

# Validation of Noise Figure Measurements by Means of MR Imaging

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**Introduction** In order to maximize the signal-to-noise-ratio (SNR) performance of an MR receiver coil the preamplifier used should add as little noise as possible. The amount of added noise is characterized by its noise figure (NF). Standard NF measurement of a preamplifier requires a tuner to present reference noise at varying complex impedance to the input of the device. Such tuners are not commonly available at MR frequencies but it has recently been shown that they can be reliably replaced by suitable lumped-element circuits between the noise source and the preamplifier [1]. The aim of the present work project was to cross-validate this method of NF measurement by SNR measurements in actual MR data obtained with a commercial imaging system.

**Materials and Methods** In order to calculate the expected NF of a preamplifier at any given source impedance its so-called noise parameters  $F_{\min}$ ,  $R_n$ ,  $G_{\text{opt}}$  and  $B_{\text{opt}}$  [2] have to be known. The relationship of the noise parameters and the noise factor is given by Eq. (1), which can be used to extract noise parameters from NF measurements by fitting [3,4]. In a cascade of active devices the contribution of each device to the overall noise factor  $F_{\text{tot}}$  is given by Eq. (2), which is known as Friis' formula where  $F_i$  are the individual noise factors of the different devices and  $G_i$  are the corresponding available gains. Looking at an assembled receiver coil the coil element, the matching network, and the preamplifier can be regarded as the different stages. Their noise factors must be determined individually before the overall noise factor can be calculated. As long as the available gain of the preamplifier is large ( $> 20$  dB) the contributions of the rest of the receiver chain can be neglected.

Since the coil element and the matching network usually do not contain any active devices their available gain can be assumed to be 1. The noise factor  $F_c$  of the coil element can be calculated from Eq. (3), where  $\text{SNR}_1$  and  $\text{SNR}_2$  are taken at the input and output of the coil element, respectively,  $G_c$ ,  $N_c$  and  $R_c$  denote the gain, noise power, and equivalent series resistance of the coil element, and  $N_s$  and  $R_s$  are the noise power and equivalent series resistance of the sample. For a given measurement setup,  $R_c$  and  $R_s$  can be readily calculated from unloaded and loaded Q-factor measurements of the coil element. Similarly the noise factor  $F_m$  of the matching network can be calculated from a Q-factor measurement. The noise factor  $F_{\text{preamp}}$  of the preamplifier can then be calculated from Eq. (1) if the source impedance seen by the preamplifier is additionally measured. In total Eq. (1) can be rewritten in the form of Eq. (4). Since the signal level at the very input of the receive chain is not known, ratios of total noise factors and SNR values of two measurements must be calculated according to Eq. (5).

MR measurements were performed on a 3T Philips Achieva system (Philips Healthcare, Best, The Netherlands) using a 2D gradient echo sequence. The flip angle was set to the Ernst angle, which was determined empirically. The measurement setup is shown in Fig. 1, including a homogeneous phantom filled with copper sulfate solution. A proprietary preamplifier with a minimal noise figure of 0.6 dB was used. Its matching to the preamplifier was varied in a way similar to that described in Ref. [5]. For each matching configuration image as well as noise data were acquired and the source impedance seen by the preamplifier was measured using an Agilent E5071 C network analyzer. SNR maps were calculated from the image and noise data as described in Ref. [5], taking the square of the resulting values to obtain SNR in terms of power as underlying Eqs. (3,5). Overall SNR values with high statistical power were then determined by averaging over the whole phantom.

**Results and Discussion** Table 1 shows the results of this study, juxtaposing total noise factors and SNR values as well as their ratios between different matching configurations. Notably, the noise factor and SNR ratios agree to within 5%, indicating the validity of both the bench method for NF measurement and the noise analysis of the receive chain described above. This agreement offers the important confirmation that optimizing the NF on the bench actually translates into quantitatively corresponding SNR benefits in MR experiments. To the best of our knowledge such cross-validation has not previously been reported.

**References** [1] Massner et al., Proc. ISMRM, p. 328 (2007) [2] "IRE Standards on methods of measuring the noise in linear two-ports", Proc. IRE 48,p.60 (1960) [3] Lane et al., Proc. of the IEEE, p. 1461 (1969) [4] Caruso et al., IEEE Trans. Microwave Theory and Techniques 26(9) p. 639 (1978) [5] Nordmeyer-Massner et al., MRM, DOI 10.1002/mrm.21868 (2008)

## Equations

$$(1) F = F_{\min} + \frac{R_n}{G_s} |Y_s - Y_{\text{opt}}|^2$$

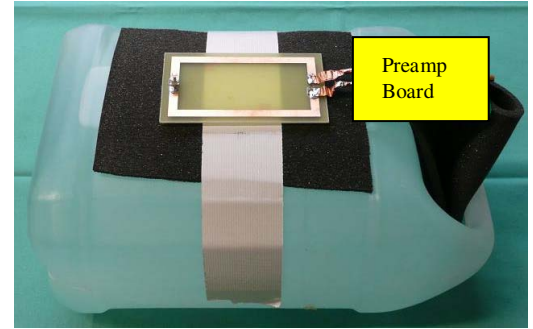
(2)

$$F_{\text{tot}} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \dots + \frac{F_n - 1}{G_1 G_2 \dots G_{n-1}}$$

$$(3) F_c = \frac{\text{SNR}_1}{\text{SNR}_2} = \frac{G_c N_s + N_c}{G_c N_s} = \frac{R_s + R_c}{R_s}$$

$$(4) F_{\text{tot}} = F_c + F_m - 1 + F_{\text{preamp}} - 1$$

$$(5) \frac{F_{\text{measurement 2}}}{F_{\text{measurement 1}}} = \frac{\text{SNR}_{\text{measurement 1}}}{\text{SNR}_{\text{measurement 2}}}$$



**Fig. 1:** Measurement setup with coil, preamplifier board and phantom.

Matching configuration	$F_{\text{tot}}$	SNR	F ratio	SNR ratio
1	1.6958	34.47	1.0686 1.1930 1.1199 1.1012	1.0845
2	1.8122	33.10		1.1320
3	2.1619	31.11		1.1031
4	2.4211	29.62		1.1303
5	2.6661	27.86		

**Table 1:** SNR Results and corresponding noise factors. Since F is calculated based on noise power, the SNR ratios have to be squared for comparison.