Ringing Down Time Measurement of a Receive Coil for NMR Tomography

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Abstract. *The paper describes studies dealing with problems of the receive coil for NMR scanner connected via a preamplifier with high input impedance. Behaviour of the coil with preamplifier after pulses of RF signal was studied and an equation was derived and verified for investigation of it. The theory is demonstrated on a one-turn surface coil with rather large dimensions. Some parameters of a coil are measureable with difficulties and the derived theory can help to determine them more accurately. The technique of the high–impedance preamplifiers is seldom in experimental systems, though it can simplify their adjustment.*

Keywords: Ringing Down Time, Receive Coil, NMR, Tomography, Low Field

1. Introduction

Receive coils for experimental scanners based on the nuclear magnetic resonance (NMR) are manufactured by users frequently. Mostly the coil is tuned to the working frequency and matched to the impedance of the transmission line and the preamplifier. At lower frequencies also a preamplifier with high input impedance can be used and the coil adjustment can be simplified in the way. Authors [1] introduced interesting solutions of the receiving systems with preamplifier with high input impedance. While the solution of Raad and Darrasse [1] does not need fine tuning the coil, our system is tuned using a variable capacitor. A square-shaped one-turn loop coil was selected for the experiments, arranged as a surface coil. Due to the high-impedance load the transient response of the coil was studied. The equation describing the behaviour of the coil after a signal pulse was derived. The performed experiments proved that it increased number of coil parameters and besides of study of the ring-down problems [2] also the circuital parameters of the coil can be determined more accurately using its help. Authors [3] developed a technique of balancing a receive coil. Authors [4] developed a technique of the magnetic field mapping. Purpose of the article is to help with design of dedicated receive coils for NMR experiments, mainly using the preamplifier with high input impedance. Qualities of the experimental coil system have been verified with an experimental NMR scanner equipped with the low static magnetic field. The coil system is intended for whole-body measurements or for different bigger samples measurements. The solution with the high-impedance preamplifier simplifies tuning and matching the coil and such preamplifier can be used for more purposes.

2. Subject and Methods

A receive coil of an NMR scanner changes pulses of RF magnetic field induced from a sample into an electric signal, usually the voltage. Fig. 1 depicts equivalent circuit diagram of a simple tuned coil, connected to the preamplifier with high input impedance. The voltage V_0 represents the voltage induced from the measured sample, the voltage V_g is the voltage at the input of the preamplifier (with input resistance R_{in}) of the receiver. After switching on the sample voltage V_0 the output voltage V_g can be described by the equations

$$LC\frac{d^2V_g}{dt^2}+\left(R_sC+\frac{L}{R_{in}}\right)\frac{dV_g}{dt}+\left(\frac{R_s}{R_{in}}+1\right)V_g=0, \quad (1)$$

$$V_g(0)=\frac{V_0R_{in}}{R_s+R_{in}},$$

$$\frac{dV_g}{dt}(0)=0.$$

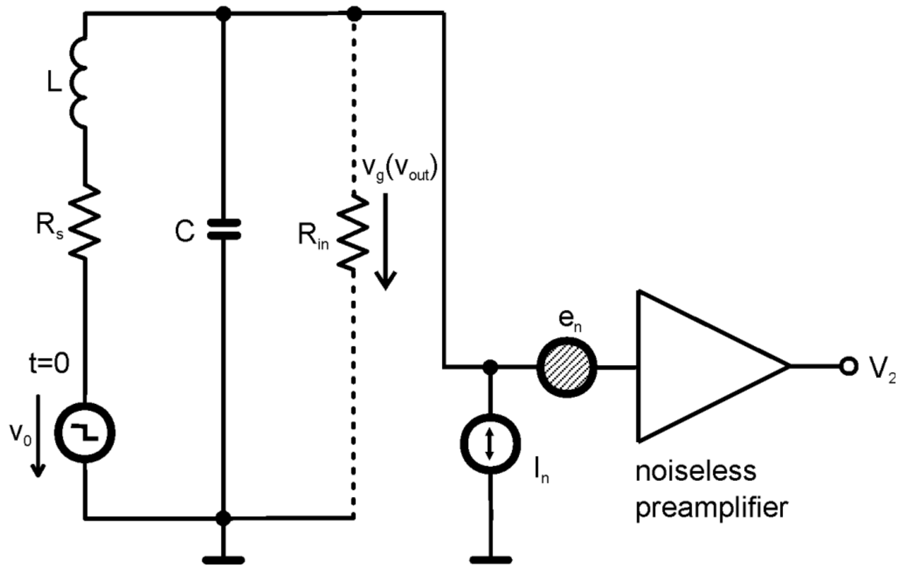

Fig. 1. Equivalent circuit diagram of a single tuned coil connected to a preamplifier with high input impedance. The coil is switched into electrical circuit in the time instant of t=0. A noiseless preamplifier together with voltage and current noise sources simulate noise in the real circuit. In practice the preamplifier always has finite input impedance, represented by R_{in}.

For some calculations it is advantageous to define the following expressions

$$p_1=\frac{-(CR_sR_{in}+L)+y}{2LCR_{in}}, \quad (2)$$

$$p_2=\frac{-(CR_sR_{in}+L)-y}{2LCR_{in}}, \quad (3)$$

$$y=\sqrt{(L+CR_sR_{in})^2-4LCR_{in}(R_{in}+R_s)}. \quad (4)$$

If y is a real number, the coil circuit is stabile after pulse of the V_0 voltage. If it is an imaginary number the coil starts its work with oscillations. For stabile work the following condition must be fulfilled

$$(L+CR_sR_{in})^2-4LCR_{in}(R_{in}+R_s)\geq 0. \quad (5)$$

Considering $LC\cong\frac{1}{\omega^2}$ and $4R_{in}^2\gg R_sR_{in}$ the Eq. (5) can be modified to

$$\omega L\geq 2R_{in}. \quad (6)$$

It is the condition for the work without oscillations. Nevertheless the quality factor of such coil would be very low ($Q=\frac{\omega LR_{in}}{R_s(R_s+R_{in})+\omega^2L^2}$) and sensitivity of the measurement would be also low. Therefore the conditions must be found under those the oscillations can be acceptable. The solution of Eq. (1) can help it.

The solution of Eq. (1) is given by

$$V_g = \frac{R_{in}V_0\left(-Le^{p_2 t}+Le^{p_1 t}-CR_{in}R_s e^{p_2 t}+CR_{in}R_s e^{p_1 t}+e^{p_2 t}y+e^{p_1 t}y\right)}{2(R_{in}+R_s)y}. \tag{7}$$

If the expression (2) or (3) has its imaginary part, it represents the angular frequency of the oscillations, the real part determines exponential damping of the oscillations. In practice a receive coil must fulfill several requirements. Very important requirement is sensitivity of the measuring system. Mostly a coil is designed to maximal possible sensitivity and other parameters are checked or calculated and the qualities of the measuring sequence are accommodated to them. The derived expression can help to do it.

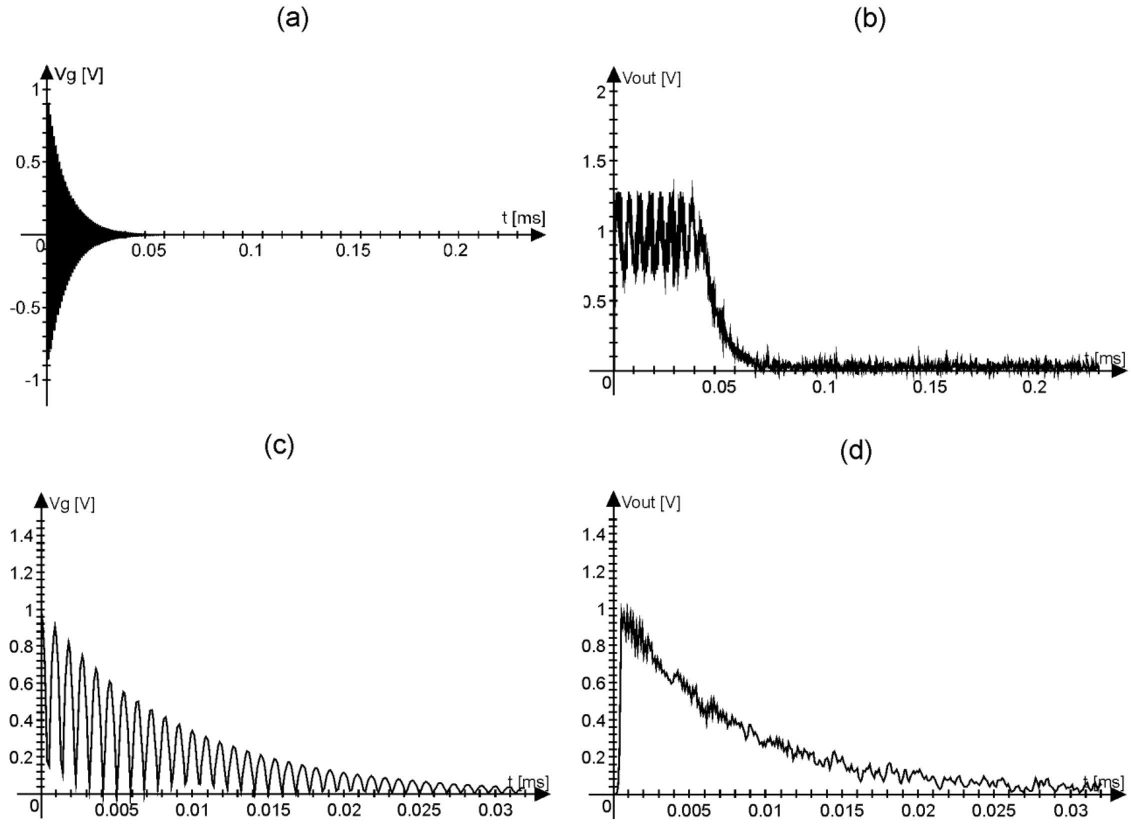

Fig. 2. Transient responds of the coil to switching the signal on: (a) the calculated characteristic, R_{in}=45000 Ω; (b) envelope of the measured and detected signal, R_{in}=45000 Ω. The detail comparison of the measured and the calculated relaxation of the coil: (c) and (d). The calculated values (c) and the measured values (d) are in very good agreement.

3. Results

The verification experiments have been performed on an experimental NMR scanner equipped with home-made resistive magnet of 0.1 T and the Apollo (Tecmag Inc., Houston, TX) console. The coil was made of a copper tube with diameter of 6 mm. Its dimensions are 30 cm × 30 cm. The coil, including non-magnetic ceramic tuning capacitors was encapsulated in a PVC shell. The coil is connected to the preamplifier using a short transmission line which is a part of the tuning capacitance. The electrical parameters of the coil are: L=1.066 µH, C=1200 pF, R_s=0.2079 Ω. The working frequency of the coil is 4.45 MHz. Figure 2(a) depicts transient respond of the coil to switching the signal on, calculated using Eq. (7). The oscillations are at the working frequency of the system and after 0.1 ms they are damped to

0.0027% of the original value. It can be sufficient for most of applications. The transient characteristic of the realized coil was measured using the NMR scanner (the RF hard pulse width of 2 μs, start of the acquisition min. 10 μs after the RF pulse, the sampling interval of 100 ns). The measured course is influenced by radiation damping [2] and only its last part can be compared with the calculated values (figure 2(b)). While the calculated course is a real only signal, the measured signal is a detected signal with its real and imaginary parts making possible to depict its absolute value - an envelope of the signal. The real or imaginary parts are exponentially damped harmonic curves, their frequency after detection determines the frequency deviation between the coil tuning and the working frequency of the scanner.

4. Discussion and Conclusions

The purpose of the studies was to show possible problems occurring in experiment with a preamplifier with high input impedance and to suggest their solutions. The derived theory and the performed experiments proved that such way is possible and the acquired results are promising, mainly using the low-field NMR scanners.

Users needing their own receiving solutions must look for appropriate systems. The article can help in their effort. The derived theory also can help to identify electrical parameters of the individual parts of the system with higher accuracy, mainly difficultly measureable parameters of the coil.

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