Optimised LNAs for 3 T, 7 T and 9.4 T

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Introduction

In this contribution, we present the design and optimisation of a novel single and dual-stage low-Z LNAs for 3 T, 7 T and 9.4 T. All LNAs share the same topology and PCB layout. They are built around an Avago ATF-54143 GaAs HEMT [1]. The small-signal behaviour of the LNA is represented by cascaded two-port networks. Matlab [2] is used to optimise the component values to fulfil the desired matching conditions at the input and the output of the LNA together with a minimal noise figure, a maximum gain and unconditional stability.

Theory

The isolation of adjacent coils by geometric overlapping is a well-known technique since the beginning of array development. Decoupling of non-adjacent elements is however performed by either separate transformers or by low-Z LNAs [3]. We have developed a optimisation routine for Matlab to design LNAs with the lowest possible noise figure. The input matching network of the LNA has to fulfil two conditions: When you look into the LNA, a very low input impedance is desired, at the same time, the transistor wants to see a noise-matched impedance. To design this network we tested some possible topologies and had the best result with the network depicted in fig. 1. The resistors are needed to stabilise the amplifier. They are placed at the output of the FET and so will not increase the noise figure noticeably. This topology is then represented as a cascaded two-port network. From each component the corresponding two-port matrix (in ABCD form) is built. The data of the FET is available as a touchstone file at several bias points. The touchstone file is then also converted to a two-port matrix for each frequency. The optimisation routine works as follows:

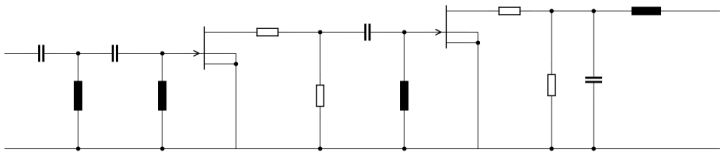

Fig 1. LNA small-signal circuit

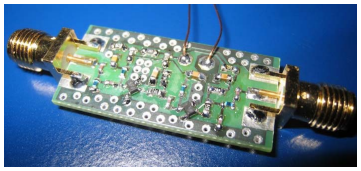

Fig 2. Picture of the PCB of the dual-stage LNA.

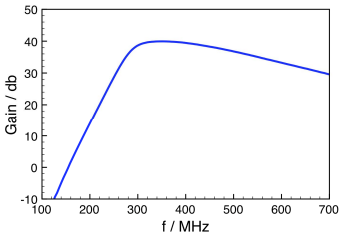

Fig 3. S_{21} of the 7 T dual-stage LNA

Matlab's optimisation function (fminsearch.m) calculates a set of component values (12 parameters). The according two-port matrices are formed for each frequency in steps of 10 MHz from 100 MHz to 1 GHz or more. These are then cascaded with one or two FETs and form a resulting two-port matrix that represents the small-signal behaviour of the LNA, again one matrix for each frequency. The matrices are then analysed: The algorithm calculates the gain, the stability factor and the noise figure over the desired frequency range. The input and output impedance and Γ_{opt} are computed and compared with the desired values. Together with the resulting noise figure, they form a weighted sum as the cost function to be minimised by the optimisation. All LNAs have a low imput impedance of 1.5 Ω at their input and 50 Ω at their output terminal. They are all noise noise-matched to 50 Ω.

Experimental

From the optimised design, we produced a set of PCBs for single- und dual-stage LNAs. For this step, the small-signal circuit has to be modified to bias the two transistors by some resistors and additional capacitors. The size of the PCBs is 27 mm x 13 mm for the single-stage, and 30 mm x 14 mm for the dual-stage LNAs. It can be used for all MR frequencies, we realised LNAs for 3 T, 7 T and 9.4 T. Fig. 2 shows a picture of the populated PCB of a dual-stage LNA. The component count is 24.

Results & discussion

In order to verify the result of the optimisation, we first measured the S-Parameters of the LNA with an Agilent N5071C network analyser. Fig. 3 shows a measurement S_{21} of the 7 T dual-stage LNA. The resulting noise figure of the LNA was measured by an Agilent N9000A spectrum analyser together with a N4000A noise source. It shows a minimum at the operating frequency of only 0.3 dB.

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References: [1] Avago Technologies, San José, CA, USA; [2] The Mathworks, Inc; [3] RLE Computational Prototyping Group, MIT, Cambridge, MA; [3] Roemer et al., Magnetic Resonance in Medicine 16, 192-225 (1990); [4] Agilent GmbH, Böblingen.