Wideband LDMOS power amplifier, 100W, 5-250 MHz

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***Abstract* - This document describes the design, building and measurements of a prototype wideband LDMOS amplifier based on the NXP MRF101AN. The design is made as a contribution to NXP Homebrew RF Design Challenge 2019. The results show that it is possible to build a power amplifier giving reasonable performance covering the entire frequency band from 3.5 MHz up to 250 MHz with one amplifier, thus covering 13 HAM radio bands from 80 m up to 1.25 m.**

***Index Terms* - NXP Homebrew RF Design Challenge, LDMOS, wideband, power amplifier, ham radio applications, SDR, HF, VHF**

1. INTRODUCTION

NXP introduced a new interesting device during spring 2019, the MRF101AN/BN. A LDMOS device in a cheap TO-220 package capable of delivering 100W of RF power. There are narrowband reference circuit designs available ranging from 13.56 MHz up to 230 MHz. An interesting challenge would be to see if it is possible to achieve a single design for the entire frequency range. This will of course affect some of the performance parameters. The application of such an amplifier would be as power amplifier for the now so popular SDR transceivers that have transmit capability. These transceivers often cover large frequency bands from HF-bands up to the microwave frequencies but can just deliver low power levels normally 0 to 10 dBm. Those low power levels are not really sufficient for establishing CW or SSB contacts over the HAM bands today.

Design goal for the design is to cover from 5 MHz to 220 MHz and to get at least 20 dB of small signal gain. A 1 W driver amplifier would then be sufficient to drive the MRF101 amplifier to the 100 W level. The efficiency for a wideband design would be lower than for a narrowband design due to the wideband output matching. The output matching can not be used for any second or third harmonic termination for improvements of efficiency.

2. SIMULATIONS

Simulations have been carried out using QucsStudio, a free circuit simulator that are very usable, capable of both linear and harmonic balance simulations. Unfortunately there are no models available other than the models for the costly AWR and ADS softwares. QucsStudio can use Verilog-A models and it would be nice if NXP could provide Open-source model data for devices like MRF101/MRF300 to facilitate simulation capabilities for private enthusiasts and small company use.

Due to the model situation, the simulations have to stay at the linear s-parameter level. NXP provides a s-parameter file for the MRF101AN/BN that cover frequencies from 30 to 300 MHz at a bias point of Vd=50V, Id =1 000 mA, which is not sufficient for simulations down to 3 MHz.

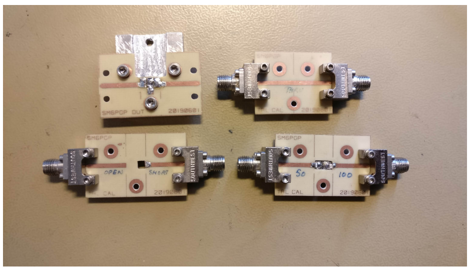

Fig 1. TRM-calibration kit and fixture for the MRF101AN

A fixture and a TRM-calibration kit was built to be able to measure s-parameters over a larger frequency range, 1 MHz to 1 GHz. The measurement had to be done at a very low power level of -40 dBm due to the high gain of the device at low frequencies, measurement was taken at the bias point 48V, 300mA with an HP8753D VNA.

Device Optimum load

To find optimum load for the device the datasheet was carefully read and data extracted from the narrowband reference circuits. A s1p-file was created from these values showing optimum load over frequency.

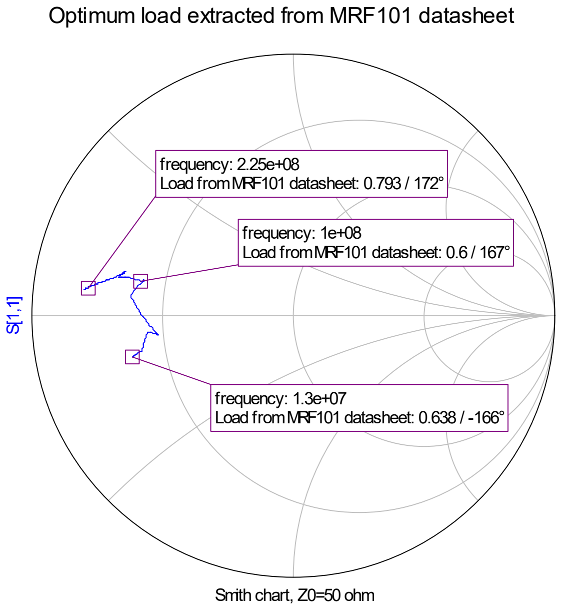

Fig 2. Optimum load as extracted from the datasheet

Using Cripps load line theory with POPT=100W=1/2*VDC*IDC , VDC=50V and IDC=4A, gives that ROPT=12.5ohm (neglecting the knee voltage, the difference will be small as the drain voltage is rather high). It is important to remember that this is the impedance at the transistor current generator reference plane. It will be transformed towards lower impedances by the device output capacitance, Cds, as the frequency increases.

Comparing the load line theory and the datasheet values gives that a good approximation would be to transform 50 ohms to 12.5 ohm. A 12.5 ohm load should at least give acceptable output power for the lower frequencies.

Simulation of possible gain and input match

A simple simulation was setup for checking the possibility to realize this design. Resistive feedback is needed to reduce low frequency gain and also results in an input impedance close to 12.5 ohm. This means that the same type of wideband impedance transformer can be used at the input and output.

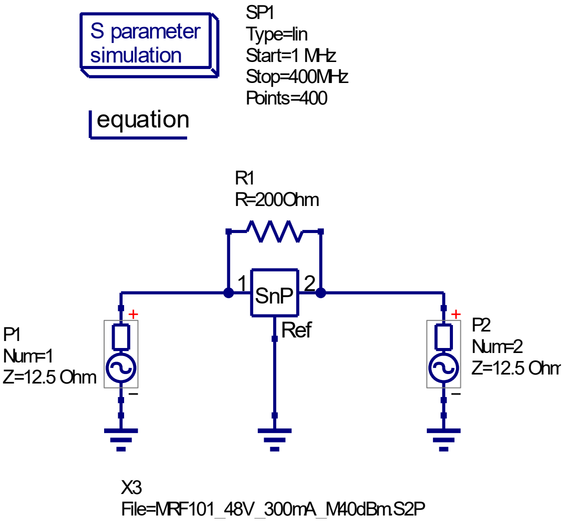

Fig 3. Simulation setup for selecting right amount of resistive feedback and input/output impedances.

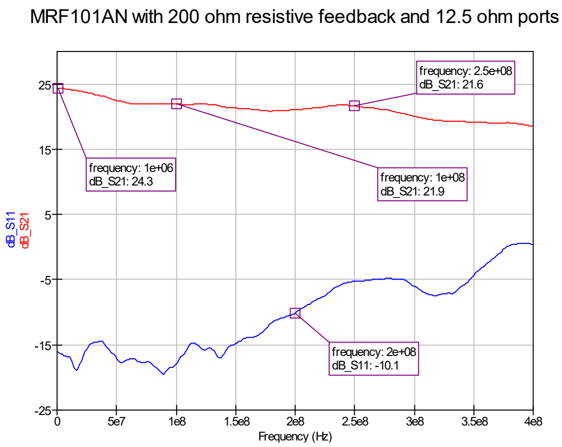

Fig 4. Simulated gain and input match when terminated in 12.5 ohm ports.

The simulation shows that it is possible to build an amplifier with the wanted gain and good input match if a 4:1 wideband transformer can be built for the required frequency range.

UNUN 4:1 (12.5 ohm to 50 ohm)

Search for a possible wideband transformers gave that a Ruthroff 4:1 unbalanced to unbalanced transmission line transformer would be a good choice.

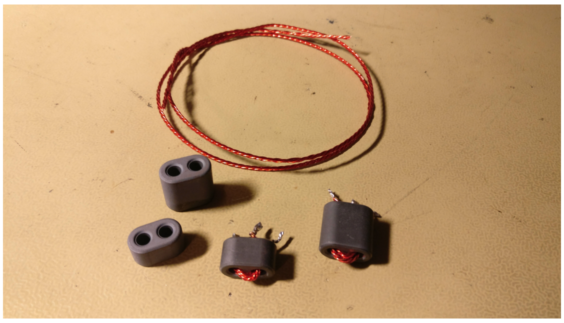

Fig 5. Several trials has been done.

The transmission line transformers are wound on 2-hole ferrite cores, B62152A4K1 / B62152A1K1, bifilar wound with double twisted 0.5 mm Cu wire. The larger core is used at the output and the smaller at the input.

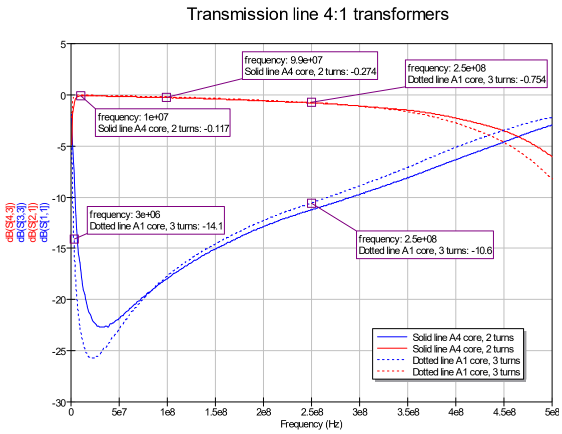

Fig 6. Ruthroff 4:1 Unbalanced to Unbalanced transmission line transformers, no high frequency compensating capacitors used at in/out put.

Complete amplifier simulation

A simulation of the complete amplifier with measured 4:1 transformers and measured s-parameters of the MRF101 was done showing that the goals could be fulfilled, small signal gain at 21 dB over the band, slightly higher, 24 dB, at the lower end < 30 MHz. Input RL is around 14 dB.

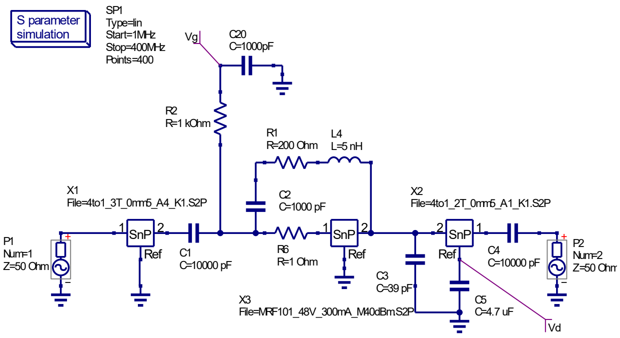

Fig 7. Simulated schematic, measured s-parameters are used for the active device and for the impedance transformers.

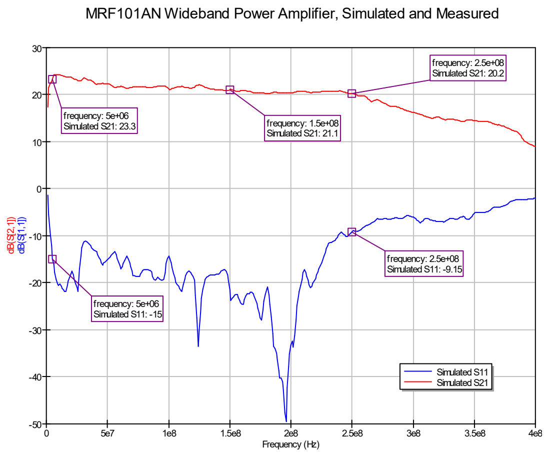

Fig 8. Simulation result.

3. BIAS CIRCUIT

Bias circuit is reused from old Freescale Semiconductor Application note AN1643. LP2951 is used as regulator.

It works very well if good thermal connection is established between the sensing transistor and the RF device.

4. MANUFACTURING

A layout were designed and a board etched, groundings added by riveting copper wire into the grounding vias. A good method for "homebrewing" RF-boards. Board material is 0.8mm (30 mil) FR4.

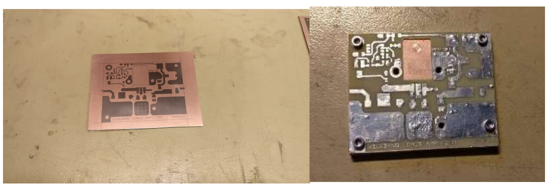

Fig 9. Board before etching to the left and the board attached to a 5 mm thick copper heat spreader to the right.

The FR4 board is fixed to a 5 mm Cu-heat spreader with 7 screws (M2.5) and the MRF101 is fixed to the board with a screw (M3), heat transferring paste is used between the heat spreader and the heatsink.

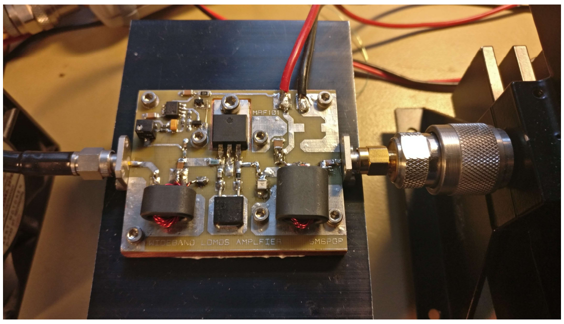

Fig 10. Finished amplifier, ready for measurements.

5. MEASUREMENTS

Small signal performance, Gain and input match.

Measurement of small signal s-parameters where done with a high power 30 dB attenuator at the amplifier output. The amplifier has a nice flat frequency response with gain close to 21 dB, somewhat higher at the low frequency end (up to 24 dB) and shows good input return loss, >10 dB from 3.5 MHz to 280 MHz. Measured with Vd=50V, Idq=400 mA and Pin = 0 dBm.

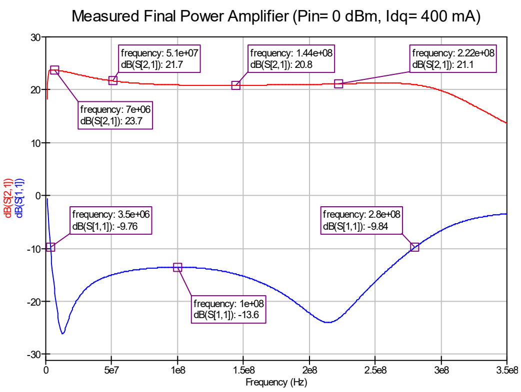

Fig 11. 30 dB attenuator de-embedded from the gain measurement.

Pin - Pout and Drain efficiency

Pin-Pout measurement was setup with a signal generator + driver amplifier, a power meter (NRP-Z11) at the input via a resistive power divider, a 150W 30 dB attenuator at the output with a power meter (E4418A+8485A). Current is measured with a Fluke79. Vd=50V, Idq=400 mA

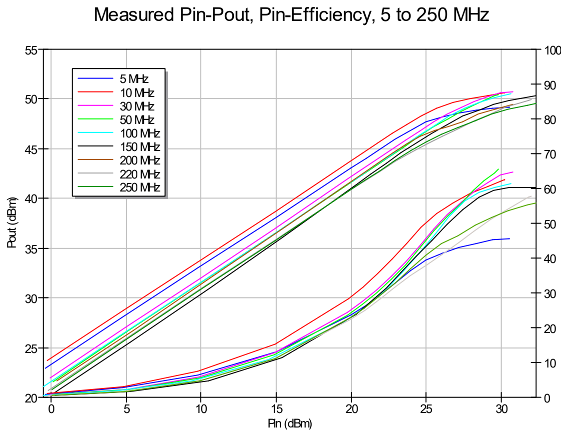

Fig 12. Measured Pout & Efficiency vs Pin, drain efficiency at right axis (%).

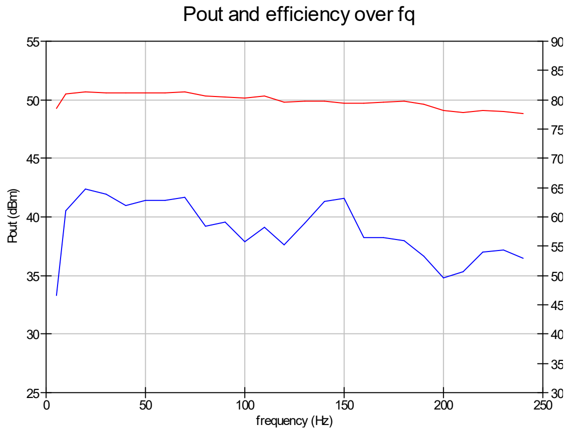

Fig 13. Output power (dBm) and efficiency over frequency, Pin held constant at 30 dBm (1 W), drain efficieny at right axis (%).

In table form with power presented in Watts

FQ (MHz)	POUT (W)	Drain eff (%)	FQ (MHz)	POUT (W)	Drain eff (%)
5	85	46.5	130	98	58.9
10	113	61.1	140	97	62.7
20	117	64.7	150	93	63.1
30	115	63.8	160	93	56.5
40	114	62.0	170	96	56.5
50	115	63.8	180	97	55.6
60	114	62.8	190	92	53.2
70	117	63.3	200	80	49.6
80	108	58.4	210	78	50.6
90	105	59.2	220	80	54.1
100	104	55.8	230	79	54.3
110	108	58.3	240	75	53.0
120	96	55.2	250	73	52.3

6. CONCLUSION

It has been shown that it is possible to design a wideband (5-250 MHz) 100W power amplifier around the MRF101.

The NXP MRF101 is a very useful device and will surely be seen in a lot of designs in the future, both for HAM radio and for other applications.