RF Resonator Array for MR Measurement System

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Abstract. *The contribution reports on the possibilities of the fabrication of resonator array structures for MR imaging purposes. Suitable array configuration may improve the RF field homogeneity. The key issues of resonators fabrication are introduced together with achieved results from the samples parameters measurement.*

Keywords: Planar Resonator, Periodical Structure, Magnetic Resonance, Metamaterial

1. Introduction

Magnetic resonance (MR) is continuously evolving measurement, spectroscopy and imaging technique for examination of specific samples and biological tissues. RF magnetic field distribution and its homogeneity in the MR system's resonator are crucial parameters. They can be influenced by proper resonator design. The attention of scientific community has been recently pointed at the new possibilities of manipulation of the RF magnetic field distribution. Certain effort in this field is directed to the possibilities of manipulation of RF magnetic field with the goal of improving the received signal, which leads to better MR image quality [1]. Such approaches exploit novel properties of composite metamaterial (MTM) structures, which found applications in various research directions [2], [3]. The components of MTM structure can be fabricated as they have insignificant response in the DC magnetic field. Simultaneously, they can exhibit strong effective susceptibility around a certain resonant frequency. The components of MTM structure are mutually coupled and magneto-inductive waves are formed in the structure [4].

2. Resonator Array fabrication and measurement

Examined MTM structure is based on array of electromagnetic (EM) resonators with RF response. The resonator exhibits an effective inductance and capacitance matched in such way that it resonates closely to Larmor’s frequency. The resonant frequency relates to its dimension, mainly due to its inductance. The resonator dimension has to be smaller than quarter of the operating wavelength. This sets the constraint on its maximal dimension. Another constraint is given by the dimension of the sample to be imaged. Since the RF field should be uniform in sample’s volume, the minimal dimension requirement on the MTM device is given. These constraints lead to design of a resonator array with the total number of components *i*. The simple resonator can be in form of a single split ring (SSR), which is a loop conductor with narrow slit. It can be deposited on printed circuit board (PCB) substrate (FR4). The resonant behavior of SSR (d = 5 mm, w = 0.2 mm) is shown in Figure 1a), which exhibits resonance around 6 GHz. If we take into account the operating frequency in RF domain (around 200 MHz for 4.7 T system) and given dimensions constraints, the form of the resonator would be a SRR tuned with lumped capacitance of tens of pF as shown in Figure 2b).

The capacitor loaded SSR array structure is shown in Figure 2a). Figure 2b) shows the rings dimensions and Figure 2c) the fabrication of the SSR) array.

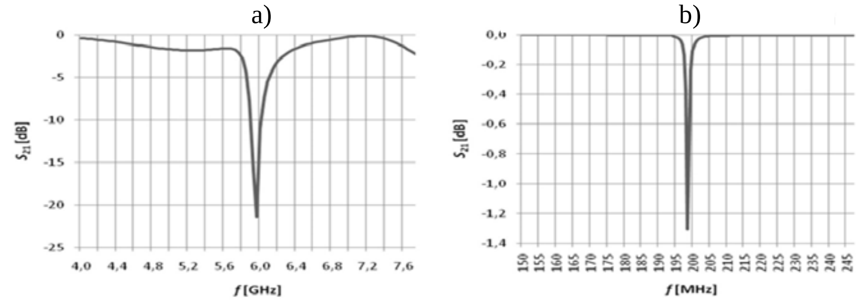

Fig. 1. SSR‘s scattering parameter s_{21} for transmitted wave; without a) and with b) capacitor.

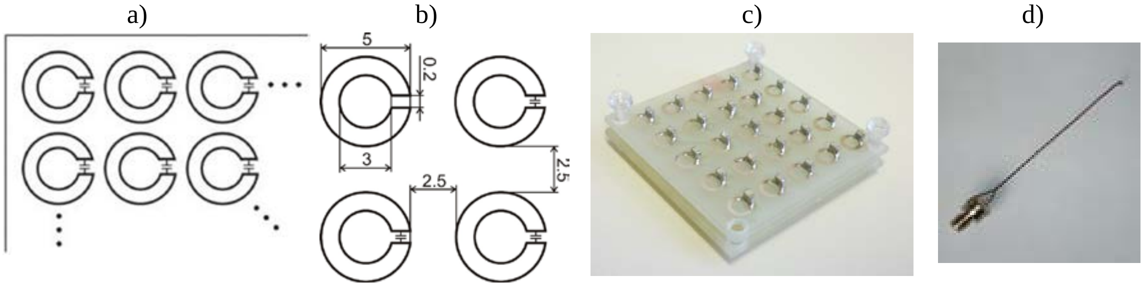

Fig. 2. Array of single split rings (SSR) a); ring dimension b); resonator array fabrication c); inductive probe for examination of SSR resonant frequencies d).

The alignment of resonant frequencies $f_{r,i}$ of all of the resonators is important and influences the quality of the modified RF field. Besides this, other parameters determine the overall structure properties (as the quality factor Q_i). Above all, the mutual coupling (capacitive and inductive) between resonators in the array has a great importance. The particular resonant frequencies of all of the resonators are strongly influenced by the coupling. The coupling magnitude is determined by resonators design and significantly by their spacing. The spacing influences also the uniformity of modified RF field. Since the resonators mutual coupling has complex influence on the overall array properties, it is most advantageous to design the array (consequently the resonators spacing) by means of numerical modeling and simulation.

Since the tuning of each resonator is a critical point determining the structure parameters, it deserves significant attention. There are three basic factors that influence the resultant resonance behavior of the array. Firstly, all resonators shall have exactly identical dimensions (inner and outer diameter, thickness, slit width). This depends on the PCB manufacturing technology and its precision. Classical approach is wet etching. The second factor is the value matching of all capacitors used. Common ceramic chip capacitors have the lowest production value tolerance ±1% for capacitances over 10 pF. At 200 MHz, the 1% capacitance variation causes the resonance frequency shift of 1 MHz, which is unacceptable for MR purposes. The third factor is the precision of chip capacitor assembly on the SSR. Variation of solder amount used and the quality of each soldered connection influences the inductance and capacitance of each resonator and also its Q-factor.

In case of perfect resonator matching, the mutual coupling comes into play. The coupling causes splitting of all of the particular resonant frequencies and the resultant structure’s resonant curve becomes broad.

In order to handle and evaluate the above mentioned issues, two experimental SSR arrays with 5×5 resonators have been designed and fabricated using 35 μm thick cooper on FR4 substrate. The first array dimensions are defined in Figure 2b). The modified Wheeler formula [5] was used for SSR inductance calculation. To achieve the desired resonant frequency of

200 MHz, a combination of three, precise selected capacitors was used (100 pF, 10 pF, 1.2 pF). The capacitors were manually soldered. The fabricated array (Figure 3a)) underwent the measurement of the resonant frequencies. Each frequency can be measured by positioning a loop probe in vicinity of each resonator [6]. In this measurement, an improved inductive loop probe (Fig. 2d) has been used together with network analyzer, which has measured a dip in s_{11}. The improved probe minimized the influence of the probe-SSR coupling on the measured resonant frequency value. The results of the measurement are shown in Figure 3c), which graphically shows the mutual differences in particular resonant frequencies by means of intensity scale. It is apparent that large differences occur, despite the careful selection of the capacitors. Obviously, the effect of non-uniform capacitor assembly and hand soldering came into play.

In the second attempt, a single capacitor with nominal value of 100 pF per resonator has been used. All the capacitors have been carefully selected in order to minimize the value tolerance. To achieve the same resonant frequency, dimensions of the SSR were recalculated according to [5]. The new ring diameter was 5.3 mm. In order to preserve similar mutual coupling, the resonator's spacing was increased in the ratio of the diameter change to 2.65 mm. Within the fabrication, the flux was deposited by the help of a precise mask; the capacitors were assembled by the manipulator and the reflow soldering was finally used. This resonator array (Figure 3b)) underwent measurement of the particular resonant frequencies as described above. The results of measurement are shown in Figure 3d). A significant reduction in the resonant frequencies differences is apparent from the intensity map.

The mutual coupling of the resonators leads to effect, when the total resonance curve of the structure is not identical with the curve of a single resonator. The array resonance curve will be broadened and its peak will be significantly reduced. In order to obtain the total resonance curve of the array, a measurement device has been designed and built, Figure 4a). The device comprises of cubic cavity equipped with two N-type connectors. Connector's middle conductors are connected through the cavity.

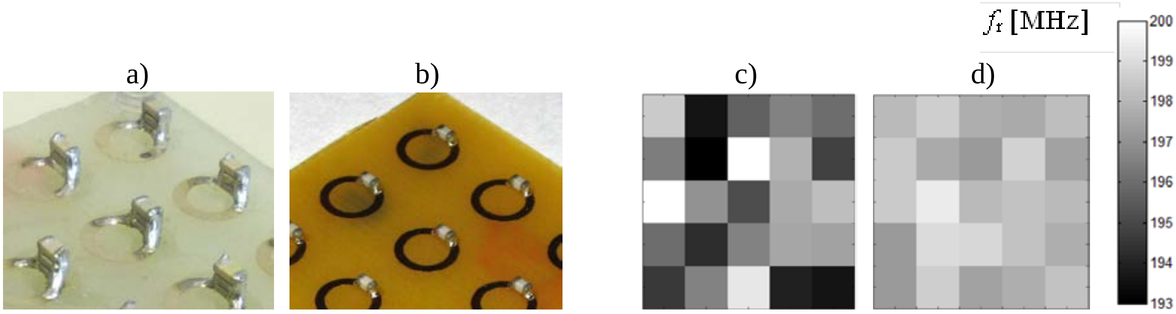

Fig. 3. Detail of the array with 3 capacitors combination a) and array with 1 capacitor b).

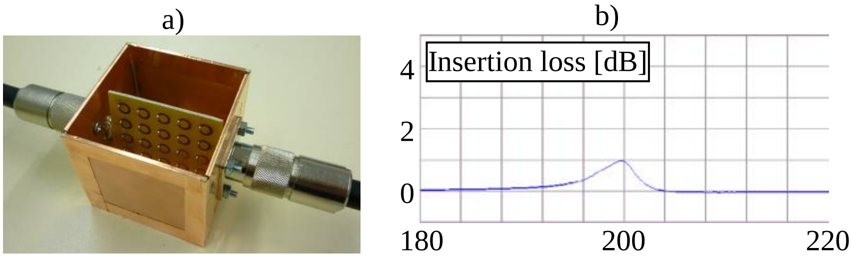

Fig. 4. Cavity for resonance measurement a); result for array-1 capacitor per resonator b).

The resonator array is placed inside the cavity and the insertion loss of the cavity is measured. Figure 4b) shows the resultant insertion loss of the array from Figure 3b). It is obvious that the resonance curve is broad with very low peaking, due to mutual coupling of the resonators. This effect is even raised by the non-ideal tuning of each resonator on the same desired frequency.

3. Conclusion

From the above described experiment can be concluded, that fabrication of the SSR resonator arrays is accompanied with severe issues. The key issues are selection of capacitors in view of the exact capacitance value and reproducible capacitor assembly. It has to be mentioned also, that capacitors with very low susceptibility has to be used in order to avoid MR image distortion. In order to overcome these limitations, the resonator design without lumped capacitors is proposed. Such resonators have only distributed capacitance, which leads to a more complicated layout design as shown in Figure 5. Numerical analyses of these resonant structures have been started and they give very promising results. Details on the new resonators structures, computed and measured parameters will be reported in the near future.

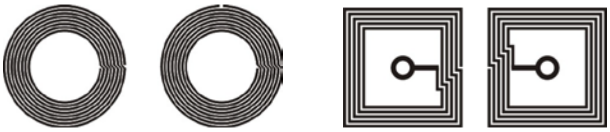

Fig. 5. Variations of the resonators with distributed capacitance.

Acknowledgements

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