inbuilt libraries.

The directional coupler used on the output was designed to have 30 db coupling in the forward direction by calculating the needed Odd and Even mode impedances for a quarter-wave coupler from the normal design formulae, and then using the Rogers Microwave synthesis tool for coupled microstrip lines in an iterative way to determine the needed width and spacing of the two lines. The design was then checked by plotting the coupled port response using the APLAC analysis tool, which indicated that the coupling would be -29.5 db, close enough for a monitoring coupler.

![Figure 1. Schematic of 5.76 GHz Power Amplifier, showing nominal operating voltages.](image-url)

The milled aluminium enclosure was bought at an SHF flea market, and was designed for the normal 2 transistor PA line-up used at 5.7 GHz or 10 GHz. The final transistor was a direct match for the housing, so it was a matter of ensuring the PCB matched the physical position in the housing for that stage. Advantage was taken of the slot milled for the driver transistor (1.3 mm deep) to place a copper heat spreader for the TC3531 MMIC directly under the chip.

The TC3531 MMIC is designed to be mounted by soldering it to a PCB where there are a large number of via’s directly under the chip. These must be filled with solder to improve the conductivity in order to provide adequate heatsinking for the chip, which dissipates about 4 watts in the quiescent state, a bit less when driven. This presents rather a challenge for the home constructor, where through-hole plated via’s are not normally possible. The author considered several schemes before finally coming up with a solution which seems to work pretty well, and which basically only requires accurate drilling and soldering skills.
Figure 3 shows a cross-section of the MMIC, PCB and copper heat-spreader. The copper heat spreader was printed with the layout of the via’s under the MMIC plus the mounting holes. Then all the holes were drilled in the heat spreader, including the mounting holes which were drilled at 2 mm diameter at this time. The PCB was then drilled for all other areas, plus the mounting holes for the heat spreader at 2 mm diameter. The PCB and heat spreader were attached together with 2 mm nuts and screws, and the holes in the PCB drilled using the heat spreader as a guide. This ensures that they line-up quite accurately. After cleaning-up the heat spreader and PCB for any burns left from the drilling process (600 wet-and-dry paper with water), a coating of liquid flux is given to the heat spreader and the underside of the PCB where the heat spreader is placed, the two are lightly attached with screw and nuts made from stainless steel or other non-solderable material, and the rivets inserted from the track side of the PCB. The rivets are soldered on the track-side of the PCB, leaving some solder on the PCB under the place where the MMIC will later be attached.

Then the rear side of the PCB plus heat spreader is soldered together, using a rosin-cored solder and soldering iron(s) of sufficient capacity to heat the whole area. Apply the iron(s) to the heat spreader only. If everything was clean and well-fluxed, you will see the solder flow suddenly under the heat spreader, filling all the spaces when the temperature is correct. At this stage trim-off the excess length of the rivets (a sharp knife can be used, makes less mess than using a fine file), and drill-out the mounting holes to 2.5 mm.

The next step is to mount the TC3531 MMIC in place, this is the only device mounted on the PCB before mounting the PCB in the housing. The MMIC is first placed carefully in the correct position, after applying liquid flux to its gold coated base. A stiff bracket (for example a 0.5 mm copper spacer with two holes matching the already-made heat spreader) is placed on top of the MMIC package, and the PCB plus heat spreader, MMIC and bracket are held together with non-solderable 2.5 mm screws and nuts, with several alternated spring washers and plain washers under the nuts securing the bracket in place. The goal is to keep the MMIC in place and allow sufficient “springiness” in the mounting that it is always forced lightly to the PCB when the solder under it melts and flows. Don’t tighten too much ! Don’t solder any of the MMIC pins until the soldering of the underside is done ! When all is correctly placed, heat the heat-spreader from the backside of the PCB with a soldering iron(s) until the solder clearly flows. Wait a few seconds, then check the solder under the MMIC. It should also flow, the MMIC will settle on the rivet tops, and the space under will be filled with solder. There is no need to heat the track-side of the PCB or use hot air, to correctly attach the MMIC. The rivets filled with solder provide sufficient heat transfer to the track-side of the PCB to melt the solder and heat the MMIC underside to a temperature sufficient to allow good soldering to take place without excess thermal stress. After all they have to cool the MMIC in normal operation !

After this operation is complete (you can re-heat if the solder hasn’t flowed under the MMIC), solder the earthed pins of the MMIC in place. This is more easily done before mounting the PCB to the case, requires less heat ! Then mount the PCB into the case. If you have a 1.3 mm deep hole where the MMIC is, and use 0.8 mm copper, you will need another 0.5 mm copper piece to keep everything level. It’s the same shape as the heat spreader attached to the PCB, only needs two 2.5 mm holes in it. Now build the amp. as you normally would. The power/bias supply should be built in stages and checked, before adding the RF devices. Set the gate bias to about -2.5 volts for each device, whilst you are doing this checking.

After the RF devices are in place (or connected in the case of the TC3531 device), connect the amplifier to a 50 ohm dummy load or power meter via a power attenuator suitable for operation at 5.7 GHz, apply the 12.6 V supply and adjust the bias on the driver and final amplifier to give about 0.5 amp current through the TC3531 and 1.2 amp through the final transistor, if it is a 4-5 watt device. The current can be measured by measuring the voltage drop on the protective drain resistors R10 and R12. Then apply some small amount of 5.7 GHz signal to the input (under 1 milliwatt) and if you are using pre-matched devices for 5.7 GHz, check that the amp. is performing correctly. If you are using a device intended for other frequency ranges, add the needed copper snowflakes to optimize the performance, starting
with the gate of the final transistor, then moving to the drain, then back to the gate. Before placing the lid on the box, make sure it is lined with a suitable microwave absorber material. The amplifier will oscillate (45 db gain !) for sure if you don’t.

Figure 3. Milled aluminium case with all holes drilled and tapped (including relief holes where the through-hole connection rivets are placed) PCB etched and drilled, the drilled copper heat spreader for the 1W driver MMIC, the driver MMIC and some of the 0.8 mm OD copper rivets before assembly.

Figure 4. Completed Amplifier mounted on heatsink, with copper snowflakes added during the tune-up. The final configuration had small additional snowflakes added to the drain circuit.
5. Results.

The final measurements of the PA after tuneup, with the cover attached to the enclosure, are as below:

Power Output at onset of saturation was 37 dbm (5 watts).

DC current drain at max signal out was 1.70 A at the 12.6V supply.

The amplifier gain was measured at 44 db in the linear region (up to 4W output).

The monitor voltage was 0.27v DC at 5W output and 0.22v at 3.4W output.

6. Acknowledgements, References and Notes.

The author wishes to thank Michael, OH2AUE for the many discussions, stimulating ideas and “junk parts”. Without his assistance and enthusiasm this project probably never would be started.

Ideas used in the design of the amplifier came also from many others such as the products of DB6NT, ARRL and RSGB publications such as the Microwave Handbooks and Microwave Projects. There is not much here that has not been seen before.

1. RSGB Microwave Projects 2, . Edited by Andy Barter, G8ATD. Chapter 3, “Power Amplifiers”

2. Transcom Inc. Private communication and updated data sheet for TC3531 MMIC.

3. Mitsubishi data sheets for MGFC36V7177A GaAs FETs.


5. In Finland, Step Systems Oy in Lahti is a source for small copper rivets in small quantities (1000), also small amounts of 0.1 mm, 0.5 mm and 0.8 mm copper sheet. The rivets are not a standard catalogue item, but can be ordered through them.