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A low noise preamplifier for the 70cm band with a gain of 25dB and a noise figure of approximately 0.4dB

This design was presented at the 2012 VHF meeting in Bensheim, it described the development of low noise LNAs for the frequency range from 1 to 1.7GHz The lecture was published in expanded form in VHF reports. It documented the current state in development of low noise MMICs. The approach for a successful design was demonstrated using a model amplifier. Measurements confirmed the good simulation results. The performance of the circuit at low frequencies was also tested.

1. Overview

The properties of modern MMICs, from the article mentioned above [1] for a 1 to 1.7GHz amplifier, are briefly given below for the 1 to 1.7 GHz amplifier. The advantages are:

- Input and output are matched for 50Ω
- Noise figures are below 0.5dB even at frequencies below 500MHz
- More than 20dB gain up to 2GHz.
- Minimal external circuitry.

The author struggles with the following disadvantages:

- The dimensions are now tiny and only tiny solder pads are used instead of connecting pins.
- The common ground is a small spot of solder in the middle of the underside of the package.
- The layout design requires very high accuracy; tracks and connection pads on the IC are typically 0.25mm with a maximum width of 0.5mm
- The supporting components must be SMD size 0603 (1.25 x 0.75mm) or less to work.
- The cut-off frequencies of the components are so high that stability control is necessary even when operating below 1GHz and up to 10GHz therefore appropriate measures must be taken.
- The operating point must be carefully controlled and very carefully stabilised partly due to the high currents (often over 50mA per device). The supply voltages are decoupled even more carefully and for a broadband

The thickness of the PCB was reduced, for all applications, to 0.25mm due to the extended frequency range; this prevents the emergence of unwanted modes of the signals on the strip lines. The time for vias made from silver plated tubular rivets is over - now you have to have Printed Circuit Boards professional made.

The LNA development described in [1] was very successful; therefore, a step

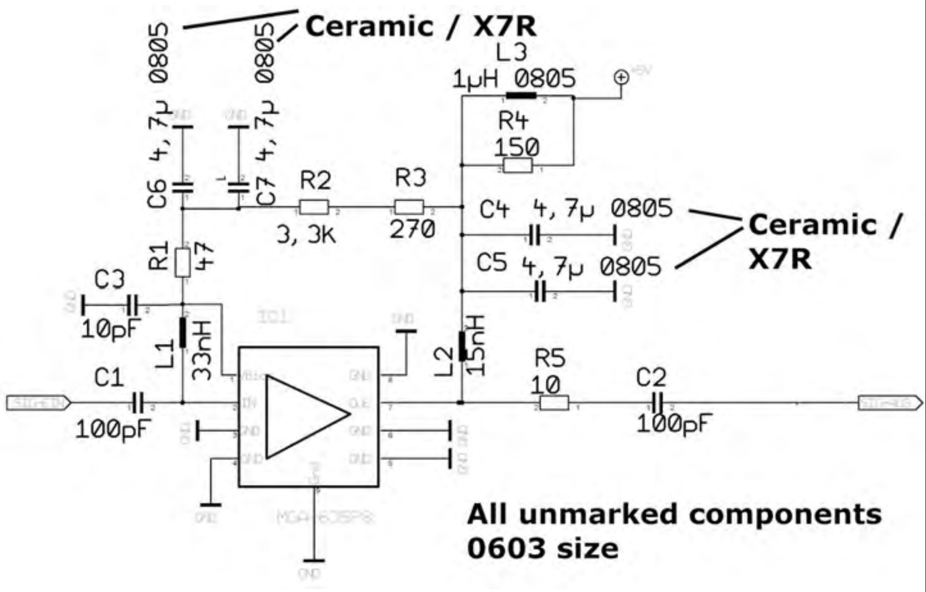

Fig 1: The circuit diagram of the predecessor to this design.

down in frequency has been examined for the possibilities of use on the 70cm band. This is more difficult, because the manufacturer of this MMIC only gives usage data above 1GHz therefore the MGA635-P8 documentation for the properties at low frequencies (e.g. noise parameters) is very, very poor. So, a request list was formulated and checked how far it can be met:

- Noise figure: maximum 0.4dB
- Gain (S21) at least 20dB
- Absolute stability (k greater than 1 up to 10GHz)
- The output reflection S22 should be as low as possible (-20dB at 438MHz = dream value).

2.
The circuit development

The LNA for 1 to 1.7GHz (Fig 1) and the PCB layout were used. A cascode GaAs-pHEMT amplifier and bias circuit are inside the MMIC device. Pin 1 sets the operating point of 55mA through the bias circuit with a resistor (Rbias = R1 + R2 + R3 = 3.6kΩ). The generated bias feeds the first gate on pin 2 via L1. The inductor L2 on pin 7 forms the load resistance of the second stage.

A major problem of the HEMT components is stability at low frequencies - their tendency to oscillate. So a simple trick is used: with decreasing frequency the 50Ω value of R1 is presented more and more to the input pin 2. This is effective and prevents oscillation. The way this works:

- The reactance of L1 decreases with decreasing frequency, but the reactance of C3 increases. So at some point R1 = 50Ω is the only thing active at the input pin 2.

The circuit was adjusted for noise at 438MHz using ANSOFT Designer SV. The values of L1, L2 and C3 were gradually changed using the simulation

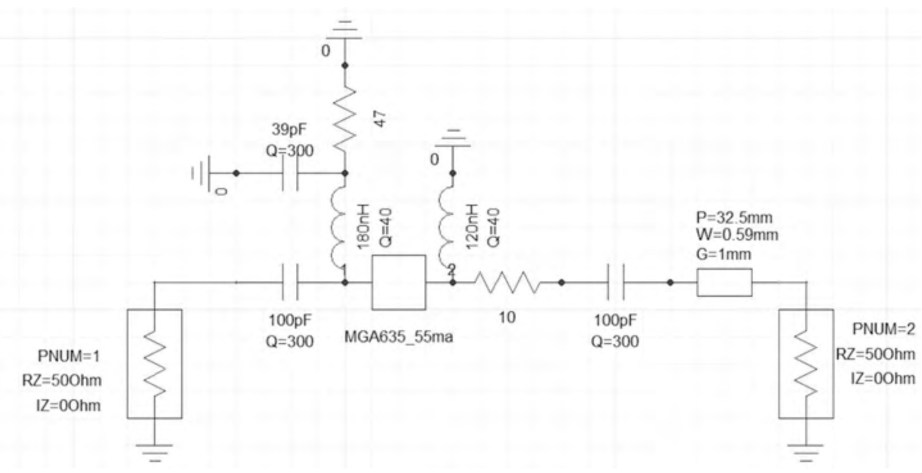

Fig 2: The simulation circuit diagram for Ansoft Designer SV. It offers no great mystery for the optimisation of noise figure and stability.

results for the noise figure, "NF in dB", and under a permanent control of the stability.

The intention was to create the minimum noise at 438MHz and to optimise the noise figure NF. The minimum value achieved was considerably lower than 0.4dB (simulation result: NF = 0.12dB) with L1 = 180nH / L2 = 120nH and C3 = 39pF. Up to 10GHz, a small resistor of 10Ω in the output circuit gave sufficient stability (fitted closed to the output pin of the MMIC). The output micro strip line (more correctly: "Grounded Coplanar Waveguide") with a width of 0.59mm and a "gap" of 1mm on each side and a length of 32.5mm should not be omitted from the simulation. The final simulation results were obtained using the simulation schematic shown in Fig 2 with the noise data as shown in Fig 3. This is a

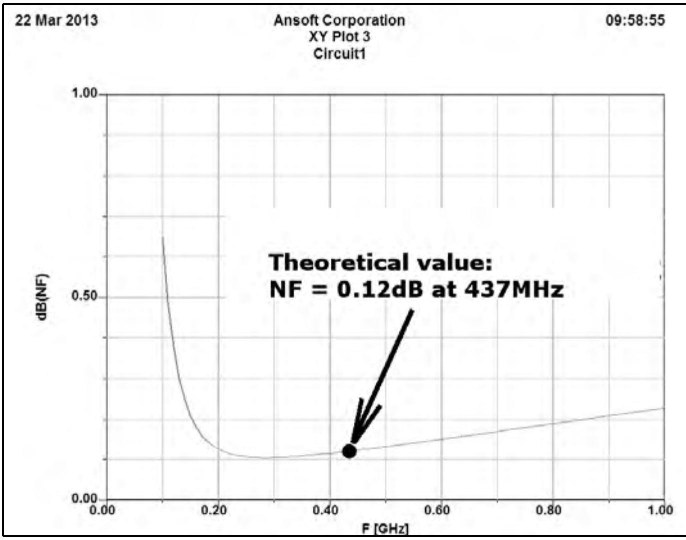

Fig 3: These noise levels would be a dream but are they realistic?

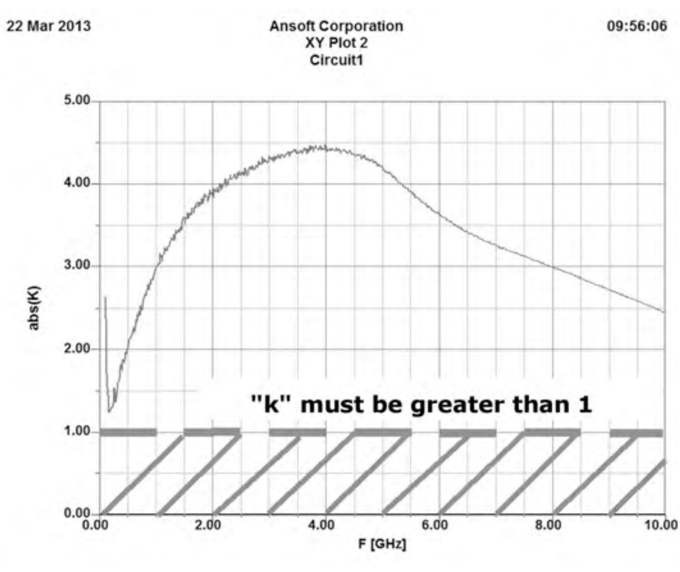

Fig 4: No stability problem up to 10GHz.

dream, of course it must actually be checked using a prototype to see if this is true. Finally, no noise data is contained in the S parameter file for this frequency range so the simulation program simply used a linear decrease of the noise figure with decreasing frequency!

The required stability (k greater than 1 to 10GHz) was no problem as shown in Fig 4 and the simulated S parameters for this frequency range gives no cause for concern (Fig 5).

No extra development work was necessary for the board because the version developed for the 1.7GHz version could be used. The material is the "flame retardant version" of the familiar and proven Rogers material RO4003 called

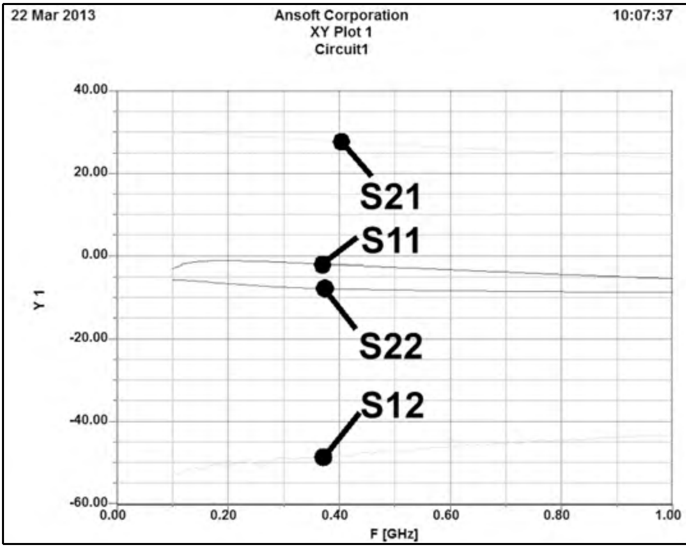

Fig 5: You can be satisfied with these simulated S parameters up to 1GHz.

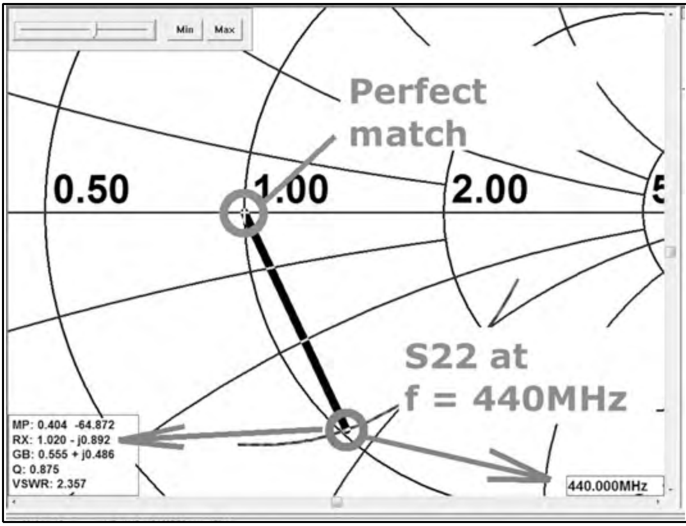

Fig 6: The diagram for S22 at the required frequency shows that correction is needed (see text).

RO4350B and in stock at the circuit board manufacturer [2] in the desired thickness of 10 mil = 0.254mm. To produce such a thin PCB with countless vias in perfect quality a Proffesional PCB manufacturer is necessary but the supplier [2] was very cooperative and is therefore recommended.

The Board size is 30 x 50mm with the bottom surface as a continuous ground plane (a matching milled aluminium case is used). Input and output use SMA connectors and the +5v power supply uses an SMB female as usual.

The central ground connection on the underside of the MMIC package requires its own 0.6mm wide ground island with 6 vias. All other ground planes on the PCB are carefully separated having enough vias. Actually, that's old hat, but it is purely and simply to give "neutral point grounding" that is recommended at low frequencies to avoid a tendency to oscillate. By the way: all vias have a diameter of only 0.3mm.

More on the Board follows in Chapter 3.

3. Improvement of output reflection S22

First start a new Ansoft simulation for the frequency range from 200 up to 600MHz and display result of the S22 S parameters as a Smith chart (Fig 6). There is something very pleasing:

The 32.5mm long 50Ω line at the output moves the phase of S22 just so far that the S22 point for 440MHz is almost exactly on the reactance circle that runs through the centre of the chart. That means that S22 can be improved with a small additional inductance between the end of the line and the SMA output connector to compensate the capacitive reactance of S22 at this location.

Thus the chart centre (perfect match) comes close.

A small interim is calculation is required:

According to Fig 6 for the point "f = 440MHz", Ansoft designer SV gives a normalised impedance of:

Z = 1.101-j0. 892

This results in a capacitive reactance of

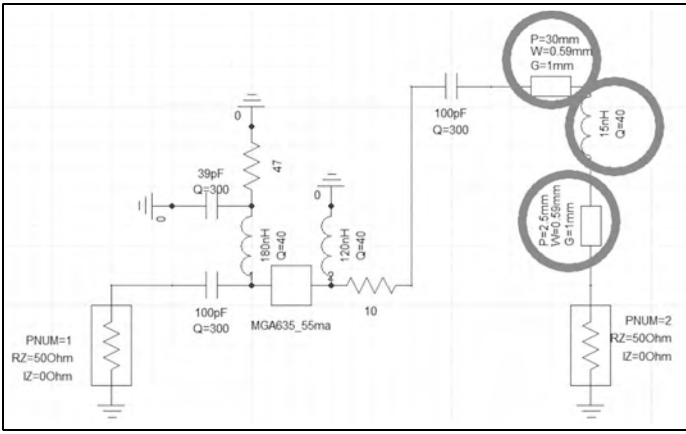

Fig 7: These modest changes will do the trick.

$X_C = (50\Omega) \times (0.892) = 44.6\Omega$

The required inductive reactance gives an inductance of

$$L = \frac{44.6\Omega}{2 \cdot \pi \cdot f} = \frac{44.6\Omega}{2 \cdot \pi \cdot 440MHz} = 16.1nH$$

This is something that cannot be bought "off the shelf", the closest standard value chosen was 15nH and the simulation diagram corrected accordingly is shown in Fig 7. The connection point for the SMD inductor is as close as possible to the output SMA connector. A 30mm long section of 50Ω line from the MMIC is connected to the 15nH inductor followed by the remaining 2.5mm of line up to the SMA connector.

It is worthwhile to analyse the result (Fig 8) and looking at the the Smith chart you can see that it has landed not far from the chart centre for a perfect match.

You should not miss the result for S22 as a Cartesian chart together with S21 (Fig 9). The comparison with Fig 5 is very interesting showing the matching. But,

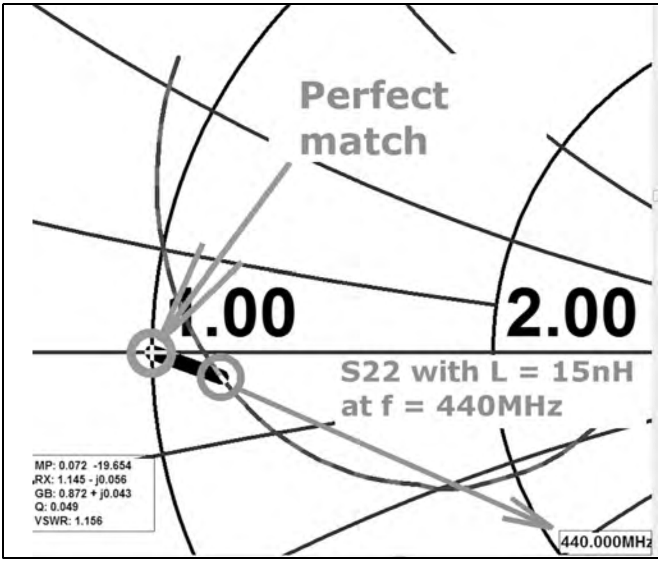

Fig 8: The changes give almost the ideal matching point.

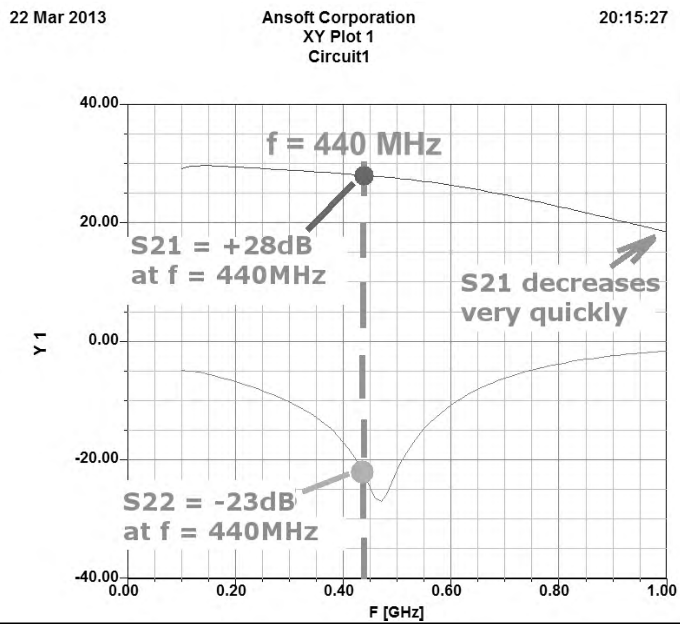

Fig 9: Such beautiful simulation results look really good.

S21 will now decrease much faster with increasing frequency because of the inductance inserted in the output line since its reactance is also increasing. Therefore the stability factor "k" should be checked very closely up to 10GHz so that there are no unpleasant surprises, however Fig 10 is reassuring.

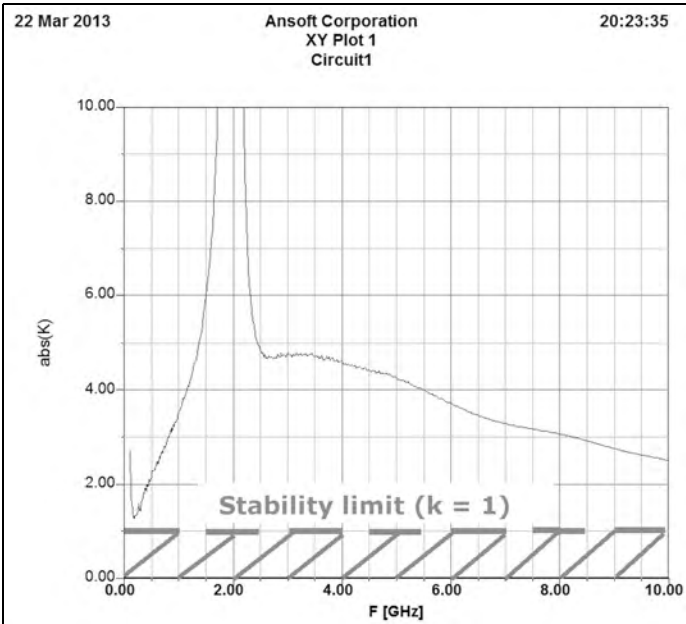

Fig 10: The modified circuit has a positive effect on the stability.

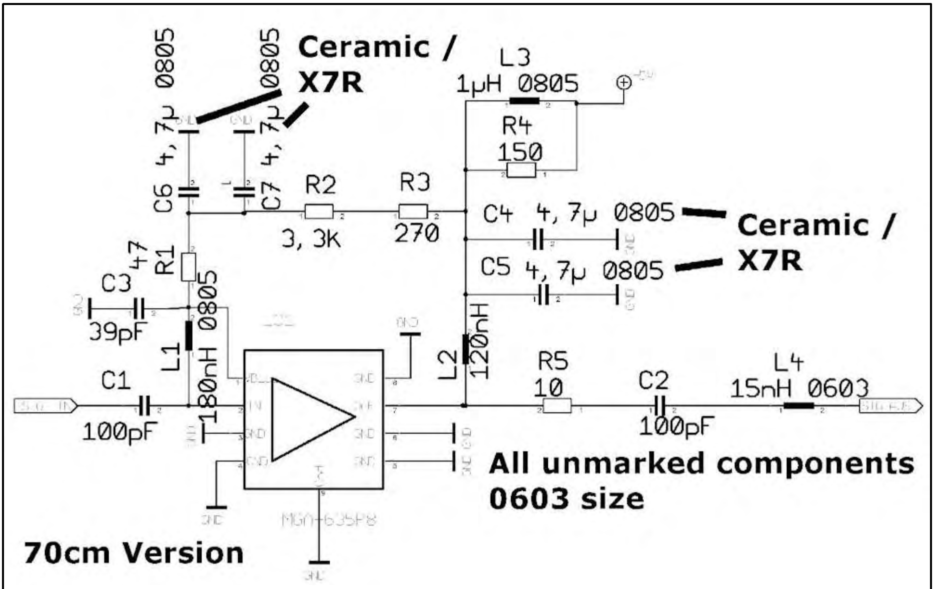

Fig 11: Who can spot the few changes from the 1.7GHz version?

4.

Measuring the S parameters of the prototype

Starting with the circuit diagram (Fig. 11) showing the changes from Fig 1 that are minimal but extremely effective. This is followed by an almost identical board with a break in the output line after a distance of 30mm to insert the additional 15nH inductance. The revised layout is no problem (Fig 12), but the existing board can be used. A gap can be made on the original 1.7GHz version. A small piece of the conductor can be cut out

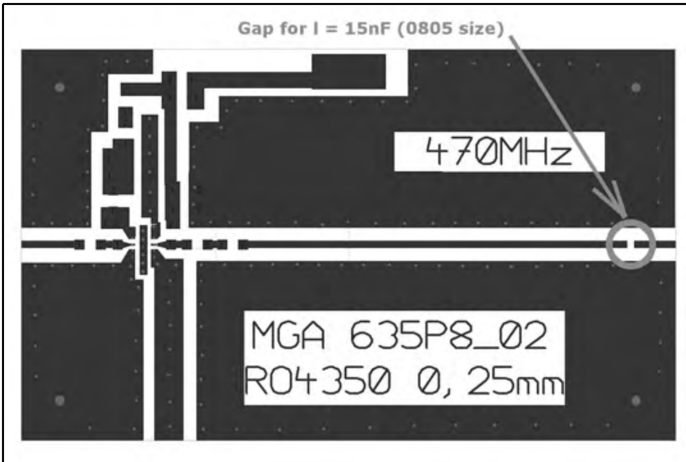

Fig 12: This is the only change to the previous PCB: a small gap for the additional inductor.

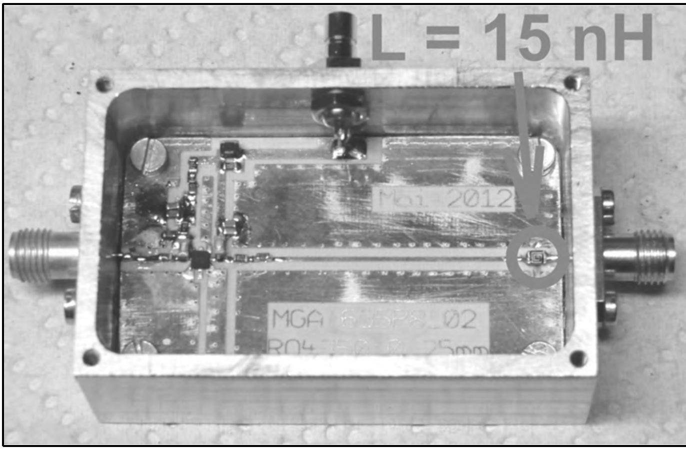

Fig 13: When you finally see this sight you know that you have done a lot of work to produce the finished prototype.

with a scalpel but this requires a warning:

The copper layer of the Rogers RO4350B material does not adhere as well to the substrate as the previous RO4003 substrate so it is easy to remove the whole track with such an operation!

It is best done using a "Dremel" (small universal electric hand drill) with a small diamond cutting disc.

The finished board fitted into the aluminium housing, marked as a test Board and waiting for the Vector Network Analyser is shown in Fig 13.

The measurements were performed with an HP8410 true vector analyser and the associated S parameter test set (HP87-45A). A 20dB attenuator was used in front of the input for the S21 measurement to avoid clipping.

The graph of S21 can be seen in Fig 14 and it leaves no wish unfulfilled.

Convincingly, Fig 15 demonstrates the success of the measures to improve the output reflection S22, giving satisfaction.

It is advisable to disconnect the input of the DUT for the measurement of the output "Port 1" of the Network Analyser

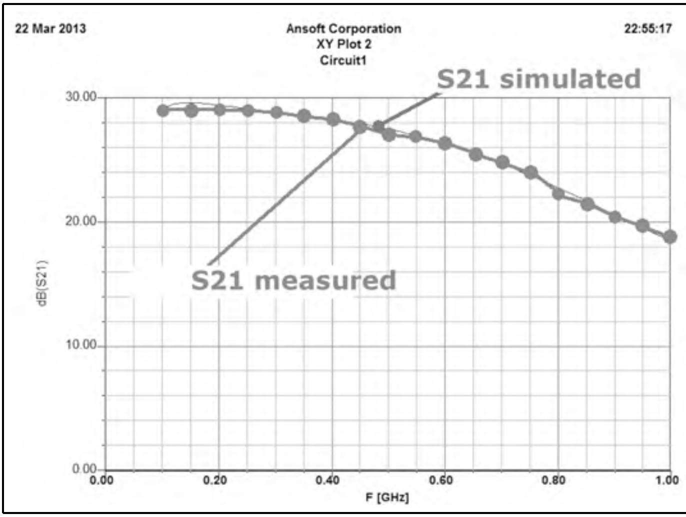

Fig 14: Without measurements we do not know how the prototype works. S21 is as expected.

and to fit a 50Ω terminating resistor on the SMA socket instead. This results in a significantly more accurate result; because the transmitter output has more reflections than "little blue" (this is not only a joke, but a note on the blue paint of SMA termination made by Watkins Johnson. It is proven that Watkins Johnson together with the "Huber and Suhner" company are the front runners for making good devices with very low reflections over a wide frequency range).

One strange result is the shift of the "resonance peak" at low frequencies despite the use of the next standard value for the additional inductance (15nH instead of 16.6nH). This resonance frequency is lower by 20MHz.

For the measurement of S11 the amplifier output was separated from the analyser and connected to a "little blue" termination. Fig 16 shows the measurement of S11 at the amplifier input together with simulation. The result of 2.5 dB is not great but at least shows that theory and practice match.

Measuring S12 is more difficult due to the low amplitude but the measurement for a frequency of 440MHz is around the simulated value of approximately 45dB.

5.

The noise

The precise measurement of small noise figures (NF about 0.4dB) for the first amplifier version last year (see [1]) proved to be a major hurdle for the basement workshop and it was completely dependent on the help of friends with appropriately high quality measuring equipment. In response to the article, there were some important tips and emails from readers who themselves have already struggled with the same problems. Therefore some experimentation and additional brooding suddenly produced a solution to solve this task successfully.

Fig 17 shows an overview of the schematic for the slightly modified measurement setup from last year that suddenly delivered the desired results with sufficient accuracy using changed settings of instruments. The crucial difference is the 6dB precision attenuator inserted between generator output and input of the amplifier being measured. As a result, 6dB is added to the expected noise figure and that fits perfectly with the lowest output level range of the SKTU noise transmitter from Rohde and Schwarz with NF = 0 to 8dB.

The measurement is as follows using the practical setup shown in Fig 18:

The HP8555 analyser is used as a measuring receiver to measure the power at f = 440MHz (scanning function switched OFF to get a selective level meter). Once the whole chain is in operation check the influence of the noise floor of the 20dB post amplifier in this manner:

Set the output level of the SKTU to Zero and remove the supply voltage from the amplifier being measured and determine that this decreases the indicated noise level on the spectrum analyser screen by more than 20dB. That should be enough to not distort the result.

Here we go with the measurement:

The amplifier to be measured is switched on again and the noise transmitter turned on. It is very nice to see how increasing the noise is displayed as a "marching point" on the screen. But to determine an increase by 3dB (then the LNA noise is exactly the same as the external input and displayed on the instrument of the noise transmitter), the following steps are required:

- Start with the noise transmitter output power set to “Null”.
- The bandwidth of the spectrum analyser must be set to 30kHz to get a tiny and little "wriggling" point on

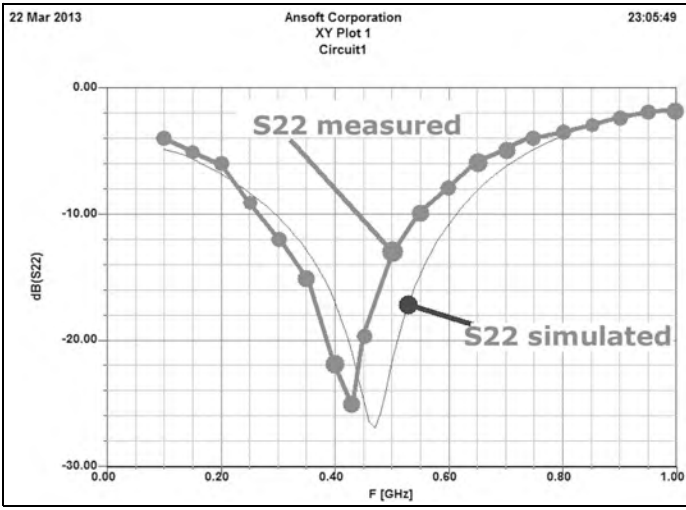

Fig 15: S22 is hopefully satisfactory despite the small difference compared to the simulation.

the screen (more decreasing bandwidth always gives a restless display). The video bandwidth is set on "b = 10Hz".

- Move this dot (with the help of a magnifying glass!) to be exactly in the centre of the screen.
- Increase the noise output level with one hand until the dot moves by exactly 3dB upwards (using a magnifying glass in the other hand to watch the analyser's screen!).
- Read off the indicated noise level on the SKTU instrument and subtract the 6dB of the attenuator.

The exciting result as the average of 10 measurements:

NF approximately 0.38dB

That does not agree with the simulation but is exactly the noise figure of the 1.7GHz version that had a NF = approximately 0.3dB at 1GHz.

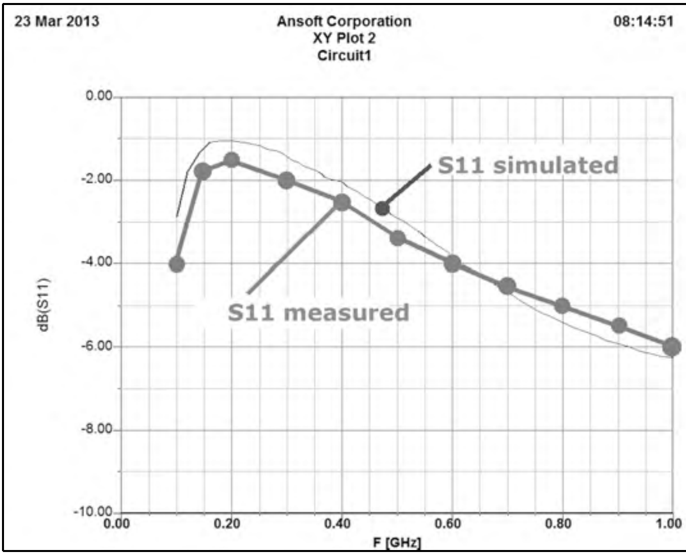

Fig 16: S11 theory and practice are the same but by favouring noise adjustment means the values not quite the same.

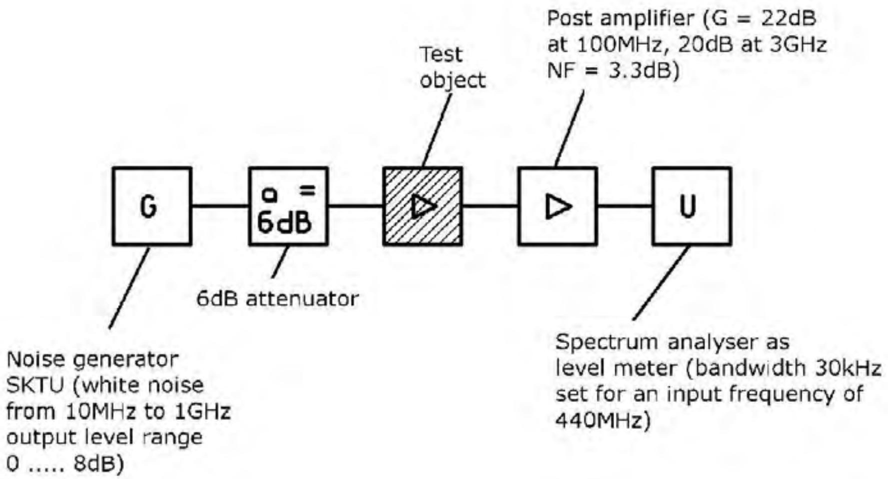

Fig 17: This is the improved DIY noise figure measurement setup (see text).

6.

What does a professional quality measuring instrument give?

I was really happy with my own measurement results but because the elderly meter results should be verified with the latest equipment with greater accuracy. Uli Kafka (from the electronics company Eisch, Ulm) was able to help again.

The following results were as follows and the comparison with Figs 14 to 16 is really worth while (again: thank you,

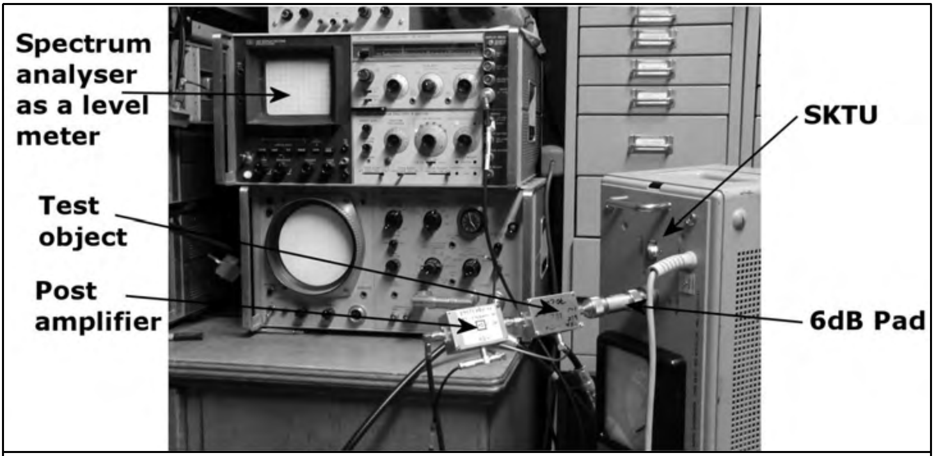

Fig 18: This is what the noise measurement system looks like: however it is important to understand the operation (see text).

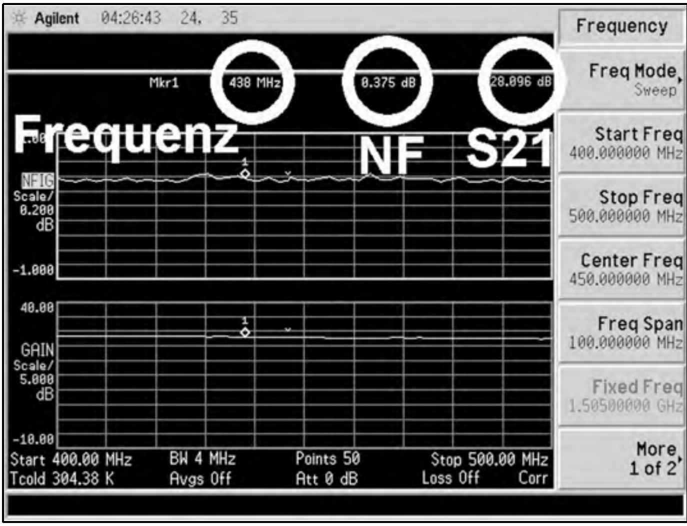

Fig 19: The crowning glory are the results from the professional measurement equipment. The reward for a lot of work is a noise figure of 0.375dB and a gain of 28dB at 438MHz.

Uli):

With f = 438MHz S11 lies between -2.7dB (for an input level -20dBm) and -2.5dB (with an input level of zero dBm).

S22 = -21dB with the minimum at f = 438MHz (the best fit to my measurement is not reached with -25dB at 430MHz).

The exact graph of S21 (approximately 28dB) and the noise figure NF between 400 and 500MHz is shown in Fig 19. The value of NF = 0.375dB at 438MHz is very reassuring and convincingly confirmed the accuracy and reliability my own noise measurement described above. But it does have a considerably greater operation and calibration time.

S12 is where the simulation predicts (much less than -40dB) and my own measurements gave the same result.

7.

Summary

The electronics developer's life is full of surprises and there is no opportunity to be comfortable and relax. You could write that as a conclusion - but it does show the very fine line between simulation and prototype designs and encourages new projects.

Since this worked out so well is a 144MHz version of the amplifier possible?

8.

Literature

[1] Development of a preamplifier from 1 to 1.7GHz with a noise figure of 0.4dB, Gunthard Kraus, DG8GB:. VHF Communications Magazine, issue 2/2013 pp 90 - 101

[2] Board manufacturer in Munich: www.aetzwerk.de