Simple Method of Distributed Tuning of RF Sensor for NMR Imaging System

J. Přibil, I. Frollo

Institute of Measurement Science, Slovak Academy of Sciences, Dúbravska cesta 9, SK-841 04 Bratislava, Slovak Republic; E-mail: umerprib@savba.sk.

Abstract. *The paper describes automatic remote tuning system of the NMR tomograph receiving/sending RF sensor based on a coil and two rotating capacitors driven by special DC motors. The tuning unit is permanently located in the NMR scan area, with the stationary magnetic filed B_0 needed for DC motors functionality. The tuning control unit equipped by the microcontroller is located in the tomograph operating room, where cooperates with the RF impedance analyser. The conversion, tuning, and regulation characteristics introduced in this paper document obtained results of the first experimental piece of tuning system.*

Keywords: RF sensor, tuning and matching, NMR imager, automated regulation

1. Introduction

The fundamental parameter in Nuclear Magnetic Resonance (NMR) imagining is signal to noise ration (SNR) – for a small sample in a Radiofrequency (RF) coil holds that the most of the noise comes from the coil. For that reason, the accurate matching of RF coil as a sensor of the NMR imager is a basic condition to obtain detected signal and images with high quality. The manual or semiautomatic matching of RF coil is lossless [1], but more conditions must be achieved. The effectiveness of such a matching process (tuning time and accuracy) often depends firstly on the personal experiences. For the measuring of RF coil tuning values, the impedance (“Z”) meter or the RF analyzer with wobbler can be used. Practically it means, that before performing of NMR experiments the RF coil (with or without sample) must be finally matched (basic pre-tuning can be preformed separately). The next problem is that the operating person must work near the place of scanning tube of the NMR imager. In our case, remote tuning and matching can be performed from the operating room, where the control console of the imager is also located. Remote tuning with varicaps mentioned in [2] is theoretical very useful approach, but in practical realization there are some problems. The first one consist of decreasing of the RF coil circuit quality parameter (due to big parasite capacitance of varicaps), the second follows from the fact, that the RF high voltage can be induced into all of circuit components and varicaps can be damaged.

Our solution combines the advantage of lossless matching with possibility of automatic remote tuning based on two high quality rotating capacitors driven by special DC motors. We apply distributed structure of tuning system: the tuning unit together with the RF coil circuit is located in the scanning area of the NMR imager, the tuning control unit cooperating with the RF impedance analyzer are placed in the operating room of the tomograph.

2. Subject and Methods

Generally, the matching RF coil circuit consists of three components: inductance L of the coil (including the serial resistance r_L), parallel (C_p) and serial (C_s) capacitance – see Fig. 1. Main task of tuning system is to guarantee the RF coil output impedance matching for the frequency f_0. From the receiver point of view follows, that the optimal tuning of RF coil minimizes the input noise. From the RF transmitter point of view, it represents the situation, when the minimum energy is returned back after sending the excitation pulse.

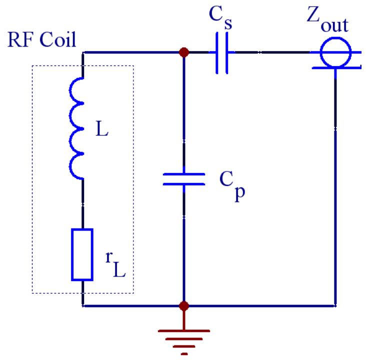


Fig. 1. Matching circuit of RF coil.

Developed tuning unit consists of two high quality rotating capacitors C_p and C_s (in the “butterfly” realization) driven by special DC motors. For the right functionality of DC motors a constant magnetic field B_0, presented in the NMR scanning area is used. By this way, the classical stator equipped by permanent magnet is practically substituted. All other components of the DC motor must be produced from the non-ferromagnetic materials. The tuning unit is connected to the receiving/sending RF coil circuit, which must be pre-tuned to frequency f_0 by the parallel fixed capacitor C_{basic}. The output of the tuning unit is connected by a 50 Ω coaxial cable to the receiver/transmitter of NMR imager console or RF impedance analyzers – see block scheme in Fig. 2.

Tuning control unit is based on the microcontroller ATMEL AVR (type ATmega16) with clock speed 10MHz. The used microcontroller utilizes the high-performance and low-power RISC architecture with peripheral and special features (Universal Serial Interface, full duplex USART, on-chip 8-channel 10-bit ADC, 32 programmable I/O lines) [3]. Thanks to these properties, the tuning control unit contains only minimum of additional components.

The tuning control unit can operate in manual (tuning drive is controlled by the user by buttons) and automatic mode (tuning is controlled by the microcontroller). For both modes it holds, that tuning unit can give data from the RF impedance meter with the analogue output (the on-chip analog to digital converter is used) or from the digital RF analyser (the serial communication via the RS232 line is used).

Parallel tuning of the capacitors C_p and C_s with non-linear conversion characteristics (see Fig. 3) by motors M1 and M2 represents generally two-dimensional regulation process, whose practical realization with sufficient precision is a difficult task [4]. Therefore a simplified control method was used – only one capacitor is tuning at the time and the second have a constant value.

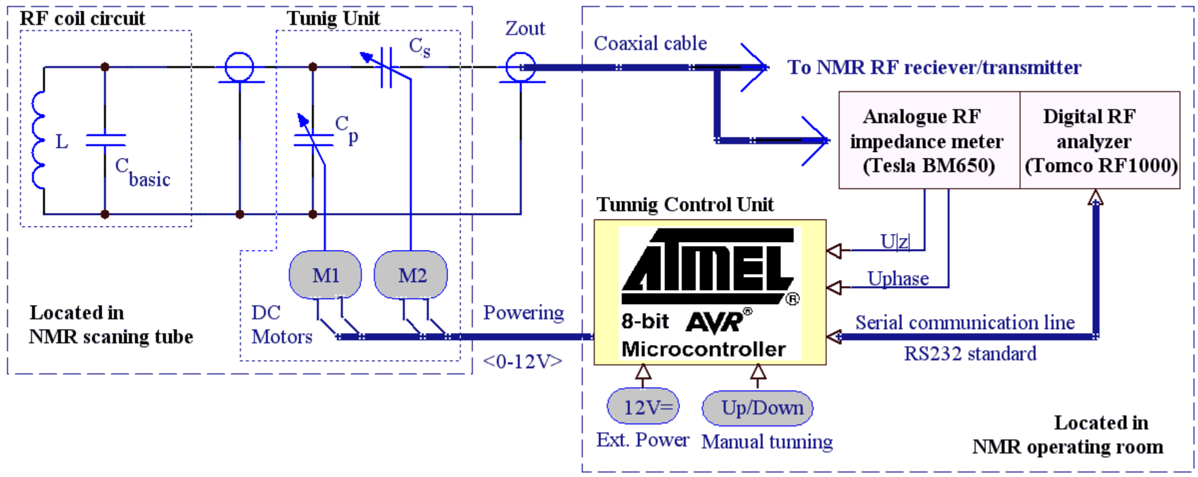


Fig. 2. Principal block scheme of developed distributed tuning system of RF coil for NMR imager.

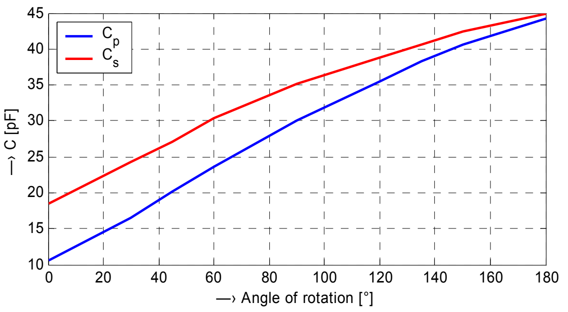


Fig. 3. Rotation characteristics of tuning capacitors C_p and C_s, measured on $f_0 = 4.45$MHz.

For giving better tuning precision, four levels of supply voltage for DC motors can be applied ($U_{M12} = 2$, 4, 8 and 12 V). Two algorithms for automatic tuning by microcontroller were developed:

a) Universal, robust – tuning process begins with initial settings of parameters (it is used for first tuning of the RF coil)

b) Fine-tuning – starting from current settings-position (it is usually used in the case when the pre-tuned RF coil is not used for long time or after inserting the sample for NMR scan to the coil).

Universal tuning algorithm consists of four steps – see demonstration example in Fig. 4a):

1. *Initial settings* of: capacitors C_p and C_s, DC motors supply voltage, tuning frequency, maximum deviation of $|Z|$ and φ values.

2. a) *Tuning of the capacitor* C_p, finding the minimum of $|Z|$ value (during this tuning process the φ values must change the polarity) – stop on this position.
   b) *Tuning of* C_s, finding the absolute minimum of φ – stop on this position.
   c) *Switch supply voltage* to lower value.

3. a) *Tuning of* C_p, finding the minimum of $|Z|$ value.
   b) *Tuning of* C_s, finding the absolute minimum of φ.
   c) *Switch supply voltage* to lower value (if it is possible).

4. a) *Tuning of* C_p, finding the $|Z|$ value equal to 50 Ω.
   b) *Tuning of* C_s, finding the absolute minimum of φ.
   c) *Test:* is the condition of the maximum deviation of $|Z|$ and φ values fulfilled?
   No = *continue* with step 3c),
   Yes = Stop (end).

In the fine-tuning algorithm, the last step of the universal algorithm is practically applied (see example in Fig. 4b):

1. a) *Tuning of* C_p, finding the $|Z|$ value equal to 50 Ω.
   b) *Tuning of* C_s, finding the absolute minimum of φ.
   c) *Test of the maximum deviation condition*:
   Fulfilled = end,
   No = *switch supply voltage* to lower value (if it is possible), *continue* with step 1a).

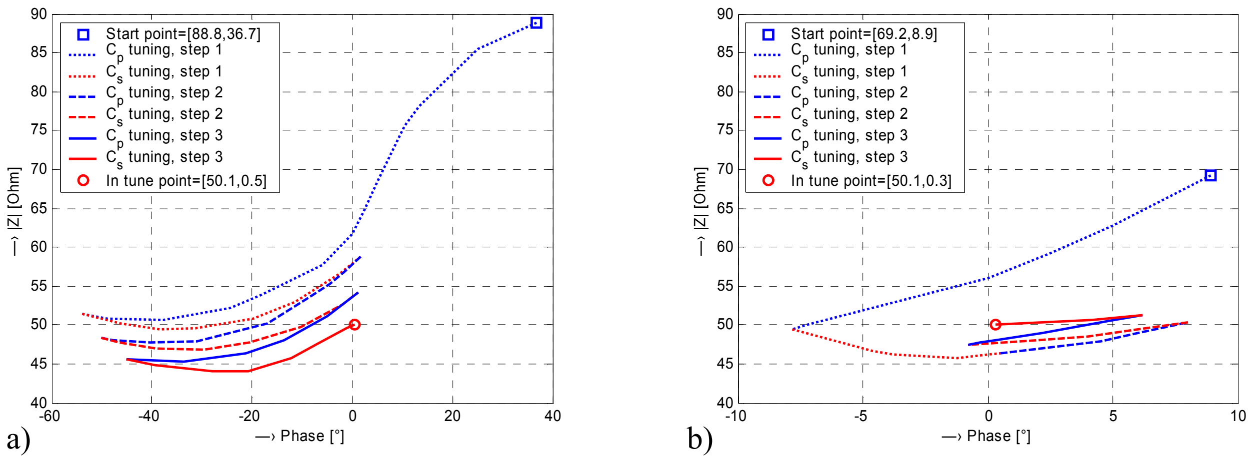


Fig. 4 Demonstration example of implemented tuning algorithms: the universal (a), fine-tuning (b).

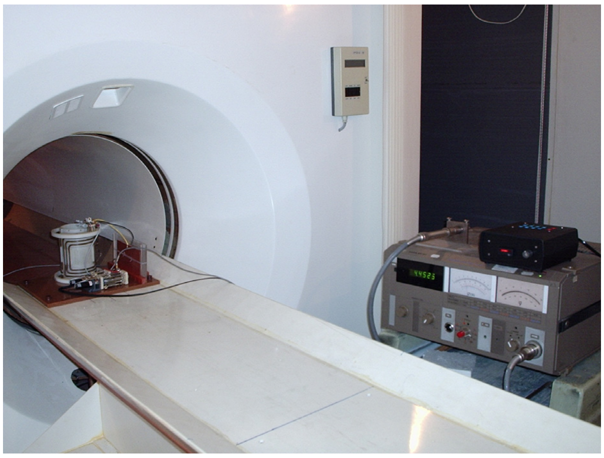
Automated tuning process can be manually interrupted by the user in any step (when the maximum deviation condition is not fulfilled and the regulation process does not converge).

3. Experiments and Results

Developed RF coil tuning system on the 0.1 T whole-body NMR imager TMR-96 has been tested. For experimental verification the solenoidal RF coil (with 14 threads winded up on diameter 50 mm, length 220 mm, pre-tuned by the capacitor $C_{basic} = 300$ pF) was used – see documentation photos in Fig. 6.

Measuring, tuning and matching at the frequency $f_0 = 4.45$ MHz were preformed, maximum deviation of $|Z|$ and φ values was set to $\Delta|Z|_{max} = \pm 2\ \Omega$, $\Delta\varphi_{max} = \pm 2$ deg. For the tested RF coil was firstly manually confirmed, that there exists a real matching point ($|Z|_{out} = 50\ \Omega$, $\varphi_{out} = 0$) – see fast tuning characteristic in Fig. 7a) and detailed tuning characteristic for value of $C_p = 30$ pF (Fig. 7b).

Subsequently, the automatic tuning by microcontroller with analogue RF impedance meter TESLA BM650 and digital RF analyzer was tested TOMCO TE1000 [5]. Resulting frequency characteristics of in tune RF coil are shown in the Fig. 8.



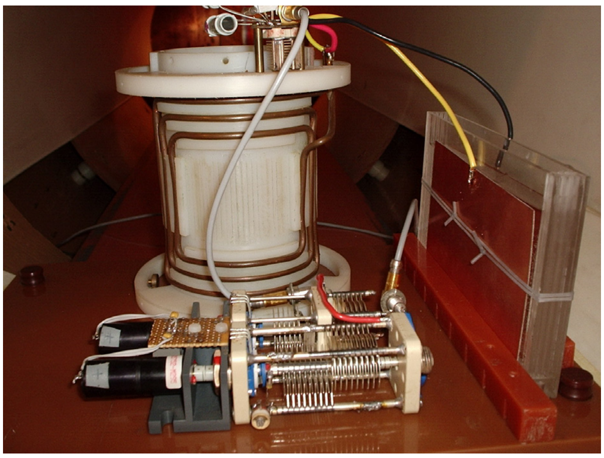
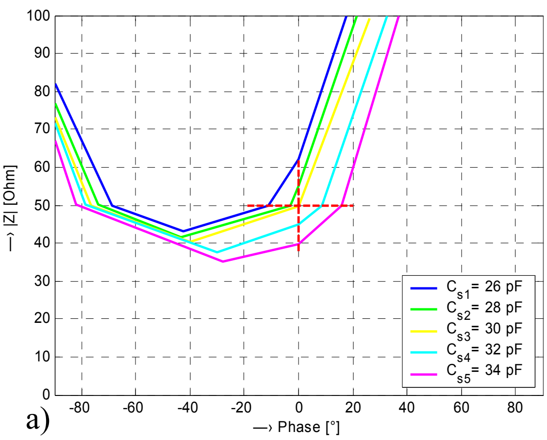
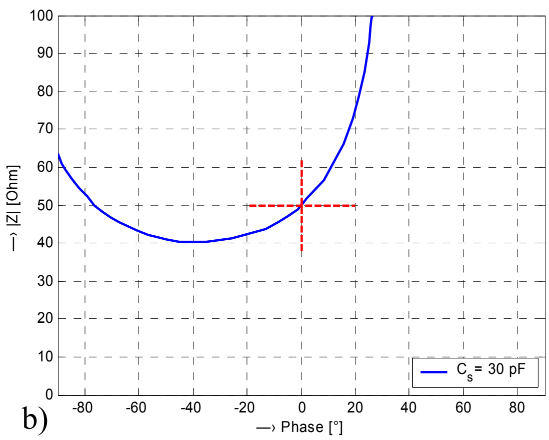


Fig. 6. Tuning control unit with the analogue RF impedance meter near the NMR image (left), detail of the matching RF coil circuit with two high quality rotating capacitors driven by special DC motors (right).



a)



b)

Fig. 7. Measured tuning characteristics of testing solenoidal RF coil (with the help of the RF Impedance meter Tesla BM650): Fast tuning characteristic of C_p on $f_0 = 4.45$MHz, $U_{M12} = 12$V (a), detailed tuning characteristic - $U_{M12} = 2$ V, resulting matching point: $|Z|_{out} = 48.5\ \Omega$, $\varphi_{out} = 1.8$ deg (b).

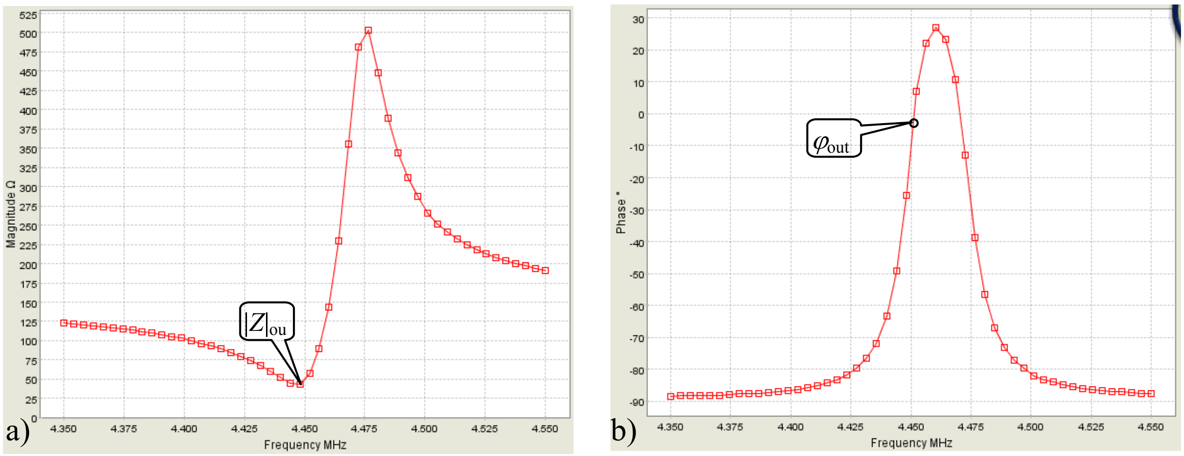


Fig. 8. Frequency characteristics of in tune RF coil: $f_0 = 4.45$ MHz, $Z_0 = 50\ \Omega$ - $|Z|_{out} = 50.2\ \Omega$, $\varphi_{out} = -0.8$ ° (measured by the digital RF impedance analyser Tomco RF1000); $|Z|$ characteristic (a), phase characteristic (b).

4. Conclusions

From performed tests of automated tuning RF coils with the help of the analogue RF impedance meter and the digital RF analyzer follows, that in both cases the tuning process was successful. Better accuracy was achieved by using the digital analyzer.

The problem can be observed in the long time temperature stability of tuning capacitors and oscillators of RF measuring devices. Because we are performing mostly short time NMR scans, this effect practically have not influence on the resulting quality of obtained NMR images. The main advantage of the automated tuning system consist in elimination of human intervention to the tuning process, which brings speeding of matching operation together with increasing accuracy of finally tuned RF coil circuits.

Acknowledgement

The financial support by the Grant Agency of the Slovak Academy of Sciences, project VEGA no. 2/5043/27 and by the Science and Technology Assistance Agency, project no. APVV-99-P06305 is gratefully acknowledged.

References

[1] Andris, P.: Matching and Tuning of RF Coils for NMR Tomograph. *Measurements Science Review*, Vol. 1, No. 1, Section 3, 2001, pp. 115-118.

[2] Andris, P., Frollo, I.: Sensitivity of NMR Receiving Coil with Varicaps. In: Proc. of the 5th International Conf. Measurement 2005, Smolenice, May 15-19, 2005, pp. 178-181.

[3] 8-bit Microcontroller with 16K Bytes In-System Programmable Flash ATmega16. Preliminary & Summary. © Atmel Corporation 2006.

[4] Kamenský, M., Kováč K.: Sensor Nonlinearity Error Correction by Algorithmic Technique. In: Proc. of the 16th International Czech-Slovak Scientific Conference Radioelektronika 2006. Bratislava, April 25-26, 2006, pp. 181-184.

[5] TE1000 RF Vector Impedance Analyser USER'S GUIDE. Document Number T001223 Issue H. © Copyright Tomco Technologies, 2005.