A new electronically controllable tuner system for precise noise figure measurement

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Introduction

In order to achieve the minimum possible noise figure for a low-noise amplifier (preamplifier, LNA) such as they are used in local coils of MRI systems, it is necessary to know the optimum source impedance Γ_{opt} of the preamplifier. Usually the optimum source impedance of the input transistor is given in the datasheet of the vendor, but as most low-noise transistors are used for much higher frequencies, this information is not available at typical MR frequencies between 40 and 300MHz. Recently some efforts to measure noise figure versus input impedance for MR frequencies have been made [1,2]. However, these approaches either have neglected the additional losses in the tuner circuit or they are not automated systems. As it is necessary to take many measurements for an accurate determination of Γ_{opt}, it can be very cumbersome to take them manually, while exchanging components in the tuner from measurement to measurement. Therefore we propose an automated system based on an electronically controlled tuner with fully automated calibration and measurement evaluation. With that system we expect to get deeper insight in both the reproducibility of the noise parameters over a series of amplifiers as well as the noise added by the preamplifier when the coil does not present the optimum source impedance to the preamp (varying load situation from patient to patient).

Method and Experimental Setup

The electronically controlled tuner uses three varactor-diodes and an impedance transforming network which allows to achieve almost any source impedance point within the Smith chart (the absolute of the reflection factor Γseen into the tuner can range from 0-1, the phase can vary from 0-360°). The measurement procedure is as follows: First the user can pick the desired points for the source impedance using a graphical user interface on the computer controlling the measurement system. Second the user calibrates the tuner with a network analyzer so that its losses and the actual source impedances presented to the preamp can be accurately evaluated. Third the preamp is connected to the tuner and the gain and noise figure is recorded for the desired source impedances. Fourth the measured noise figures are corrected for the losses of the tuner and the values are fitted with the analytic results (equation 1, [3]) using a least squares algorithm. The major parameters derived from the measurement are F_{min}, Γ_{opt} and the steepness C_n of the paraboloid describing the change of noise figure versus source impedance.

$$F = F_{min} + \frac{4R_n}{Z_0|1+\Gamma_{opt}|^2} \cdot \frac{|\Gamma - \Gamma_{opt}|^2}{1-|\Gamma|^2} = F_{min} + C_n \cdot \frac{|\Gamma - \Gamma_{opt}|^2}{1-|\Gamma|^2} \text{ with } C_n = \frac{4R_n}{Z_0|1+\Gamma_{opt}|^2} \qquad (1)$$

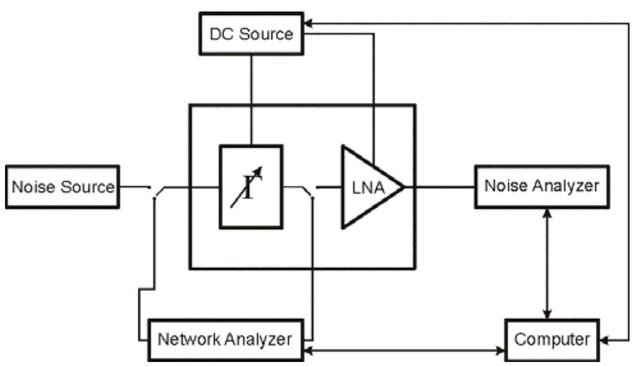

Fig. 1.: Block diagram of the measurement setup

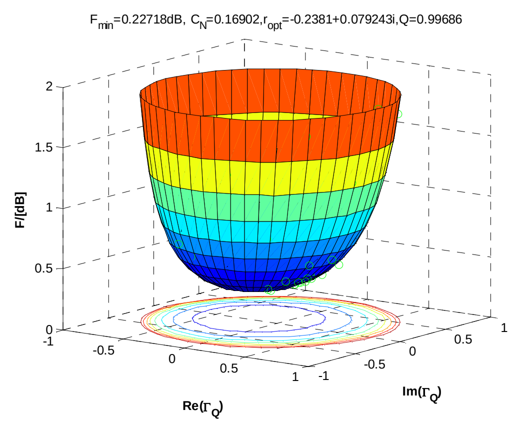

Fig. 2: Results directly derived by the automated measurement system show the noise figure versus input impedance (small dots represent the actually measured figures)

Results and Discussion

The results are shown in Fig. 2, which shows the noise figure as a function of complex source impedance. The 2D surface is calculated from the model, while the points refer to the actual measurements. In the least squares fit, there is a 98% correlation between the measurements and the fitted model, which confirms the accuracy of the measurement. For the validation of the measurement system, we used an exemplary 1.5T preamplifier. With the described system we measured F_{min}=0.22 dB for Γ_{opt}=-0.24+j0.08 (equals 30Ω+j5Ω), C_n=0.17. In order to verify the repeatability of the measurement system, we repeated the measurement on the same preamplifier 20 times. The changes we found in noise figure F_{min} and Γ_{opt}, were only ΔF_{min}=±0.015dB, $\Delta\Gamma_{opt}$=±(0.01+j0.04) and ΔC_n=0.015, respectively. With such a high accuracy in the determination of the noise parameters, even subtle changes over a series of preamps could be monitored.

Conclusions

A unique measurement system for the determination of noise parameters versus input impedances at frequencies typically used for MRI was developed. It was shown that the experimental and theoretical results are in very good agreement. The extremely high accuracy of this fully calibrated system allows to precisely monitor variations of noise parameters over a series of preamps. To our current knowledge, the presented instrument is the most accurate measurement system for noise parameter extraction, reported so far for low frequencies (<500MHz).

Reference

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