70 Watts Cheap on 2304 MHz
Modifying a 1900 MHz PCS Amplifier for 2304 MHz

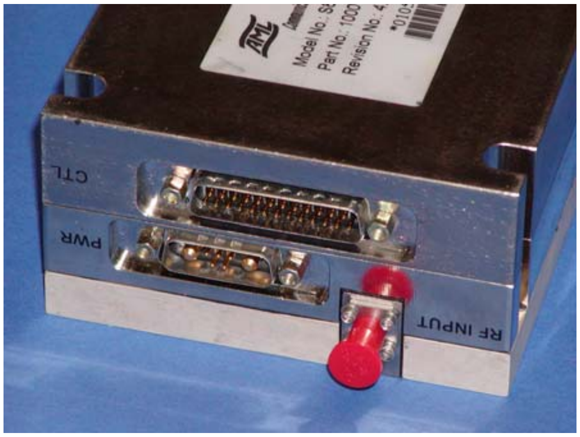
R. L. Frey – WA2AAU   Eastern VHF/UHF Conference   April 22, 2006

Introduction With the widespread deployment of PCS communications systems at 1900-2000 MHz, some equipment for that frequency band is now beginning to appear as surplus. Three years ago, a substantial number of surplus power amplifiers became available to the amateur radio community here in the northeastern US. The challenge was could we make any good use of these amplifiers on a nearby ham band. The 2304 MHz band was the closest in frequency, only 300 MHz away, but it is above the original design frequency making it more difficult to get good performance from the semiconductors. The 1296 MHz band is below the design frequency, but the frequency is more than twice as far away from the original design frequency, again making it difficult to make things work. This paper describes one set of modifications that allow the amplifier work on 2304 MHz. There may be better solutions. Please share any you have found.

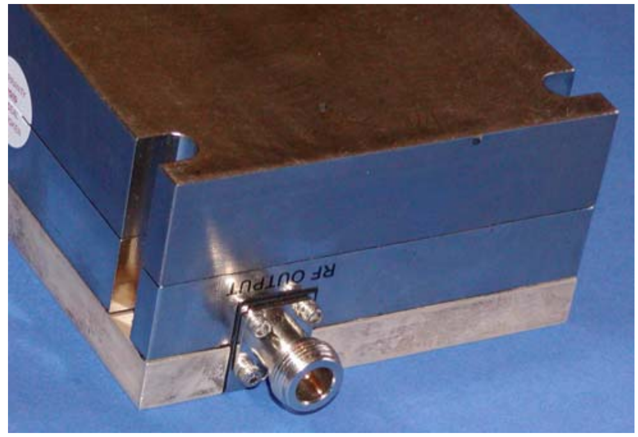
The AML Model S80PCSA Amplifier is constructed as a three-layer sandwich of milled aluminum enclosures and plates that measures 4¼ x 10 x 2¼ inches giving the impression of a very solid brick. The top two sections of the amplifier contain the control electronics and the RF amplifier circuit board is mounted on the bottom place that is ½ inch thick. The amplifier absolutely, positively requires a large external heat sink. The amplifier is designed to use 28 vdc.

AML PCS Power Amplifier

Power and control signals are connected at one end of the amplifier that also has an SMA connector for the RF input. The power connector uses 2 thick pins that will make it difficult to find a mating connector. During these modifications and tests, no effort was made to use any of the control circuitry. Only the final stage was modified and a very simple biasing circuit works well. A type N connector is used for the RF output at the other end of the amplifier “brick”.

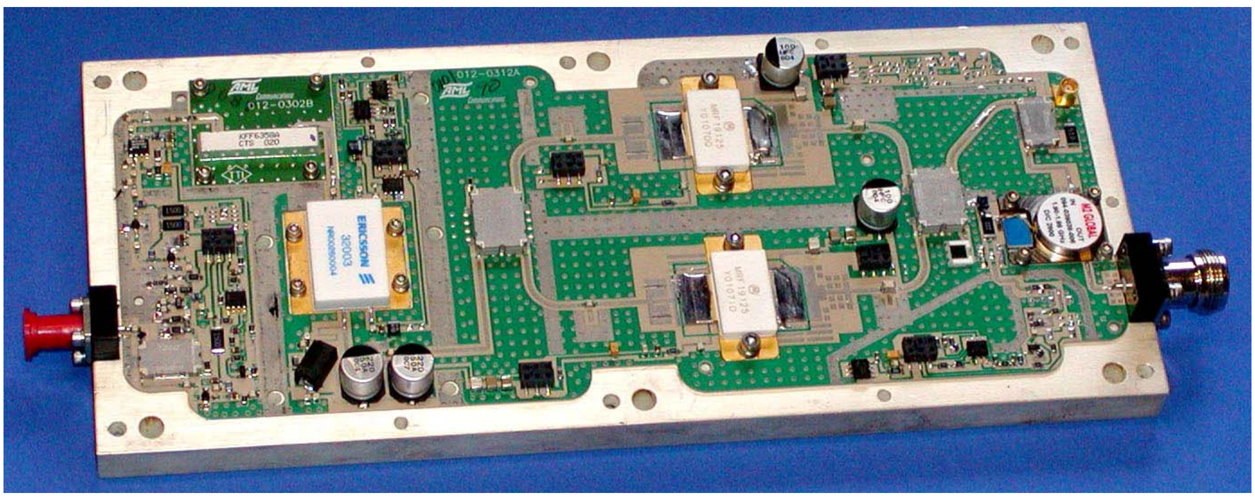


Input End of the AML Amplifier



Output End of the AML Amplifier

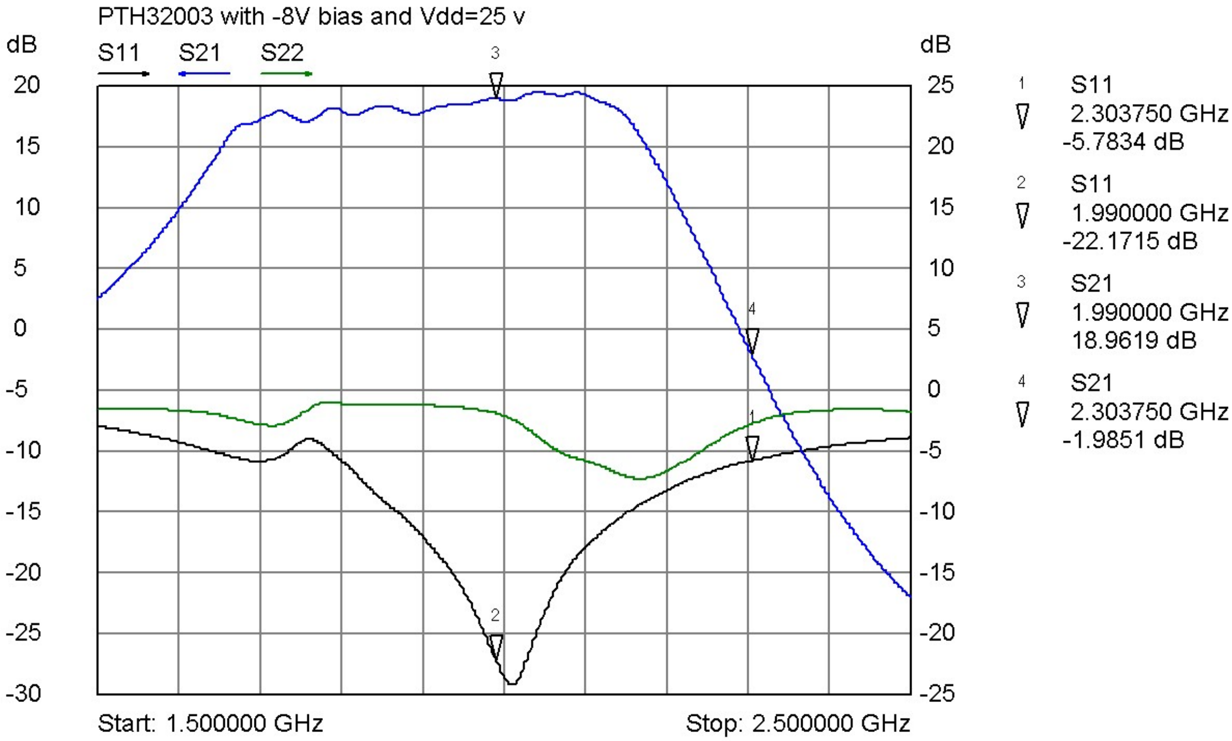
The figure below shows the RF circuit board mounted to the aluminum bottom plate of the amplifier. Forget about getting the board off the base plate – it is soldered (or glued?) on.



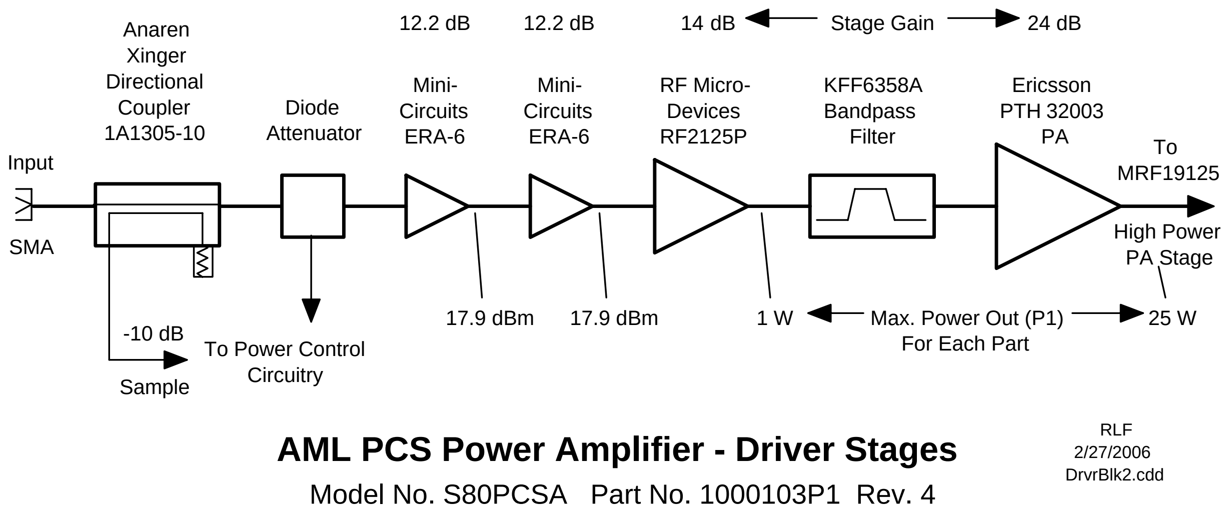
RF Amplifier Board On Base Plate

Several major components are visible in the photo. The two transistors just to the right of the middle are of primary interest. They are MRF19125s, rated to deliver 130 watts ***EACH*** of CW at 1990 MHz at their 1 dB compression point. Easy does it folks… this PA will not deliver that kind of power at 2304 MHz, but it's still worth the effort to make it work, I think you'll agree. The two rectangular objects on either side of the MRF19125s are a pair of 90-degree hybrid splitter/combiners. The one on the left divides the drive power between the two big transistors and the one on the right combines their output. The round object near the output connector at the right is a ferrite isolator to protect the amplifier if there is no load attached.

The large white device near the left end of the board is an Ericsson PTH32003 multistage hybrid driver amplifier module rated to deliver 25 watts at 1900 MHz. It is most disappointing that this device does not function at all at 2304 MHz because of the interstage matching circuits buried inside the device. Adding matching components at the input and output will not improve the interstage match so this device is most unfortunately quite useless at 2304 MHz. The figure below shows its measured performance at 2304 MHz. The module has less than 0 dB of gain at 2304 MHz, in fact 2 dB of loss. Too bad! We are left without a driver stage that we really need!

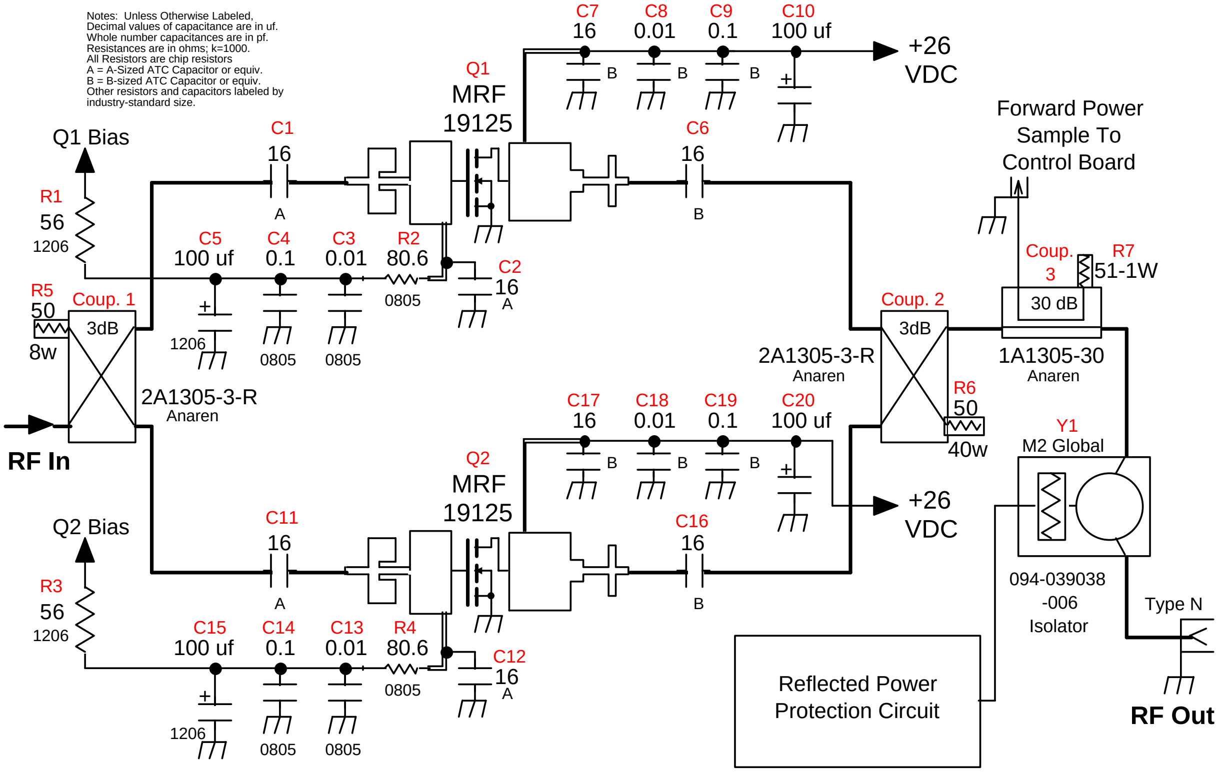


The circuitry at the far left end of the board is the low-level amplifier section that might be useful to boost signals from the milliwatt level to perhaps a fair fraction of a watt. The figure below shows a block diagram of the low level stages. Two Mini-Circuits Labs ERA-6 MMICs drive a



RF Micro-Devices RF2125P. The ERA-6s can be used as is and will deliver as much as +17 dBm or more before saturating. RFMD does not offer matching information for the RF2125P at 2304 MHz, but perhaps someone can engineer input and output matching circuits for this device in the future. Since the device is rated to deliver 1 watt at 1885 MHz, it might deliver between ½ and ¾ watts on 2304. The three low-level stages certainly have enough gain to boost the output of a raw mixer in a transverter to about ½ watt or more. This could be useful, as we shall see. The band pass filter is of no use for amateur operation at 2304 MHz as it is obviously made to pass frequencies in the 1900 MHz PCS band.

Power Amplifier Schematic – The figure below is a detailed schematic of the final stage of the AML amplifier. This amplifier uses a pair of 90-degree hybrid couplers to split and combine



Drawn From Inspection
R. L. Frey - May 10, 2005

AML PCS Power Amplifier - Final Stage

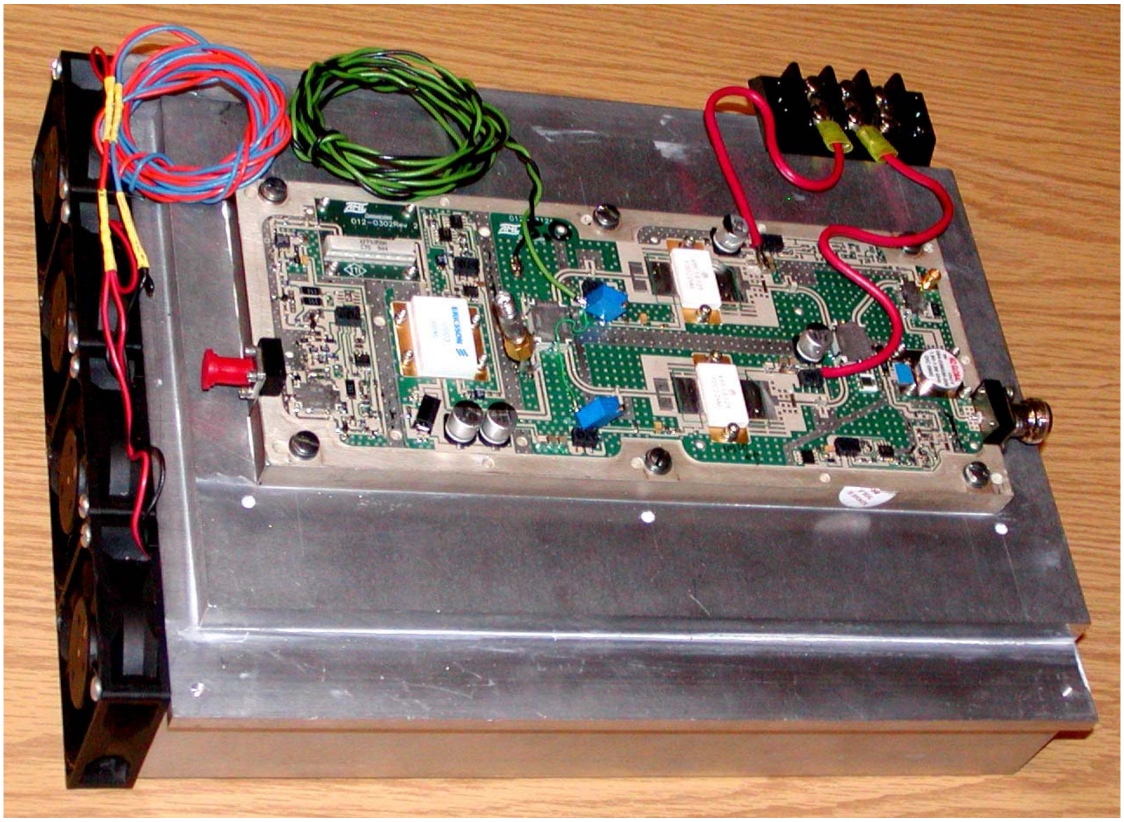
Model No. S80PCSA Part No. 1000103P1 Rev. 4

the power between two MRF19125 Lateral MOSFET RF power transistors. The 2A1305-3-R hybrid couplers are made by Anaren, and are designed for 1900 MHz, but hybrid couplers are inherently very broadband devices and might be useful at 2304 MHz. A careful inspection of the data sheet and the typical S-parameters published for the part shows the amplitude split becomes quite uneven at 2304 MHz, although the angle remains fairly close to 90 degrees. That will probably limit the maximum combined power that the pair of transistors could deliver at 2304 MHz.

The input and output of each transistor is independently matched to 50 ohms and then the two amplifiers are combined. Each FET is capable of delivering 130 watts of CW at 1990 MHz but they are used at much lower power levels in PCS service. According to the data sheet, in multi-carrier service each device is typically operated at 25 watts output to minimize distortion as much as possible, so this power amplifier was probably used to deliver only about 50 watts of output power. The devices are capable of much, much greater power when amplifying just one signal.

The output of the two transistors passes through a 30 dB directional coupler that picks off a small sample to run the power control circuits. Then the output passes through an isolator where the power in the dump load is monitored and delivered to a circuit that protects the amplifier against bad output loads. Unfortunately the 1900 MHz isolator used in this amplifier is not useful at 2304 MHz. We can probably live without an isolator especially if we don't use the amplifier near the full power rating of the transistors.

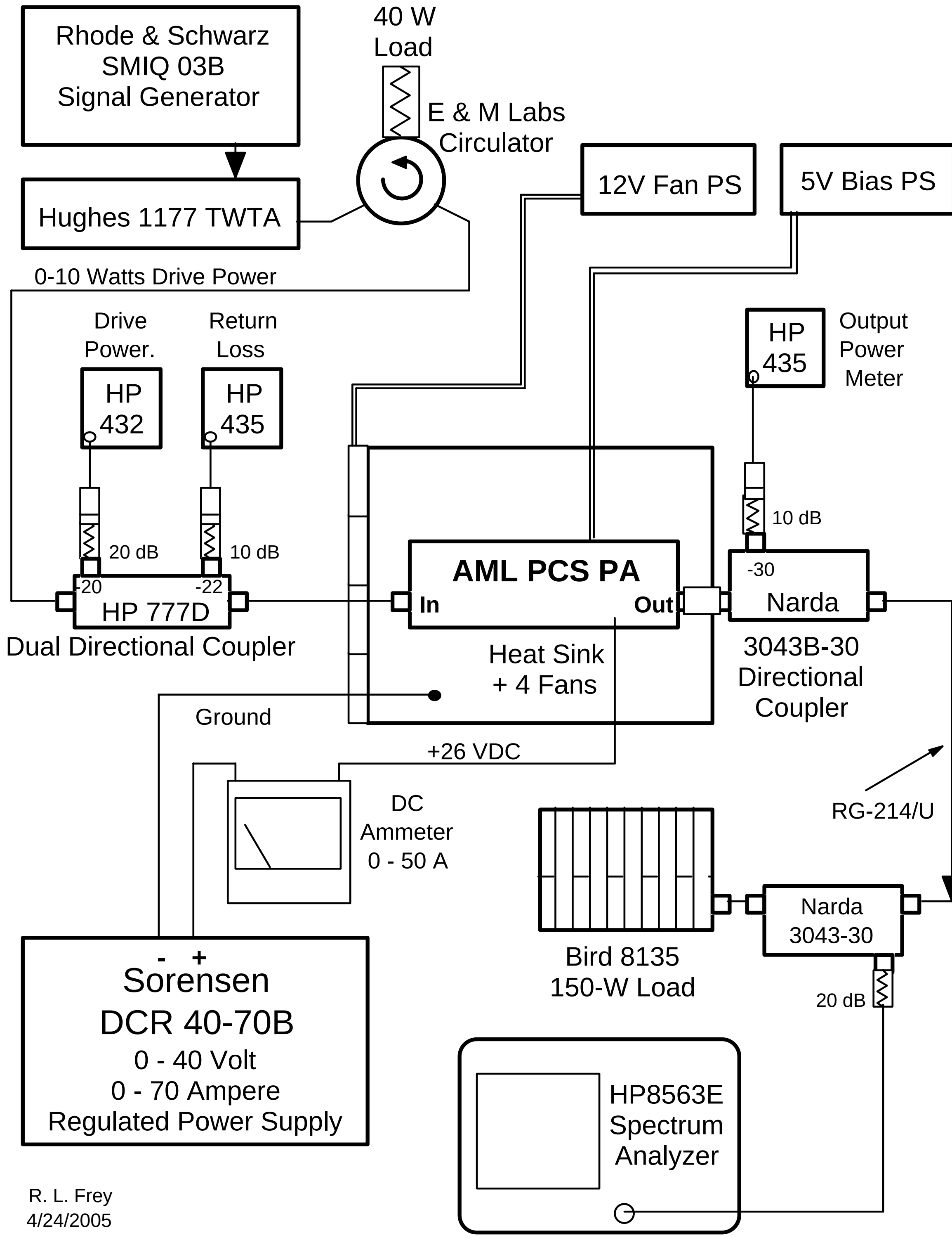
As Is Tests – Before modifying the amplifier, it was tested on the original frequency to make sure it was working and to see just how well it worked to compare to its performance after it was modified. The photo below shows the amplifier mounted to a heat sink with fans for testing.



AML Amplifier Mounted to Heat sink with Fans for Testing

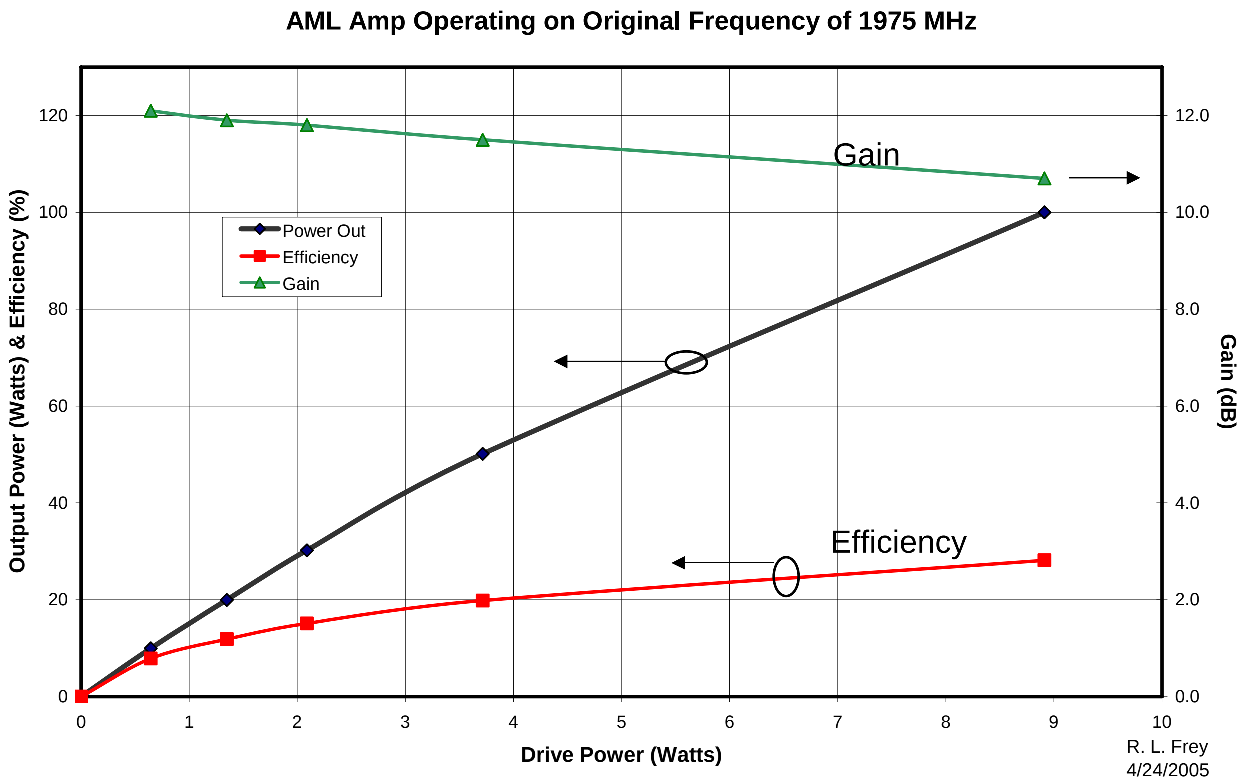
A ½ inch aluminum heat spreader plate was sandwiched between the amplifier base plate and the heat sink to make sure the lowest possible temperature could be maintained. The heat sink measures 12" x 10" x 3" and was cooled by 4 miniature 3-inch muffin fans. This is probably overkill, but it prevents heating effects from changing the test results. Without a heat sink, the amplifier gets very hot very quickly. The efficiency of the amplifier is only fair at 1900 MHz and it gets considerably worse when the transistors are operated above their design frequency at 2304 MHz. It cannot be used, even in intermittent ham radio service, without a heat sink. Probably a heat sink half the size of this one with fans would be adequate to cool a single transistor running at about 80 watts output.

Considerable test equipment was required to make accurate performance measurements of the amplifier. The figure below shows how the equipment was connected to test the amplifier.



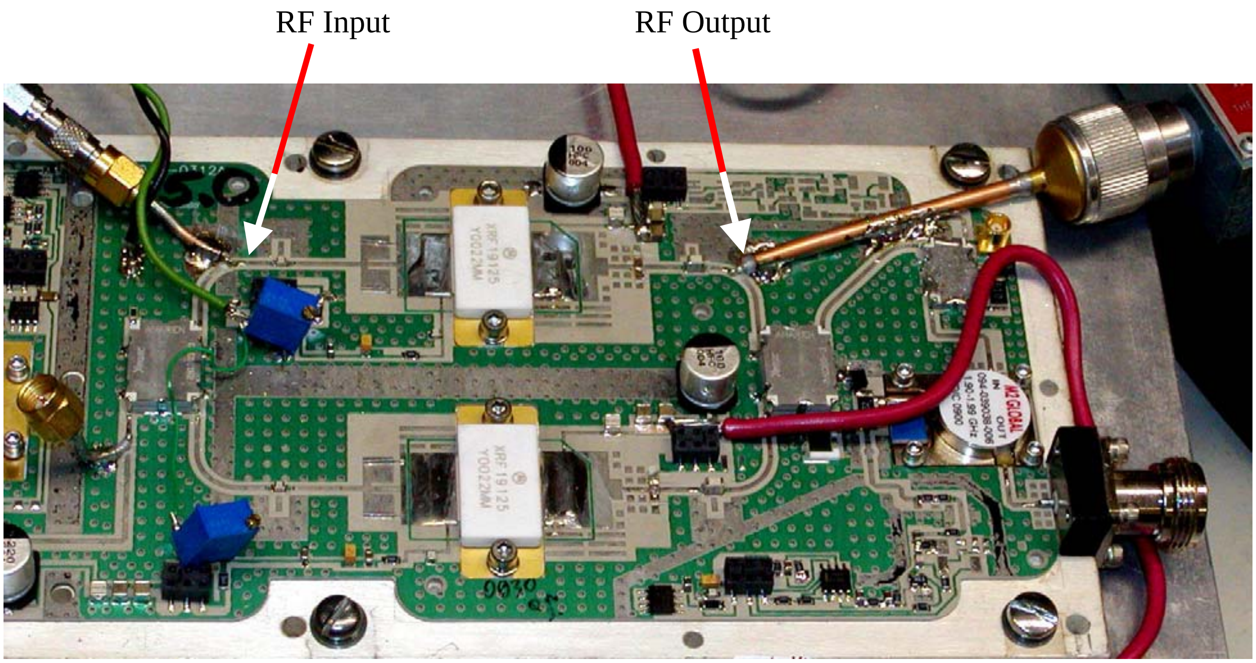
Test Jig For 1900 MHz AML Amplifiers

Because the driver stage of the amplifier is not useful at 2304 MHz, a high power drive source was required for testing. An old Hughes TWT amplifier was used to drive the final stage directly with 10 watts or more at either 1975 MHz or at 2304 MHz. The TWT amplifier was protected with an isolator to prevent damage when the input of the amplifier had a bad VSWR as the input match was adjusted. RF drive was connected to the input of the input hybrid splitter on the board by cutting the microstrip and splicing in a small piece of UT085 copper coax. The two RF transistors were individually biased with two 25-turn 500-ohm trim pots running from a separate regulated 5-volt DC power supply. In final operation, a small 3-terminal regular can provide 5 volts. All the components used in the test setup were tested and calibrated so powers could be accurately measured. The figure below shows the performance of the 2-transistor PA with drive applied to the input hybrid and the output measured at the original Type-N output connector.

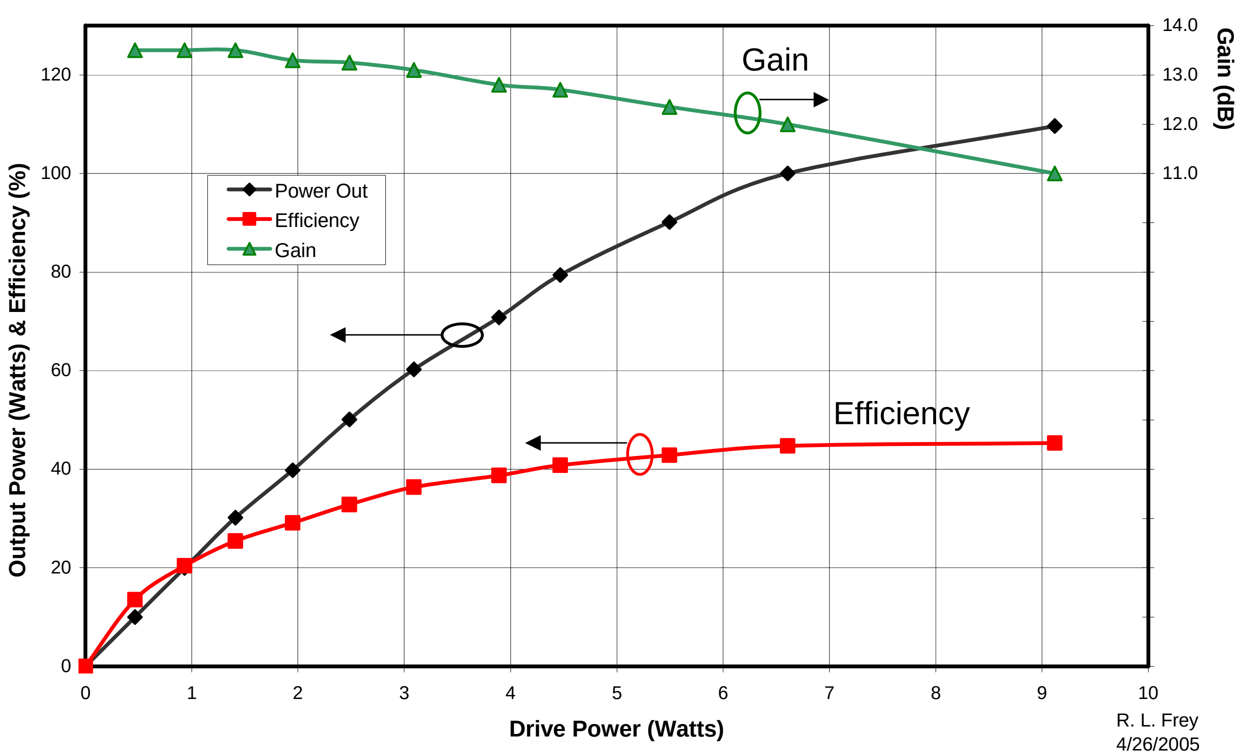


The test showed that the amplifier could deliver 100 watts of output with about 9 watts of drive at 1975 MHz. The linearity looks pretty good from the input-output power curve but the overall efficiency is only 28% at 100 watts output, not very good at all, but remember, the amplifier was designed for linearity at about 50 watts output, NOT for overall power efficiency. Remember that big heat sink? Now you know why it's needed. The amplifier draws 13.5 amps at 26.3 volts to deliver 100 watts. This amplifier is using 355 watts of DC to make 100 watts of RF. The heat sink must dump 255 watts. The gain of the two-transistor final stage ranged from 12 dB at low levels to 10.7 dB at 100 watts output including all the losses of the splitter and combiner, power coupler and the isolator.

Since the following step in the modification process would require retuning a single transistor stage from 1975 MHz to 2304 MHz, it was important to determine the performance of a single transistor alone without any splitters or combiners, couplers or isolators. We need to know the raw performance of just one transistor with its associated matching circuits. To do that, the microstrip leading to the gate of the upper transistor was cut before the blocking capacitor and a small piece of UT085 copper coax was spliced in to provide drive power. Similarly the 50-ohm microstrip leading away from the drain of the upper transistor was cut after the blocking capacitor and a piece of UT141 copper coax was spliced into the circuit to measure the output power. The picture below shows where and how the input and output connections were made.



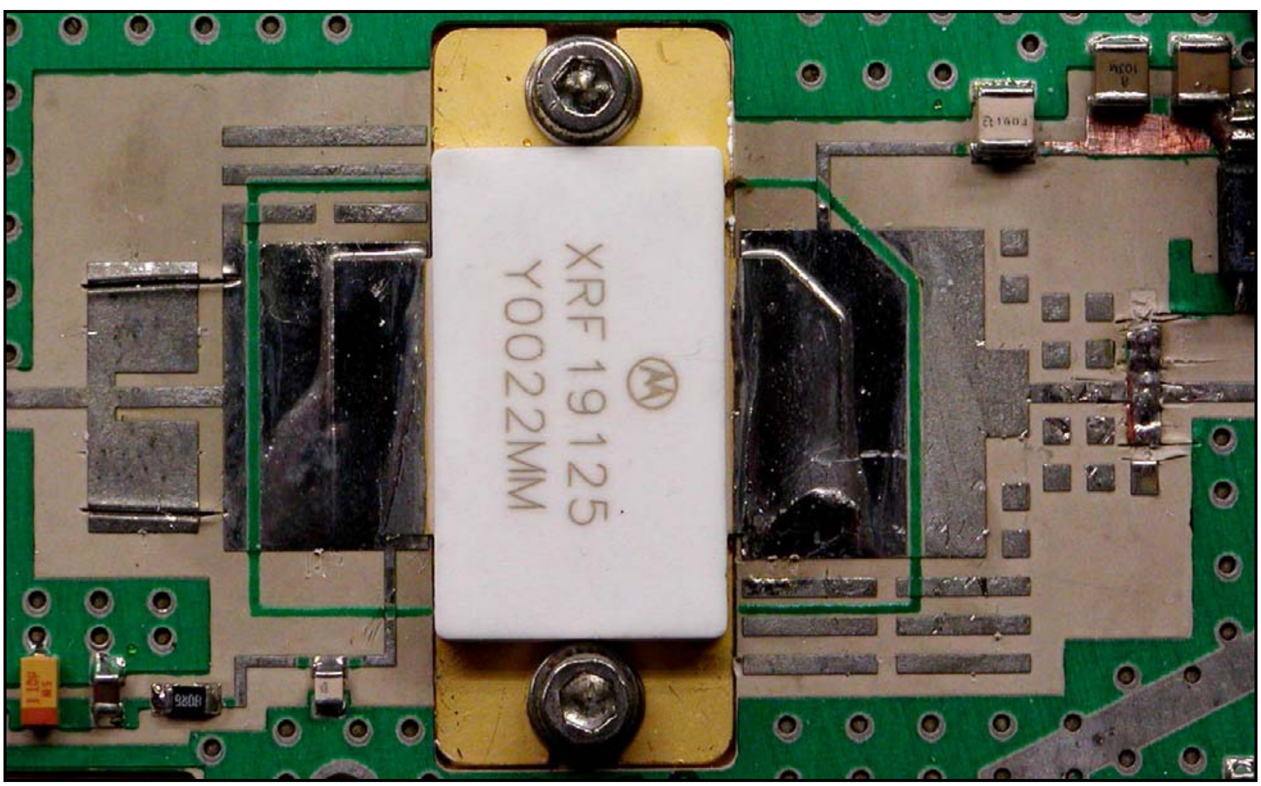
Copper Coaxial Cable Connections To Test Single Transistor



Top Transistor of AML Amplifier Operating on Original Frequency of 1975 MHz

The results of the tests of a single transistor are shown in the figure above. It was possible to drive a single transistor much harder than the pair, and the single transistor shows much higher efficiency than the combined pair did. The single transistor delivered 110 watts of output with 9.1 watts of drive at an RF/DC efficiency of 45%. The single transistor has 13.5 dB of gain at low signal levels and its gain drops by 1 dB at about 85 watts of output. At 100 watts of output, the gain has dropped 1.5 dB to 12.0 dB. The manufacturer's data sheet claims a small signal gain of 13.5 dB so the gain meets specifications. The data sheet claims that the transistor can deliver 130 watts at 1 dB of compression but those tests were done in a different test fixture with somewhat different matching than is used in this amplifier. This amplifier was almost certainly optimized for lowest possible distortion. The manufacturer also claims the transistor will operate at about 45-48% efficiency at 130 watts, so we're not far from the mark there. All things considered, the measurements of one side of the AML amplifier closely agree with the performance specified on the transistor data sheet.

Moving The Amplifier To 2304 MHz – With a good idea of how the amplifier works on its original frequency, it is now time to retune it to 2304 MHz. The first step is to try various changes to the input matching circuits to improve the input return loss (SWR). Once the input return loss was reduced to at least -10 dB, with low drive power, the drive power was slowly increased until the drain current to the device rose from the no-signal value of about 1.3 amps to perhaps 2-3 amps. The output match of the device was then adjusted for maximum output. The input match was then readjusted for best return loss, and then the drive power increased more. Once again, the output match was adjusted for the greatest power output, and so on. When no further improvements could be made, the following patterns had been created. These might be good starting points for others attempting to modify these amplifiers for 2304 MHz, but other patterns might work better. There is no one correct solution. The photo below shows the input and output microstrip matching circuitry on the unmodified lower power transistor.



Input Microstrip Matching Network

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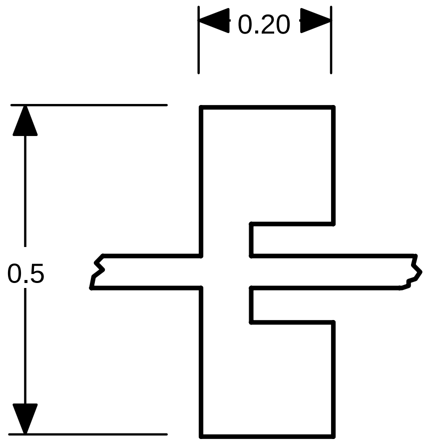
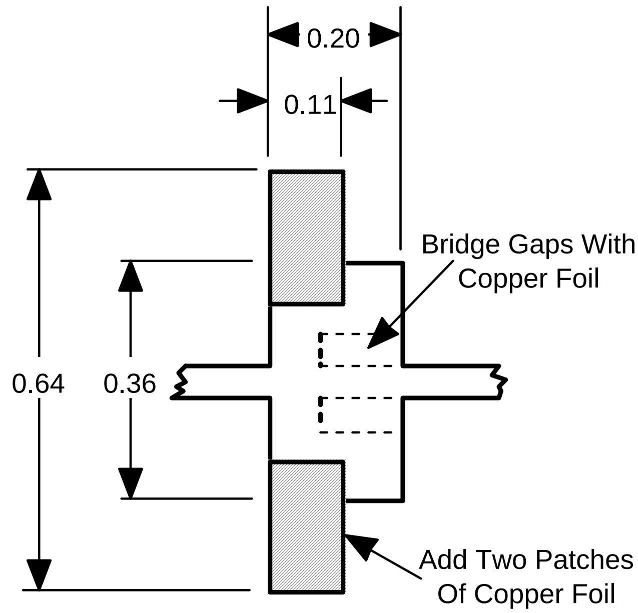
3/1/2006

(Second Pad Back From Power Transistor)

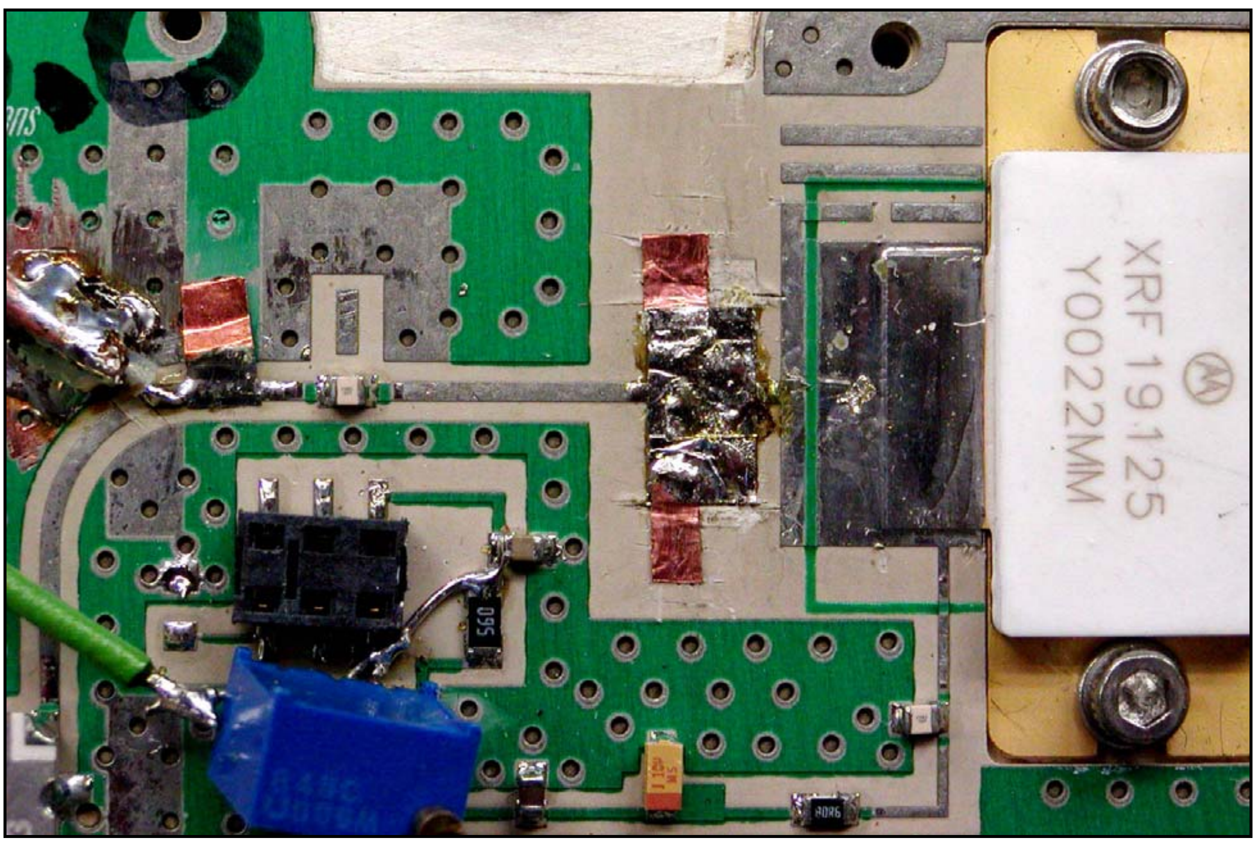


Original Design

All Dimensions are in Inches



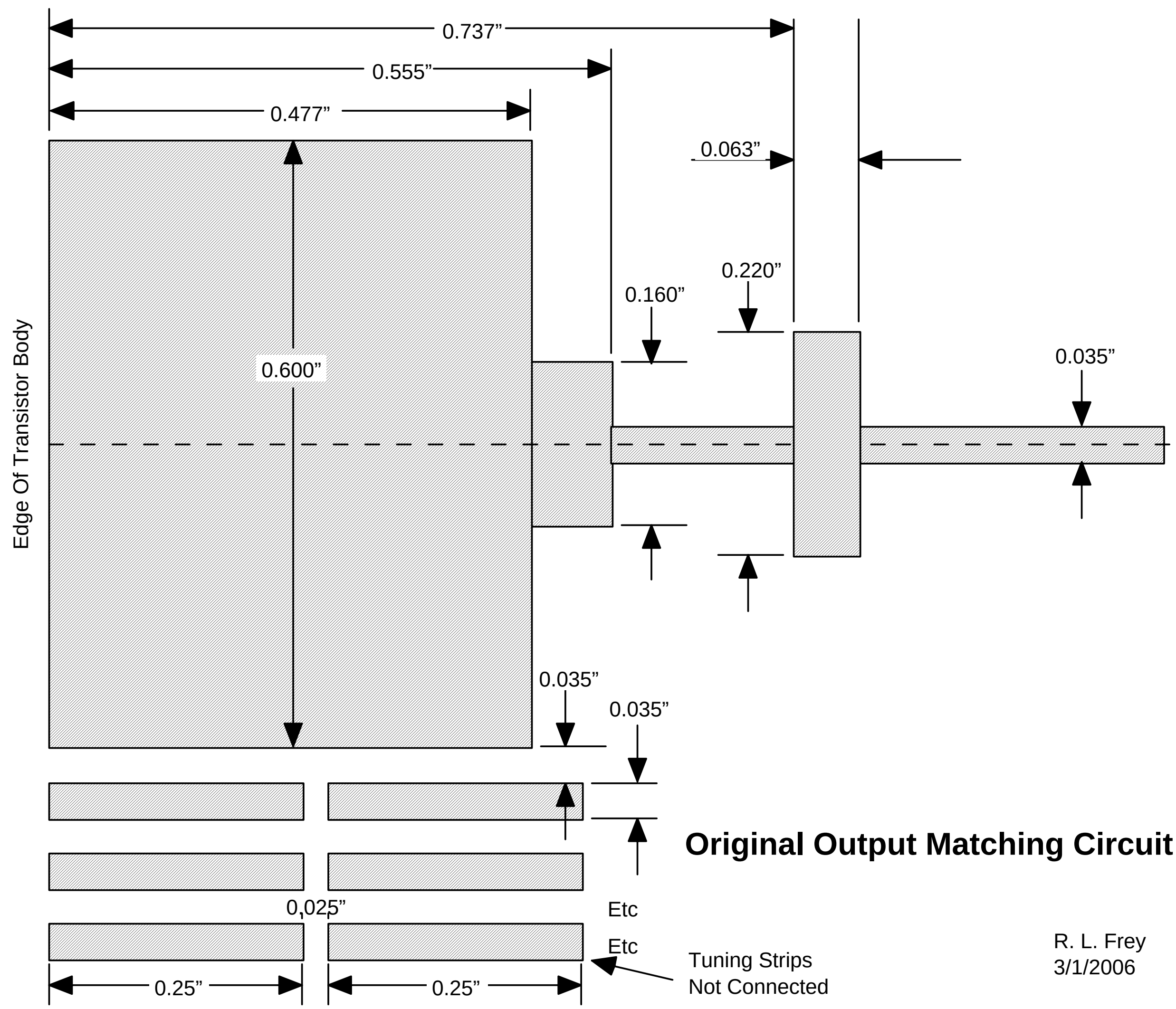
Modified for 2304 MHz



Input Match Modified for 2304 MHz

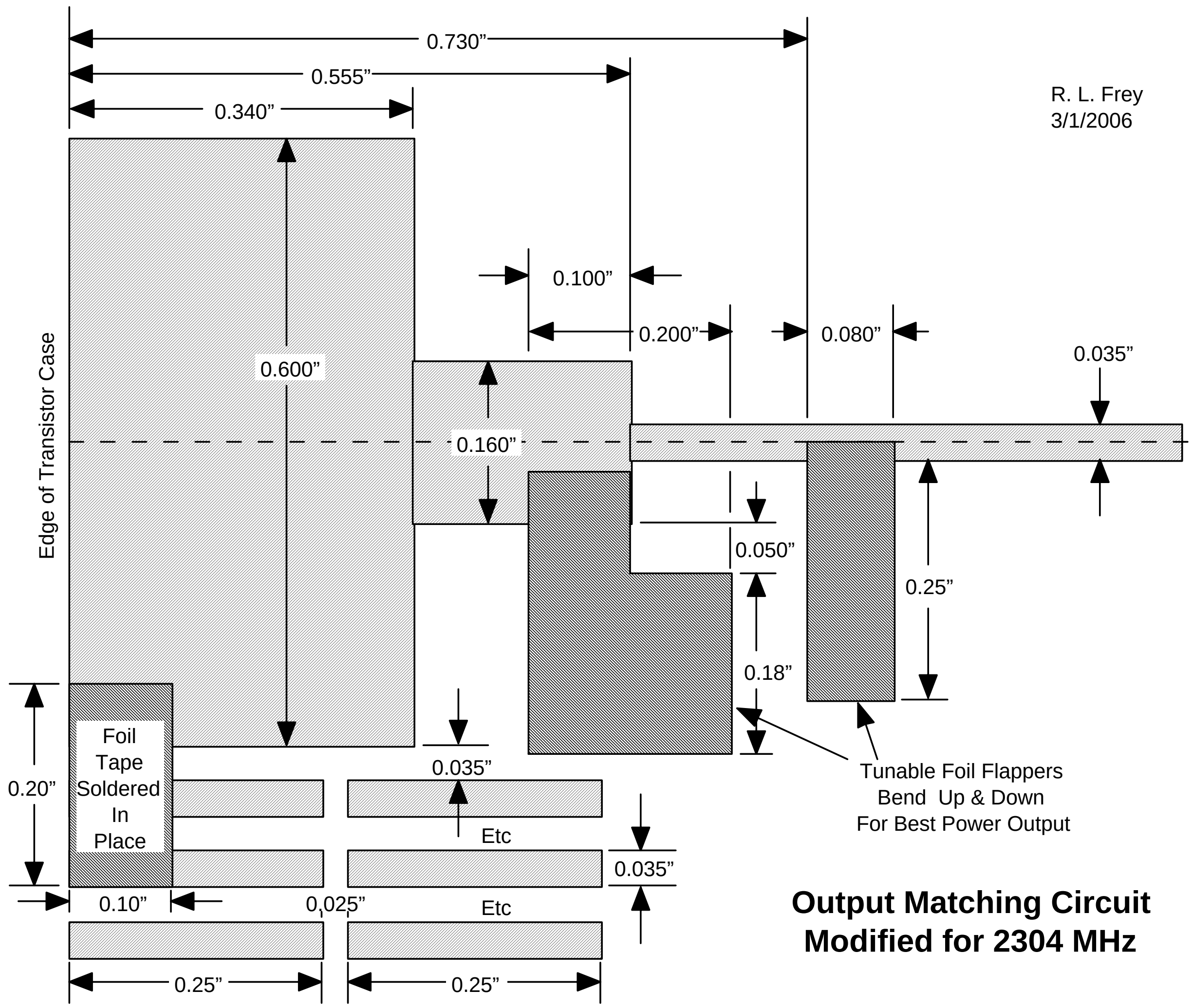
In addition to modifying the input matching network near the transistor shown above, it was found by experiment that the input match could be greatly improved by adding a small piece of foil 0.125 wide by 0.200 long near the input cable connection 1.35 inches from the body of the power transistor. This tab can be seen near the left edge of the photo above. This tab was bent up and down to give the best input return loss. Note… the tab is NOT pushed down hard against the ground plane of the circuit board, or it will short out the input RF. A small microwave trimmer capacitor might also work well at this location.

The changes to the output matching network are more complicated and are described in the next two figures shown below. First, here is a drawing of the original microstrip matching circuit.



Notice that none of the tuning stripes below the large pad are connected. Each of these stripes are 0.25” inches long and 0.035” wide. They are also spaced 0.035” apart side to side and 0.025” end to end. A small piece of copper foil was used to connect two small tuning pads at the right end of the drawing. This shows up as a vertical trace 0.063 inches wide 0.737” from the edge of the transistor package.

The next drawing shows how the output microstrip matching circuit should look after modification for operation on 2304 MHz. First, the main pad has been cut down in size.



But for whatever reason, the amplifier worked best with more capacitance added very close to the drain lead of the device, in the form of connecting two of the tuning stripes to the main pad. In addition, two tunable copper foil "flappers were added as shown in the photo. They are made of thin, stiff copper foil that can be bent up and down and will thereafter hold its shape. The flappers are adjusted for best output power and then simply left in that position. Since they are stiff and have little mass, the flappers will stay in position with nominal amounts of vibration. Even if they should change position, they only affect performance a little bit, and a piece of foil with adhesive on one side could be substituted and then cut to the size that gives the best results.

The photo below shows the output matching circuit modified to operate on 2304 MHz. Notice the transistors in this particular amplifier are XRF19125s indicating they are early production versions of the MRF19125. The matching circuit that works best for the XRF version might be slightly different from what works best for the MRF device so be prepared to experiment a little.

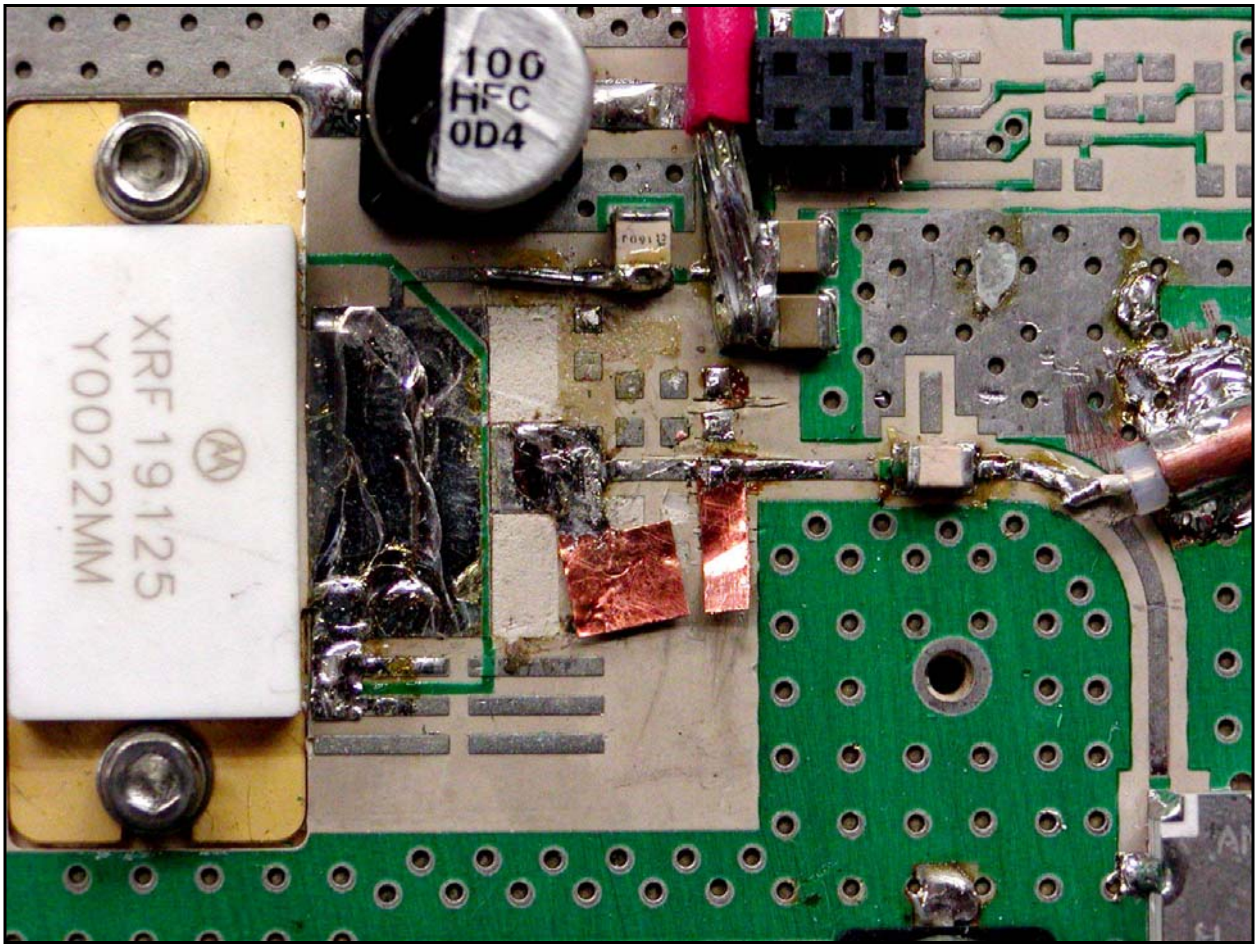
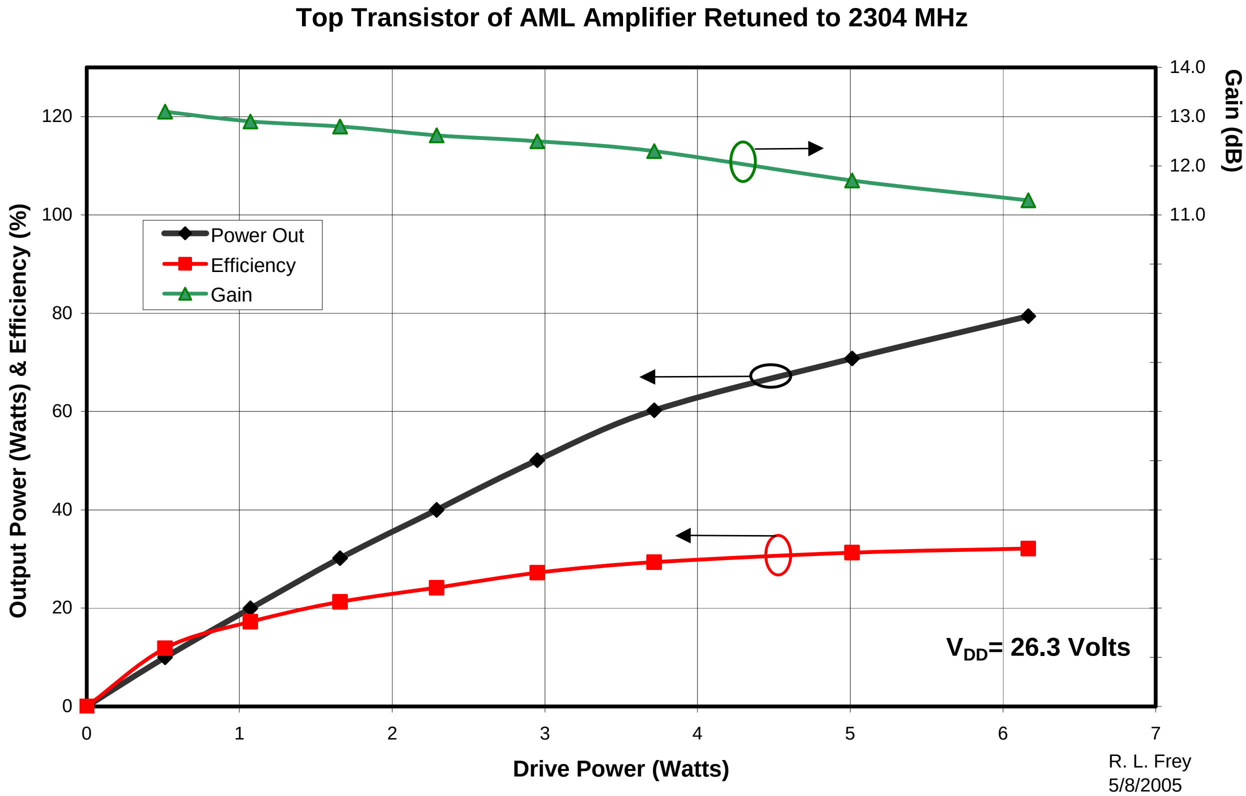


Photo of Output Matching Circuit Modified for 2304 MHz

Amplifier Performance On 2304 MHz – The next two figures show the performance of the AML amplifier on 2304 MHz after it was modified as shown above. For the first graph, the power supply voltage was set to 26.3 volts and the bias current through the device was set to 1.3 amperes with no drive applied by adjusting the gate voltage with a multi-turn trim pot. The most obvious difference in the amplifier performance at 2304 MHz is that it will not deliver as much power as it did on 1975 MHz. The amplifier struggles to deliver 80 watts as compared to 110 W.

The efficiency is also much lower at 2304 MHz only reaching a maximum of about 32% as compared to 45% on 1975 MHz. The amplifier uses 9.4 amps at 26.3 VDC to deliver 79 watts of RF at 2304 MHz. The small signal gain is just a little bit lower at 2304 MHz giving 13 dB rather than 13.5 dB at 1975 MHz, but the gain compresses more at lower output power levels at 2304 MHz than it did at 1975 MHz. One troubling artifact of the amplifier at 2304 MHz not seen at 1975 MHz, is a quick droop in output power of about ½ dB within a few seconds after the RF is first applied. From that point on the output holds steady at the power levels reported here. Still, let's not look a gift horse in the mouth! 75 to 80 watts at 2304 is not a power level to be sneezed at! That's quite a bit more than most stations run today.

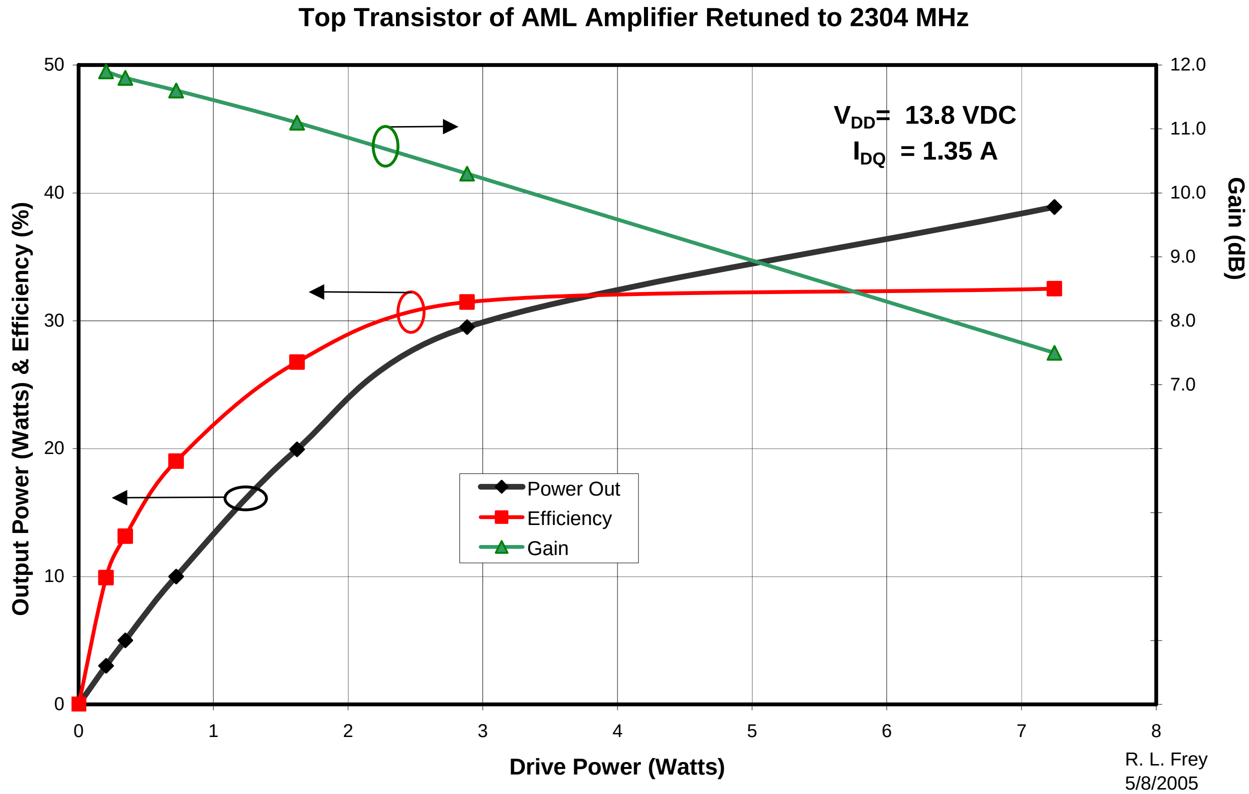


Could we do better? Quite possibly. Maybe a better output matching circuit could be found that will give better power output and efficiency. We simply do not know how much better these devices can do at 2304 MHz. Several people have modified these amplifiers over the last two years and have seen very similar results including the quick downward power drift on turn on.

Some operators will certainly ask if the amplifier will work on 13.8 VDC automobile voltages. In fact, it does but at much lower output powers. Still the PA provides considerably more output power than can be obtained easily any other way, so operating it at 13.8 volts should be attractive for many.

Amplifier Performance at 13.8 VDC – The figure below summarizes the performance of the AML amplifier modified for 2304 MHz but operated with a power supply voltage of 13.8 VDC. Some minor retuning was attempted at 13.8 VDC, but no significant improvement was seen. The amplifier delivers 20-25 watts at 13.8 VDC before it begins to seriously compress. The efficiency is not much different than at 26 volts.

The small signal gain remains at almost 12 dB even at this much lower power supply voltage. The 1 dB compression point occurs at just a little bit over 20 watts output, making this configuration a very nice driver or medium power amplifier. The amplifier requires 5.4 amps at 13.8 VDC to deliver 20 watts of RF. The amplifier is very well behaved at this lower voltage and operation is quite stable. Running the amplifier at 13.8 volts sure beats messing around with a 13.8 to 26-volt DC-DC converter especially if only a low power driver stage is required.

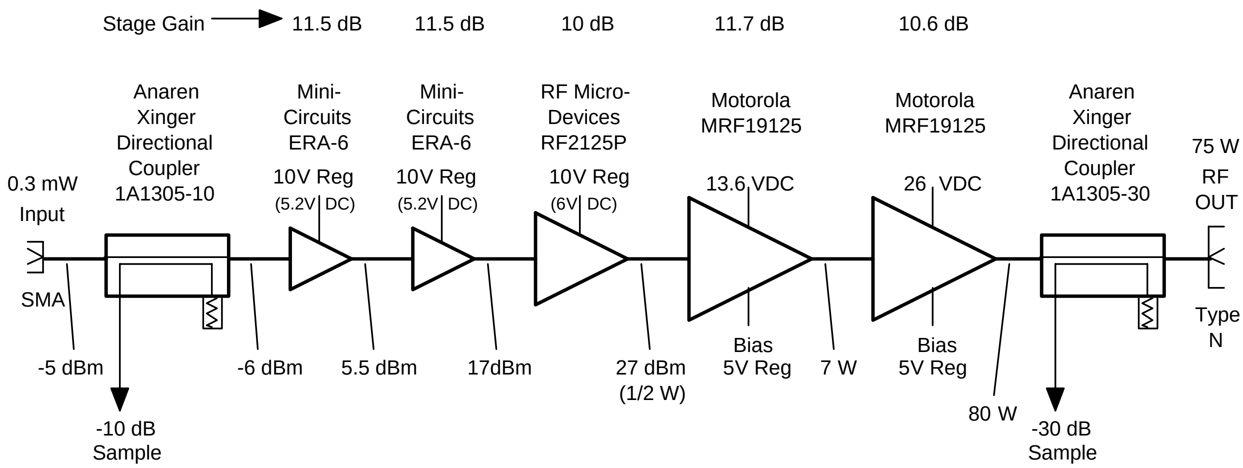


How To Use The Amplifier – OK, so enough with the measurements… how can we use these power amplifiers? Obviously, if you have a 2304 station with a transmitter that produces 4 watts or more, you're in luck. Just modify one of the two output transistor stages as described in this paper and you will get 60 to 80 watts output. Of course you will need a 26 VDC power supply to get full power out of the PA. As mentioned earlier, you will need a BIG heat sink with a fan to keep things cool. Unfortunately, running both stages as a hybrid combined pair does not seem to work much better than using just a single transistor, and the pair uses more DC power than a single transistor. This is apparently because the 90-degree hybrids in the original design no longer split power very evenly 300 MHz away from their design center. Adventurous readers might want to replace the Anaren hybrids with a similar model on the correct frequency, and try to make the combined pair work better. Replacing the hybrids on the amplifier pallet will be a challenge, as they are either epoxied or soldered to the base plate. (My best guess is that they are soldered in place.) Tough, but it may be rewarding.

Alternatively, if you really don't want to deal with 26 VDC power supplies, a single transistor will still deliver 25 watts or more with a 13.8 VDC automotive power supply. The gain will be about 1 dB lower, but the amplifier will deliver 25 watts with just a bit more than 2 watts of drive. 1 watt of drive will yield about 12 watts of output power on 2304. When operated on 13.8 VDC this amplifier will be extremely rugged and hard to kill since the voltages are so far below the maximum voltages and currents for the devices.

It will be very attractive for many hams to use one side of the two-transistor final stage to drive the other side. The first stage can be used as a driver, operating at 13.8 volts and the final stage will deliver up to 80 watts when operated from 26 VDC. From the measurements presented above, we see that 6-7 watts of drive power to the final stage will result in full power out. A driver stage operating from 13.8 VDC will deliver 7 watts with only 0.5 watts of input. Many transverters will deliver up to 1 watt of power on 2304 MHz, and can drive this cascaded combination directly.

It may even be possible to modify the low-level stages of the power amplifier so that the RFMD RF2125P provides ½ watt or more of drive. No matching information for that part has been found for using it at 2304 MHz, but the part can probably be made to function there. The RFMD part has 14 dB of gain below 2 GHz but let's assume it only provides 10 dB at 2304 at ½ watt output. The second ERA-6 amplifier will provide +17 dBm of output before saturating, so we have enough drive power. The two ERA-6 MMIC amplifiers in the low-level section will work just fine on 2304 MHz, providing at least 11 dB of gain each, even assuming 1 dB of board loss for each. That means that an input of -5 dBm will give 0.5 watts out from the RF2125P. That, in turn, will drive the cascaded final amplifier stages to a full 80 watts, making a very nice high power package that can be driven by less than 1 milliwatt from a low-power transverter. The figure below shows the proposed line-up. This arrangement avoids the parts that don't work on 2304.



AML PCS Power Amplifier On 2304 MHz

Model No. S80PCSA Part No. 1000103P1 Rev. 4

Mechanical Construction – The power amplifier can be used in a number of different ways, but will require a large heat sink in any application. A fan is highly recommended. If the builder plans to use several of the stages, it would make the most sense if the original milled-out enclosures were retained even if the control electronics are not used. It is pretty easy to jumper over the unused circuits and connect power directly to the pins that interconnect the control section and the RF pallet. This way, the original shielding and mechanical protection is maintained. Small solid copper coaxial cable can be used to jumper over unused stages like the filter, driver amplifier, hybrid splitters and the output isolator. The smaller gauge cable with an outside diameter of 85 mils is best for most connections, because very short and direct connections are possible. It would be best to use the most common 141-mil cable for cables carrying the final output power levels, to minimize losing the power we fight so hard to make at these frequencies. If the builder wishes, the input and output directional couplers can be used to monitor the amplifier power levels. Those couplers will work adequately at 2304 MHz.

If only one or two of the power amplifier stages are of interest, the mounting plate can be cut with a band saw to the extract the desired sections. The pieces of the base plate can then be bolted to a heat sink and a cover can be made from sheet metal to shield and protect the amplifier. This approach will reduce the losses to an absolute minimum and may also be indicated if the builder wants to combine two amplifiers with external hybrids.

Conclusion – Although this amplifier does not deliver the huge amounts of power that the transistor specifications for 1975 MHz promise, it will still deliver far more power than most amateur stations now use on 2304 MHz. The amplifiers can be used at low power levels directly on a 13.8 VDC automotive supply, making them convenient for rover operations. Most importantly, there is a significant quantity of these amplifiers available to the amateur community. Please contact the author if you would like to obtain an amplifier for your station at rlf2gpa@localnet.com. Also please contact the author with any test results you may gather and any new ideas about using the amplifiers. The information will be posted on the web sites below.

Much more detailed information about these amplifiers can be found at the following web addresses:

http://www.mgef.org/amps/index.htm and
http://www.wa1hco.net/PCS_index.html

Acknowledgements – The author wishes to gratefully acknowledge and thank the following individuals for their help. Without their assistance, this project would never have been possible.

- WA1HCO who arranged for the donation of these power amplifiers for amateur use.
- WS2B who discovered the first set of microstrip matching circuit elements that worked on 2304 MHz.
- WA1ZMS for long and patient consulting on how to make RF power amplifiers work.
- W1SZ for his detailed evaluation of the PTH32003 driver amplifier including measurements and internal analysis.
- And many other members of the Mount Greylock Expeditionary Force (W2SZ/1) who helped transport the amplifiers, and test the modifications to make sure they worked.

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