The Development of Power Amplifiers Utilizing MOSFET Hybrid Modules

By Steve Kostro, N2CEI

Bipolar hybrids have been the standard in solid-state VHF/UHF transceivers and transverters ranging from 50 MHz through 23 CM. Chances are that if you have 3 watts or greater of solid state power on 33 or 23 cm, it is generated by a bi-polar hybrid. To date, hybrids have been the easiest way to achieve gain and power output in a small amount of space. Recently with the advent of multi-band HF/VHF/UHF transceivers, it has been the only way manufactures could get all of that stuff in one box! Now with the popularity of personal communications equipment such as FRS transceivers and other commercial VHF/UHF radio services, hybrid manufactures are being asked to decrease the size and eliminate support circuit components while improving efficiencies. They have met the challenge. Figure 1. is one of the newest UHF versions available off the shelf. Yes, it is that small!

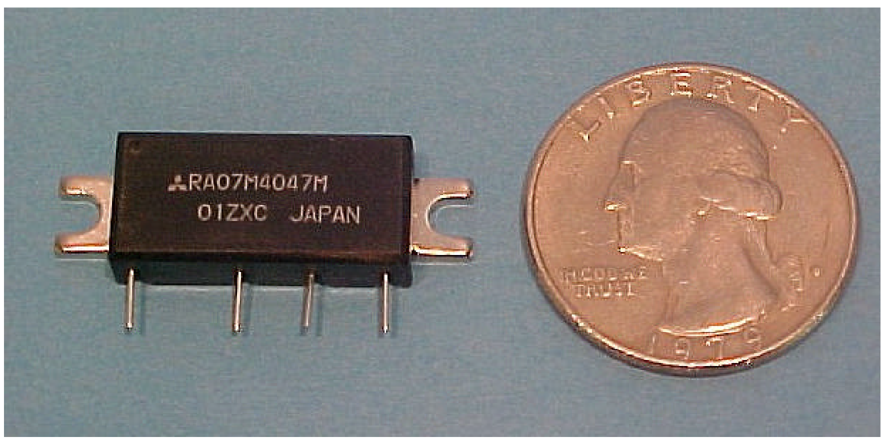


Figure 1. The 7 Watt RA07M4047M and a Quarter

The picture above is proof that MOSFET hybrids are here to stay. Further proof is that manufactures of hybrids are making Bi-Polar hybrids obsolete. The problem in the future will be that if you damage your bi-polar, for whatever reason, it will need to be replaced with the newer, and more economical MOSFET type in its class. This is OK and considered an “Upgrade” in performance but the newer MOSFET hybrids are not completely drop-in replacements. This paper will discuss the differences in operation and provide the direction of either replacing the Bi-polar with a MOSFET or building a completely new amplifier using the newer MOSFET type hybrids.

Since this a paper is being generated for Hams interested in Microwave frequencies, we will not refer to any of the VHF/UHF hybrids and concentrate on the 23 CM band of operation. It is important to understand that all principles and techniques will apply to the VHF/UHF bands. Because of the higher gains at VHF frequencies, (Some VHF hybrids exhibit more than 50 dB!) the construction techniques become more demanding and exact. Also under stand that this information has been complied from over a year, though not full time, of testing, experimenting, and consulting with the manufactures of these hybrids and various end users of the hybrids. I have also given presentations at various VHF/UHF/Microwave conferences reporting the results as I progressed with all versions.

A popular bi-polar hybrid, the Mitsubishi M57762 has been declared obsolete. Soon, (maybe 2 years) you will not be able to find this hybrid anywhere. This should be a concern if you own an amplifier that utilizes two or more of these hybrids in a combined circuit. Amplifiers do exist with 2,3,4,5, 8 or 16 hybrids in a circuit. If you have a “single brick” amplifier, you may decide not to use the obsolete part and elect the new MOSFET. The specifications of the M57762 will vary depending on whom you talk too, (like everything else in the Ham world!) but directly paraphrasing from Mitsubishi’s data sheet it says 18 watts linear output with up to 1 watt of drive, 12 VDC operation (13.8VDC preferred) at around 5 amps of current drain. It requires a maximum of 9VDC @ .5 amps on the control pin for maximum power output. The reality was 20-25 watts output with ½ watt of drive, 5-6 amp current drain with a regulated +9 VDC on the control pin. The hybrid would handle the occasional “oops” of up to 2 watts of drive and +17 VDC from an un-regulated mobile installation. It has been a very rugged and reliable device that many have been considered a miracle in the mid 1980’s after building a few 20-30 watt linear amplifiers on 1296 MHz from discrete transistors. Compare this to the electrical specifications of its replacement, the RA18H1213G.

ELECTROSTATIC SENSITIVE DEVICE
OBSERVE HANDLING PRECAUTIONS

MITSUBISHI RF MOSFET MODULE

RA18H1213G

1.24-1.30GHz 18W 12.5V, 3 Stage Amp. For MOBILE RADIO

DESCRIPTION

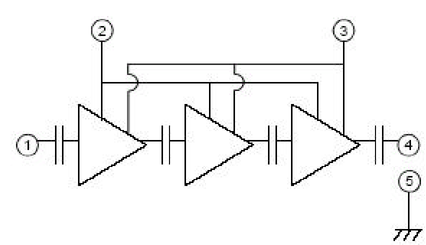
The RA18H1213G is a 18-watt RF MOSFET Amplifier Module for 12.5-volt mobile radios that operate in the 1.24- to 1.30-GHz range.

The battery can be connected directly to the drain of the enhancement-mode MOSFET transistors. Without the gate voltage (V_{GG}=0V), only a small leakage current flows into the drain and the RF input signal attenuates up to 60 dB. The output power and drain current increase as the gate voltage increases. With a gate voltage around 4V (minimum), output power and drain current increases substantially. The nominal output power becomes available at 4.5V (typical) and 5V (maximum). At V_{GG}=5V, the typical gate current is 1 mA.
This module is designed for non-linear FM modulation, but may also be used for linear modulation by setting the drain quiescent current with the gate voltage and controlling the output power with the input power.

FEATURES

- Enhancement-Mode MOSFET Transistors (I_{DD}≅0 @ V_{DD}=12.5V, V_{GG}=0V)
- P_{out}>18W, η_T>20% @ V_{DD}=12.5V, V_{GG}=5V, P_{in}=200mW
- Broadband Frequency Range: 1.24-1.30GHz
- Low-Power Control Current I_{GG}=1mA (typ) at V_{GG}=5V
- Module Size: 66 x 21 x 9.88 mm
- Linear operation is possible by setting the quiescent drain current with the gate voltage and controlling the output power with the input power

BLOCK DIAGRAM

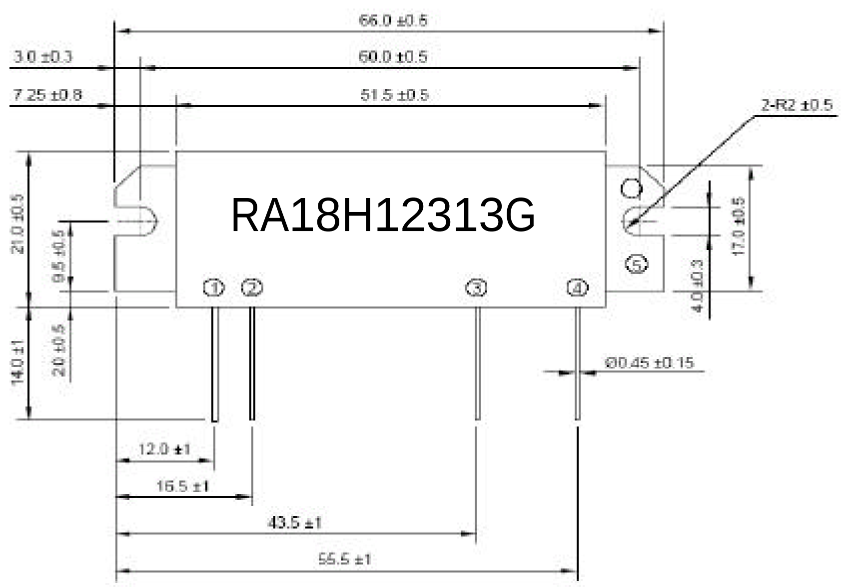


1. RF Input (P_{in})
2. Gate Voltage (V_{GG}), Power Control
3. Drain Voltage (V_{DD}), Battery
4. RF Output (P_{out})
5. RF Ground (Case)

PACKAGE CODE: H2S

Referring to the 1st page of the data sheet found on the Mitsubishi web site, (If interested, please down load a full copy) please find and notice that the part number says it all. Reading RA18H1213G, the “RA” is the designator for the MOSFET line. The “18” is the established specified output power in watts. The “H” is the designator for the package size and pin out spacing, (H3 is the M57762) “1213G” is the frequency range “1.2 to 1.3 G” Hz. So far, this is good. Read the part number and it self identifies! Therefore, a RA20H8994M is, besides my favorite new hybrid, a 20 watt unit operating between 890 – 940 MHz. OK? Well, more on this one later!

Further details of the data sheet reveal that the new MOSFET only has four pins. Input, Gate, Drain, and Output. The M57762 had five. Input, 1st DC supply, Base, 2nd DC supply and Output. The RA18H1213G is specified at the same output power but only requires 200 mW of drive and a gate voltage of +5VDC at only 1 mA compared to the M57762 which was specified at 1 watt of drive and +9VDC @ 500 mA on the control line. So we now have a hybrid that has one less pin (less bypass components) requires less drive, (can be driven with a low cost MMIC directly) and does not require a regulator mounted on a heat sink for the control or gate pin. Sounds better so far? Well a quick check of figure 2 shows that the pin alignment and mounting hole spacing are the same or close enough for direct physical replacement in a M57762 circuit.



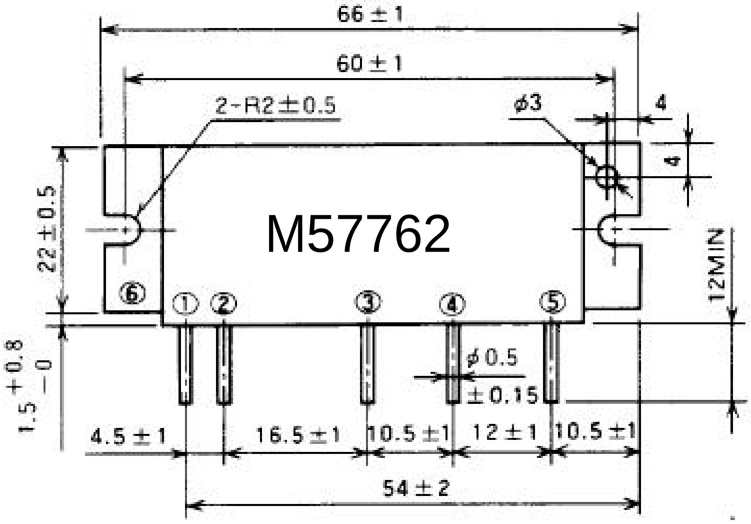


Figure 2. Physical dimensions of modules.

Great! Lets just drop it into a M57762 circuit, change the regulator, and rewire the pins and get on the air! ----Well, if you do this, which is what I did, you will have limited success. You may see the current meter spike up to 10-12 amps and see some output flash on your power meter. It may be the fastest 50 watts you have ever saw! The disappointing fact is there is no noticeable smoke from the blown hybrid you have!! Yes, it will self destruct in the mater of seconds!! Lets continue to find out what is required to make this MOSFET work correctly.

Reviewing the 2nd page of the data sheet shows the maximum specifications (The specs “Hams” use) and the electrical characteristics for normal operation. (non-Ham types) In the maximums, there is lots of good stuff +17VDC. Most mobile charging systems connected to a battery will not reach that. The gate voltage is 6VDC so a 5 volt regulator is not a problem no mater how bad the tolerance is and it will tolerate 300 mW of drive! Now the best part of this maximum rating data is the 30 watts of output power.

MAXIMUM RATINGS (T_{case}=+25°C, unless otherwise specified)

SYMBOL	PARAMETER	CONDITIONS	RATING	UNIT
V_{DD}	Drain Voltage	V_{GG}<5V, Z_G=Z_L=50Ω	17	V
V_{GG}	Gate Voltage	V_{DD}<12.5V, P_{in}=0mW, Z_G=Z_L=50Ω	6	V
P_{in}	Input Power	f=1.24-1.30GHz, Z_G=Z_L=50Ω	300	mW
P_{out}	Output Power		30	W
$T_{case(OP)}$	Operation Case Temperature Range	f=1.24-1.30GHz, Z_G=Z_L=50Ω	-30 to +110	°C
T_{stg}	Storage Temperature Range		-40 to +110	°C

The above parameters are independently guaranteed.

ELECTRICAL CHARACTERISTICS (T_{case}=+25°C, Z_G=Z_L=50Ω, unless otherwise specified)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
f	Frequency Range		1.24		1.30	GHz
P_{out}	Output Power	V_{DD}=12.5V, V_{GG}=5V, P_{in}=200mW	18			W
η_T	Total Efficiency		20			%
$2f_o$	2nd Harmonic				-30	
ρ_{in}	Input VSWR				3:1	—
I_{GG}	Gate Current			1		mA
Gp	Linear power gain	V_{DD}=12.5V, V_{GG}=5V, P_{in}=10dBm	23			dB
IMD3	3rd Inter Modulation Distortion	V_{DD}=12.5V, V_{GG}=5V Delta f=f1-f2=10KHz P_{out}=14W P.E.P. (P_{in} control)			-20	dBc
IMD5	5th Inter Modulation Distortion				-25	dBc
—	Stability	V_{DD}=10.0-15.5V, P_{in}=0-25dBm, P_{out}=1 to 18W (V_{GG} control), Load VSWR=3:1	No parasitic oscillation			—
—	Load VSWR Tolerance	V_{DD}=15.2V, P_{in}=200mW, P_{out}=18W (V_{GG} control), Load VSWR=8:1	No degradation or destroy			—

When reviewing the Electrical Characteristics, always check the conditions. The point to be made here is that 18 Watts is listed as the ***minimum output power required*** at 12.5 VDC, with 200 mW of drive operating at 20% efficiency. What does this mean? It means that higher output power may be possible if the efficiency is better than 20 %. If the DC power consumption remains the same and the RF output power increases, then no harm is done concerning total power dissipation of the hybrid. Lets review what we know so far and develop a “Interpretation” of the specifications so far. We know that the hybrid is specified at 18 watts minimum and 30 watts maximum at 20% efficiency. All data provided is at 12.5VDC. The total current drain is established by the efficiency. The gate voltage controls the gain and the idling current drain. We can also include the maximum of 17 VDC in the interpretation if desired but since it will be for mobile operation, it’s a safety factor. Then not regarding the case temperature specification for now, lets form the interpretation.

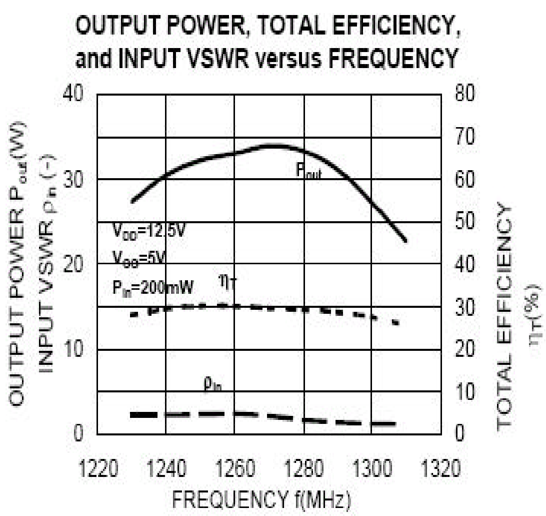
Interpretation of Mitsubishi Maximum Specifications

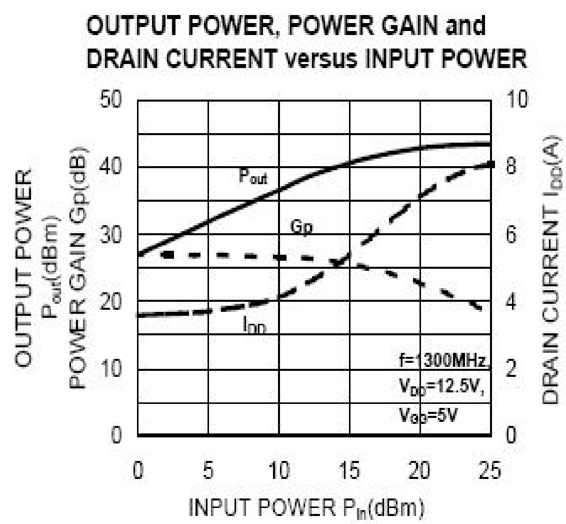
30 Watts power output Maximum @ 20% Efficiency

If 30W = 20% then 150W = 100% total power dissipation

150W (total dissipation) minus 30W (RF output)
Equals 120 Watts of heat dissipation!
150W total dissipation @ 12.5VDC =
12.0 Amps of total current!

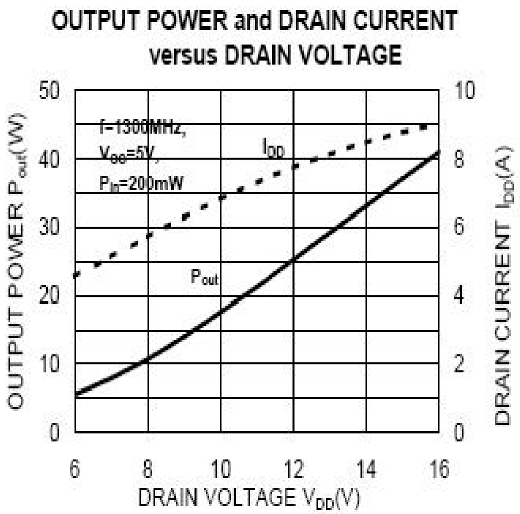
Questions now come up about the heat sink required for 120 watts of heat and how to keep the case temperature of the hybrid within specification. Also, the 12 amps of current drain is large but at 13.8VDC, 150 watts is lower at 10.9 amps. The physical mounting will be discussed later so for now, lets look at Mitsubishi's RF test data to verify that the interpretation of 150 watts of total power dissipation is real and is what we have to play with. Below is another copy of a page from the data sheet. The first graph shows power in watts and the second is in dBm. It's just something you need to be careful about with when reading this data sheet.

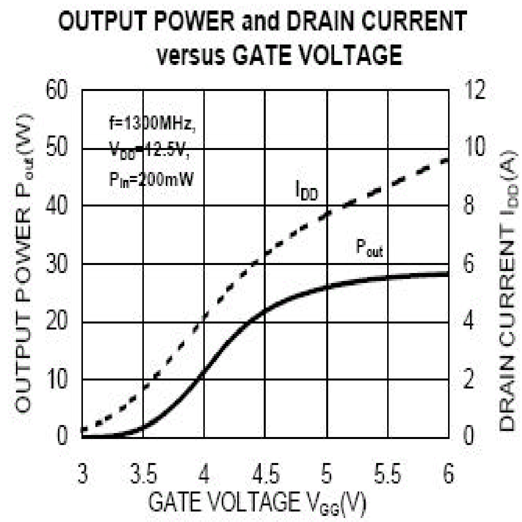




The first graph shows that at 1270 MHz, the hybrid will produce 35 watts output at 12.5VDC, with 200 mW of drive and +5VDC on the control pin. This example shows that it is just under 30% efficiency. The second graph shows that at 1300 MHz, it only requires 100 mW to saturate the output power at +44 dBm, (or 25 watts) and 7 amps of current drain at 12.5 VDC. That's a total dissipation of 88 watts. It also demonstrates that the hybrid is approaching compression. Not good! So are we ahead of the game or at the end of the line?

A quick look at the next two graphs shows that if we increase the drain voltage the output power and current drain increases, but if calculated, the efficiency also increases. That's Good! Now if we increase the control or gate voltage, it allows the hybrid to draw more current but doesn't make a large change in output power. One could deduce that the gain will increase so it would require less drive but for now that is not the issue. We are looking for total power and efficiency. If calculated, the increase in drain current will allow the output power to increase but will not increase the efficiency. That's not so good! So maybe we need a compromise or find the sweet spot for the control voltage. Being the optimist, I think we are ahead of the game if we can do >30 watts with less drive than the M57762. The good thing to notice is that at 16VDC on the drain, 40+ watts output is acceptable with 9 amps of current drain. That's 28.4 % efficiency with 144 watts total dissipation!! Close enough to 150 Watts for me! That proves that the hybrid can do it. What will it take to do it at 13.8 VDC? Or worse case, at 12VDC in a mobile operation. Testing to find out is the only way.





Now its time to review the text printed on the data sheets. This is where you pick of most of the "DO'S AND DONT'S" It should cover all of the precautions, special operation functions, and handling of the component. It may also cover the description of the test set up all of the recorded data was complied on. It may even specify certain value components to be used or special support circuits. One needs to scrub the "VERBAGE" thoroughly. Sometimes information is lost in the translation or misinterpreted. Look at everything and question anything that goes against your norm.

Output Power Control:

Depending on linearity, the following two methods are recommended to control the output power:

a) Non-linear FM modulation:

By the gate voltage (V_{GG}).

When the gate voltage is close to zero, the RF input signal is attenuated up to 60 dB and only a small leakage current flows from the battery into the drain.

Around V_{GG}=4V, the output power and drain current increases substantially.

Around V_{GG}=4.5V (typical) to V_{GG}=5V (maximum), the nominal output power becomes available.

b) Linear AM modulation:

By RF input power P_{in}.

The gate voltage is used to set the drain's quiescent current for the required linearity.

Oscillation:

To test RF characteristics, this module is put on a fixture with two bias decoupling capacitors each on gate and drain, a 4.700 pF chip capacitor, located close to the module, and a 22 µF (or more) electrolytic capacitor.

When an amplifier circuit around this module shows oscillation, the following may be checked:

a) Do the bias decoupling capacitors have a low inductance pass to the case of the module?

b) Is the load impedance Z_L=50Ω?

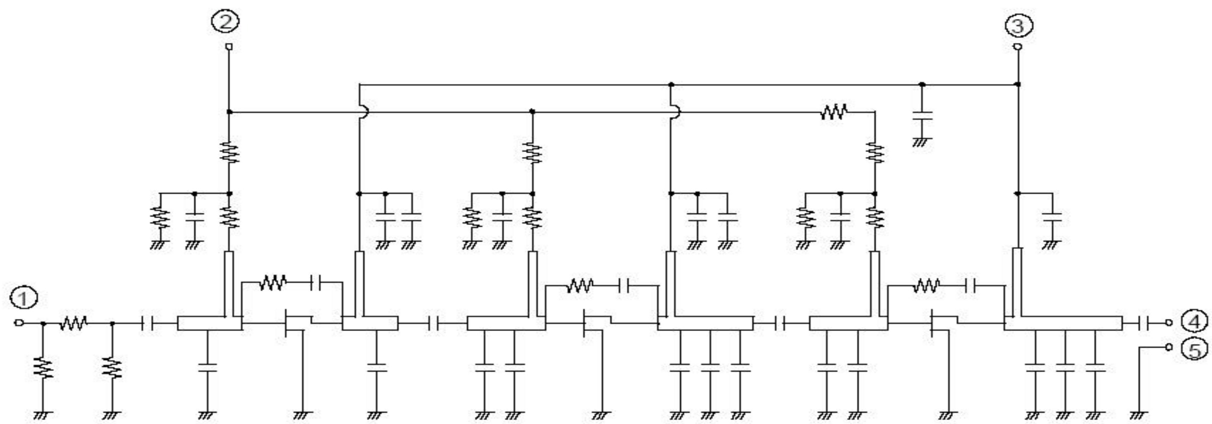
c) Is the source impedance Z_G=50Ω?

Frequent on/off switching:

In base stations, frequent on/off switching can cause thermal expansion of the resin that coats the transistor chips and can result in reduced or no output power. The bond wires in the resin will break after long-term thermally induced mechanical stress.

Reviewing this page of the data sheet from top to bottom reveals a bunch of information. First is says that if we use the hybrid in a beacon, we could key it by toggling the control line. It offers 60 dB of isolation in the off state. Then it says that frequent on/off switching is bad! Therefore, the beacon thing will require further testing. It does state the hybrid may be used in a linear system and suggests how to use it which is very similar to the way hams use SSB. The section under Oscillation is what caught my eye. It states what values to use for bypassing the voltage leads and asks a question to ensure that you provide a low inductance path from the bypass capacitors to the ground of the power supply and hybrid. I thought I did that when I dropped the 1213G in the M57762 circuit as mentioned before. It broke into oscillation when I applied the control voltage. What could be wrong? We need to keep reading the data sheet. Meanwhile, lets look at the circuit equivalent of the RA18H1213G.

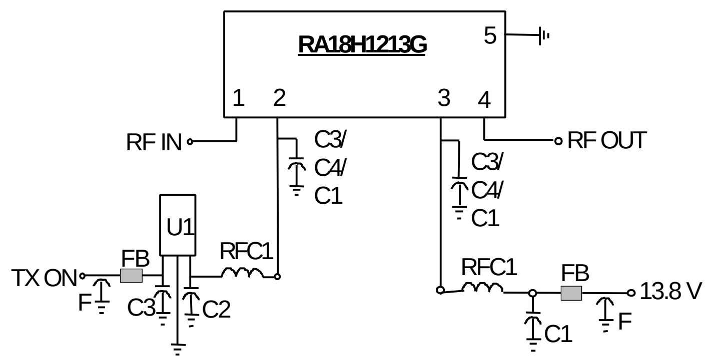
EQUIVALENT CIRCUIT



It looks plain and simple. Just a standard circuit with three MOSFET's in series sharing a common gate and drain supply lines separated only by the resistive divider networks on the control line. Nothing shown here should require anything special on the power supply circuits. Examining the modified M57762 circuit and component list (show below) does not reveal anything that could be a problem. Therefore, the only question is how good is the grounding of the M57762 circuit and if it worked with the Bi-polar, how could it be a problem with the MOSFET? Well, we need to look at the physical design of this potential amplifier anyway, so let check out the Heat Sink requirements.

Component List

	Qty.	Description
C1	3	100 ?F electrolytic
C2	1	2.2 ?F electrolytic
C3	3	0.1 ?F chip
C4	2	100 ?F chip
RFC1	1	8 Turns 1/8" dia #24 enamel
RFC2	1	8 Turns 1/8" dia #24 enamel
U1	1	78L05 regulator
	1	RA18H1213G



One of the next pages of the data sheet specifies the mounting of the hybrid and how to determine the type of heat sink that will be required. Mounting is simple. The flatter, the better.

Mounting:

Heat sink flatness must be less than 50 µm (a heat sink that is not flat or particles between module and heat sink may cause the ceramic substrate in the module to crack by bending forces, either immediately when driving screws or later when thermal expansion forces are added).
A thermal compound between module and heat sink is recommended for low thermal contact resistance and to reduce the bending stress on the ceramic substrate caused by the temperature difference to the heat sink.
The module must first be screwed to the heat sink, then the leads can be soldered to the printed circuit board.
M3 screws are recommended with a tightening torque of 0.4 to 0.6 Nm.

Thermal Design of the Heat Sink:

At P_{out}=18W, V_{DD}=12.5V and P_{in}=200mW each stage transistor operating conditions are:

Stage	P_{in} (W)	P_{out} (W)	$R_{th(ch-case)}$ (°C/W)	I_{DD} @ η_T=20% (A)	V_{DD} (V)
1st	0.2	1.3	4.5	0.55	12.5
2nd	1.3	6.0	3.2	2.00	
3rd	6.0	18.0	1.6	4.50	

The channel temperatures of each stage transistor $T_{ch} = T_{case} + (V_{DD} \times I_{DD} - P_{out} + P_{in}) \times R_{th(ch-case)}$ are:

$T_{ch1} = T_{case}$ + (12.5V x 0.55A – 1.3W + 0.2W) x 4.5°C/W = T_{case} + 26.0°C
$T_{ch2} = T_{case}$ + (12.5V x 2.00A – 6.0W + 1.3W) x 3.2°C/W = T_{case} + 65.0 °C
$T_{ch3} = T_{case}$ + (12.5V x 4.50A - 18.0W + 6.0W) x 1.6°C/W = T_{case} + 70.8 °C

For long-term reliability, it is best to keep the module case temperature (T_{case}) below 90°C. For an ambient temperature T_{air}=60°C and P_{out}=18W, the required thermal resistance $R_{th\,(case-air)} = (T_{case} - T_{air}) / ((P_{out} / \eta_T) - P_{out} + P_{in})$ of the heat sink, including the contact resistance, is:

$R_{th(case-air)}$ = (90°C - 60°C) / (18W/20% – 18W + 0.2W) = 0.42 °C/W

When mounting the module with the thermal resistance of 0.42 °C/W, the channel temperature of each stage transistor is:

$T_{ch1} = T_{air}$ + 56.0 °C
$T_{ch2} = T_{air}$ + 95.0 °C
$T_{ch3} = T_{air}$ + 100.8 °C

The 175°C maximum rating for the channel temperature ensures application under derated conditions.

The thermal design of the heat sink isn't that simple. Without going into to many details, the formula giving by Mitsubishi determines the required thermal resistance of the heat sink (the rating that heat sinks are designed too) that will ensure that the channel temperature of the hybrid (the internal working of the individual MOSFET within the hybrid) can not be exceeded when operated under the given conditions. In this case, the conditions are 20% efficiency with 18 watts of output power. This will require a heat sink with a .42-degree C/W of thermal resistance to maintain a channel temperature of 100 degrees C worst case. The maximum is 175 degrees C. Channel temperature cannot be measured without a IR scanning device accurately. We can only measure the case temperature and the maximum is 110 degrees C as stated on the second page of the data sheet. Lets review what we know.

Mitsubishi's Operating Specification

18W output with 200mW input drive
12.5VDC @ 7.2 Amps = 20% Efficiency
R = (90°C- 60°C) / (18W / 20% - 18W + 0.2W) = **0.42 °C/W**

If we now substitute the maximum specifications into the formula, we see that it will take a bit more heat sink to maintain a 100-degree C channel temperature.

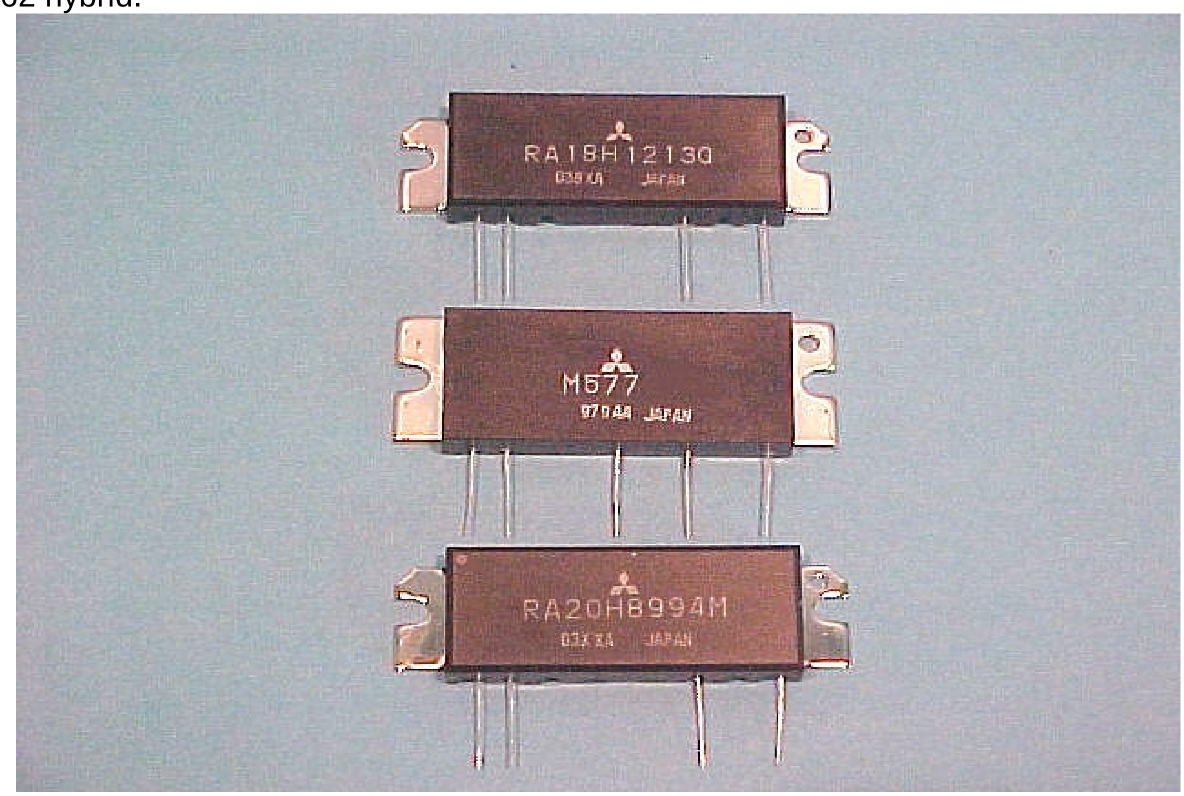
Interpretation of Mitsubishi Maximum Specification

30W output with 200mW input drive
12.5VDC @ 12.0 Amps = 20% Efficiency
R = (90°C- 60°C) / (30W / 20% - 30W + 0.2W) = **0.25 °C/W**

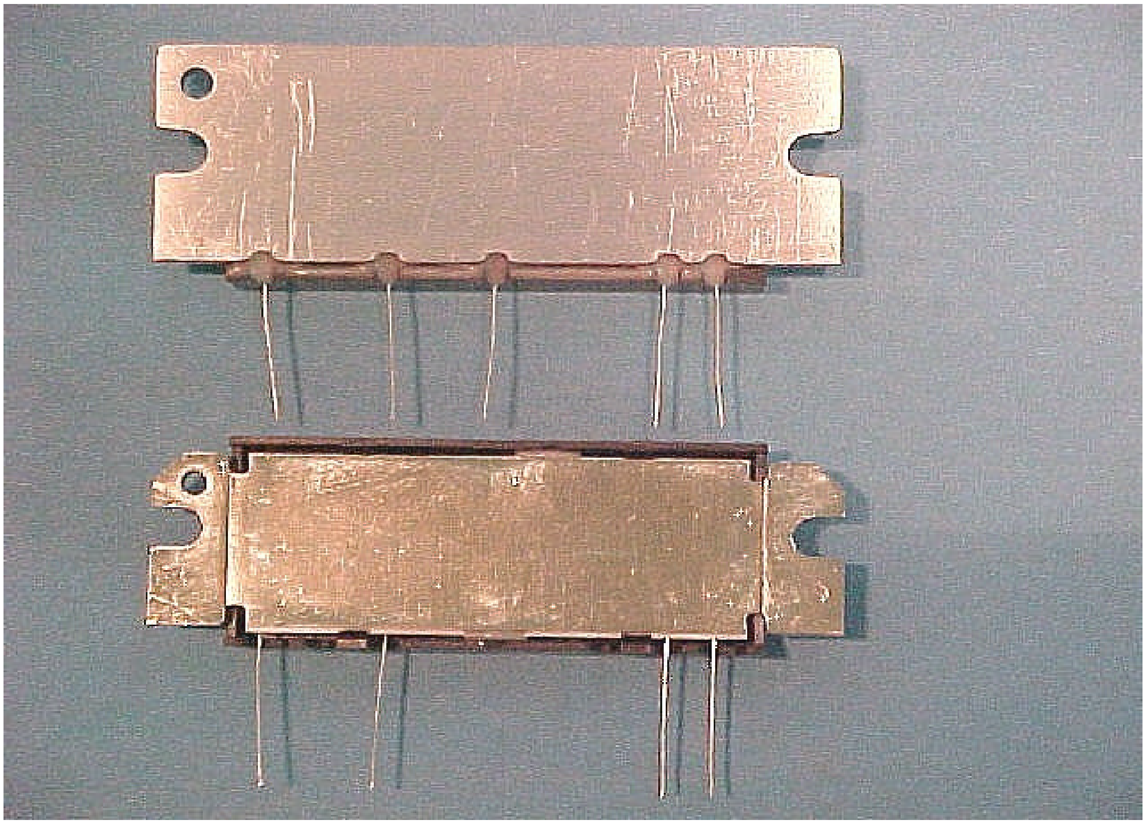
A heat sink with a thermal resistance rating of 0.25 °C/W would need to be solid copper and is quite a demand to only generate 30 watts of RF at 1296 MHz. It is more than what would be expected to be under an “H” size hybrid module. To reduce the thermal resistance requirement, the efficiency would need to be increased to keep this hybrid from self-destructing during operation. It is also understood that this is a worst-case condition.

Now, is this the reason for the first failure? The first failure was instantaneous. When the hybrid broke into oscillation, it exceeded the maximum channel temperature. In theory, if the heat sink were large enough, the hybrid would still be oscillating as long as it didn’t exceed the channel temperature maximum. However, even in theory, I can’t imagine how large the heat sink would need to be! The hybrid popped like a fuse instantly! Therefore, the heat sinks thermal characteristics were not actually the problem. They would have been a problem if the amplifier operated over a period of time with a poor efficiency resulting in over heating the hybrid and allowing the channel temperature to exceed the maximum limit. That would be a slow burn! We need to solve the oscillation problem and the amp will have a chance.

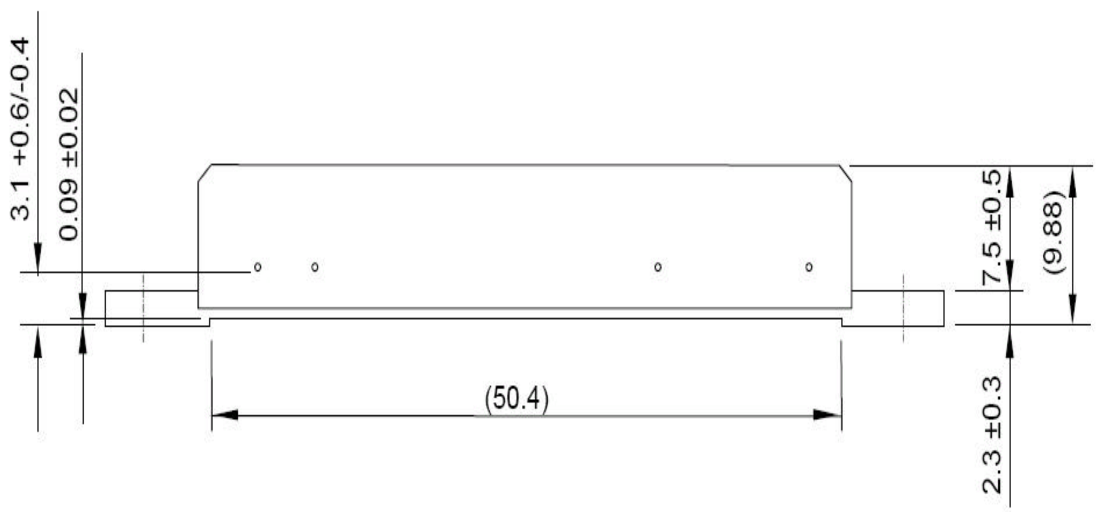
There isn’t much data sheet left to review so lets examine both types of hybrids visually. The five units I received as prototypes for the 33 cm band (RA20H8994M) looked identical to the M57762 hybrids. They worked great as drop-ins to the circuit and produced beyond specifications in performance. The 23 cm samples did have a slightly different appearance and in fact look identical to the production 33 cm units we received at a later date. From the topside, the flange is cropped a bit and the plastic cap is smaller. The pins line up to the detailed drawing shown before. The new hybrid just has one less pin than the M57762 hybrid.



A further examination reveals that the big difference is the bottom of the flange



The mounting precautions went into detail of how flat the heat sink should be to expect the best performance so I didn't expect to see the "Flange" and I over looked it on the data sheet.



The detailed drawing on the data sheet shows it all. It is enlarge in this document for better clarity. This is new to the industry. The measured gap under the flange will vary from 4-6 mils. I went back the only know set of data I had which was with the 900 MHz amplifier built out of the original RA20H8994M samples. As I had mentioned, the new production units had the new style flange. I replaced the old style hybrid (operating flawlessly) with the new type flange hybrid and had a marginal amplifier that wasn't stable and exhibited thermal problems until it just stopped working. (It self destructed) I tested the next 900 MHz. hybrid with brass shim stock between the flange and the heat sink. This unit appeared to be more stable but still had thermal problems when I pushed the drive up to produce more than 35 watts. A transceiver manufacture then relayed a brief explanation to me of what Mitsubishi recommended. They stated to just fill up the gap with thermal compound. This process was on lower frequency hybrids and they were not being used beyond the stated operating conditions. I tried it on both the 8994M and the 1213G with limited success at 900 MHz and no success at 1.3 GHz.   I next machined a heat sink to fit the 8994M hybrid. It worked great! Stable, and thermally under control while producing more than 60 watts output. That's it! Problem solved! I replaced the 8994M with the 1213G in the same circuit. As I was tightening the last mounting screw, I heard that "TIC" sound that makes you sick to you stomach (or is that just me!). I knew I broke the ceramic in the hybrid. While tightening the flange, which is copper, the flange bent down and cracked the inside of the hybrid. Why? The tolerance of the depth of the flange is to great to machine a one size fits all heat sink. This 1213G was shallower than the 8994M. I modified the heat sink to fit the next 1213G. It worked. It behaved correctly concerning thermal management but still exhibited some slight instabilities but nothing that would cause it to self-destruct.

For production reasons, we cannot machine every heat sink to match a particular hybrid nor would I expect a ham in his shack to be able to "Tweak" their heat sinks if they needed to replace their hybrid with a new one. So I experimented with various manufacture's versions of heat transfer inserts and thermal pads with bad results if you desired to push the hybrid to their maximums. Nothing works better than metal-to-metal contact for heat and this caused me to think about this for RF!

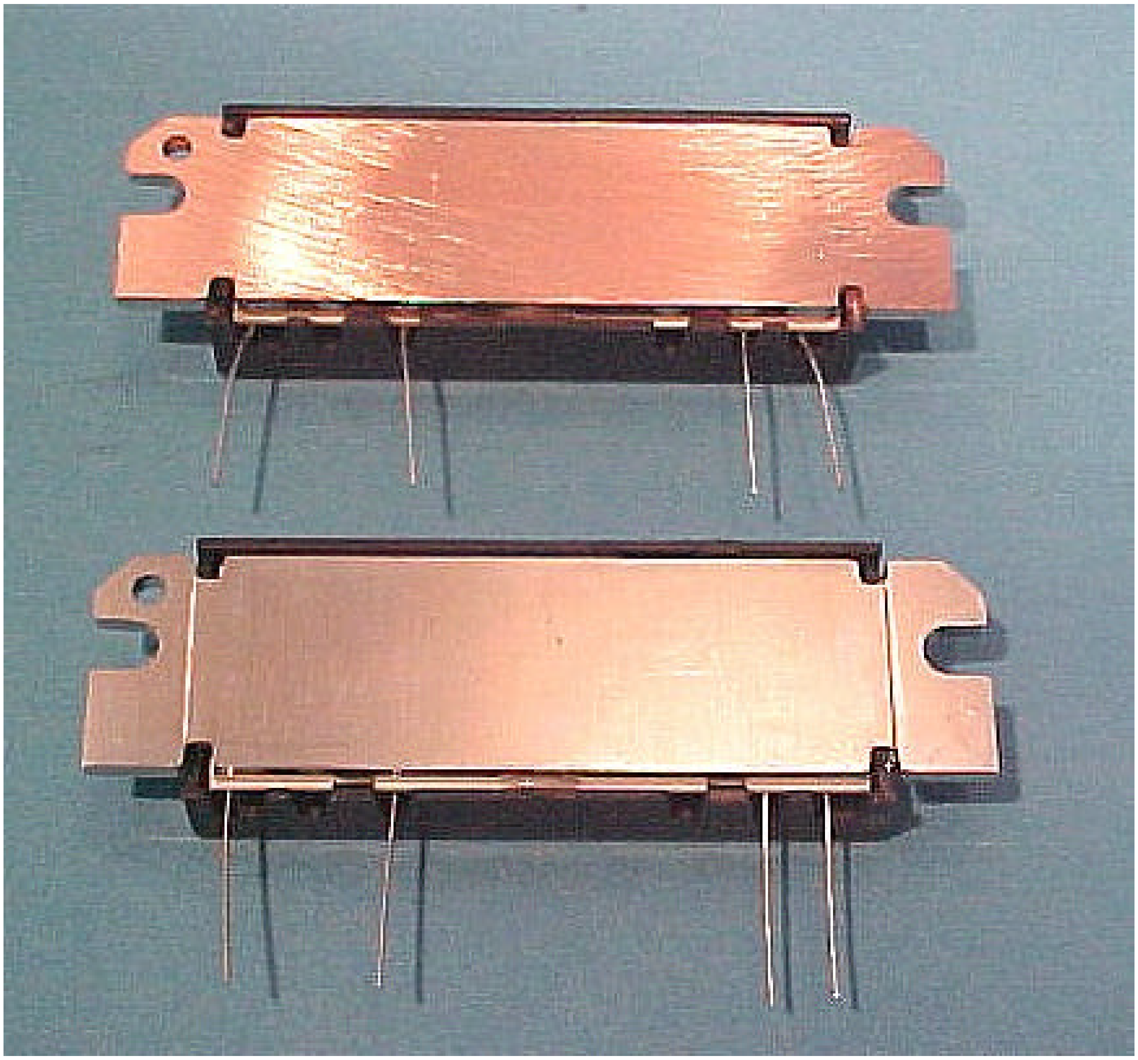
In the section of the data sheet under "Oscillation", it asked the question.

When an amplifier circuit around this module shows oscillation, the following may be checked:
a) Do the bias decoupling capacitors have a low inductance pass to the case of the module?

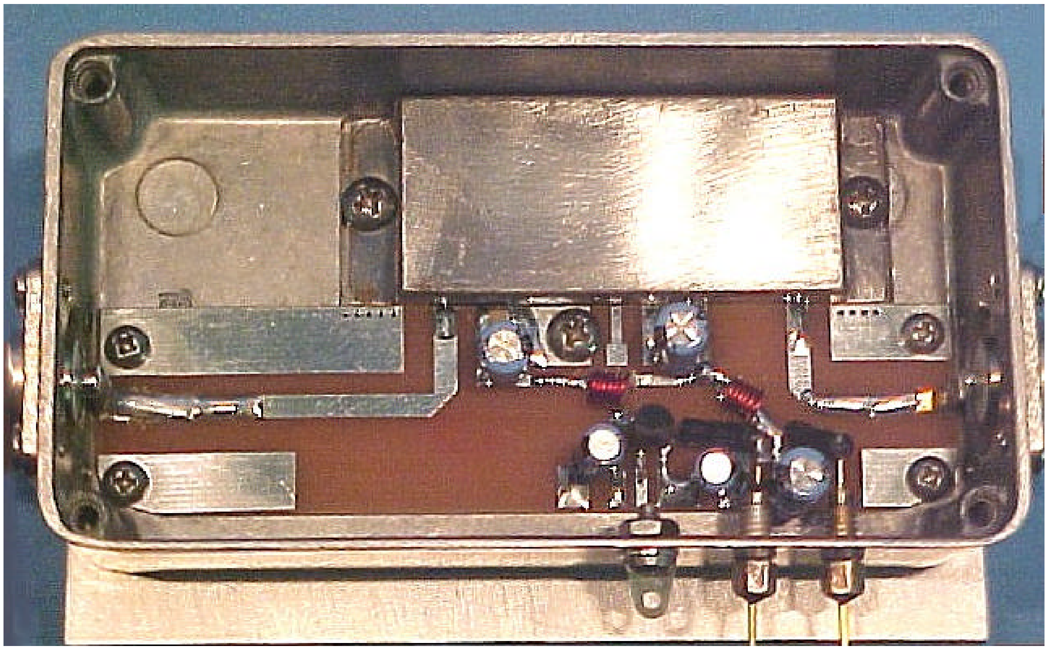
The answer is NO with a stock hybrid. How can it if the flange is only making contact to the heat sink at the mounting screws and he gate and drain voltages are bypassed to the circuit board in the middle of the Hybrid. The inductance may only be in the nanohenry range but would be a worse problem as the frequency is increased. This is also, what my data showed.

It became obvious to me that the hybrid manufacture realized a few thing during he development of this new MOSFET line. They realized that the RF design outperformed the thermal management design and took steps to ensure that OEM's would not attempt to abuse the product. If the hybrids are used at the recommended operation specifications, they will perform as specified. Another assumption is that the manufacture made a million of these hybrids upside down and have tweaked the data sheet to solve the problem. If it wasn't a mistake why isn't there a recommendation that the mounting surface should be machined to match the hybrid instead of just a flatness specification?

Using what we now know, I started from scratch to build a 23 cm amplifier with the RA18H1213G. If the machining process of the heat sink is not desirable for future M57762 replacements, the next best thing is to machine the hybrid. This is simply done on a belt sander

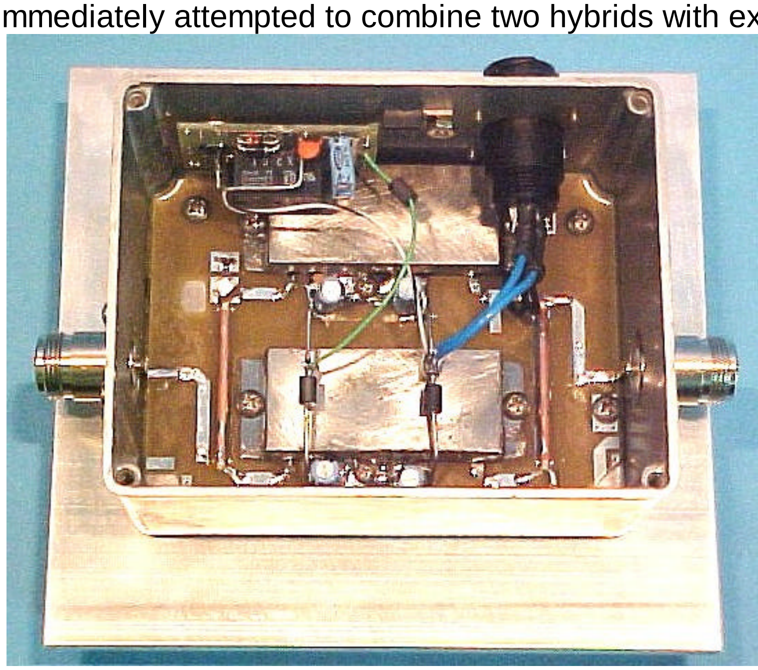


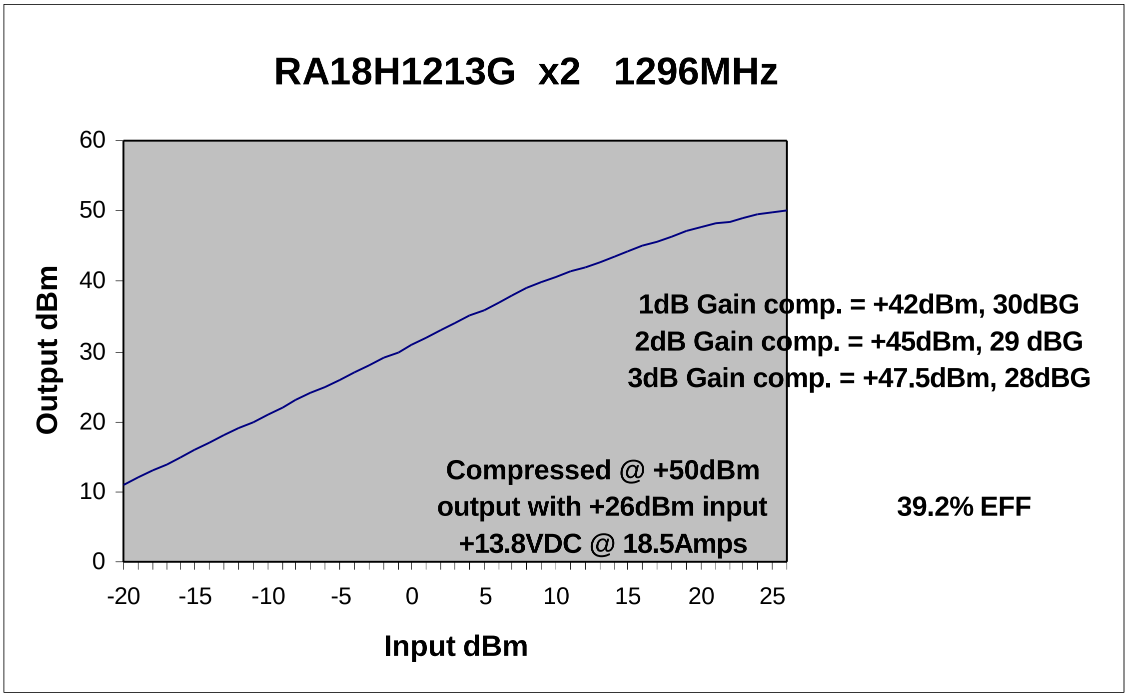
The surface is as smooth as the original M57762. It is very simple to do but care must be taken not to over heat the hybrid. Copper conducts heat fast! To eliminate the amount of inductance from the bypass capacitors to the flange, a few further steps have been performed. The important things to notice are the shield and the extra mounting screw between the gate and drain voltage pins.



In combination, the screw holds the bottom of the PCB down to the heat sink to ensure the shortest path of the by-pass capacitors to modified flange of he hybrid. The addition of the shield after it is soldered to the ground connections on the PC board is to now reduce the inductance even further. This design is now unconditionally stable and ready for the RF test.

During the RF testing, it was then found out that the output load impedance of the hybrid changed above the 30-watt output level. (DAH!) Additional line width or capacitance added to the output 50-ohm line produced higher output and increased efficiency. This could have been Mitsubishi's problem with the design. If the hybrid was allowed to be pushed up in power, it was no longer 50 ohms and would require additional matching. This isn't a problem for Hams or a microwave armature radio equipment manufacturer. The testing proved to be so encouraging, that I immediately attempted to combine two hybrids with excellent results.





100 watts of output was achieved at saturation. With the additional tuning, the pair of hybrids achieved almost 40% efficiency. The unit had a total of 256 watts of power dissipation. That's only 156 watts of heat for 100 watts of RF. 78 watts of heat per hybrid and each hybrid is drawing 9.25 amps. If we break this down further and apply it to the formula to calculate the thermal resistance of the heat sink, it looks very favorable. The loss of the combiners should be included in this calculation because it is heat dissipated in the splitter/combiners and not the heat sink. Therefore, a single hybrid will look like this.

Power divider/combiner has @ ½ dB loss
50 W (@ 55 W) output with 200mW input drive
13.8VDC @ 9.25 Amps @ 43% Efficiency
R= (90°C- 60°C) / (55 W / 43% - 55 W + 0.2W) = **0.41 °C/W**

The recommendation by Mitsubishi for normal operating conditions was **0.42 °C/W.** A modest heat sink 6 inches square and greater than 1 inch tall with a rating of .4 or better would keep the channel temperature within specification for a two-hybrid amplifier. Adding a low CFM muffin fan will increase the heat sinks performance. If the goal of replacing a M57762 with a RA18H1213G is desired, the modifications shown previously will produce a great amplifier.

With the development of this hybrid and simple circuit, a 30W, 60W, and 120W-assembled amplifiers are now available. All components (capacitors, regulators, and shields) shown are also available along with modified RA18H1213G hybrids for upgrading older 18-watt designs. Kits for the 30-watt unit is also available as a PCB or as a complete kit with larger heat sink. The biggest kick is the recent development of a high power 33 and 23 cm transverter. Two versions are available (25 watt and 50 watt) with many different configurations to drop into your existing system or to build a new one! If you decide to experiment with this series of hybrids, have fun!