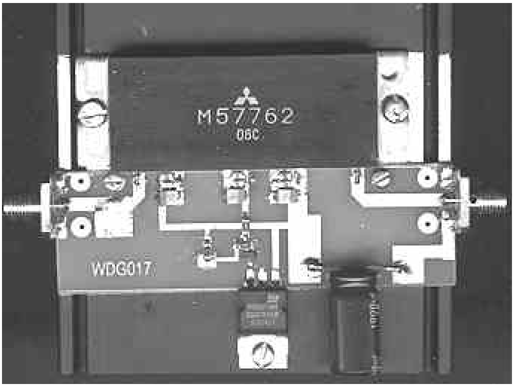
Chapter 5

Power Amplifiers

TheWDG017 20W 1.3GHz Linear Amplifier

by Charles Suckling, G3WDG



Editor's note

This design is now obsolete as the module is no longer available, but these amplifiers and modules appear from time to time on the surplus market , so worth publishing as an example of a good design before we move on to the module's replacement.

The WDG017 20W PA uses the well-proven Mitsubishi M57762 power module which is designed to cover the whole 1.3GHz band. The power seems to peak around 1260MHz and the module still works very well at 1296MHz. The WDG017 employs a transistor switch to enable the PA to be shut down during receive periods, to save energy and lower the heatsink temperature.

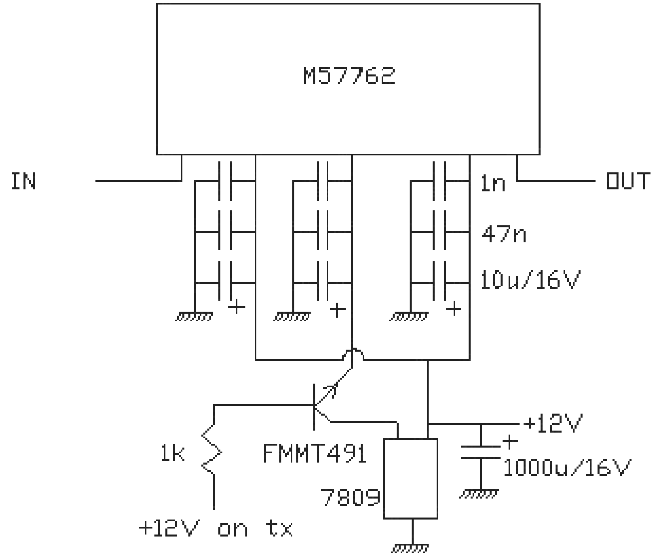
Construction

The original prototype was constructed using a commercial heatsink as the chassis. The heatsink measured 80 x 100 x 30mm (Farnell 738-906) and the construction notes refer to the use of this heatsink. Other prototypes have been built on a 6mm (or 0.25") thick aluminium plate as the chassis.

This has some advantages, in that any heatsink out of the junk-box can be used (provided it is big enough!), or the plate may be water-cooled. In these cases the plate chassis is just screwed on to the main heatsink. Also, most aluminium plate is easier to work than the metal used to make heatsinks, which tends to be rather soft, and there is no need to scrape off the anodising (a rather tedious operation!).

1. For 1W PA, cut heatsink to size (45 mm). 18W PA uses full size heatsink.
2. Drill and tap holes for securing the module to the heatsink. Refer to assembly diagrams for location of holes. Drill 2mm and tap M2.5 (1W), drill 2.5mm tap M3 (18W).
3. Temporarily, fit module to heatsink.
4. Locate pcb onto heatsink - refit and tighten module screws so that pcb aligns to edges of heat sink without

circuit diagram



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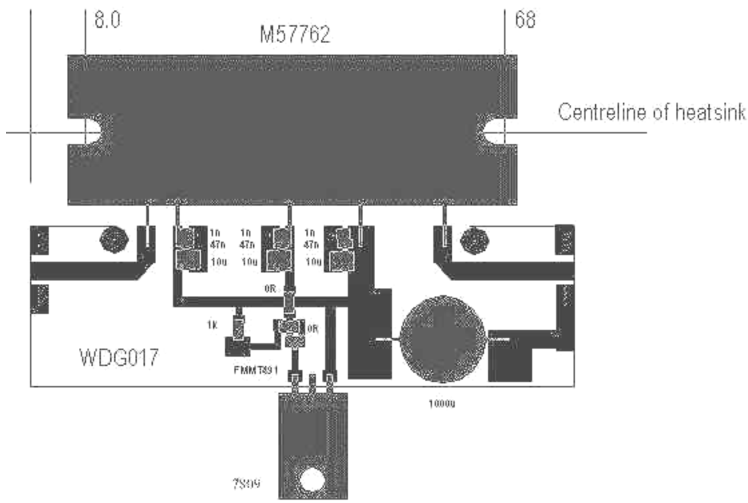

under/overlap and module pins align to tracks on pcb.

5. Temporarily, sellotape pcb in place and drill through holes in pcb either side of RF lines part way in to pcb (to make drill location holes).

6. Drill through heatsink in marked places 1.6mm diameter and tap M2. Drill carefully, with lubricant, to avoid breaking drill. Also tap with lubricant.

7. Open holes previously drilled through in pcb to 2mm dia.

8. Fit pcb temporarily to heatsink with M2 screws.

9. Locate voltage regulator and drill 2.0mm hole and tap M2.5 for its fixing screw

10. Locate connectors and drill/tap heatsink for retaining screws. Use 2 x M2 if using SMA types.

11. Skip 12-14 if using plated through hole pcb

12. File ends of heatsink to allow clearance for ground pins

13. Drill through grounding holes in rectangular pads near module leads to mark heatsink (6 places) and drill these out a few mm into the heatsink to sufficient diameter (4mm suggested) to give clearance to ground pins and associated solder fillet).

14. Fit veropins to pcb, heads on ground plane side, cut to leave about 1mm protruding on pcb side,
and solder to both sides. File excess solder off heads on ground plane side. Keep solder fillet within confines of blind relief holes or scrape off excess so board still sits flat on heatsink.

15. Scrape anodising off heatsink under pcb and module area.

16. Reassemble pcb to heatsink and fit connectors. Solder connectors to ground strips on track side of board using decent sized iron. If you have only a small iron, preheat the heatsink to 150C approx and while hot make the solder joints.

17. Mount other components including the module to pcb.

Testing and using the PA

Apply volts, apply drive and you should have output! Performance of one of the prototypes at 1300MHz is shown below. The data sheet for the M57762 quotes an absolute maximum supply voltage of 17V, and that the device should survive a 16:1 VSWR with a 15.2V supply at 18W output power. For most applications, a supply voltage up to 14V is recommended. If equipment is available to measure the input VSWR, a small improvement may be possible by adding a tuning tab to the input line (see photo at the beginning of this article).

It is recommended to shut down the PAs on receive. This can be done by removing the 1k resistor and applying +12V on transmit via a 470R resistor to the pad previously connected to the bottom end of the 470R resistor. On receive, the lack of a voltage effectively shuts off the module.

Vcc=12V				
Pin (dBm)	Pout (dBm)	Pout (W)	Gain (dB)	Icc (A)
no rf				0.66
20.0	37.67		17.67	2.24 (small signal operation)
24.2	40.95	12.5	16.75	3.25 (1dB gain compression)
27.0	41.96	15.7	14.96	3.85 (near compression)
Vcc=13V				
Pin (dBm)	Pout (dBm)	Pout (W)	Gain (dB)	Icc (A)
no rf				0.68
20.0	38.47		18.47	2.39 (small signal operation)
24.3	41.72	14.9	17.42	3.48 (1dB gain compression)
27.8	42.86	19.3	15.06	4.27 (near compression)
Vcc=14V				
Pin (dBm)	Pout (dBm)	Pout (W)	Gain (dB)	Icc (A)
no rf				0.70
20.0	39.05		19.05	2.45 (small signal operation)
24.5	42.5	17.8	18.0	3.70 (1dB gain compression)
28.6	43.8	24.0	15.2	4.69 (near compression)
Vcc=15V				
Pin (dBm)	Pout (dBm)	Pout (W)	Gain (dB)	Icc (A)
no rf				0.67
20.0	39.2		19.2	2.50 (small signal operation)
24.8	42.98	19.9	18.2	3.87 (1dB gain compression)
28.2	44.06	25.5	15.9	4.74 (near compression)

Precautions using Mitsubishi RF Power Modules

Charlie Suckling, G3WDG

Many stations are using RF power modules very successfully, but on occasions there have been problems where modules have failed or degraded. The most likely cause for this is overheating, particularly where modules are driven hard or are operated continuously.

The extract reproduced below may be useful regarding this and other general precautions. It is important to ensure that the heatsink surface is flat and free from burrs, and that the heatsink is adequate to dissipate the heat generated by the module. Also note that Mitsubishi recommends the use of thermal grease to improve the heat conduction from the module. Mitsubishi states that the temperature of the module flange should not exceed 90C or irreversible damage may occur.

I have recently had occasion to dismantle a degraded M57762 and found a cracked chip capacitor in the output network and some fried thick-film resistors, so this may well be true! Under high drive conditions, the M57762 module, used by many stations on 1.3GHz, may dissipate over 40W of heat. The heatsink specified in the article in Microwave Newsletter above may not be large enough for continuous use. Also note that for optimum operation, the heatsink should be mounted with its fins vertical so that air can flow freely and achieve optimum cooling. Measurements show that mounting the heatsink flat with the fins downwards will increase the thermal resistance by as much as 50%!

It has been found that as supplied the modules are slightly bowed, which means that the centre of the heatsink may run considerably hotter than it does at the ends, near the mounting screws.

Measurements with a thermocouple have shown that centre of the module flange seems to run some 20-30 degrees hotter than the heatsink to which the module is bolted, suggesting that the heatsink itself should not be allowed to run hotter than about 60C. The temperature of the flange near the mounting screw only runs 10 degrees or so hotter than the heatsink and may lead to an optimistic view of the temperature of the flange where it really matters!

Mike Willis G0MJW has come up with an interesting suggestion to prevent operation continuing if the heatsink gets too hot. This is to use a bi-metallic thermal switch bolted to the heatsink to shut down the module if the heatsink gets too hot. Once the heatsink cools, the switch resets automatically and the PA can be used again (and the overs kept shorter!). Suitable switches are available from Farnell and RS at relatively low cost. One option, suggested by Andy Talbot, G4JNT, is to used forced air cooling of the heatsink. This should enable a physically smaller (and cheaper) heatsink to be used.

Various small fans are available quite cheaply these days (e.g. computer cooling fans). This is an excellent suggestion for situations where air can move freely around the PA.

In applications where two modules are mounted on a common heatsink for combining, excessive temperatures are even more likely and great care needs to be taken in selecting an adequate heatsink.

Mitsubishi 23cm 'Brick' PA Replacement

Gleanings from the Internet Reflectors

When Mitsubishi introduced the replacement 23cm power module, some interesting discussion took place on the WA1MBA microwave internet reflector. The emails refer to the ***RA18H1213G module***

From Sam G4DDK

Mitsubishi 23cm PA module

I mentioned in an e-mail last week that I had ordered one of these new Mitsubishi 23cm PA modules from the UK distributor, now that they are in stock. I have received my module and built it into a suitable heatsink case and have some preliminary results.

I am currently achieving 25W saturated output from 13.5V supply and Vgg set at 4.6v. This is about 0.1V above the apparent recommended Vgg value. I will experiment with the bias level when I can get the amplifier onto IMD testing. 4.6V bias gives 1.7A quiescent current. At 25W output the supply current is about 8A. The required drive is about 500mW for this output power.

A few observations are in order. The power leads are not thick enough (or maybe too long - they need to reach my only available PSU!) and so I get about 0.7V drop at the amplifier at 8A. When I shorten these I expect to get about 1dB more output. At this level the efficiency is about 25 percent.

When switched to transmit but no RF drive the quiescent current slowly increases to about 1.8A and then stabilises. After several seconds of hard RF drive and then removing the drive the result is the quiescent current slowly falling back to about 1.7A over several minutes. The heatsink is more than adequate to dissipate several hundred watts for a reasonable temp rise above ambient.

I am surprised at how much drive the amplifier needs. I haven't analysed this yet, but initial reaction is that it is more than expected even allowing for the saturated output condition. I will have to re-think the transverter drive chain levels!

I have posted a few pictures on my web page at **www.g4ddk.com.** Follow the links from Technical information.

One well-known amateur radio equipment producer has posted information on his commercial single and dual module amplifiers using the Mitsubishi module. The claims appear to be that two bricks will give 90W saturated output. Maybe there is an even more powerful version of the module available now?

I am pleased with the initial results. I haven't blown up the brick yet despite a pessimistic comment regarding the new LDMOS amplifier modules!! 45W? Ummmmm!

I have had a number of responses to my comments about the new Mitsubishi module. I'm responding to the group instead of to individuals. I think the information may be of general interest. Now that I have further examined the 'full' data sheet mentioned by Jeffrey Pawlan a few days ago I think it is now likely that I have been very cautious with the module (nothing wrong there!) and that the quiescent current can be increased beyond the 1.7 amps I'm now using. The data sheet suggests it should be possible to get 40W sat. out at Vgg of 5v, corresponding to something like 4A quiescent! Increasing the VCC to 15V may be how to achieve 45W but I can't help thinking that could be expensive. The data sheet shows 200mW drive should be sufficient to achieve 30W output and that 300mW is the maximum so I will definitely need to back off from the 500mW tried. My tests were all done at 1296MHz but a brief check showed a little more gain available mid band and useable gain to 1325MHz (the top of the band in the UK).

Does anyone have any new information on the LDMOS bias 'memory effect' mentioned in one or two professional LDMOS HPA papers? A colleague, who was working on these devices for cellular amplifiers until a year or so ago, thought that the concerns were overstated.

I will continue my tests later this week. I am extremely hopeful that these modules will help to 'drive' interest in the band. LDMOS does look like the way forward for those of us who don't want to use valve amplifiers for various reasons and yet want to run more than the usual 10W bricks.

BTW, it does seem that these modules may be somewhat cheaper to buy in the southern hemisphere leading to thoughts of cost-effective multi-module amplifiers without it costing an arm and a leg!

From Grant G8UBN

The data sheet says that the absolute maximum O/P power is 30W so I wouldn't recommend trying to get more than 25W out - they are designed to be 18W devices. Also, the devices are well into saturation at this point; fine for CW (or FM ATV if you have a big heatsink) but not very desirable for SSB.

I've built an amp with this module but haven't had time to test it yet, but the quiescent current was 3.5A@13.8V. I don't recommend going above 13.8V. I'll do the RF testing when I get time - too busy with other things at the moment. LDMOS devices definitely have a 'memory' effect, although often it manifests as a 'drift'. Some manufacturers of mobile phone (cellular) base stations go to extraordinary lengths to ensure that the long term (several years) bias conditions are maintained; this is essential to maintain linearity for the new generation systems such as EDGE and W-CDMA (aka '3G').

However, I am not sure if the Mitsubishi modules are LDMOS - they are certainly enhancement-mode MOSFETs, but I'm not convinced that they are laterally diffused (LD). If they are, then this would explain the poor efficiency - most, if not all, LDMOS FETs that work above 1GHz will only work properly at ~26 -28V DC, and I believe that there is some development in 48V LDMOS devices. Running them from 12V gives poor performance - which would explain the high quiescent current of the RA18 .... if it is indeed LDMOS.

As for combining them - it should work OK as long as the splitters/combiners have good isolation between ports; Wilkinson, Gysel, 90 degree hybrids and 'Rat-races' can all exhibit good enough isolation if designed and built properly.

I'm working on a design for a combiner/splitter that can be configured as a Wilkinson for the input and a Gysel for the output; initial results look promising but there's a bit more tweaking to do.

More information on the Mitsubish Power Amplifier Modules

Sam Jewell, G4DDK

These Measurements are the results I obtained in my own shack workshop. Please note that these results are for my module, operating at 13.4V and with the bias set to 5V. The module heat spreader has not been sanded flat and the module is mounted to its (substantial) heatsink with two screws into the heatsink and a small amount of standard silicone heat sink compound used between the module and the heatsink. Prolonged use in this way has not resulted in any failure (so far!). No screen has been used over the top of the module and the output connections are via UT141 coaxial cable as shown on my web page at: **www.g4ddk.com**

Test System

The test system consisted of one R&S SMG signal generator and one HP 8640B signal generator combined with a Hatfield Instruments 3257-03 hybrid combiner.

The combined generator output was carefully measured on the R&S FSB spectrum analyser to ensure 3rd order products were <-46dBc at 144MHz.

The separation of the two tones was 100kHz (1296.250 and 1296.350MHz).

The resulting 40mW PEP 144MHz IF signal was fed into my new homebrew 23cm transverter.

A Mini Circuits ZHL42 broadband amplifier was connected at the output of the transverter and with the transverter TX IF input attenuator carefully adjusted to give 40mW PEP at the ZHL 42 output the 3rd order products were measured at -42dBc. The transverter couldn't quite achieve this good an IMD performance at it's rated 50mW output, hence the assistance from the ZHL42 in order to reduce any contribution from the transverter IMD.

The ZHL42 40mW PEP output was then connected to the Mitsubishi amplifier and the RA18H1213G amplifier output power measured on an HP435 power meter with HP8481B sensor and Weinschel 30dB/50w attenuator. The indicated power was 10W. Since the amplifier was driven by two tones at equal level, the output PEP was 20W.

Results

When measured on the FSB the 20W PEP output spectrum showed:

- the 3rd order products to be -17dBc,
- the 5th order about -24dBc.

At 16W PEP output

- the 3rd order products were -20dBc
- the 5th order -30dBc
- the 7th order -42dBc.

Higher order products were well suppressed.

Conclusions

My conclusion is that the amplifier, whilst not outstanding on 3rd order, has very acceptable 5th and higher order IMD performance and should sound very clean on air (assuming it is used with a sufficiently clean IF rig and transverter......).

Note that this is a single amplifier measurement. Varying the operating conditions could and probably would cause significant changes in the IMD performance.

I am happy with what I've seen and I hope this will go some way towards redressing the balance about these new amplifiers. Some previous posts have been quite pessimistic.

As always, your mileage may vary. I hope this information will be of some interest to other 23cm band users.

Using Mitsubishi Power Amplifier Modules

Grant Hodgson, G8UBN

Introduction

There have been various discussions on the US microwave reflector regarding the use of the new Mitsubishi RA... series power amplifier modules as amplifiers for both 1.3GHz and for VHF/UHF talkback. This article is intended to explain how to get the most out of these very useful and versatile devices and to counter some of the myths and half-truths that have developed over the years about PA modules in general.

This article may seem rather long but it is surprising how such an easy-to-use component as a 12V 50 ohm PA module can be abused and even destroyed though lack of understanding of how these devices should be handled and operated. So what follows is an attempt to explain in detail some of the more subtle points.

History

The RA… series of Power Amplifier modules from Mitsubishi follow on from the hugely successful M5/6xxx series which were introduced in the 1980s as a means of easily amplifying RF power in the VHF and UHF frequency ranges. Literally millions of M5/6xxx series PA modules were sold worldwide to both commercial and amateur radio customers. They offered many advantages compare to RF amplifiers using discrete power transistors and everything was included in a single module – all that was required externally was a heatsink, a main DC supply (which could be taken directly from a 12V car battery), a regulated bias supply and some de-coupling capacitors.

Output powers ranged up to 60W at 144 and 432MHz and many of the modules could be used for SSB, although not at the full rated output power.

The M5/6xxx series are now obsolete; the last ones rolled off the production lines around 2003/2004. Many of these PA modules are still available, but as time goes on it is getting ever more difficult to find them, as the old stock gets used up.

New RA… series PA modules

One of the main problems for Mitsubishi with the M5/6… series was that the modules did not have a very wide frequency range and consequently, in order to meet the needs of thousands of different customers, together working at nearly all frequencies from 50MHz to 1.3GHz, many different modules had to be produced. In fact, at one time there were more than 200 different types of Mitsubishi PA module in production, each one with a separate part number and the overheads involved in managing such a huge number of relatively similar devices were enormous. Mitsubishi's solution to this problem was to scrap the old M… series entirely and develop a range of new modules which would offer a much greater frequency range, thus reducing the number of variants. One of the knock-on effects of this was that, generally speaking, the new RA.. series modules are cheaper than their M5/6xxx counterparts.

The technology used for these new modules still uses silicon (as opposed to other semiconductor materials such as Gallium Arsenide amongst others) but, instead of using bipolar transistors, the new modules use MOSFETs. MOSFETs offer a number of significant advantages over bipolar transistors, including wider frequency range, higher gain, higher power output, better linearity and practically no bias current. The supply voltage remains the same, which means that some applications can use the new modules with only a small number of changes, which will be described later. Note that the new modules do not use a technology called 'LDMOS' (Laterally Diffused MOS) – this is a slightly different type of technology, which usually requires a 28V DC supply. The MOSFETs used in the RA... series modules are 'enhancement mode', which means that a +ve gate voltage is required for them to operate, and zero gate voltage completely turns them off.

The modules that will be of most interest to radio amateurs are the high power modules, and these are the ones that will be discussed in more detail.

Part numbering

The M5/6… series of PA modules simply took numbers from a list, in sequence, as they were developed. It was impossible to determine the performance of a module simply from the part number; one had to have access to the data sheet or have a very good memory (think of how many devices there were!) .

The new RA series have part numbers that relate directly to the device's performance. Therefore, it is possible to ascertain many of the operational parameters without access to data sheets, and conversely it is possible to find the part number of a module from a specification.

The new part numbers are of the form :

RAaabccdde
RA RF PA Module
aa nominal ouput power in Watts
b supply voltage code
cc lower frequency limit
dd upper frequency limit
e Frequency Multiplier – either M or G.
The supply voltage code is as follows :-
H 12.5V
N 9.6V
M 7.2V
If the frequency multiplier is M, then the lower and upper frequencies are in 10s of MHz. This gives the operating frequency to within 10MHz, the exact operating frequency limits are specified on the datasheet.
There is only one module with a 'G' suffix, with is the RA18H123G.
Examples: RA45H4047M
45W, 400 – 470MHz, 12.5V
RA30H0608M
30W, 68 – 88MHz, 12.5V
RA03M8894M
3W, 889 – 940MHz, 7.2V
RA18H1213G 18W,
1240 – 1300MHz, 12.5V
Note that in practice the modules can be used outside of their stated frequency range, for example the RA30H0608M can be used at 50MHz, with good performance.

Using the new RA series modules

None of the RA series modules are a direct replacement for any of the M5/6… series modules.

There are a number of detail changes that the user must be aware of, in order to avoid the possibility of damage to these modules.

Static Discharge

All electronic components that use FETs are susceptible to damage from static discharges, and as such the same precautions must be taken when handling the new PA modules as when handling GaAsFETs and similar devices. The older M5/6xxx series used bipolar transistors and as such were not easily damaged by static. In addition to the possibility of damage from static, the modules can also be damaged by small leakage currents from the tip of a soldering iron. Therefore, it is imperative that any soldering iron used has a ground connection to the tip, and that this connection is checked with a multimeter – the author has managed to destroy at least one module due to a fault with the earth connection on a high-quality (Metcal) soldering iron; a fault that took a lot of time to investigate but was easily corrected.

Package and Pinout

All of the new high-power PA modules operate from a nominal +12.5V supply, and can be operated at 13.8V without damage. The package and location of the pins are the same as previously, which is very convenient. However, the new modules have only 4 pins instead of 5 for the M5/6xxx series.

The pin connections are :-

Pin 1 RF in
Pin 2 Bias supply
Pin 3 Main DC supply
Pin 4 RF out

Note that the bias connection has moved from pin 3 to pin 2. Therefore, if a PCB is being used which was designed for the M5/6xxx series modules, then the PCB will require modification, although this will usually be a simple track cut and wire link.

Bias supply

This is probably the biggest difference between the M5/6xxx series and the RA… series. Most of the M5/6xxx modules required a bias supply of 9V, although there were some exceptions where an 8V supply was needed. The bias current for the M5/6xxx series varied from module to module but as an example the M57762 used on 23cms required approximately 700mA, which would typically have been supplied from an L78S09CV or similar voltage regulator in a TO-220 package. The RA… series modules require a bias voltage of between 4.2 and 5V, and the bias current is tiny - in the order of 1mA or so. Therefore it would be possible to use much smaller, lower-current voltage regulators, although high current regulators will still work of course.

With no bias supply, the FETs are completely turned off, and the PA module acts as an attenuator. Therefore, it is possible (and desirable) to connect the main DC supply to a constant +12V supply; there is no need to use a separate high current relay or switch. PTT operation can then be accomplished by keying the bias supply.

The setting of the bias voltage is the subject of some discussion. Unlike the M5/6xx series PA modules, there is no one, single optimum bias supply voltage. In fact it is possible to set the bias voltage to suit individual requirements. The Mitsubishi data sheet is very vague in this area, although the device parameters have been characterised with a bias voltage of 5V. However, many users report good results with bias voltages lower than this, and in one case as low as 4.2V. What is known is that the drain current, output power and gain increase as the gate voltage increases,particularly above 4V. Also, the RF/DC efficiency of the modules decreases as the bias voltage is increased, due to the fact that the drain current increases more rapidly than the output power.

Decoupling and PCB

The supply pins require decoupling in order to reduce the possibility of instability. Mitsubishi recommend a 4.7nF capacitor in parallel with 'at least 22uF'. The 4n7 needs to be placed as close to the PA module as practicable. This is easily accomplished, especially since there are only 2 DC supplies.

The gain of the RA… series modules is much greater than the M5/6xxx series. The modules have been designed to be stable into any output load with a VSWR of up to 3:1. However, this assumes that the supply pins are sufficiently de-coupled. In order to achieve the best decoupling performance, a very low impedance path must be provided to ground. The best means of achieving this is with a printed circuit board that uses plated-through holes. These PCBs are more expensive to produce than 'non-PTH' boards, but give much better performance than boards where the grounding has been achieved by other means, especially at 1.3GHz. This is one case where it really is worth spending a little extra in order to achieve the best performance. One further note which is related to both de-coupling and static discharge – it is worth placing a high-value resistor in parallel with the 2 DC supply pins and the RF output pin in order to further reduce the possibility of damage due to static discharge. This is best done by soldering the resistors to the PCB before the module is fitted; that way the pins of the module will be grounded as they are soldered. The author uses 68k, but any value from 10s of kohms to 1Mohm could probably be used. Note that the RF input pin is internally connected to ground with a PI attenuator, and does not require an external resistor.

Grounding

There is some considerable confusion as to how the PA modules are grounded. The modules are designed to be mounted on a large, flat heatsink. With theM5/6xxx series modules, the best thermal performance is achieved by applying a thin, even layer of thermal compound on the flange of the heatsink. The application of the thermal compound means that a good electrical contact between the flange of the module and the heatsink cannot be guaranteed. Therefore, the electrical ground path for both DC and RF from the module to the PCB is via the mounting screws and the heatsink! This may seem totally counter-intuitive, but this is indeed the situation, which leads to some interesting points that need to be considered :

- The mounting screws should be made of brass and be bright zinc plated; screws made of other materials such as steel will not give as good performance and should be avoided.
- The mounting holes in the heatsink must be tapped; it is not sufficient to drill clearance holes in the heatsink and use long screws with a nut on the other side.
- The mounting holes must be clean – this means that any residual cutting fluid must be removed with a cotton bud or similar, and great care must be taken to ensure that no thermal compound gets on the screw thread.

(The author is aware of several 1.3GHz amplifiers that were unstable and actually oscillated; in all cases the instability was cured simply by cleaning the mounting screws.)

Black anodised heatsinks can be used without the need to remove the anodisation from under the module.