Jefferson Lab
E94010 Technical Note 18
January 1999

Estimation of the NMR RF field amplitude

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Abstract

We present a method to estimate the amplitude of the NMR RF field amplitude.

1 Method

The amplitude of the H_1 field can be estimated by measuring directly the flux induced through a loop, which dimensions are small compared to the RF coils dimensions. The loop will be placed right above the pick-up coils, in contact with them and will be held in place using a long wooden stick to prevent from any local magnetic inhomogeneities. The output of the loop is connected to a standard RG58 C/U coaxial cable, and the induced flux is observed with an oscilloscope. The loop and the stick have been designed by K. Slifer.

Neglecting first the effect of the coaxial cable, the system can be modelized as shown on Figure 1. We use the following definitions:

- R_l stands for the resistance of the loop ; $R_l = 5\Omega$
- L_l stands for the inductance of the loop ; $L_l = 5$mH. It can be estimated from the ideal solenoid approximation in vacuum, which inductance is given by $L = \mu_0 NS/l$, where $\mu_0 = 4\pi 10^{-7}$ SI is the vacuum permeability, N/l is the number of turns per unit of length : here, $N/l = 29/0.02 = 1450$ turns per m, and S is the solenoid section, here $S = 2.3\ 10^{-4}$ m^2, with a diameter $D = 1.065$ inches. We get : $L_l \sim 4\mu$H.
- R_o represents the oscilloscope input impedance ; $R_o = 1$ MΩ
- e stands for the EMF induced in the loop
- V_{meapp} is the peak-to-peak voltage measured by the oscilloscope (measure feature)

The voltage V (later called called V_{meapp}) measured by the oscilloscope is given by :

$$V = R_o I = e - ZI \tag{1}$$

where the circuit is running at a pulsation $\omega = 2\pi f$, where f is the RF frequency: $f =$ 91 kHz and the complex impedance Z of the circuit is written:

$$Z = R_l + iL_l\omega \tag{2}$$

Then :

$$V = e - V\frac{Z}{R_o} \tag{3}$$

and returning to real numbers :

$$V = \frac{e}{\sqrt{\left(1 + \frac{R_l}{R_0}\right)^2 + \frac{L_l^2\omega^2}{R_0^2}}} \tag{4}$$

Numerically, we obtain $1 - V/e = 5.10^{-6}$. Consequently, the effects of the coil self inductance and resistance are negligible.

Now, taking into account the effect of the coaxial cable, the system can be modelized as shown on Figure 2. We use the following definitions:

- R_c stands for the resistance of the coaxial cable ; $R_c = 0.9\Omega$
- C_c is the capacitance of the coaxial cable, with a length of $L = 1.6$ m and a lineic capacitance of 30 pF per foot [1]; $C_c = 1.83 \times 10^{-11}$ F
- R_o represents the oscilloscope input impedance ; $R_o = 1$ MΩ
- V_{meapp} is the peak-to-peak voltage measured by the oscilloscope (measure feature)
- V_{pp} stands for the actual peak-to-peak voltage induced in the loop

The circuit is running at a pulsation $\omega = 2\pi f$, where f is the RF frequency: $f = 91$ kHz. The complex impedance Z of the circuit is written:

$$Z = R_c + \frac{1}{i\omega C_c + \frac{1}{R_o}} \tag{5}$$

or

$$Z = \left[R_c + \frac{R_o}{1 + R_o^2 C_c^2 \omega^2}\right] - i\left[\frac{R_o^2 C_c \omega}{1 + R_o^2 C_c^2 \omega^2}\right] \tag{6}$$

Then, V_{pp} and V_{meapp} are related using:

$$V_{pp} = V_{meapp} + R_c I = V_{meapp} + R_c \frac{V_{pp}}{Z} \tag{7}$$

and returning to real numbers we get :

$$V_{pp} = V_{meapp} \frac{1}{|1 - R_c/Z|} \tag{8}$$

The actual induced voltage V_{pp} is proportional to the induced RF field $B = 2H_1$. H_1 is one of the rotating components of B. The induced voltage e is given by the Lenz law:

$$e = -\frac{d\Phi}{dt} = N\omega BS sin(\omega t) \tag{9}$$

where:

- N=29 is the number of turns in the loop
- $B = 2H_1$ is the amplitude of the RF field
- S is the loop section, with a diameter $D = 1.065$ inches

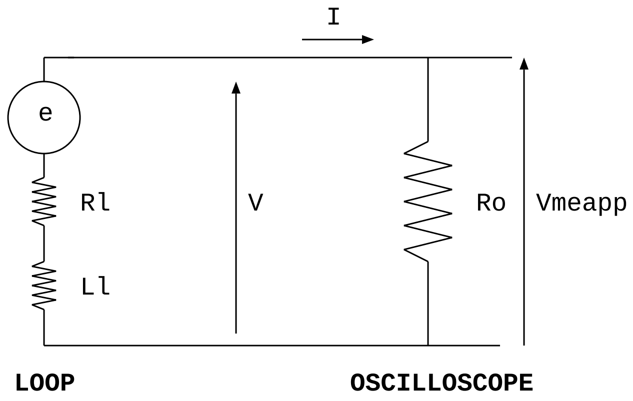

Figure 1: Model of the detection circuit taking into account the loop self inductance.

so we get:

$$H_1 = \frac{V_{pp}}{4N\omega S} = \frac{1}{4N\omega S} V_{meapp} \frac{1}{|1 - R_c/Z|} \tag{10}$$

We measure with the oscilloscope $V_{meapp} = 346 \pm 2$ mV. Therefore, we obtain :

$$H_1 = 90.8 \pm 0.5 mG \tag{11}$$

corresponding to a HP function generator voltage setting of 2.4 Vrms in the counting house. Figure 3 shows the linear relation between H_1 and V_{meapp}. The difference $1 - V_{pp}/V_{meapp}$ estimated with Mathematica is equal to 9.10^{-7} ; the effect of the coaxial cable is then negligible.

References

[1] Building Scientific Apparatus, J. Moore, C. Davis and M. Coplan, Second Edition, p. 374, Addison Wesley (1989)

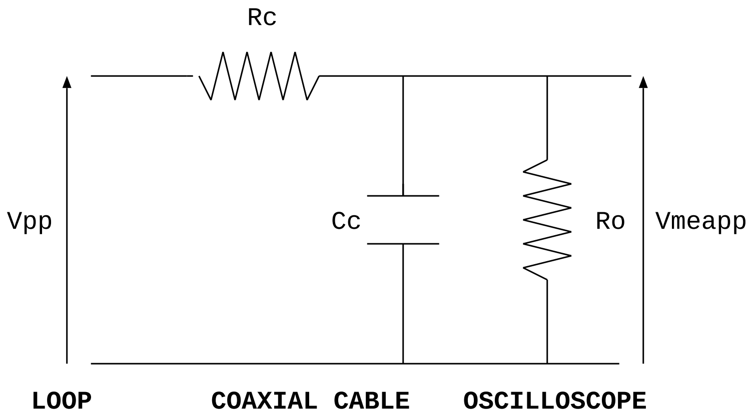

Figure 2: Model of the detection circuit with coaxial cable.

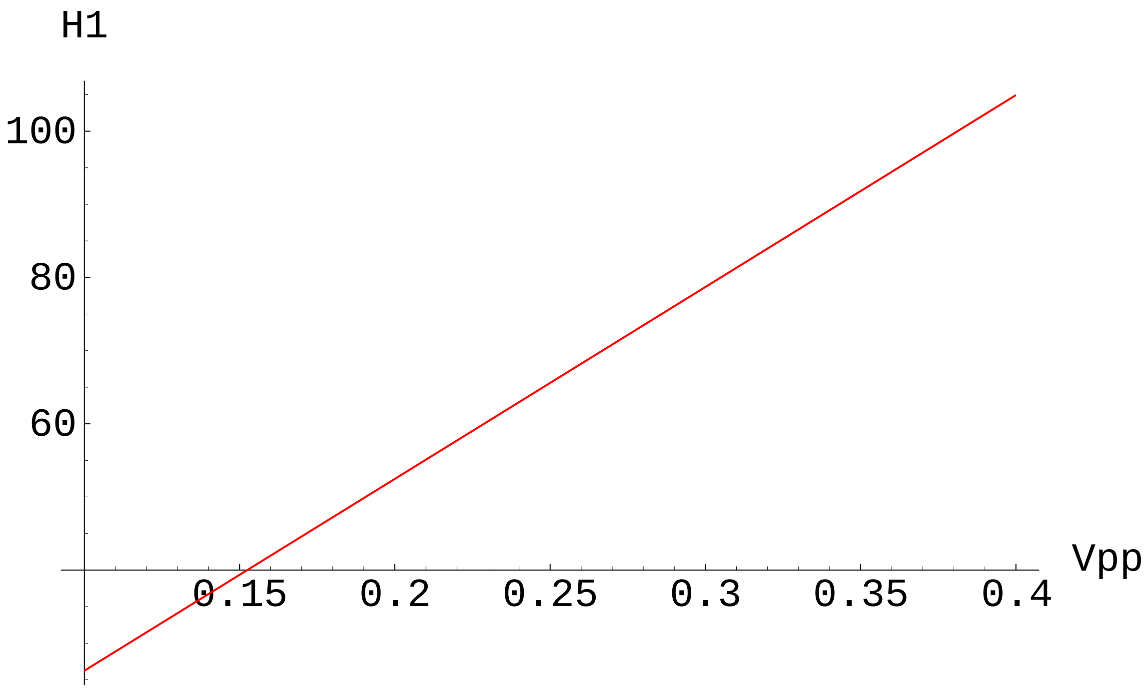

Figure 3: Dependence of H_1 (in mG) as a function of the measured induced voltage (in Volts, peak-to-peak).