1296 MHz Remote 100W PA and LNA

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I. INTRODUCTION

This paper details the development of a remote mounted PA and LNA unit. It is keyed by detected RF drive. It is intended for operation near the antenna for improved transmit power and receive system noise figure. The construction presented here was not weather proofed for external operation because the author's amplifiers are mounted in the attic of his house and power supply is remotely controlled by network browser interface.

II. BACKGROUND

Remotely operated amplifiers can provide significant performance benefits at VHF and higher frequencies. This is due to increased feed-line losses as the operating frequency is increased.

Consider first the contribution of coaxial cable losses to receive signal to noise ratio. For more about noise-figure and noise in two port systems, see references[1,2]. A good front-end with a 0.5 dB noise figure is capable of hearing a SSB signal 10 dB above the noise floor with only 0.08uV (-129.2 dBm). A CW signal 6 dB above the noise floor can be heard from 0.02uV (-140.5 dBm). When attenuation is placed in front of this receiver the desired signal is attenuated while the thermal floor is constant. At 1296 MHz, 100 ft of LMR400 has greater than 5 dB of loss. The required input signal for the same signal to noise performance must increase by 5 dB. This translates to SSB and CW sensitivities of 0.14uV (-124.2 dBm) and 0.037uV (-135.5 dBm), respectively. Loss degrades the signal to noise ratio. The degraded system NF is 5.5 dB.

Now consider placing a LNA with 0.5 dB NF and +18 dB gain in front of the 5 dB coax loss. The cascaded result is +13 dB of gain and 0.6 dB NF. The corresponding SSB and CW sensitivities are now 0.08uV (-129.1 dBm) and 0.021uV (-140.4 dBm), respectively. Clearly, the overall NF is set by the remote LNA. The relationship between RX sensitivity and NF is shown in Figure 1.

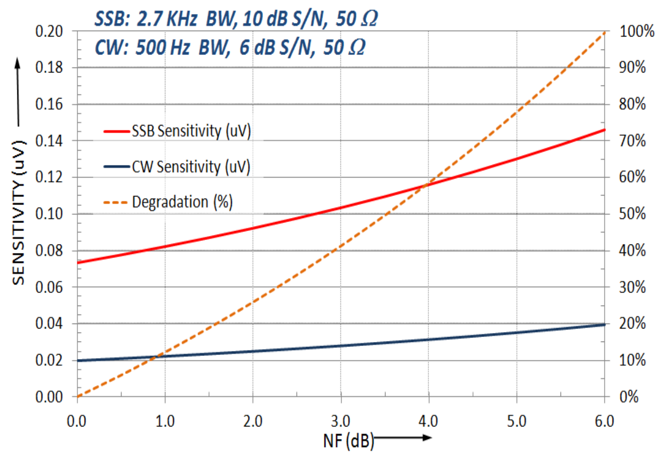

Figure 1 RX sensitivity vs noise figure

The benefit of a power amplifier placed after line losses is a direct increase in ERP by an amount equal to the loss of the coax. For example, by moving a PA to the antenna end of a 100 ft run of LMR400 results in a 5dB increase in ERP at 1296 MHz.

The remote PA and LNA effort reported here was preceded by two earlier projects. The first was simply a remote LNA with RF sensed switching control. A photo of this can be seen in Figure 2.This worked extremely well.

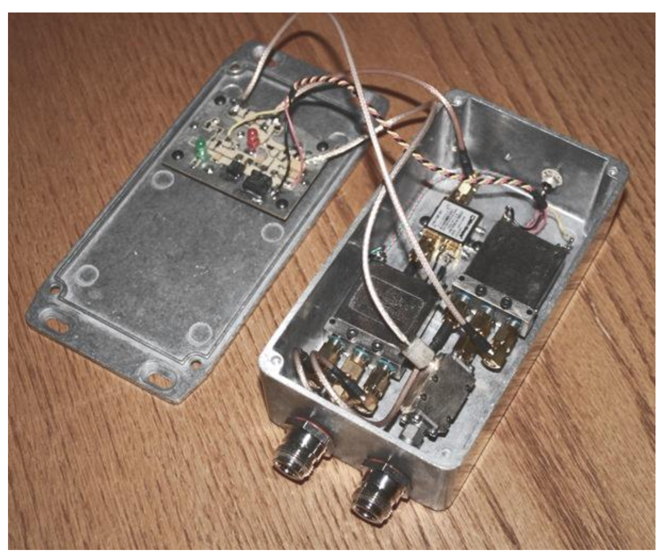

Figure 2 Remote 1296 MHz LNA

The addition of a power amplifier to the remote unit was the second step. The basic detector and control from the remote LNA could be reused in a remote PA/LNA combination. Initially, a much modified 860 MHz MASTR-III PA was used. The original PA utilized a MRF899 pushpull BJT. The modification to that amplifier included replacing the MRF899 with a MRF186 pushpull LDMOS device, modifying the bias circuits to accommodate the device technology change, and significant PC board surgery and retuning to make the change to 1296 from 860. This early PA/LNA unit in a MASTR-III housing can be seen in Figure-3. This worked very well and was used for more than a year. The PA to be presented here is a new design that replaces the modified MASTR-III board.

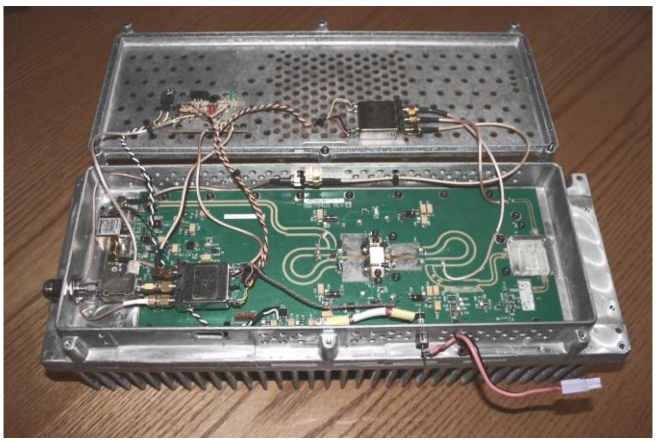

Figure 3 Initial 1296 MHz remote PA/LNA

III. CONTROL CIRCUIT

The key to realizing a remote RF keyed amplifier, whether PA, LNA , or both, is in the detector and control circuit. The detector must be sensitive to react to the rising edge of transmitter RF, yet able to survive peak transmitter drive. The control circuit provides several functions:

- Protect the LNA in the unpowered state
- Switch the LNA on when in powered state
- PIN protect the LNA when drive RF is detected
- Switch coaxial relays to TX state when drive RF is detected
- Power off LNA when drive RF is detected
- Apply gate bias to PA when drive RF is detected
- Delay switching to receive state for 1 second after RF drive is removed

The one second delay is essentially an rf vox to minimize unnecessary TX/RX switching and relay abuse. Figure 4 shows the PC board with SMT components and Figure 5 illustrates the schematic of the control and detector circuits.

Coaxial relays were 24v non-latching type with low current 5v logic control. The control circuitry can be easily modified to accommodate relay drivers to switch more standard 24v relays directly. Latching relays were avoided to provide additional insurance of proper switching and LNA protection.

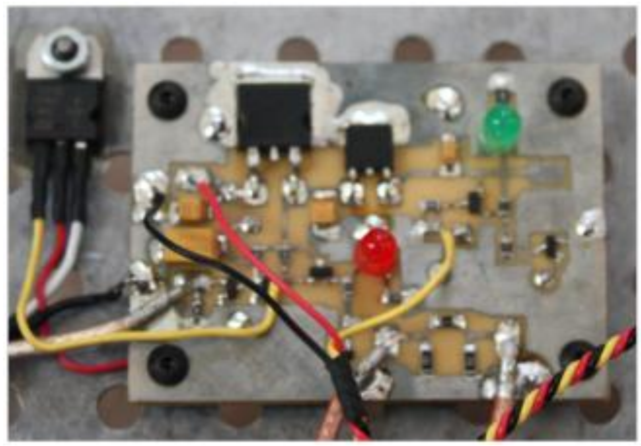

Figure 4 Control board

IV. LNA

A Minicircuits ZX60-P162LN+ is used as the LNA. It is relatively inexpensive SMA module that provides a NF of 0.5 dB and high IP3. Figure 7 shows a photo of the LNA**.**

LNA protection is paramount. Since the LNA's output port is normally connected to the transceiver during receive, transmitter RF will toast the LNA if it is not protected, powered off and quickly switched out of line when transmitting. We have already discussed the need for a highly sensitive detector. Several LNA protection measures are taken at it's output port. First, in order to tolerate more RF level on the rising edge of the drive envelope, a 6 dB pad is placed in the output path of the LNA. This LNA typically has greater than +20 dB of gain, so the overall NF won't be significantly degraded. Secondly, the shunt PIN diode is turned on to "crowbar" protect port-2. Since this PIN is in parallel with the LNA side of the π-pad, attenuation jumps to around 50 dB. Of course, the relays are also quickly switched and the LNA is powered off.

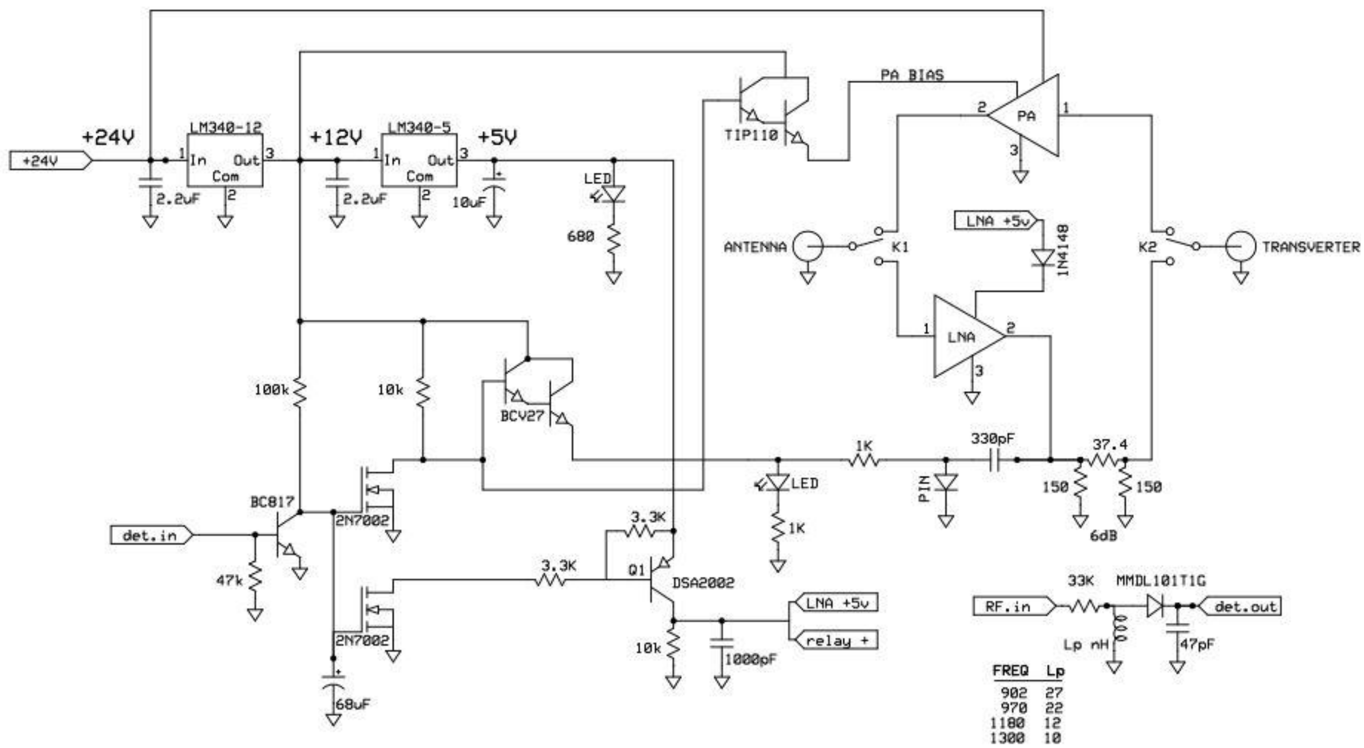

Figure 5 Control and detector schematic

The detector circuit shown in Figure 5, provides high sensitivity to drive RF. Typically, the control circuit can be keyed by 10 to 15 dBm. The module assembly is constructed in a surplus air strip-line housing and can be seen in Figure 6. Construction uses 0804 SMT components in free standing “ugly” form. The 33K resistor simply taps along the 50 ohm strip-line. The high resistive value and low body capacitance provide a very small perturbation to the input RF line. Under high peak RF drive, this hign impedance coupling provides current limit protection to the detector. The key to achieving high sensitivity to low drive signal levels is by tuning the parallel inductor to resonate with the schottky diode and circuit capacitance. This is accomplished by test selecting the correct chip inductor. The high-Q resonance boosts the RF voltage at the detector. At high drive levels, when the diode and NPN input transistor are turned on, the loaded Q is considerably lowered.

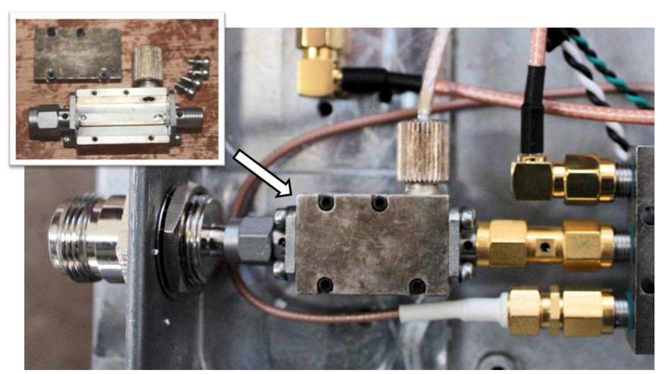

Figure 6 Detector module

Figure 7 ZX60-P162LN+ LNA module

V. PA

The PA board, shown in Figure 8, contains a single pushpull LDMOS final and bias circuitry. At lower out of band frequencies, negative feedback enhances stability. The collector supply voltage is +26V. The gate bias regulator runs from a switched +12V line.

Usually 23cm power amplifiers that operate at power levels above 30W use thin (< 0.032”) circuit boards. Low impedance interface to the power transistor and ground return inductance are the dominant reasons for this. Pushpull operation provides a differential impedance interface 4x higher than with a single-ended design at the same power level. This allows the possibility of using relatively inexpensive PC board shops such as ExpressPBC, where standard material is 0.062” FR4. Boards for this project utilize this vendor.

Device selection for solid-state 23cm power amplifiers is made difficult since LDMOS transistors usually have internal LC input matching; but tuning is always for other bands. The common choices are 800 MHz, 900 MHz, 1 GHz, 2 GHz and 2.4 GHz. Use of a part that is designed for a lower frequency can encounter low gain, due to lower f_T, while use of higher frequency parts can lead to stability challenges. Input matching can be a challenge in both cases, since 1296 MHz impedance data is virtually never published.

In contrast the output match impedance targets are relatively easy to predict based on loadline (supply voltage and output power), output capacitance, and package parasitics. More about this can be found in Cripps[3], chapters 2.5 and 2.6.

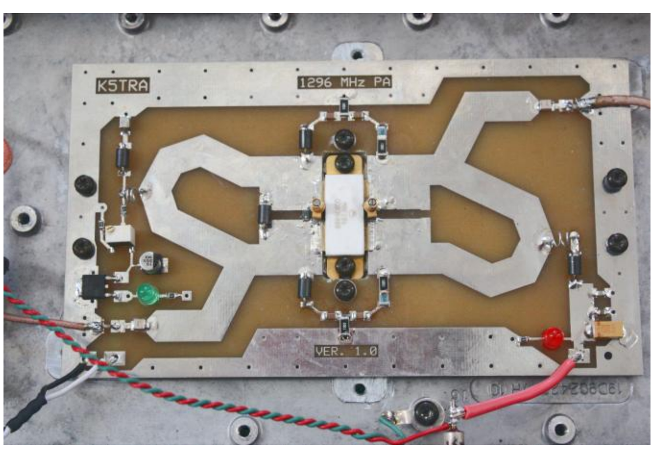

Figure 8 Pushpull 100W PA board

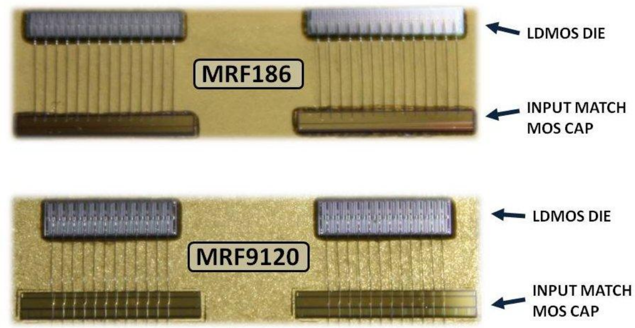

Figure 9 LDMOS internal view

Two Freescale LDMOS parts were considered for this PA: MRF9120 and MRF186. A photo of the chip and wire internal assembly of these two parts can be seen in Figure 9. The 9120 is a more rugged device; but, the input matching has a lower corner frequency. The MRF186 has more parallel input wires for lower series inductance. The MOS cap is also a bit smaller. This is all consistent with the MRF186 being a nominal 1GHz part and the MRF9120 being a 880 MHz part. The lower frequency part is more VSWR rugged to 10:1 compared with 5:1 for the MRF186 (both at 120W CW).

Both transistors were tested in the PA. Based on overall tunability and stability the MRF186 was selected. More on the subject of stability will be discussed in the circuit details.

Input and output matching networks are similar. A 50 Ω 1:1 balun is formed by a pair of 25 Ω lines. Between the two differential terminals is a ½ λ line. The line that interfaces with the external 50 Ω port is a ¼ λ line that acts as an impedance transformer to 12.5 Ω. The ½ λ portion is the same as the familiar coax (4:1) balun. Overall, this structure provides a 50 Ω differential feed to the lower impedance (wide) lines. From that point each side of the network can be equivalently viewed as an impedance match from 25 Ω to one side of the final. This balun technique is also used in Motorola 150 W cellular and GE/Ericsson MASTR-III 860 MHz (110 W) power amplifiers.

Figure 10 shows the circuit details for input and output network simulations. The transformer at port-1 is simply used as an ideal balun in order to allow a view of the transistor's differential load (or source) impedance. Tuning is done with high-Q piston capacitors. The series inductance of these capacitors cannot be neglected in the simulation. Figure 11 shows the simulated transistor interface impedances. The real part of the load is just under 4 Ω. The input source impedance is approximately 7 - j7 Ω.

The overall PA schematic can be seen in Figure 12. DC feeds are at differential balance (virtual ground) points at the electrical center of the ½ λ balun lines. Gate bias is set from +5V regulator with 5K pot. LDMOS transistors designed for 1 GHz operation have excessive gain at HF and VHF frequencies that can lead to stability problems. In order to avoid this, negative feedback and low frequency loading branches using ferrite beads have been added. Power output of 100 W is easily achieved. PA gain is set by gate bias to around +13 dB (quiescent current is approximately 800 mA).

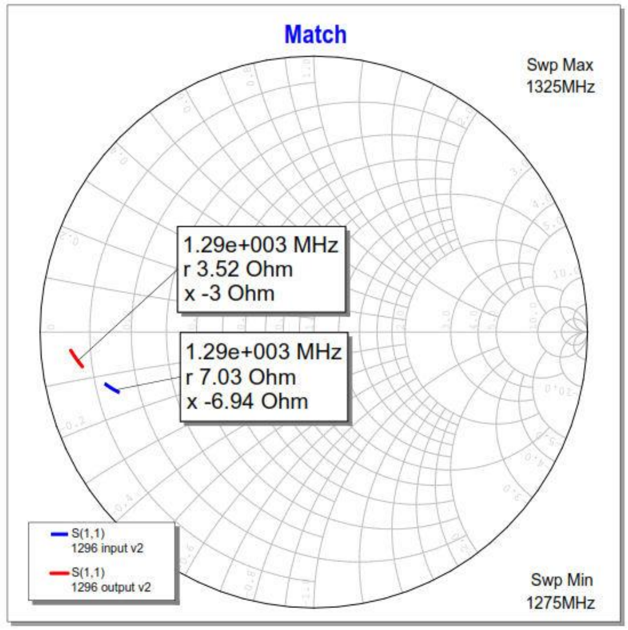

Figure 11 PA match simulation

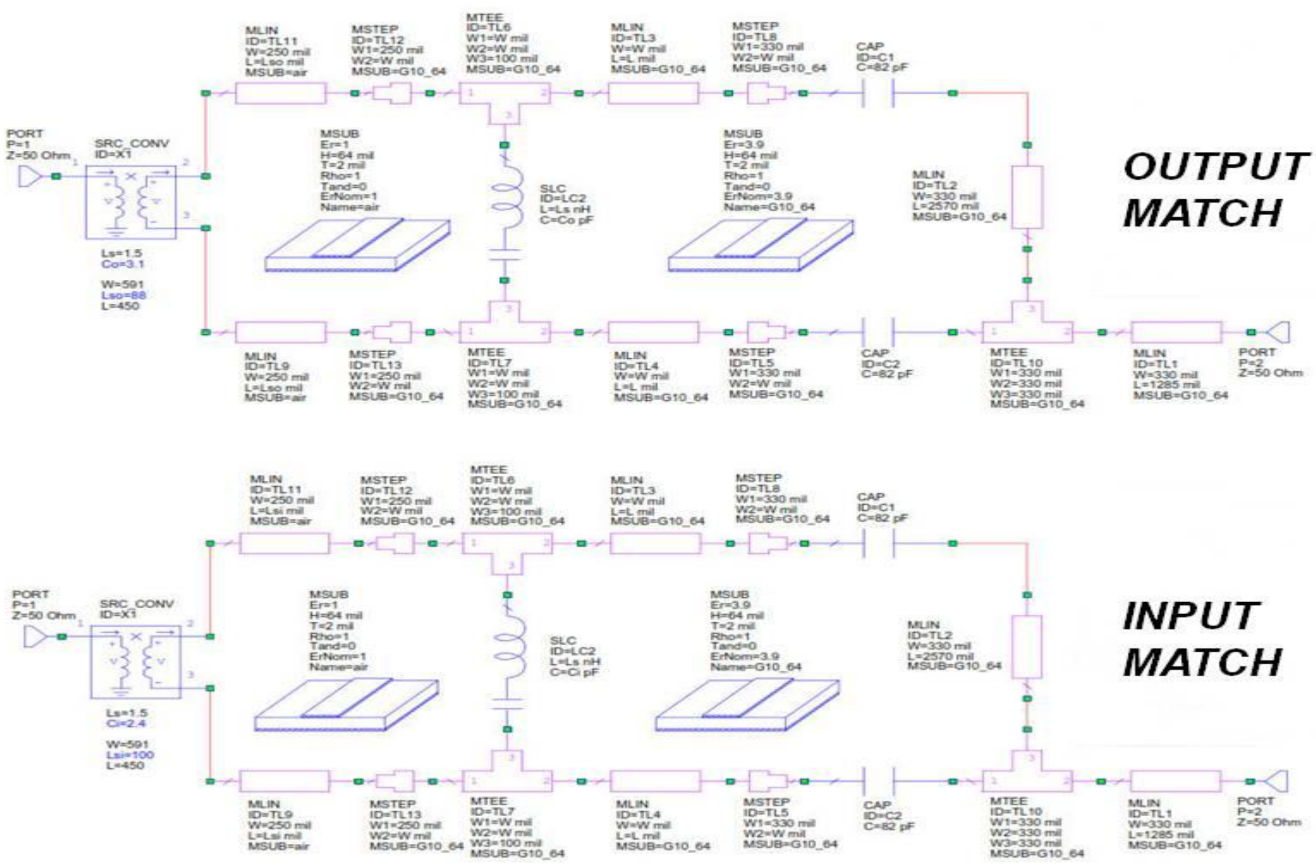

Figure 10 PA match design

VI. Summary

The development of a remote RF keyed PA and LNA has been presented. Advantages of remote amplifier operation, both for receive and for transmit performance were discussed. Since this work was preceded by a remote RF keyed LNA and it's control circuit was reused here, it was also discussed. The earlier modification of an 860 MHz MASTR-III PA for 1296 MHz operation formed the basis for the new PA board design presented; so, it too was discussed. The PA LDMOS selection and impedance matching details were presented. On the air results have been very good.

References

[1] S. Adam, "Microwave Theory and Applications," *HewlettPackard, Prentice-Hall.*, 1969, chapter 6.3, pp. 490-499.

[2] G. Gonzalez, "Microwave Transistor Amplifiers Analysis and Design," *Prentice-Hall.*, 1997, chapter 4.2, pp. 295-298.

[3] S. Cripps, "RF Power Amplifiers for Wireless Communications," *Artech House.*, 1999, chapters 2.5 and 2.6, pp. 24-35.

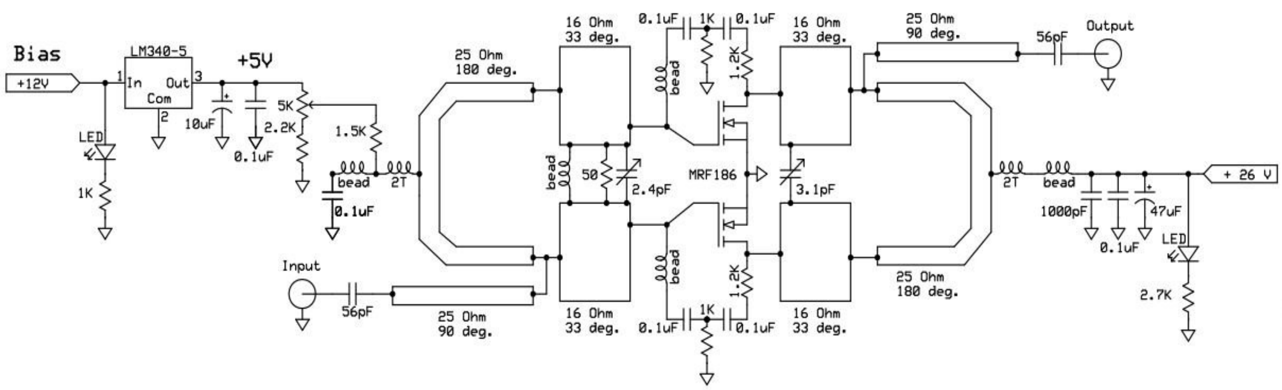

Figure 12 PA schematic

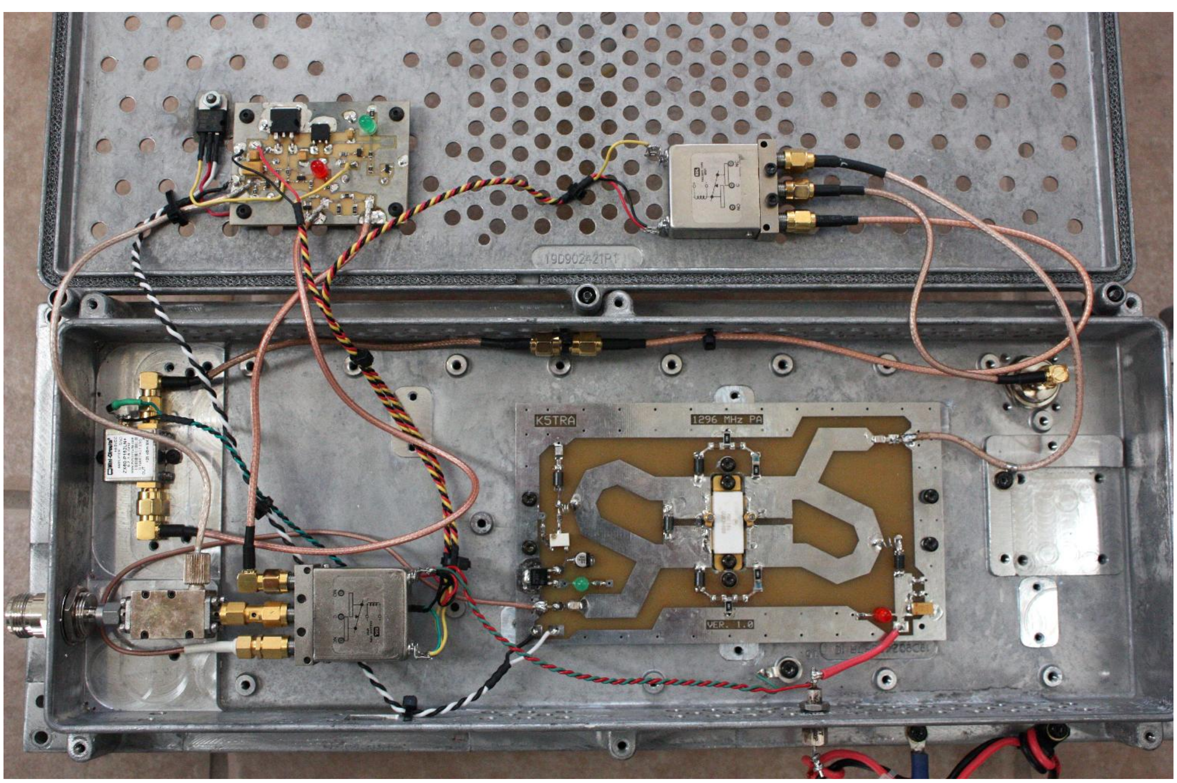

Figure 13 1296 MHz remote PA and LNA