Roemer's Amplifier

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***Abstract*—A brief discussion of Roemer's amplifier design for a parallel MRI coil.**

I. Background

In a previous technical note [1] the importance of isolating the multiple coils used for pMRI imaging from one another was mentioned. In this paper we look at one circuit-based attempt at confronting this problem. It is from the work of Roemer et al. [2].

II. Roemer's Receiver

Roemer considered an MRI coil consisting of inductive and capacitive elements designed to resonated at the Larmor frequency of the system (see Fig. 1 which is a copy from Roemer's paper).

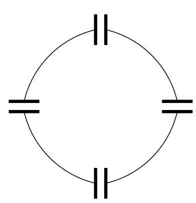

Fig. 1. A representation of a resonant pick-up coil.

A circuit equivalent of this coil is shown in Fig. 2. Now, our concerns are

1) How to minimize coupling between (different) coils.
2) How to amplify the signals in each coil (to the rest of the receiver).

Looking at Fig. 2, it is apparent that right away, we will have a coupling problem: current flows through the self-inductance element of the pick-up coil, this will support a changing magnetic flux that will couple to adjacent pick-up coils. Luckily, Roemer's circuit took care of both problems simultaneously. A full sketch of his solution is show in Fig. 3. On the far left of the schematic we have the pick-up coil. On the far right of the schematic we have the transistor used to amplify its signal. In between these blocks we have the interface circuitry separated into its three main stages, S1, S2, and S3. The benefit of this interface is that looking into S1

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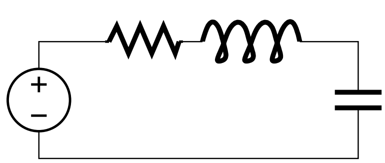

Fig. 2. The circuit equivalent of a resonant pick-up coil.

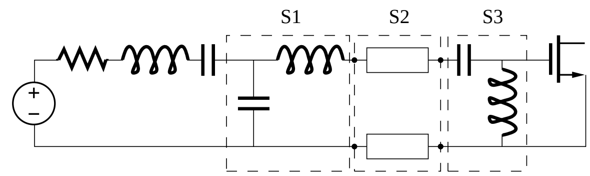

Fig. 3. A sketch of Roemer's solution.

from the pick-up coil we see an open circuit (thus taking care of the coil-to-coil coupling problem) and looking into S3 from the transistor we see a very low impedance (needed to realize an optimum noise factor, F, and thus maximize the SNR at the output of the amplifier). In between S1 and S2 is a 50-Ω transmission line (S2). Using a line $\lambda/2$ long makes it act (as far as signals of wavelength λ are concerned) as a short between S1 and S3.

III. Design Procedure

Roemer begins the design of the network shown in Fig. 3 by designing S1 to match a 50-Ω transmission line to the pick-up coil. In other words, the network S1 is used to match the coil loss, to the transmission line.

When working properly, the coil inductance, L, and capacitance, C_{2a} resonate-out leaving S1 to match $R1$ to 50 Ω. Since C_{2b} in parallel with R_1 can be approximated as C_{2b} in series with $\omega_0^2 C_{2b}^2/R_1$ (where ω_0 is the Larmor frequency) the impedance seen looking into S1 from S2 is

$$Z_b = \frac{X_{C_{2b}}^2}{R_1} + j(X_{L_{2b}} - X_{C_{2b}}). \tag{1}$$

Matching R_1 to 50 Ω then requires that

$$X_{L_{2b}} = X_{C_{2b}} = \sqrt{50R_1} = X_2. \tag{2}$$

Thus S1 transforms the coil into a 50-Ω load (looking in from S2). Assuming that the transistor amplifier has minimum noise factor when driven from a source of 1 to 2-kΩ, the S3 stage transforms the 50-Ω impedance seen looking into S2 (from S3) into 1250 Ω.

The discussion so far has really only accounted for the second consideration above (i.e. amplifying the signal to the rest of the receiver). Specifically, S3 was chosen to optimize the noise performance of the amplifier. Now we consider the nuance involved in minimizing coupling between coils.

We start by noting that a typical MOS amplifier will present a high impedance across S3, therefore this matching network is left being essentially a series resonant circuit with low resistance at resonance. This is important because seen through the $\lambda/2$-long 50-Ω transmission line the network S1 is loaded with this low impedance. Hence, the network S1 is approximately a parallel resonant circuit placed across the terminals of the pick-up coil. A parallel resonant circuit looks like an open at resonance, hence preventing the flow of current through the coil (at resonance) and therefore minimizing coupling between coils. All-in-all a rather elegant design in theory.

IV. QUESTIONS

Going forward from this a number of questions arise:

1) Is the inductor in the network S1 an issue? Must it be physically small or placed well away from any MRI magnetic fields?
2) How much is the amplifier gain compromised by essentially just doing a noise match?
3) How would the circuit change if we could forgo the 50-Ω transmission line?
4) Would this resonant matching network design be possible when microcoils are used as the pick-up antennas? The worry here is that any extra matching coils could somehow severely alter the pick-up characteristics.

REFERENCES

[1] S. Magierowski, "What pMRI scientists want," Tech. Rep., June 1 2007.
[2] P. B. Roemer, W. A. Edelstein, C. E. Hayes, S. P. Souza, and O. M. Meuller, "The NMR phased array," *Magnetic Resonance in Medicine*, vol. 16, pp. 192–225, 1990.