Measuring the System Noise Figure (Coil Inclusive) of an MRI System

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Introduction

Quantifying noise in an MRI system arising from external sources has always been a difficult task that has not been well defined. For amplifiers, devices, and even complete systems, the noise figure concept has long been used to characterize their noise performance. The noise figure of a system or device is usually expressed in db and defined in terms of the input and output Signal-to-Noise Ratio (SNR).[1] Thus

$$F(db) \;=\; 10\log\frac{SNR_{input\,z}}{SNR_{output}} \;=\; 1+\frac{N_{added}}{N_0} \qquad [1]$$

where N_0 is the Johnson thermal noise power usually referenced to 290°K and N_{added} is the added noise power of the system or device. Measurements of the noise figure are most easily carried out by utilizing a calibrated hot/cold noise source attached to the input of the system or device. This concept works well for characterizing and quantifying the noise performance of an MRI system including even the preamp, cabling, and T/R switches, but has not been applied to include the rf coil. If, as would be expected, that the noise power from the coil is due to thermal noise (kTB) then a noise figure measurement involving the coil would not be particularly helpful. However, external noise sources can be coupled to the coil as well. These are often identified by spurious signals seen in an image or spectrum. Though these are easily identifiable there is no assurance that external broadband noise is not included. This latter component is not easily identifiable nor has been quantified. It is proposed that the noise figure concept can be extended to include the rf coil and is measurable by injection of the signal from a calibrated noise source into the receiver coil through a loosely inductively coupled coil. This provides a means by which external noise contributions may be quantified.

Theory

Consider the circuit in Fig.1 where a calibrated noise source is coupled to the receiver coil which is impedance matched and connected to the MRI system's preamp and receiver system. In a separate measurement it is necessary to measure the noise figure of the MRI receiver at the input of the preamp. For this measurement the noise figure is known [1] to be given by

$$F(db) \;=\; ENR \;-\; 10\log_{10}\left[\frac{N_{on}}{N_{off}}-1\right] \qquad [2]$$

where ENR is the calibrated value in db of the Excess Noise Ratio for the noise source and $N_{on/off}$ is the noise power measured with the noise source turned on/off. The ratio of the noise powers is often referred to as the Y-factor.

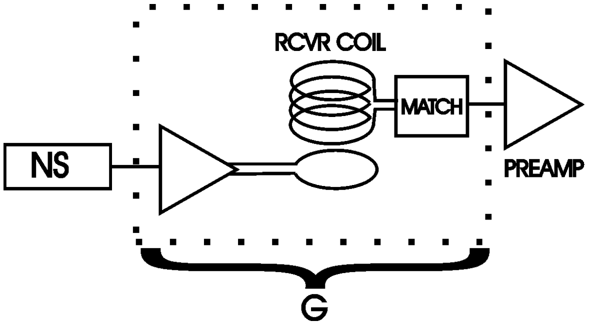

Figure 1. System noise figure setup. The noise from a calibrated noise source is injected into the coil through a loosely coupled coil.

Likewise for Fig.1, the noise power is measured with the noise source on/off. In addition it is necessary to measure the gain (G) of the coupled network (as shown by the dotted box in Fig.1) and the background noise power level (N_{bkgnd}). The gain is easily measured by injecting an rf signal of the appropriate frequency. The background noise power level is measured as the noise power as measured with the receiving coil attached but without the injected noise source channel present. Under these conditions, it is convenient to define the Z-factor, in a similar manner to the Y-factor, as $Z=\left(N_{on}-N_{off}\right)/N_{bkgnd}$. It can then be shown that the overall noise figure of the system (F*), including the coil, is given by

$$F^*(db) \;=\; ENR+G(db)-\;10\log_{10}Z \qquad [3]$$

If the noise factor (NF) is defined as $10^{F/10}$, then the coil's contribution to the noise figure is simply obtained as $NF^* \;=\; NF_{coil}+NF_{sys}-1$ [4]

where NF_{sys} is obtained from the previously measured noise figure of the system (without the coil) as given by Eqn. [2].

It should be noted that F* may be measured over a frequency range. Thus the noise figure of the preamp with respect to coil's frequency response (as the impedance varies) will be observed.

Results

The above methods were used to explore the noise that was observed on a GE Profile IV MRI scanner (0.2T), interfaced with a Tecmag Apollo console at Brigham and Women's Hospital, Boston, MA. This system is used for hyper-polarized ^{129}Xe studies.[2] An unusual amount of noise was observed at the operating frequency of 2.36MHz. One initial result is shown in Fig.2.

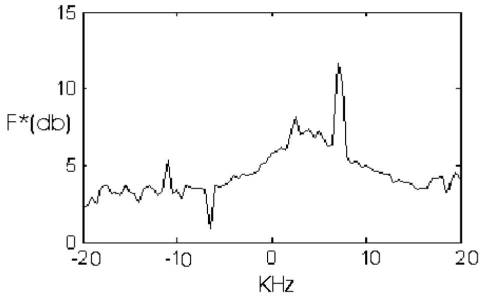

Figure 2. F* measured at 2.36MHz. Some spurious noise peaks are observed. The coil's response was centered for 0KHz with a 8KHz bandwidth.

Discussion

A quantitative method for characterizing external noise in an MRI system has been developed. The broad hump observed in Fig.2 is due to the noise figure characteristics of the GaAs preamp as the source impedance changes due to the coil's frequency response. The preamp's noise figure is seen to be highly asymmetric and significantly larger then what would be expected by a single measurement at resonance. The observed spikes are due to external spurious signals.

References

[1] Agilent Application Note 57-1.

[2] Patz, et. al. ISMRM, Seattle, 2006, #860.

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