Software for Design NMR Probes Using the Shielded Split Ring and the Shielded Symmetrical Band Resonators

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ABSTRACT

This article presents a software (NMR PROBES) for design NMR probes using closed-forms formulas of the primary and secondary parameters of the shielded split ring [1] and the shielded symmetrical band resonators [2]. These formulas are based on rigorous analysis by finite element method (FEM) [3], [4], method of moment (MoM) [5] and curves fitting techniques.

The presented software permits the design of NMR probes for a wide-range of discontinuity angles and it is suitable for all NMR probes with shielded split ring and shielded symmetrical band resonators which have respectively an outer-inner conductors radius ratio between 2 and 10 and between 2 and 7.

As applications of this software, we present results obtained from the design of NMR probes operating at 500 MHz and 1 GHz.

INTRODUCTION

Nuclear magnetic resonance (NMR) probes are vital to mate-rials research and medical applications.

The frequency region above 200Mhz and bellow 2Ghz represents a difficult problem for high sensitivity magnetic resonance. Standard cavity resonator can not be used because its radio-frequency field is inhomogeneous. Capacitively tuned solenoidal coils, which for frequencies up to ~100Mhz are good choices, become impractical at higher frequencies because they become self-resonant [6], [7].

W. N. Hardy and L. A. Whitehead [8] have developed a shielded split ring resonator with excellent field homogeneity. Beginning with this structure, it is suggested that another type of resonator be constituted from a shielded symmetrical band resonator.

With the capability of being easy to fabricate, a shielded split ring and a shielded symmetrical band resonators which have a high quality factor (Q) in the 200-to-2000-MHz range [7], [8] are flexible enough to adapt to a different range of sizes at a particular frequency.

Many NMR experiments involving very high homogeneity and high power required the redefinition of the probe. To study a sample, the probe must transmit RF energy and convert it to magnetic energy.

The probe is a resonant circuit with a selfic element (solenoid, shielded symmetrical band line, shielded split ring line,...) and other components used for the adapter (figure 1).

Figure 1 : NMR probe.

The selfic element has a fundamental role in the spectrometer. This resonator must have high Q and good magnetic field homogeneity.

NMR PROBE USING THE SHIELDED SPLIT RING AND THE SHIELDED SYMMETRICAL BAND RESONATORS [9]

The cross section of the shielded split ring and the shielded symmetrical band resonators are respectively presented in figures 2 and 3. These resonators are assumed to be lossless with inner conductors of radius r_o, negligible thickness w, a discontinuity angle θ and an outer shield of radius r_b. Dielectric materials with permittivities ε_{r1} and ε_{r2} are placed respectively in the inner of the central conductors and between the central conductors and the shield.

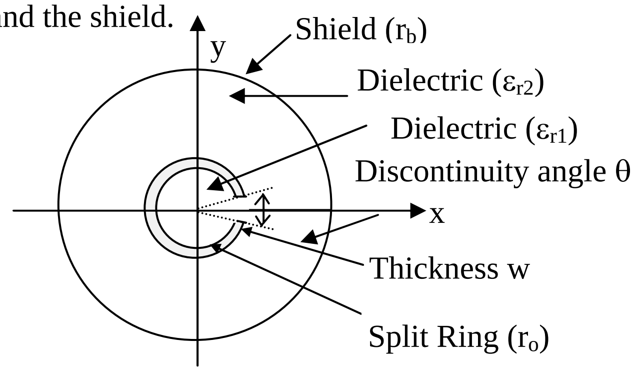

Figure 2 : Cross section of the shielded split ring resonator.

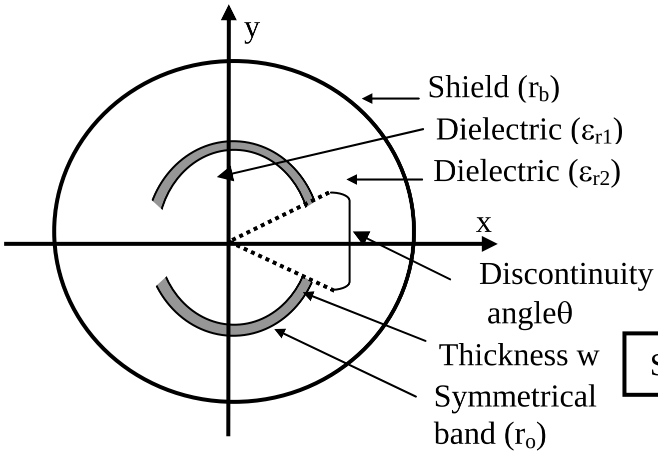

Figure 3 : Cross section of the shielded symmetrical band resonator.

In this article, we present a computer program (NMR PROBES) for design NMR probes, by a description of its components, using closed-forms formulas of the primary and secondary parameters of the shielded split ring [1] and the shielded symmetrical band resonators [2].

This computer program allows us to decide if the constraints permit the realisation of the probe.

The NMR probes presented on figures 4 and 5 are composed of:

-The buckle of current, which contains the sample.

-The components of according and adaptation, which are coupled to the buckle of current to constitute the resonant circuit.

-Finally the coaxial line excites the resonant circuit and all constituents of the probe [9].

In this work, the study of the buckle of current was dealt with the case of the shielded split ring and the shielded symmetrical band resonators.

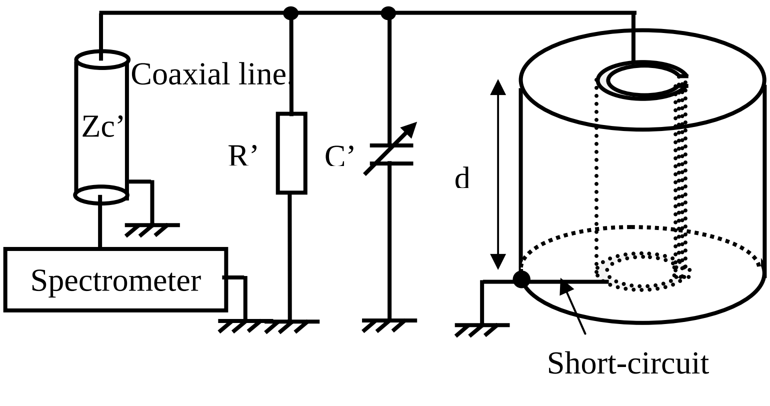

Figure 4 : NMR probe using the shielded split ring resonator.

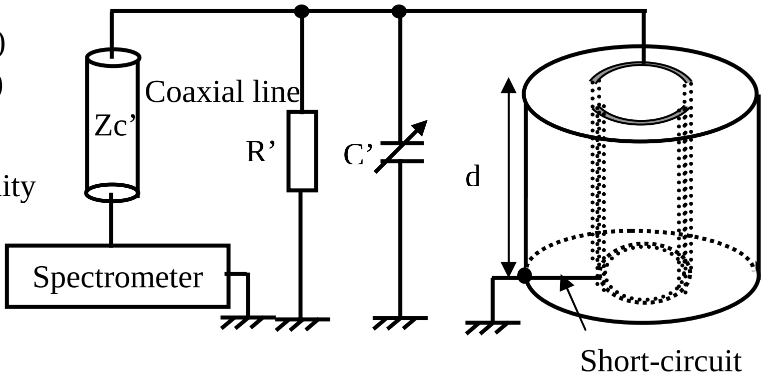

Figure 5 : NMR probe using the shielded symmetrical band resonator.

PROGRAM USAGE

The program is menu driven (Figure 6). The user can supply data of the probes using the shielded split ring or the shielded symmetrical band resonators either by typing them in, or by reading data contained in the menu.

The program input consists of :

- the geometrical and the physical parameters of the probe: the radius r_o, the radius ratio r_b / r_o , the discontinuity angle θ, the volume of the sample, the dielectric constants ε_{r1} and ε_{r2}, and the resonance frequency

The program output consists of :

- the electromagnetic parameters: the proper inductance and capacity, the mutual inductance and the coupling capacity, the even and odd mode impedances and the characteristic impedance of the isolated line.
- the geometrical and the physical parameters: the length of the resonator, the according capacitance C' and the matching resistor R'.
- Also the plot of the scattering parameters versus frequency or the cross section of the resonator are generated on the screen.

DESIGN OF NMR PROBES AT 1GHz

To design NMR probe using the shielded split ring resonator and operating at 1GHz, we have fixed the following parameters:

- Radius r_o=20 mm
- Radius ratio r_b / r_o = 2.33
- Discontinuity angle θ=1°
- Volume of the sample =30 cm^3
- Dielectric constants $\varepsilon_{r1} = \varepsilon_{r2} = 1$
- Resonance frequency = 1GHz

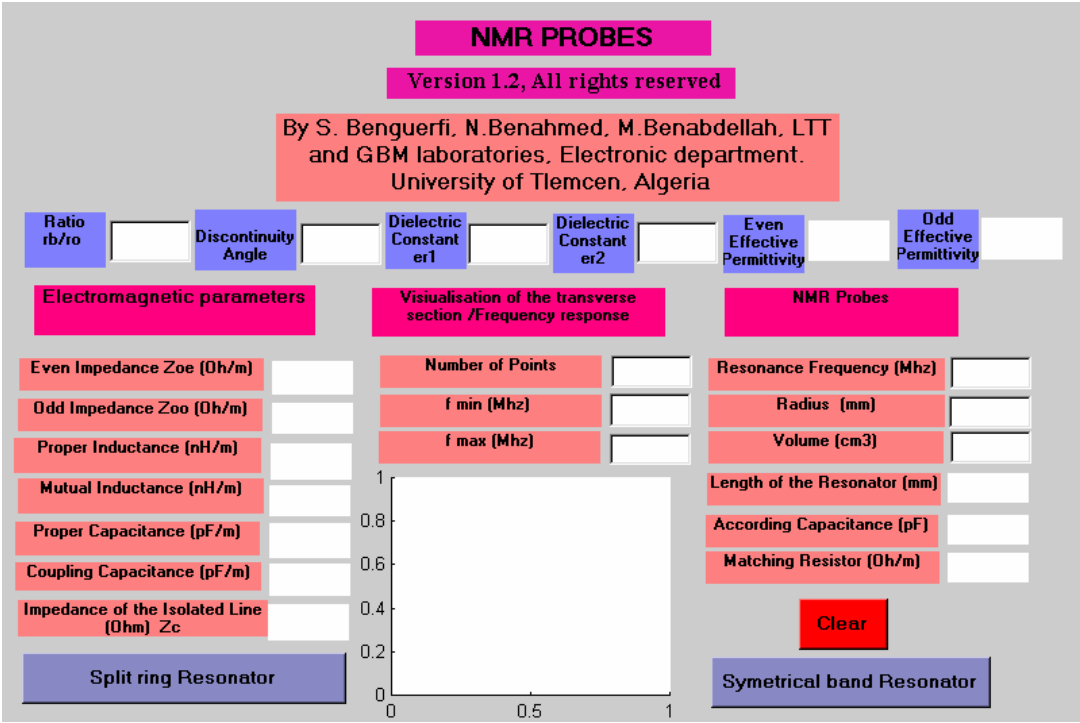

Figure 6 : Software NMR PROBES

The features of the NMR probe obtained from the software NMR PROBE (Figure 7) are:

- Proper inductance = 167.28 nH/m
- Proper capacity = 66.77 pF/m
- Characteristic impedance of the resonator = 50Ω
- Length of the resonator = 11.93 mm
- According capacitance C'=12.68 pF
- Matching resistor R'=50 Ω

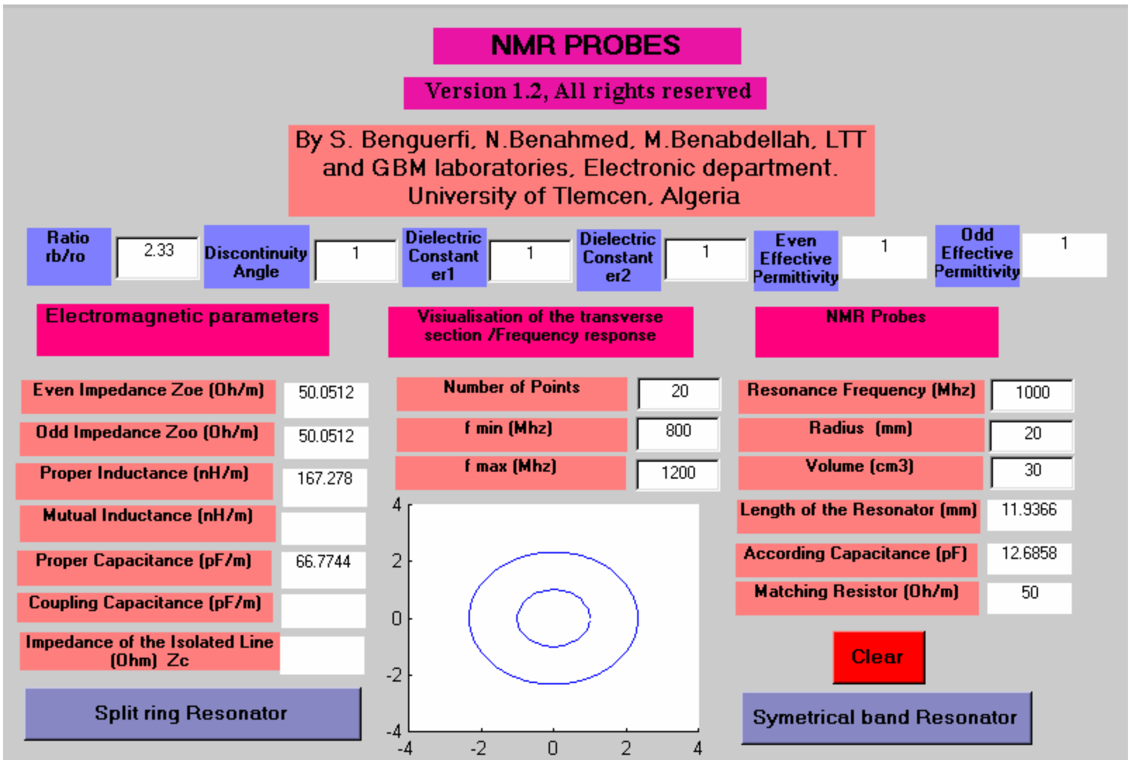

Figure 7

The response of the designed NMR probes using NMR PROBES is shown in figure 8.

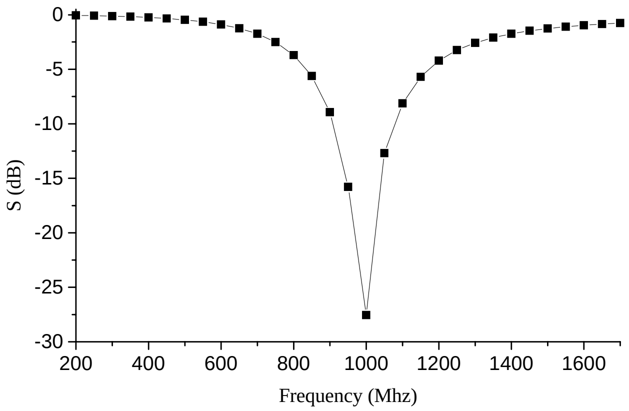

Figure 8 : The influence of the frequency on the reflection coefficient at the input of the probe operating at 1GHz.

DESIGN OF NMR PROBES AT 500 MHz

For the NMR probe using the shielded symmetrical band resonator and operating at 500MHz, the fixed parameters are:

- Radius r_o=60 mm
- Radius ratio $r_b / r_o = 2.3$
- Discontinuity angle θ=1°
- Volume of the sample =300 cm^3
- Dielectric constants $\varepsilon_{r1} = \varepsilon_{r2} = 1$
- Resonance frequency = 500 MHz

And the features of the NMR probe obtained from the software NMR PROBE (Figure 9) are:

- Proper inductance = 208.551 nH/m
- Mutual inductance =120.162 nH/m
- Proper capacity = 82.71 pF/m
- Coupling capacity = 48.004 pF/m
- Characteristic impedance of the resonator = 51.6 Ω

These features give the response shown in figure 10.

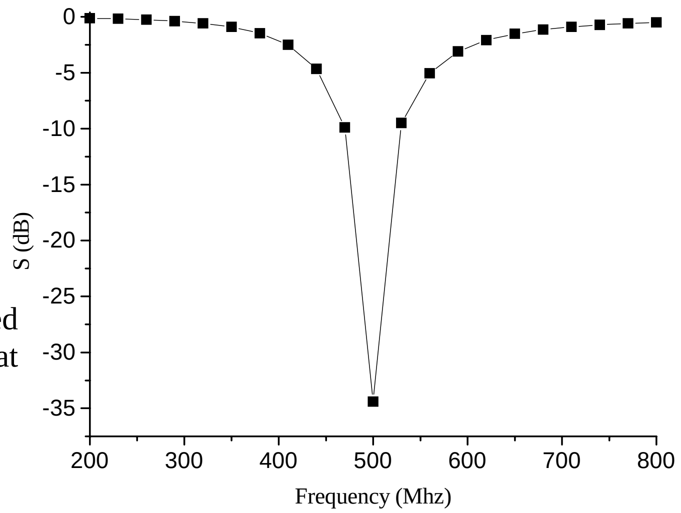

Figure 10 : The influence of the frequency on the reflection coefficient at the input of the probe operating at 500 MHz.

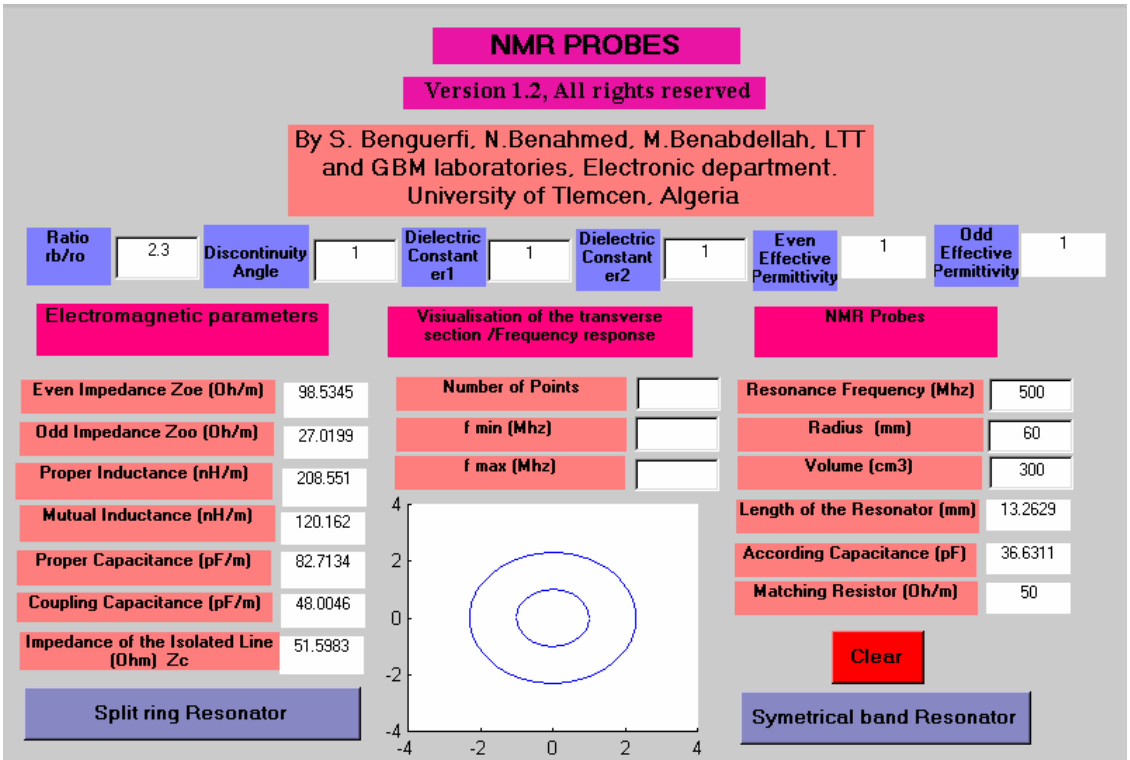

Figure 9

CONCLUSION

This article presents a software (NMR PROBES) for design NMR probes using the shielded split ring and the shielded symmetrical band resonators.

The different curves, giving the variation of the reflection coefficient at the input of the probes in function of the frequency, present a minimum at the chosen resonant frequency. All these curves show the good results obtained from the conception using the present software.

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