A simple method to measure the noise figure of preamplifiers

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Introduction: Signal-to-noise ratio (SNR) in magnetic resonance imaging (MRI) is degraded by two main sources of Johnson noise. One is the thermal noise of the sample which usually cannot be reduced, the other is noise added in the receiver chain. The amount of noise added by a 2-port device is usually characterized by the noise figure, NF=10·log(F), where $F=SNR_{input}/SNR_{output}$ is the noise factor. Since the MR signal is very small it usually must be amplified as close as possible to the coil by a preamplifier. Since the preamplifier is the first amplification stage in the receiver chain, its NF has the biggest influence on the SNR. Noise figure varies with frequency and the impedance that is presented to the input of the amplifier, i.e. the source impedance Z_s. At the optimal source impedance, Z_{opt}, the amplifier has minimal NF. Z_{opt} is one of the noise parameters that can be found in datasheets of many amplifiers or transistors. However, these values are often measured at higher frequencies than the MR frequencies and are consequently not of much use. Measurement of the noise parameters requires expensive hardware which is not widely available at MR frequencies. Here we present a simple method to measure the NF of a preamplifier in order to determine Z_{opt} at 128 MHz.

Materials and Methods: Noise figure measurements usually use a noise source that delivers two different noise powers in the 'off' and 'on' state to a tuner system which presents different complex impedances to the input of the preamplifier. A noise figure meter is connected to the output and calculates the noise figure from the measured noise powers in the two states of the noise source based on the Y-factor method [1]. Since tuner systems are expensive and not commonly available at MR frequencies used in in-vivo systems we replaced the tuner by a simple network of different lumped components in series between the noise source and the preamplifier's input to create different complex source impedances. We used an HP 8970A Noise Figure Meter and an HP 346B Noise Source. The difference in available noise power between the two states of the noise source is given by the excess noise ratio (ENR). In the 'off' state the noise power is equal to the noise power of a 50 Ω resistor at room temperature. In the 'on' state the noise power is much higher and corresponds to a 50 Ω resistor at much higher temperature. Therefore the two states are also called 'cold' and 'hot'. An additional resistor in series increases the source resistance, acts as a voltage divider and is a noise source itself. Therefore the ENR must be corrected depending on the value of the resistor according to equation (1), where R_1 is the resistance of the noise source, T_{hot} and T_{cold} the corresponding noise temperatures in °K and R_2 is the value of the series resistor. A similar expression holds in the case of the parallel resistor. Series resistor values between 0 and 1000 Ω were used. The reactive part of the source impedance was tuned with series inductors in the range 66 to 480 nH and series capacitors in the range 6.2 to 51 pF. Reactive elements do not alter the ENR and thus do not require further corrections.

Equation (1)

$$ENR = 10\log\left(\frac{R_1\left(T_{hot}-T_{cold}\right)}{290^\circ K\left(R_1+R_2\right)}\right)$$

The corrected ENR value can be entered directly in the HP 8970A. However, a second correction must be made to the values displayed by the NF meter due to the mismatch between noise source and preamp as described in several publications [2,3]. The uncertainty of the NF measurement may be calculated according to [4] and is dominated by errors in ENR. Consequently a naïve connection of high reflection preamplifiers, such as those used for preamplifier decoupling, to a 50 Ω noise figure meter can give results with relative uncertainties of 100% or more.

Results: Figure 1 shows the results of the NF measurement of a preamplifier used in our lab at 128 MHz. The minimum NF in this measurement was found to be NF = (0.49±0.22) dB at Z_{opt} = (50+100i) Ω.

Discussion: We have shown that measuring the NF of a preamplifier at 128 MHz is possible even without an expensive tuner system. Large variations in NF are seen for source impedances that are far from the optimal value. The noise figure meter could be replaced by a power meter or spectrum analyzer since the NF is calculated only from the measured noise powers. The traditional method of using a resistor at room temperature and cooled with liquid nitrogen to produce the two different noise powers is much less practical than using a commercial noise source. By correcting for changes in ENR and impedance mismatch method is not limited to 50W impedance. As expected, our measurements show clearly that choosing the right matching network is crucial since small deviations from Z_{opt} can lead to a significant increase in NF of the preamplifier and thus a degradation of the SNR.

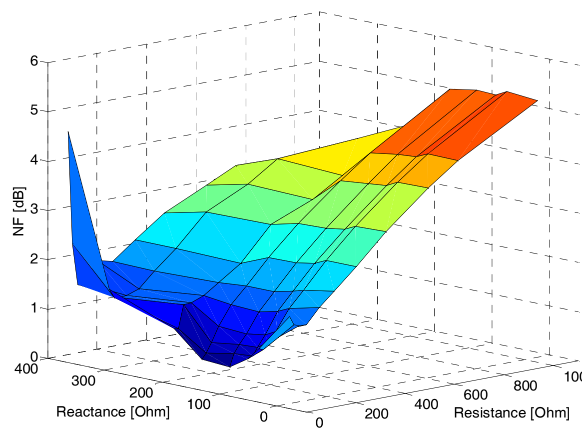

Fig. 1: 3D-plot of the corrected noise figure at 128MHz. X- and y-axes display the resistance and reactance respectively. Noise figure is plotted on the z-axis and exhibits a minimum at Z_{opt} = (50+100i) Ω.

References:

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Acknowledgements: H. Benedickter is gratefully acknowledged for assistance.