Automated Preamplifier Noise Parameter Measurement System Using a Combination Analyzer

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Introduction

Array coils for MRI use highly reflective, low-noise preamplifiers to boost signal levels while minimizing, respectively, inductive coupling [1] and added noise. The noise factor [2], i.e., the loss of SNR due to noise added by the preamp (or noise figure, NF, when expressed in dB) depends on the admittance seen by the preamplifier's input, $Y_s = G_s + iB_s$, according to the expression [3] $F = F_{min} + R_n \left| Y_s - Y_{opt} \right|^2 / G_s$, where noise parameters F_{min}, Y_{opt}, and R_n are, respectively, the minimum noise factor, the optimal source admittance at which this minimum occurs, and the equivalent noise (or correlation) resistance that describes how quickly NF rises away from Y_{opt}. These parameters are needed to design optimal noise matching networks between coil and preamp, but manufacturers often do not supply this information at MRI frequencies and/or at impedances other than the standard 50 Ω. Measuring noise parameters is also needed to identify inter-device variability for quality control.

Accurate noise parameter measurement requires multiple measurements of NF at various values of Y_s, as well as corrections for reflections of noise power at the preamplifier's input and other stages in the measurement system. The latter is a significant effect in highly reflective array coil preamplifiers used for preamp decoupling [1], because noise reflected back to the standard 50 Ω noise sources used by NF analyzers leads to incorrect NF readings. High frequencies (> 1 GHz) or high cost (> $100k) of commercial noise parameter measurement systems (for the telecom industry) are unsuitable for most MR laboratories.

We present an automated system to measure noise parameters based on a common combination vector network analyzer (VNA) / spectrum analyzer (SA) (4396B, Agilent, USA) and the LabVIEW software environment (National Instruments, USA).

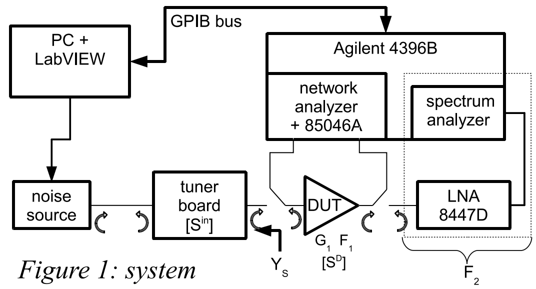

Figure 1: system diagram (curved arrows indicate reflections)

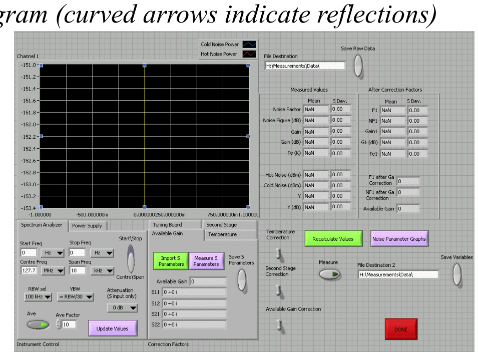

Figure 3: screenshot of LabVIEW program

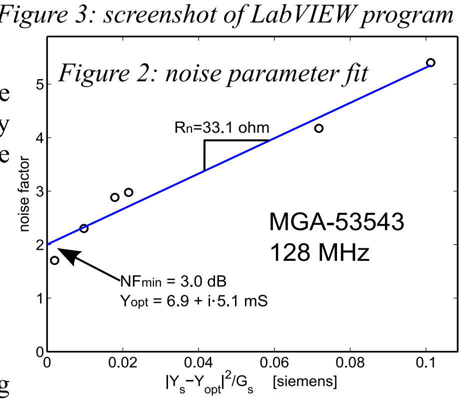

Figure 2: noise parameter fit

Methods

A standard PC running LabVIEW was interfaced to the 4396B and to a calibrated 50 Ω noise source (NW1M500-6-CS, NoiseWave, USA) whose output can be set to either room temperature ("cold") or one that is much larger ("hot", nominal excess noise ratio $ENR = 6$ dB). A low-noise preamplifier (Agilent 8447D) is used to boost signal strength and reduce the system's own noise factor (F_2). This setup (Fig. 1) allows a "Y-factor" measurement [3] to be performed at 801 frequency points, 10 averages in approximately 25 s by taking the ratio of hot (N_h) and cold (N_c) noise powers measured at the output of the device under test (DUT): $F = ENR / \left(N_h / N_c - 1 \right)$. Typical spectrum resolution and video bandwidths (RBW = 100 kHz, VBW = RBW/30) yield a standard deviation of less than 0.1 dB in noise power ratio when averaged over all frequency points.

Similarly to Ref. [4] the source admittance (Y_s) can be varied by connecting between the noise source and DUT one of several "tuner boards". Alternatively, a variable tuner [5] may be used for this purpose. When at least four NF measurements at distinct values of Y_s are stored, a least squares fit of the noise parameters is calculated as in Ref. [3, §7.11].

To obtain reliable NF values for all values of Y_s, the following corrections were included:

- 2nd stage noise: factors out system noise (F_2) using $F_1 = F - \left(F_2 - 1 \right) / G_1$ [3];
- room temperature: corrects for room temperature ≠ standard 290 K [2];
- available gain: G_1 is calculated from DUT's scattering (S) parameters [6];
- input tuner loss: composite *ENR* of noise source + tuner board [6].

The latter two require S parameter measurement using the VNA mode of the 4396B (using an 85046A test set). The LabVIEW program (Fig. 2) automates calibration, data acquisition and processing, with minimal user input.

Results

Noise figure measurements were performed at 128 MHz on an MGA-53543 amplifier (Avago, USA) at 6 unique Y_s values. Agreement with the noise parameter model is shown in Fig. 3. Repeated NF measurements typically yield a standard deviation of 0.1 dB or better.

Conclusions

Instrument control using LabVIEW allows flexible, accurate, automated measurements of the noise parameters of MRI preamplifiers using a commonly-available combination analyzer with few additional components and costs.

References: [1] Roemer et al., *Mag. Res. Med.* 16, pp. 192–225 (1990). [2] *Proc. IRE* 48(1), pp. 60–68 (1960). [3] Vendelin, Pavio, Rohde. Microwave Circuit Design Using Linear and Nonlinear Techniques, 2nd ed., Wiley (2005). [4] Massner et al., *Proc. ISMRM*, p. 328 (2007). [5] Biber et al., *Proc. ISMRM*, p. 2982 (2009). [6] Pak et al. *Microwaves & RF* 29(7), pp. 103–108 (1990).

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