DESIGN AND CHARACTERISATION OF A LOW NOISE ACTIVE ANTENNA (LNAA) FOR SKA

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This paper describes the design and characterisation of a low noise amplifier with direct noise and power matching to an antenna, without intermediate matching to the standard 50 ohm characteristic impedance. This approach should allow the design of multi-octave bandwidth low noise antenna/amplifier systems with simultaneous noise and power matching for application in SKA.

1. Introduction.

For the phased array concept of SKA a large number of broadband, low noise amplifiers is necessary for the frequency range between 200 MHz and 2 GHz. The envisaged array antennas for SKA are printed circuit type antennas (Vivaldi, bunny ear), which should preferably be integrated with the first amplifier stages. To enable optimum performance over a decade bandwidth it is advantageous to directly match the antenna impedance to the required impedances for low noise matching and maximum power transfer of the active device (HEMT), without an intermediate matching step to 50 ohm as is common for most microwave and RF systems. This defines an active device which comprises an antenna as input, integrated with low noise amplifier stages, the Low Noise Active Antenna (LNAA).
As a first step towards a fully integrated (IC-type) device a design was made for a LNAA for the 500 MHz to 1500 MHz frequency range of the THousand Element Array (THEA). This paper presents the design and measurement results of a LNAA consisting of a two-stage amplifier, which is realised on microstrip with discrete components and packaged HEMTs, integrated on the same substrate with a microstrip balun and 'bunny ear' antenna. Special attention should be given to the measurement procedure for characterisation of such an integrated device. Verification of the measurement procedure and setup will be discussed on the basis of measurements of a low noise amplifier and antenna with well known properties.

2. LNAA design

For the active part of the LNAA a two-stage amplifier was chosen to reduce the noise contribution of subsequent electronics and to provide adequate isolation from the LNAA output to the antenna. The LNAA output is matched to 50 ohm, while the overall properties are optimised for simultaneous noise and power matching between the antenna impedance and the first HEMT-stage, using the HP/EEsof simulation package Academy (Libra). To obtain simultaneous noise and power matching at the first HEMT (Fujitsu FHC40LG) source inductive feedback is used. A microstrip balun connects the 'bunny ear' antenna to the first HEMT via a gate inductor and is used as one of the matching elements during the optimisation. The antenna properties are based on an available 1-port model of the antenna and are transformed to a two-port S-parameter file for use in the circuit simulator. The S-parameters of the HEMT over the frequency range of interest are based on a circuit model, derived from S-parameters on spot frequencies as given by the manufacturer. The noise parameters are extrapolated from manufacturer's data at 2 GHz. Fig. 1 shows a block diagram of the LNAA with details of the various circuit parts. Fig. 2 presents simulation results for the gain, the noise temperature at the antenna input and the mismatch between antenna and amplifier. The LNAA shows a gain around 40 dB in the THEA frequency band, with a maximum noise temperature

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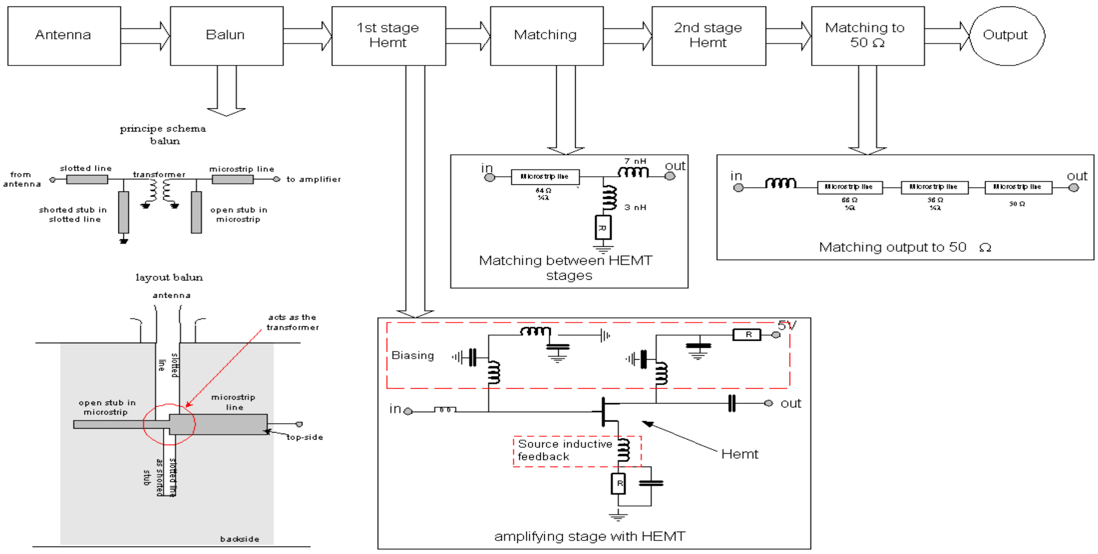

Figure 1. Block diagram of the LNAA with some circuit details.

of 35 K (0.5 dB NF). The return loss (') between antenna and amplifier does not show the optimum result that can be obtained with this design, due to a type-error in the optimiser. This performance should be improved in a new version of the design, because the poor matching over a large part of the band will adversely affect the accuracy of noise and gain measurements. Furthermore the reflection coefficient larger than one at frequencies above 1400 MHz may turn the amplifier unstable and should be reduced.

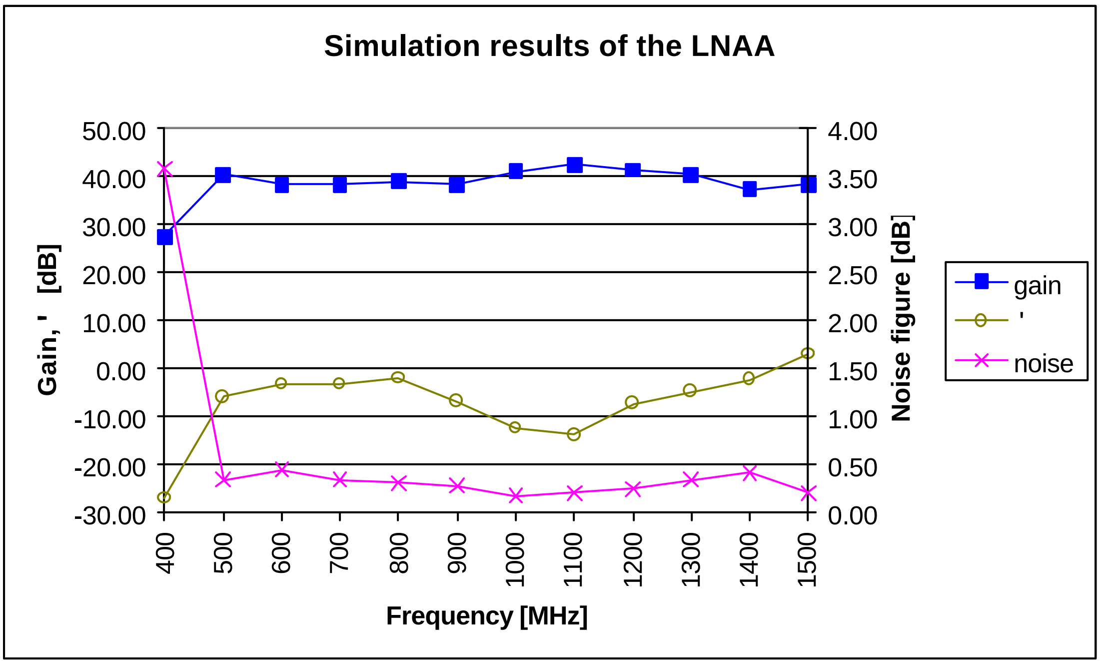

Figure 2. Simulation results of the LNAA.

3. LNAA measurement results.

Before the measurements on the LNAA were started the proper functioning of its active part was checked. Therefore a measurement was performed with a standard 50 ohm HP network analyser and noise figure meter. In this case the measurement signal was inserted directly after the balun. The properties of the active part of the LNAA were also simulated and compared to the measurement results. Figure 3 shows both simulation and measurement results for the gain and noise temperature in this situation. To obtain a reasonable agreement with the gain measurement it was necessary to increase the value of the gate inductance of the first HEMT from 27 nH to 35 nH in the simulation. Apparently in practice there is a 8 nH higher inductor in the circuit than anticipated, which has not yet been explained. The measured noise temperature curve shows an offset with respect to the calculated values. This is probably caused by inaccuracies in the noise measurement due to the large reflection coefficient at the input of the active part of the LNAA, which is not matched to 50 ohm.
The characterisation of a non-50 ohm integrated device like the LNAA requires a dedicated measurement setup to determine its gain and noise performance. In our measurements a

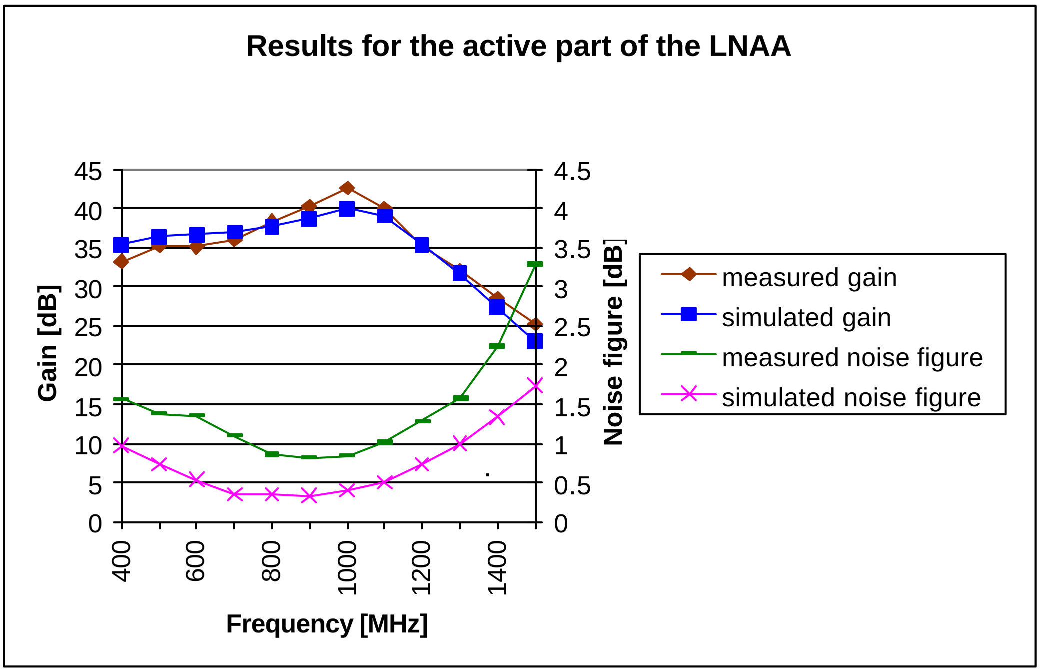

Figure 3. Measurement and simulation results for the active part of the LNAA.

reference antenna, similar to the antenna used in the LNAA, but matched to 50 ohm, is used to establish a calibrated signal path for the gain measurement in an anechoic room ([1]). The resulting gain G_T is used to calculate the noise behaviour from a separate noise power measurement, using the procedure described in [2]. Figure 4 shows the setups used for these measurements. The noise temperature of the LNAA, based on a noise power measurement referred to a 290 K noise standard, can be described according to [2] as

$$T_e = 290\, P_n / G_T - T_a \qquad (1),$$

where T_a and T_e are the noise temperatures of the antenna and LNAA, respectively.

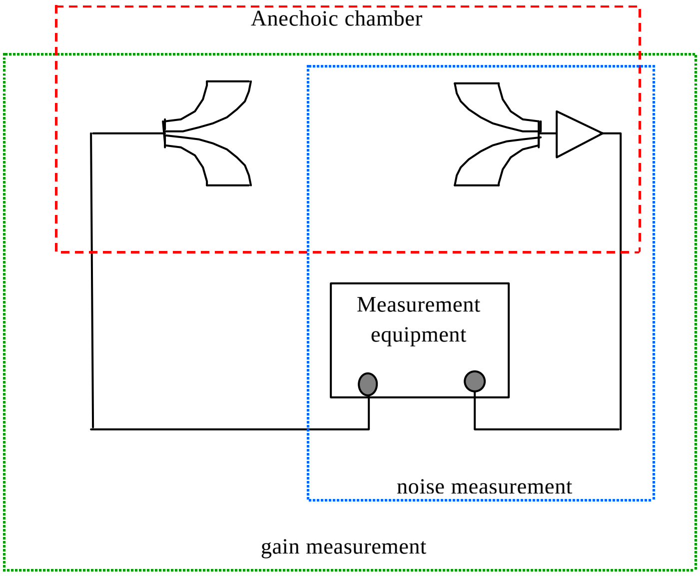

Figure 4. The gain and noise measurement setup for the LNAA.

In the noise measurement setup of Fig. 4 a low noise preamplifier is used to lower the noise temperature of the measurement system. This UHF-high amplifier ([3]) has a noise temperature below 40 K, but because of its limited bandwidth reduced the frequency band in which measurements were done from 700 MHz to 1500 MHz. Fig. 5 shows the measured gain and the calculated noise temperature from the noise power measurement, as well as the simulated performance for comparison. The simulation result differs slightly from the original one in Fig. 2 where the simulation was performed with a 27 nH gate inductance instead of the 35 nH used here. Because the measured gain differs considerably from the simulated gain, for the noise temperature calculation the simulated gain of Fig. 5 was used. Nevertheless large variations in noise temperature as a function of frequency were found, showing unrealistic values, unexpected

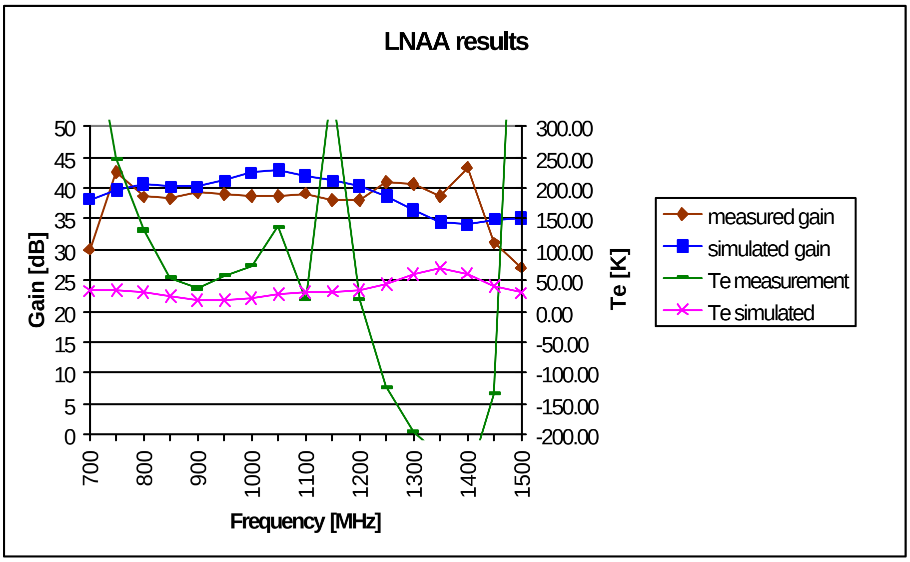

Figure 5. Measurement and simulation results of the LNAA.

after the reasonable agreement between theory and practice for the active part of the LNAA and the accuracy given in [2] (<0.4 dB). On the basis of these results the accuracy of our gain and noise measurement setups was questionned, leading to the conclusion that a reliable assessment of the measurement system was necessary.

4. Validation of the measurement setup.

To be able to assess the properties of the measurement setup a UHF-high amplifier was first characterised in a 50 ohm system with a standard network analyser and noise figure meter, providing reliable reference values for the validation measurements. As a first step in the validation of the measurement procedure a 50 ohm load was connected to the input of the amplifier and a measurement performed in the LNAA measurement setup, using T_a for the load instead of the antenna. Then T_e was calculated using formula (1), giving the result in Fig. 6 compared to the directly measured noise temperature. The calculated noise temperature (using the directly measured G_T) follows the measured values with reasonable accuracy, showing the validity of the measurement procedure in a well matched environment.

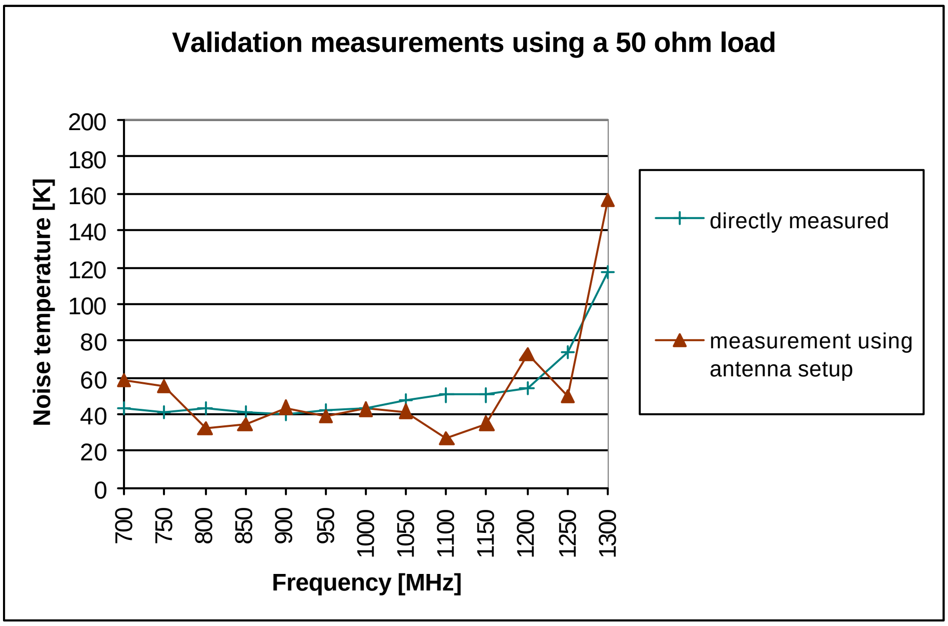

Figure 6. Noise measurement with a UHF-high amplifier.

In Fig. 7 the directly measured G_T and the result of the measurement using the LNAA antenna setup (using the 50 ohm reference antenna as input) are compared, showing reasonable agreement at first glance, although fluctuations of a few dB around the directly measured amplifier gain can be observed. These have a large impact on the accuracy of the noise temperature calculations, e.g. 1 dB gain error introduces 80 K noise temperature error. Fig. 8 shows two results of amplifier noise measurements and calculations in the antenna measurement setup, compared to the direct measurement also shown in Fig. 6. For the calculations formula (1) was adapted to the slightly modified measurement situation ([4]). The result in Fig. 8 that relatively closely follows the direct measurement is based on a calculation using the most accurately known, directly measured, gain of the amplifier. Still errors larger than 40 K (100%) are visible. The other result shows even larger fluctuations of the noise temperature, illustrating the inaccuracies introduced by errors in the gain as shown in Fig. 7.

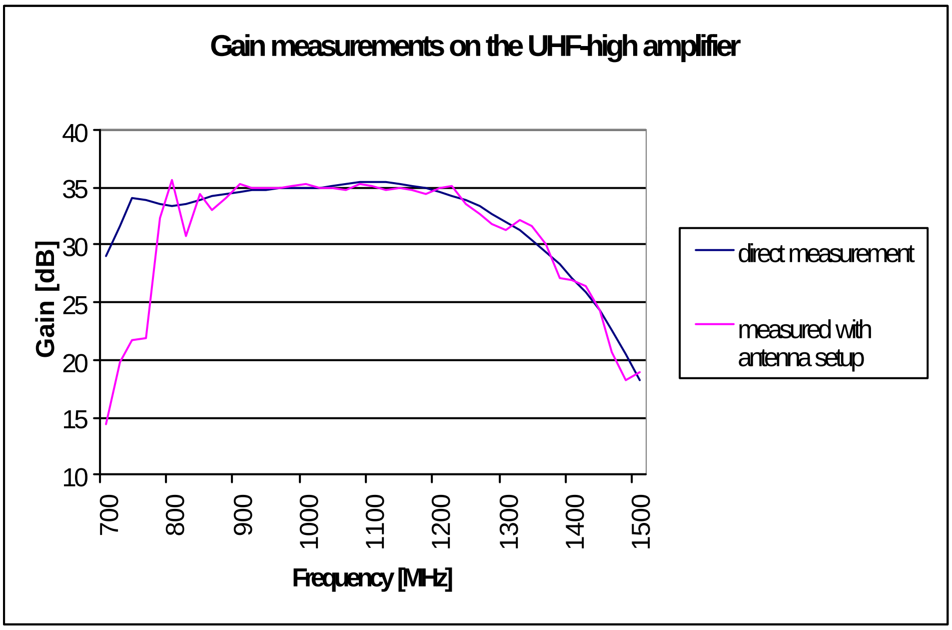

Figure 7. Measured gain of the UHF-high amplifier (see text).

The conclusion from these measurements is that the errors in the antenna setup for this noise measurement method are much larger than might be expected on the basis of the results shown in Fig. 6. The noise power and, more dominantly, the gain measurement both introduce considerable errors, which are attributed to standing waves in the measurement setups. Improvement of the measurement setup in this respect is necessary before reliable characterisation of an amplifier can be done.

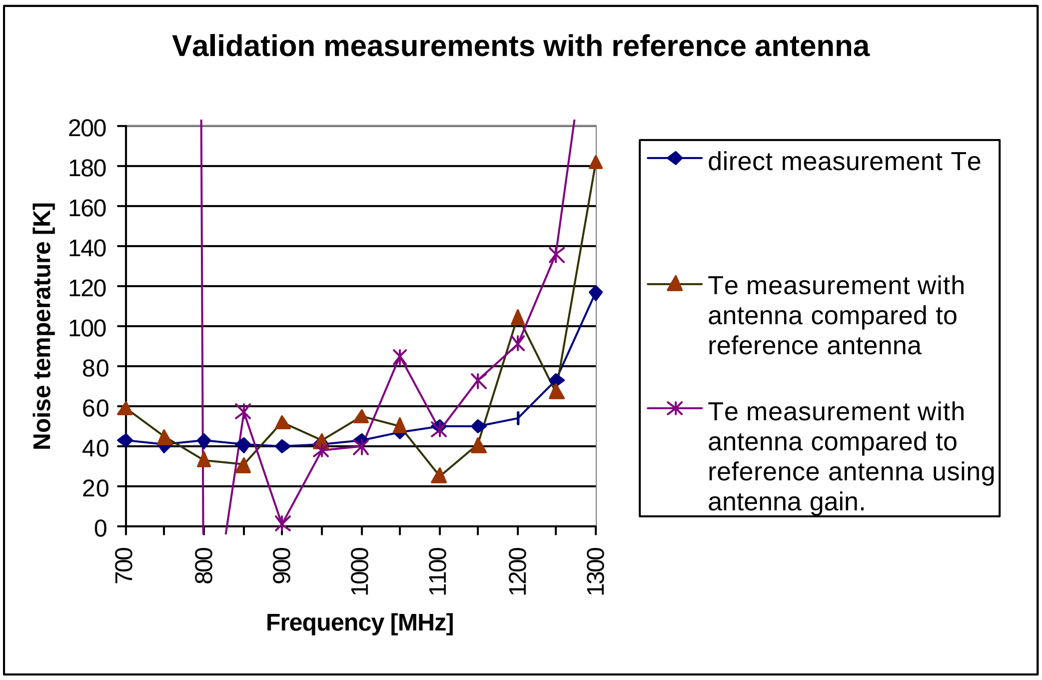

Figure 8. Results of noise measurements using the antenna setup (see text).

5. Conclusions.

The simulation results of the LNAA show that it is possible to make a design for a wide band low noise amplifier that is directly matched to an antenna. They show a bandwidth of two octaves with a noise temperature of 35 K. The measurements on the active part of the design are in agreement with simulated performance. However measurement results of the LNAA are unreliable, both for gain and noise temperature. This is attributed to inaccuracies in the antenna measurement setup. To assess the properties of this setup validation measurements were performed using a well characterised UHF-high amplifier with comparable gain and noise temperature. Results indicate that standing waves in the measurement setup are the cause for large discrepancies between measured and expected values. Improvement of the measurement setup is necessary to be able to reliably characterise the LNAA.

6. References.

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