SiGe LNA NOISE TEMPERATURE PROJECTIONS FOR THE SQUARE KILOMETRE ARRAY

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ABSTRACT

This paper estimates the noise temperature of SiGe low noise RF amplifiers and explores their performance within the context of wideband array system design. Models are developed for the noise generated by the transistors and for major sources of noise in a Luneburg Lens Square Kilometre Array (SKA). Previous qualitative studies have suggested that SiGe technology has the most potential of meeting the performance and cost requirements of the SKA [1]. This work attempts to make a quantitative assessment of the potential of SiGe technology within the SKA context.

INTRODUCTION

The Australian Square Kilometre Array (SKA) Consortium is currently investigating the feasibility of constructing an SKA from Luneburg Lenses [2]. The Luneburg Lens SKA, as all SKA solutions, requires cheap and highly robust RF systems for each antenna element. Furthermore, the noise performance of the elemental RF systems will largely determine the size and thus cost of the entire array. In this paper, a noise model for a Luneburg Lens SKA is introduced. Next, the noise performance of future SiGe MMIC LNAs is estimated. Finally, the noise performance of a Luneburg Lens SKA employing SiGe MMIC LNAs is estimated and compared to the performance achievable with LNAs using other semiconductor processes.

NOISE MODEL FOR A LUNEBURG LENS SKA

A noise model for an SKA constructed from 7m diameter Luneburg Lenses has been developed and is summarised in Fig. 1. The Galactic foreground dominates at low frequencies and the dielectric loss of the lenses dominates at high frequencies. Prior to considering the receivers, it is clear that the system will perform best in the vicinity of 1 GHz. This is the frequency at which the contribution of the LNAs to the system noise temperature is most critical.

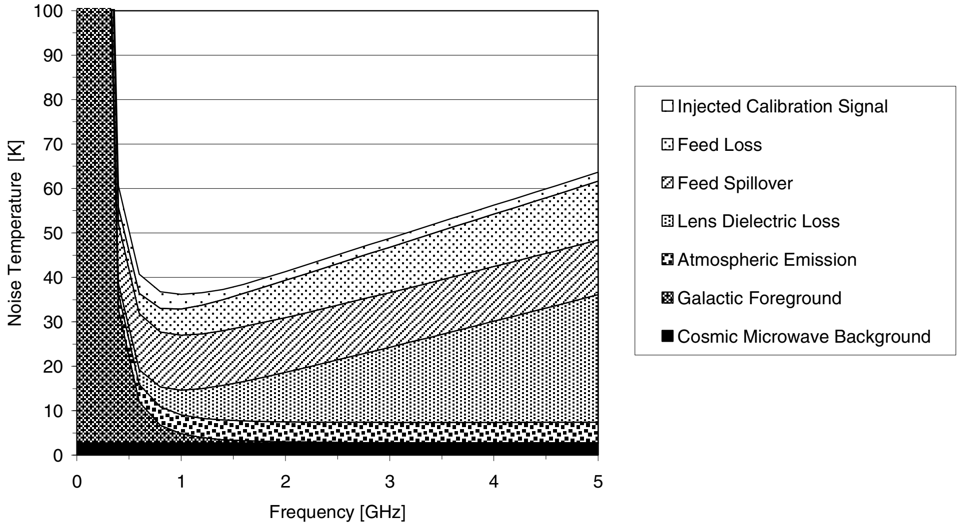


Fig. 1. Noise contributions for an SKA consisting of 7m Luneburg Lenses.

NOISE FIGURE COMPONENTS

The key specification for an LNA is the noise figure, which relates the signal to noise at the output of an amplifier to that at the input. The noise figure of a two-port amplifier may be characterised by

$$NF = NF_{\min} + \Delta NF_{mismatch} \tag{1}$$

where NF_{min} is the minimum noise figure of the active device and $\Delta NF_{mismatch}$ represents a degradation in noise figure due to deviation in source impedance from that required to achieve minimum noise figure. Detailed expressions for both terms in (1) are given for HBT LNAs in [3]. For an amplifier at physical temperature $T_p = T_o = 290$ K, and with a non-ideal input matching network of loss L_{match} this becomes

$$NF = L_{match}\left(NF_{\min} + \Delta NF_{mismatch}\right) \tag{2}$$

In order to allow the expression of the noise figure as a product of component noise figures it may be rewritten

$$NF = L_{match} NF_{\min} NF_{mismatch} \tag{3}$$

where

$$NF_{mismatch} = \left(NF_{\min} + \Delta NF_{mismatch}\right) / NF_{\min} \tag{4}$$

It is assumed here that there is sufficient gain in the first LNA stage for interstage mismatch and loss to be ignored.

NOISE PERFORMANCE PROJECTIONS FOR SIGE HBT LNAs

Here we consider the performance of the degenerate class of LNAs where L_{match} is minimised by not using an input noise-matching network. This seems valid for SiGe HBT LNAs where the input impedance for noise-matching tends to be close to 50 Ω and passive components on Si substrates are relatively lossy. This was supported by a brief investigation of input matching networks for a two stage SiGe HBT LNA MMIC. Simulations of the two stage MMIC LNA of Fig. 3 were made using measured *S* and noise parameters of the IBM43RF0100 [4] as a transistor model. The best simulated noise figure of 1.52 dB (122 K) was achieved with no input or interstage matching. Passive components were assumed to have a *Q* of 12 at 2.4 GHz reflecting performance claimed by an existing SiGe foundry [5]. The effect of packaging parasitics was ignored. The circuit is unconditionally stable in band (0.5-2GHz) and appears to be stable out of band based on *S* parameters extrapolated from a small-signal equivalent-circuit model [3] extracted from data in [4].

A recent work on the optimisation of Ge profiles in IBM's SiGe HBTs [6] shows that it is possible to increase β and hence achieve an NF_{min} of 0.2 dB (15 K) at 2 GHz. The noise figure of a MMIC LNA of the topology shown in Fig. 3 and employing HBTs with optimised Ge profile may be estimated by substituting this value of NF_{min} into (2) and assuming that the other noise figure contributions will remain of similar order. The resulting noise figure at 2 GHz is 0.66 dB (48 K). The tabulation and graphical comparison of noise figure components in Fig. 2 suggests that input mismatch will begin to limit LNA noise figure when noise optimised Ge profiles are used. This agrees with (4). Low loss passive components on Si will be necessary to achieve noise figures lower than the 0.66 dB (48 K) predicted here.

Noise Figure Contribution at 2 GHz	**IBM43RF0100 SiGe HBT** [ratios]	**Optimised Ge Profile** [ratios]
NF_{min}	1.3000	1.0471
$\Delta NF_{mismatch}$	0.0987	0.0987
$NF_{mismatch}$	1.0759	1.0943
L_{match}	1.0150	1.0150
NF	1.4196	1.1659

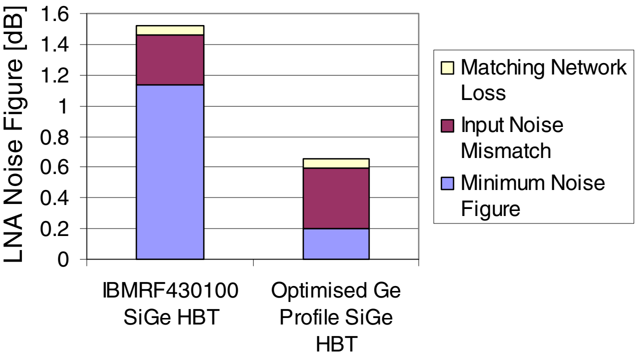
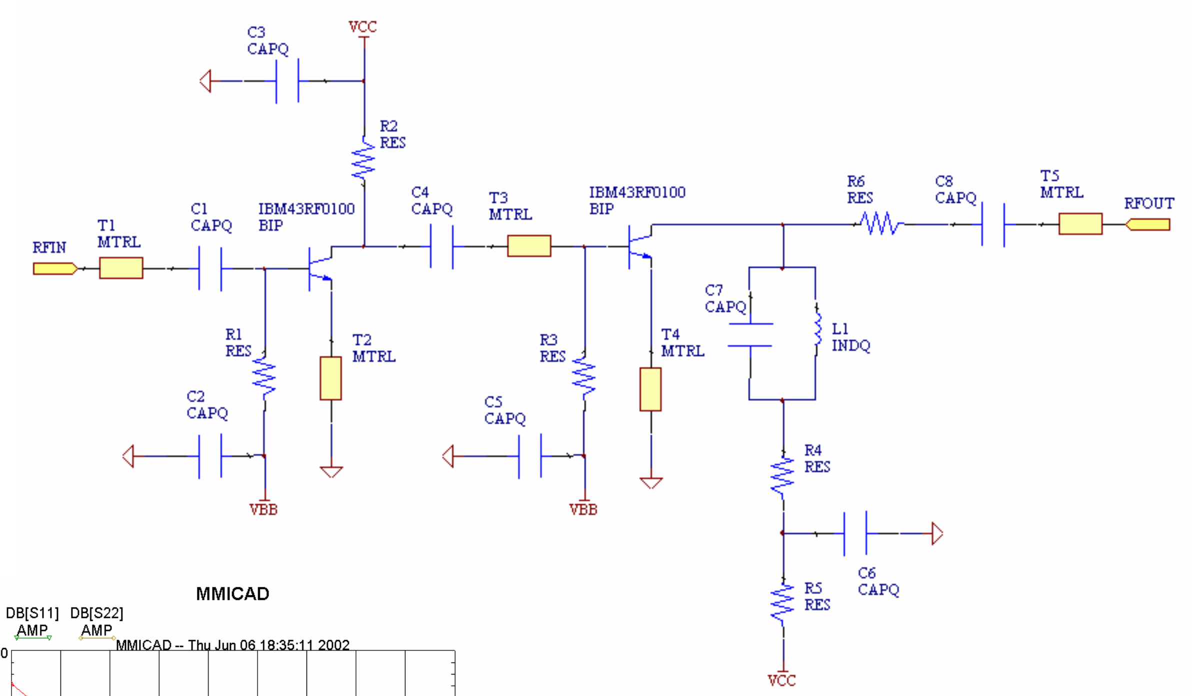
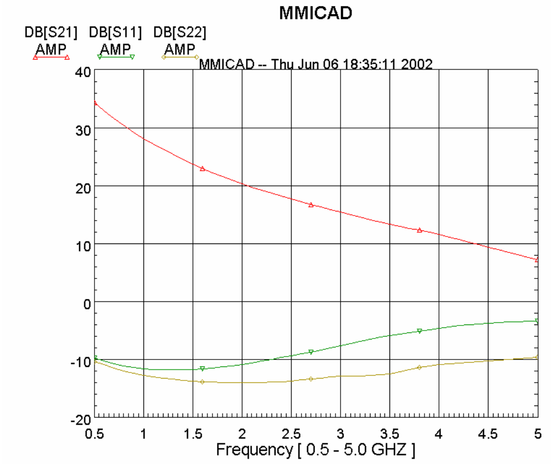
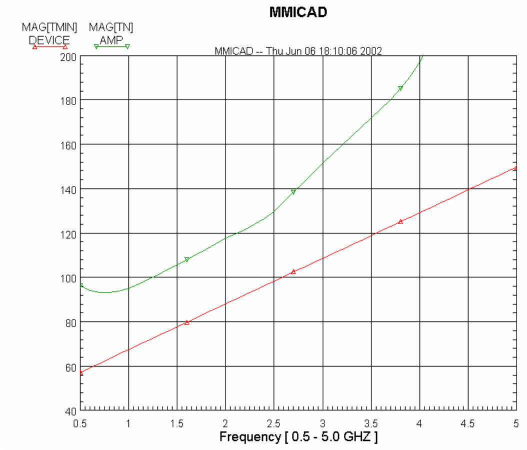


Fig. 2. Noise figure components for MMIC LNAs based on regular and noise optimised SiGe HBTs. The LNA topology is common and is shown in Fig. 3.







Circuit Reference	Value
C1, C2, C3, C4, C5, C6	50 pF
C7	0.8 pF
C8	16.6 pF
R1, R3	4.6 kΩ
R2	600 Ω
R4	118 Ω
R5	482 Ω
R6	4 Ω
L1	0.4 nH
T1	W=69 μm L=100 μm
T2	W=10 μm L=367 μm
T3	W=90 μm L=40 μm
T4	W=10 μm L=78 μm
T5	W=69 μm L=167 μm
VCC	5 Vdc
VBB	1 Vdc

Fig. 3. Schematic and simulated performance of an unmatched SiGe HBT MMIC LNA. *S* parameters of the IBM43RF0100 [4] were used to model the transistors.

NOISE PERFORMANCE PROJECTIONS FOR A LUNEBURG LENS SKA

The noise temperature projected for SiGe HBT LNAs with optimised Ge profiles may be added to the Luneburg Lens SKA noise model to yield a model of system temperature, T_{sys}. Fig. 4 uses this system temperature model to plot the array A_e/T_{sys}, a measure of array sensitivity, for a given collecting area, A_e. This performance projection is plotted along side measured and projected performances for other contemporary LNA technologies. A constant A_e of 1.3 km^2 was selected such that state of the art, uncooled GaAs MMIC LNAs will meet the SKA A_e/T_{sys} specification of 2.00×10^4 at 1.4 GHz. The performance of the VLA, the most sensitive radio telescope array in operation, is also given for comparison. It can be seen that projected performance of SiGe LNAs competes well with existing GaAs LNAs. However, it appears that 0.1 μm GaAs MMICs will yield superior noise performance, albeit at a higher cost.

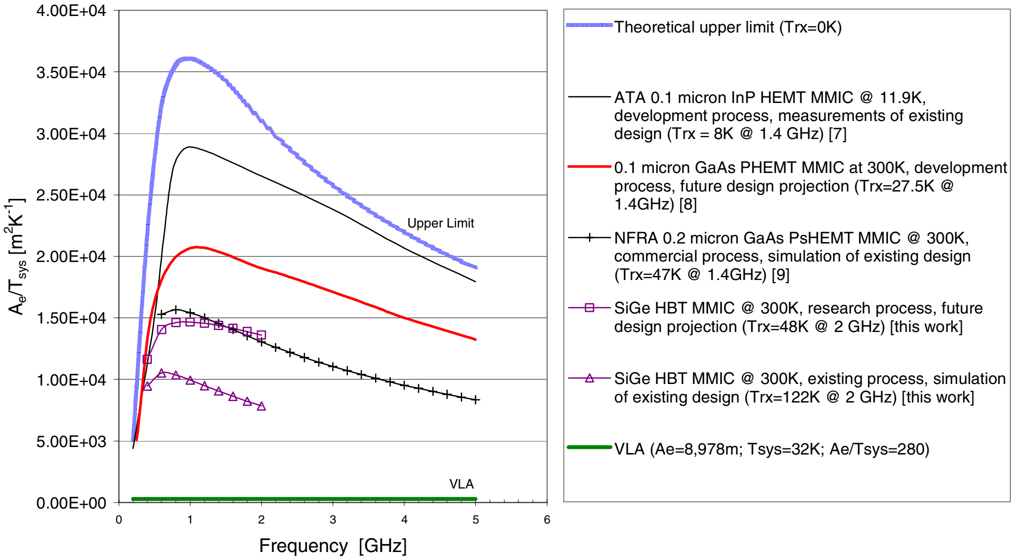


Fig. 4. A_e/T_{sys} for an SKA consisting of 7m Luneburg lenses and various receiver technologies.

CONCLUSIONS

- Matching network loss may dominate the noise performance of current SiGe LNAs.
- Input noise mismatch may dominate the noise performance of future SiGe LNAs.
- Optimised Ge profile SiGe HBT LNAs show promise of noise performance only now achievable in GaAs.
- GaAs is in the lead for room temperature noise performance, but cheaper SiGe is catching up.

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