The 24 GHz Amplifier Project Delivers!

By Paul Drexler W2PED and Tom Whitted WA8WZG
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INTRODUCTION

There continues to be steady growth in activity and interest in the 24 GHz amateur band. Equipment is becoming more readily available; noise figures on the order of 2 dB are now achievable using PHEMT devices, amateur's are making use of homebrew equipment using surplus modules such as the PCOM transmit/receiver units, as well as the DB6NT transverters, to get on the band. One barrier still remains: solid state power amplification at moderate power levels.

In 1999 a loosely knit group consisting of folks from the Microwave Update crowd and the Pack Rats (Mt Airy VHF Radio Club) got together to design and construct 24 GHz 1 watt power amplifiers for amateur use. (Keep in mind that at that time, even 100 mW was considered big power, as very few surplus solid state amplifiers were available to amateurs.) The bottom line is that the construction techniques used in the industry are fairly specialized, and aren't all that available, so several of us decided to get together and pool our resources to make this project happen. The amplifier discussed here uses state of the art MMIC die components that are wirebonded and packaged in a housing fitted with WR42 waveguide or SMA type connectors. A limited number of these amplifiers were built and made available at cost to those who were on the band or serious about getting on 24 GHz. A thorough review of the design was presented at Microwave Update 1999 in Dallas, Texas.[1] This paper will present some of the background and fill you in on how the project has progressed and where we're now at with this endeavor.

AMPLIFIER DESIGN GOALS

The project set out to design a power amplifier having roughly the following specs:

Pout	+30 dBm
Gain	45-50 dB
Connector Type	WR-42 or 3.5mm
NF	2.5 dB
DC / Baising	+12 VDC @ 1A

It was decided that the gain of this amplifier should be fairly high so as to accommodate a transmit line-up using a ring mixer followed by a bandpass filter. This would allow a simple transverter construction integration without the hassle of building additional pre-amplification. Lower gain configurations were also possible for those using DB6NT transverters. The WR42 waveguide interface is most common at 24 GHz, but some may prefer a connectorized amplifier, so the housing was designed to allow both configurations. A low noise figure design allows the amplifier to be used as an LNA as well. Additionally, to keep things simple for the end user, a DC bias board including voltage regulation and gate biasing was designed for the unit for *plug and play* operation.

DEVICE LINE-UP AND CONSTRUCTION DETAILS

At 24 GHz there are few, if any, packaged devices that are capable of generating moderate power levels. Fujitsu, UMS, and other manufactures have recently come out with some packaged devices using a "ball grid" attachment scheme, but these are still limited in performance, very new (read expensive) and difficult to work with. Bare die, or "chip and wire" devices are pretty much a requirement for the generation of 1 watt power levels at 24 GHz. This is discussed in detail in the earlier article. Since some of us had access to hybrid assembly methods and wire bonding equipment, we decided we would make use of the die MMIC components available on the market. A device line-up was chosen considering our specification wish list, cost issues, and the availability of MMIC die components.

The line-up uses 3 MMICs in cascade. The first two are CHA2192 LNA devices manufactured by United Monolithic Semiconductors.[2] The size of this MMIC is roughly 40 x 70 x 3 mils (WLH). Gain is approximately 15 dB at 24 GHz, and the device's measured NF is 2.5 dB. These devices normally cost about $70.00 in small quantities, but fortunately for us, UMS graciously decided to give us a price break even at our smaller quantity levels.

The output stage uses the TI/Triquint TGA9070[3], the same device that Charlie Suckling used in his 1 watt amplifier[4]. This is a 3-stage MMIC measuring 120 x 170 mils. It has 22-24 dB gain at our band and a saturated power level of +30 dBm. The device requires 7-8 VDC at 400 mA (MMICs aren't usually all that efficient at these frequencies!). Since the bare die is attached directly to the amplifier housing, heat sinking is not a problem. Needless to say, this is not a $25 device! We appreciate a generous donation made from TI/Triquint that has made this project possible.

As mentioned above, all of the MMIC die are attached directly to the amplifier housing for good RF grounding and thermal performance. For this reason, a professional type aluminum housing was designed for the amplifier. Several have asked why we couldn't just mount bare die on some kind of carrier arrangement, but we didn't see this as a viable option if we were to build and test nearly 40 of these amplifiers. We took a more conservative packaging approach, as we wanted the best reliability for amplifiers that would undoubtedly be subjected to harsh portable environments.

THE PROJECT TAKES SHAPE

By early to mid 2000 the electrical designs had been completed. It turned out that the amplifier and bias board design process was the easiest task to complete! Little did we realize that the next steps would end up being perhaps the most time-consuming. The next major tasks included obtaining RF and DC bias boards, amplifier housing CNC machine work, and the procurement of all of the required DC and RF components. Each task had to be done in the most cost efficient manner so that the amplifier didn't end up costing an arm and a leg; this also tended to stretch the project out longer than we anticipated.

Once an Autocad design was completed for the housing, the next task involved getting a machinist volunteer to program the housing and run all of the parts. Due to the precision nature of the machining required, and the amount of time that would be necessary to complete the task, this turned out to be challenge, as one can imagine. We'd like to thank Stan Hilinski, KA1ZE for stepping in and assisting us with the CNC machining process. Once the housing was machined, it was necessary to plate the machined parts so that the RF boards could be soldered down to the aluminum housing. We were able to sweet talk a plating shop to help us with the task for gratis, so this helped to keep costs down.

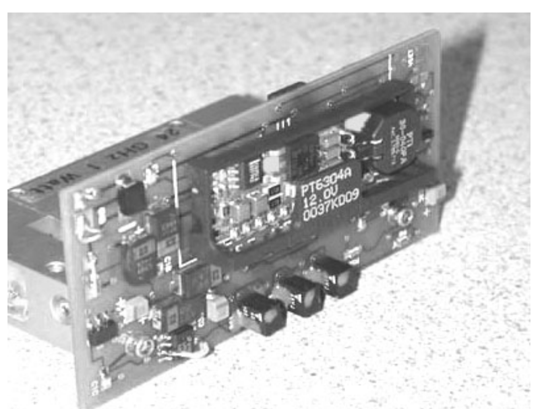
While the housing machine work was taking place, Owen, K6LEW, was doing the PC board layout for the DC bias board. Owen's contribution with the bias board layout and board fabrication is greatly appreciated.

Meanwhile, the authors were busily chasing down components and getting the assembly documentation in order. After a number of challenges, all of the necessary parts were on hand by June/July 2001. Keep in mind that all of this was being accomplished by a handful of us that had full time jobs and family demands, so things went a bit more slowly than if we were trying to do this for a living!

FIRST UNITS BUILT AND TESTED

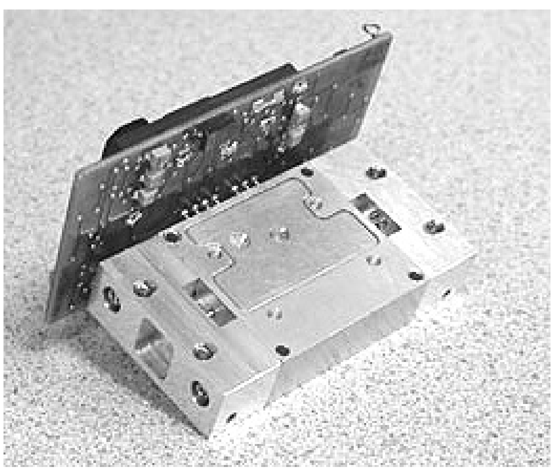
Paul, W2PED, designed the bias board, so it only made sense that he should build and debug the first boards! The first two boards tested and worked well (or so we thought). Then, Lloyd, NE8I volunteered to do a load test and a 24 hr burn-in on the bias boards. At the time, this seemed like it may have been bit "overkill," but we realized it couldn't hurt to do a burn-in. Well… we found out in a hurry that one of the tantalum capacitors had been installed backwards due to a silkscreen issue. After an extended operational burn-in, a number of the boards had tantalum capacitors that were blowing up! It was a good thing that Lloyd ferreted out this little problem before the amplifiers ended up in the field. The problem was easily corrected, and several more boards were built to mate up with the first RF assemblies. The completed bias board is shown in the figure below.

Amplifier Bias Board



Paul then worked on building the first RF assembly with some after-hours wire-bonding help from folks at his employer, mm-Tech[5]. The good news was that all of the parts fit pretty much as designed, and it looked like the amplifier had a good chance of actually working! The first amplifier was turned on and each of the MMICs were carefully biased per the recommended operating point. The first unit used the WR42 arrangement for input/output. The 0-80 waveguide tuning screws were set for best input/output return loss on the network analyzer, and *whola!*, 55 dB gain and good return loss at 24 GHz!!! The next step was to look at power output. Using a signal generator, the amplifier seemed to saturate around +29.5 dBm, so things looked pretty good. After playing around with this first unit, however, we noticed on the spectrum analyzer what appeared to be a low level oscillation several MHz removed from the desired signal. Further testing at cold temperatures showed the unit breaking into oscillation. After some trouble-shooting, the problem was resolved by using additional low frequency bypassing right next to one of the drain connection pins on the bias board. Our first amplifier was ready to be put into service by September 2001.

Amplifier without Heatsink



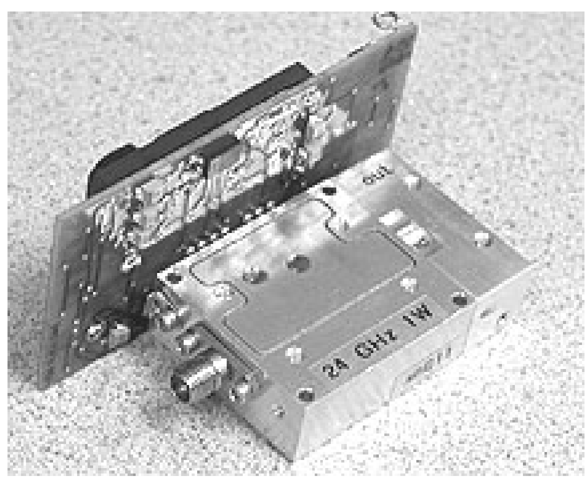
We're happy to report that Al Ward, W5LUA has had good success with this first unit in his 24 GHz portable rig. At this point others including W3HMS and KT1J have put their amplifiers on the air too.

WORK CONTINUES…

After the first unit was finished, we built several more bias board and RF assemblies in a one-at-a-time fashion, in order to make sure we wouldn't run into any significant problems. Once we had a few bias boards under our belt, the bias board team was kicked off led by Tom, WA8WZG, and Lloyd, NE8I. Along with the help of Tony, WA8RJF and Don, WW8M, a number of additional bias boards were built. The bias board assembly is not trivial, as all of the components are surface mount and require a good magnifier and/or microscope for proper assembly and inspection. We've taken the approach of building the boards and RF assemblies in small lots of 4 units each to keep things manageable, and, to catch any mistakes before we build up a bunch of units. This has worked well for us.

The final integration and testing of the first amplifiers initially took about 4 hours each. The RF assembly and testing was done at Paul's workplace after hours since this isn't the type of thing that you can easily do in your basement! Fortunately, Paul's employer was sympathetic to this sort of activity, but as you might imagine, the XYL only allows so much of this thing! By the spring of 2002, we had completed about 5 amplifiers. A real breakthrough of sorts came when some volunteer RF assembly / tuning assistance arrived on the scene. Joel, N2LRI has been able to help out with several late assembly/test sessions. Things go *much* faster when you can split up the tasks!

SMA Input Configuration



With each amplifier built, we learn a little more about the assembly process and getting the best performance from the design. Fairly recently, we took a closer look at the possibility of obtaining more power out of the output MMIC. The first amplifiers had a saturated power output of +29.7 dBm, just under 1 watt. The MMIC manufacturer's data indicated that the P1dB should be about +30 dBm at our frequency, so we *should* have been seeing a higher saturated power level. We then realized that the output MMIC device was being biased *very* conservatively, so some experimentation was in order. We found that raising the operating voltage by just 1 volt would give more than a 1.5 dB increase in output power. This was still a safe operating point for the device. Some work was required on the bias board, but **we're now seeing +31.5 dBm, or 1.4 watts saturated power on most amplifiers**!

We're continuing to build and test amplifiers in order to complete all of the units. One of the best things that we've done to move things along is the build/test sessions for the bias boards and RF assemblies, as well as the final testing. We're planning on doing more in this area to speed things along. As of this writing we've completed about a third of the total number of amplifiers, but each amplifier gets a little easier. This is a long- term project, and we appreciate the patience and understanding of all involved. Our goal is to try to complete this project by the spring of 2003.

CREDIT WHERE CREDIT IS DUE

Many people have assisted in various ways to bring this project to fruition. Special thanks are in order to the following individuals and companies (for making this project a huge success:

KB3XG, NE8I, KA1ZE, W5LUA, N2CEI, K6LEW, N2LRI, W2SZ, W3HMS, WW8M, WA8RJF, KT1J

mm-Tech, Inc.
Triquint Semiconductor
Downeast Microwave
United Monolithic Semiconductors
Richardson Electronics
Filtran Microcircuits, Inc.

CONCLUSION

At 1.4 watts output power level, this design represents what we understand to be a state of the art power level for amateur weak signal service. At the conclusion of this project nearly 40 individuals will benefit from these efforts with increased performance in their 24 GHz systems. Hopefully, many more of us will benefit due to increased 24 GHz activity levels and the possibility of greater DX contacts.

[1] Paul Drexler, W2PED and John Sortor KB3XG, "A 1 Watt Power Amplifier for 24 GHz," Proceedings of the 1999 Microwave Update.

[2] www.ums-gaas.com

[3] www.triquint.com

[4] Charlie Suckling, G3WDG, Presented at 1998 Microwave Update.

[5] www.mm-tech.com