Matching-network noise dominating regime for receive coil loops

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Introduction: MR image quality is always affected by noise present in the receive chain. Typically sample, coil loop and preamplifier are considered as noise sources [1]. However, as a tendency for coil arrays to increase the number of channels continues over the recent years every coil element continues to shrink [2]. Therefore the noise originating from coil matching-networks may have to be considered explicitly [3, 4]. Here we calculate the matching-network noise and define the concept of a matching-network noise dominating regime, which is a similar concept to the sample noise dominating regime [3]. A criterion determining when the matching-network noise dominates is formulated. Our work will be important for the design and fabrication of micro-coils, small-animal coils and receive-coil arrays with a large number of channels.

Theory: A representative coil circuit model providing the basis for our calculations is displayed in Fig 1. The receive channel is separated into different stages: sample, coil loop, matching-network and preamplifier. The coil loop is represented by its equivalent inductance L_C and resistance R_C. The coil matching-network consists of only passive components and matches the coil loop to 50 Ohm. SNR_{ori} depicts the SNR of the original MR signal measured from the coil loop directly, without attenuation by the matching-network and cable transmission. The calculation of the matching-network noise factor is based on SNR_{ori}. Only thermal noise is considered in the calculations and all components in the receive chain are assumed to be at the same temperature. In practice, high quality capacitors are always chosen for C_1 and C_2 to reduce noise contribution, so we assume $Q_{C1} = Q_{C2} = \mathrm{Q} \gg 1$ in order to simplify calculations. Based on these considerations it is possible to explicitly calculate signal and noise power before and after the matching network. Neglecting small quantities of second and higher orders, the noise factor of the coil matching-network can be approximated by

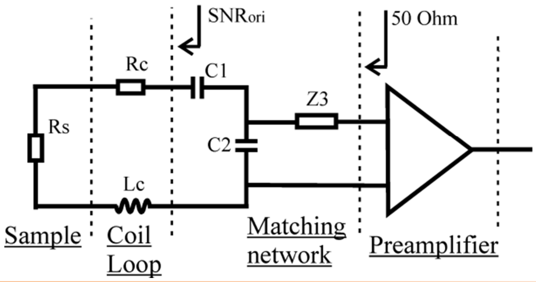

Fig 1: Effective network of a single receive channel comprising: sample, coil loop, coil matching-network and preamplifier.

$$F(network) \approx 1 + \frac{\omega_0 L_C}{Q(R_S + R_C)} - 2\frac{(\omega_r - \omega_0)}{\omega_0}\frac{\omega_0 L_C}{(R_S + R_C)}\left(\frac{1}{Q} \pm \frac{1}{Q_3}\right), \quad (1)$$

with '+' for Z_3 being an inductor, and '-' for Z_3 being a capacitor. Q_3 is the quality factor of Z_3. ω_0 is the coil working frequency, ω_r is the coil Open Port Resonant frequency and $(\omega_r - \omega_0) \ll \omega_0$. ω_r is an experimental quantity which is determined by pickup coils when the preamplifier is not connected to the coil. As seen from Eq (1), $\frac{\omega_0 L_C}{Q(R_C+R_S)}$ represents the overall scale of the matching-network noise factor and is therefore referred to as Matching-network Noise representative (MN_r). Similar to the concept of the sample noise dominating regime, we define the concept of matching-network noise dominating regime here. The expression

$$MN_r = \frac{\omega_0 L_C}{Q(R_S+R_C)} \geq const \quad (2)$$

is used as the criterion for the condition when matching-network noise dominates and cannot be ignored. The constant in the criterion can be chosen depending on the concrete noise requirements. $MN_r < const$ means that the noise from the related coil matching-network does not dominate and does not need to be considered.

Analytic calculations: Circular ring coils receiving signal from human body in a 3T scanner were taken as a model to show the matching-network noise contribution changes with loop size. A circular ring coil with loop radius 'A' and wire radius 'a' has the approximate inductance [5] $L_C = \mu_0 A\left[\ln(\frac{8A}{a} - 1.9)\right]$ and resistance $R_C = 2A\rho/(a^2 - (a - a')^2$. Here, $\mu_0 = 4\pi \times 10^{-7}\ H/m$ is the permeability in free space, $\rho = 1.68 \times 10^{-8}\ \Omega \cdot m$ the conductivity of copper at $20\ ^0C$ and $a' = 6 \times 10^{-6}\ m$ the skin depth at 123.24 MHz. The sample noise resistance seen by the chosen loop was [6] $R_S = \delta\omega_0^2\left(\frac{\mu_0}{4\pi}\right)^2\frac{16\pi^2 A^3}{3}$, where $\delta = 0.75\ s/m$ is the average human head conductivity. The calculations assumed that $Q = 100$ and A = 20 · a, which is acceptable in the range of coil radii analyzed (from *0.25* mm to *5* cm).

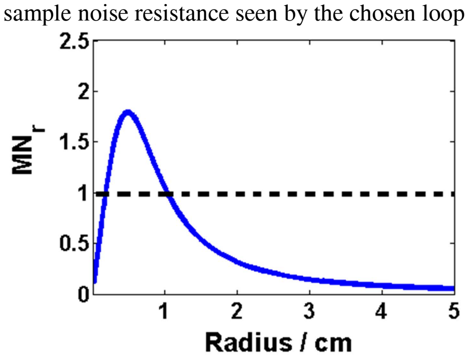

Fig 2: Matching-network noise calculated for different coil size. The criterion $MN_r = 1$ is marked by a dashed line.

Results and Discussion: The calculated MN_r from the above example is shown in Fig 2 as a function of loop radius. When the loop is large, the matching-network noise increases as coils become smaller. In this work the quantity *const* in Eq (2) is chosen to be unity, i.e., the criterion is whether the matching-network noise contributes the same power to the MR image as does the original noise. As can be seen from Fig 2, the matching-network noise begins to dominate in coil loops with radii smaller than *1.04* cm. However, for coils smaller than 0.5 cm, the coil matching-network noise decreases rapidly as the loop shrinks. This provides an advantage for the micro-scale small coils for NMR.

It is natural to assume that upon the decrease of the coil size, the impact of the matching-network noise will increase monotonically. But from Eq (2) it is found that the dominant factors affecting the matching-network noise are: the sample noise resistance, the loop impedance (L_C and R_C) and the quality factors of the components in the matching network. So it is not the coil loop size alone, but the term MN_r that defines the matching-network noise behavior. MN_r can be substituted by the coil size only for fixed Q-factors of passive components and fixed object conductivity, as shown in the example. Even so, the results show clearly that the matching-network noise does not increase monotonically upon a decrease of the coil dimensions. Note that the factor MN_r can be determined experimentally on the RF bench.

Conclusions: The concept of matching-network noise dominating regime was defined from the calculation of matching-network noise. In addition, a criterion for the condition when matching-network noise dominates has been introduced. It was shown that the matching-network noise is determined by several different factors, rather than by the coil size alone.

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Reference: [1] David H, JMR 1976. [2] Boris K, JMR 2013. [3] Ananda K, MRM 2009. [4] Xueming C, ISMRM 2014 #1336. [5] Frederick G, Dover Publications, 1946. [6] Jianmin W, IEEE 1995.