

Variation of Pre-amplifier Noise Figure With B_0 Field Strength

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Introduction

High-field arrays with large numbers of coils require preamplifiers located close to the coils to minimize SNR losses incurred in cables. The design of low-noise preamplifiers for high-field MRI must thus ensure there is no performance degradation due to the presence or orientation of high magnetic fields.

Preamplifier scattering (S) parameters have been known to vary with B_0 field strength and orientation due to the field's effects on the motion of charge carriers (i.e., the Hall effect) in semiconductor devices [1]. The objective of the present work is to measure the accompanying changes in noise figure (NF) [2], which describes the loss of SNR due to noise added by the preamp. The "Y factor" measurement of NF [2] requires a noise source whose equivalent noise temperature can switch between room ("cold") and a much higher ("hot") temperature. Typical coaxial RF noise sources use a PN diode reverse biased into avalanche breakdown [3] to produce the excess noise required for the hot state. The diode current is zero in the cold state, and an attenuator is placed between the diode and the output to control its impedance and to provide room temperature noise.

Methods

Due to the incorporation of a semiconductor diode, magnetic fields are expected to influence the noise source's hot temperature, thereby rendering its excess noise ratio (ENR) calibration table (measured at zero field in a certified laboratory), and consequent NF measurements, unreliable. Our approach circumvents this problem by locating a source (NW1M500-6-CS, NoiseWave, USA) with nominal ENR = 6 dB well outside the 5 G line of the magnet (9.4 T, 205 mm bore, Magnex, UK) as shown in Fig. 1. The optional "tuner board" [4] required to measure how NF varies with the impedance seen by the preamplifier's input, is unaffected by the field since it contains only passive components and can be located with the device under test (DUT) inside the bore. The NF measurement accounts for losses in the length of cable (RG223, approximate length 6 m) between source and tuner board by incorporating it into the "tuner loss" [5], while that of the corresponding cable at the DUT's output is calibrated out by the second stage correction [2]. A network analyzer measures S parameters required for the "available gain" correction [5]. The preamp is located within the MR system's RF screen for all measurements.

Noise figure measurements (50 Ω) were performed at 128 MHz on a monolithic amplifier (MAR-8A+, Mini-Circuits, USA) based on InGaP bipolar transistors. Bias current was set to ~32 mA at zero field using a 10 V regulated supply and a resistive current limiter; subsequent changes in bias current with field strength were monitored.

The amplifier was placed in the magnet bore with the field parallel to the ground pins that exit the device's circular body at diametrically opposite sides (Fig. 2). In this orientation the insertion gain (S_{21}) of the amplifier is reduced by ~1.5 dB at 9.4 T compared to 0 T. Noise figure was measured with the amplifier at axial positions of 0 cm, 35 cm and out to 75 cm (magnet edge, ~1.5 T) in 5 cm increments relative to iso-center.

In a second experiment at zero field the supply voltage was varied to adjust the bias current in the range 25–37 mA; NF measurements were performed at 2 mA increments.

Results

A variation in noise figure with field strength is readily observed in Fig. 2. As shown in Fig. 3 changes in bias current only partially explain this behaviour, and thus active control of the bias current is not likely to be an effective method to limit such variations in this device.

Conclusions

This approach allows precise measurements of the noise performance of MRI preamplifiers at any field strength. Variations in NF are readily observed even for relatively insensitive devices such as bipolar transistors. Detailed device models are needed to describe, and subsequently control, variations in NF with field and orientation.

References

- [1] Possanzini, Boutelje., *Proc. ISMRM*, p. 1123 (2008).
- [2] Vendelin et al. *Microwave Circuit Design Using Linear and Nonlinear Techniques*, 2nd ed., Wiley (2005).
- [3] Tiemeijer et al. *IEEE Transactions Microwave Theory and Techniques* 53(9) pp. 2917–2925 (2005).
- [4] Massner et al., *Proc. ISMRM*, p. 328 (2007).
- [5] Pak et al. *Microwaves & RF* 29(7) pp. 103–108 (1990).

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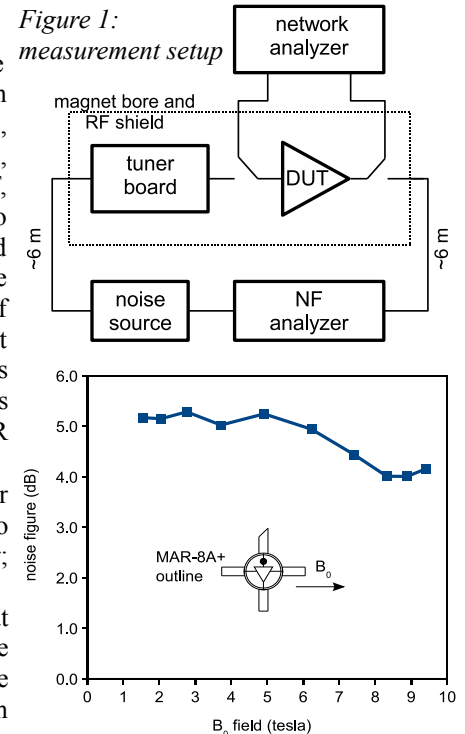


Figure 2: variation of NF with B_0 field

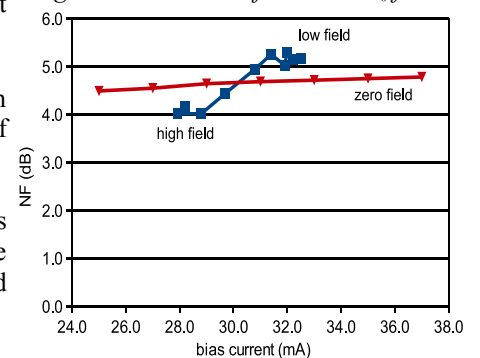


Figure 3: variation of NF with changes in bias current due to field strength (blue) compared to those due to supply voltage at zero field (red)