Magnetic Field Shaping with Quasi-Periodic Resonators

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Abstract— Utilizing negative permeability structures can increase magnetic coil range in magnetic resonance (MR) tomography. Negative effective permeability can be created by Split Ring Resonators (SRR). The resonator is constructed as a concentric metal ring with interspaces. These rings are deposited as regular matrix on dielectric substrate. It is possible to designQuasi-Periodic Resonators (QPR) for better homogeneity of the magnetic the field. QPR are composed from SRRs. The subject of this contribution is description of the design and measurement of QPR.

1. INTRODUCTION

MR is widely used and still evolving measurement, spectroscopy and imaging technique for examination of various samples and objects (biological tissues, organic and also inorganic materials) in medicine and in material research and characterization also. The material (tissue) which is the object of MR examination is typical with the nuclear response to the excitation by external magnetic field, mainly in the radiofrequency (RF) domain. The nuclear precession relaxation of the matter gives a measurable signal, further used for spectroscopy (MRS) and imaging (MRI) purposes or for measurement of material physical properties. Various MR system parameters are carefully watched in order to obtain high quality response signals with high signal to noise ratio (SNR), such as basic magnetic field strength and homogeneity, RF magnetic field strength and homogeneity, resonator quality factor, filling factor and others. Between them, the RF magnetic field distribution and its homogeneity is a crucial factor. The RF magnetic field is generated by the RF resonator and its properties can be influenced by proper resonator design.

The attention of related scientific community has been recently pointed at the new possibilities of manipulation of the RF magnetic field distribution inside the resonator. Certain effort in this field is directed to the possibilities of translation of the active region outside the resonator, by means of RF magnetic field conductive elements [1]. Another research direction represents the manipulation of RF magnetic field with the goal of improving the received signal, which leads to better MR image quality [2].

It is possible to manipulate electromagnetic field by means of dielectric materials. Electromagnetic field will be affected due to values of dielectric constant ε_r and permeability μ_r [3]. It is possible to designthis material as a periodic structure of SRRs. The main problem is the usage the surface mount device (SMD) capacitors. SMD capacitors have technological value tolerance of its capacity. This causes the problem to set up the same resonance frequencies for all SSRs. It is apparent that large differences occur, despite the careful selection of the capacitors. Obviously, the effect of non-uniform capacitor assembly and soldering came into play. The second disadvantage of SMD capacitors is their magnetic conductivity. Even very low values of the magnetic conductivity can cause high distortion of resultant MR image [4].

2. DESIGN OF QPR

In order to avoid the above described problems, QPR structure was proposed and designed. Basic element of QPR structure shows Fig. 1. The design is based on square split resonator (SQR) [3] which is periodical connected in series in a row, where the first element has one slit and each other have two slits. The motive is designed as electrically conductive layer on a dielectric substrate.

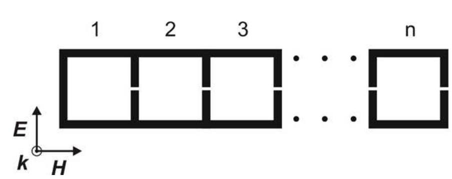


Figure 1: Basic element of QPR structure.

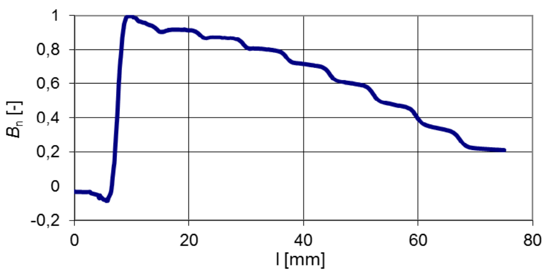


Figure 2: B_n on the cross-section of the QPR structure.

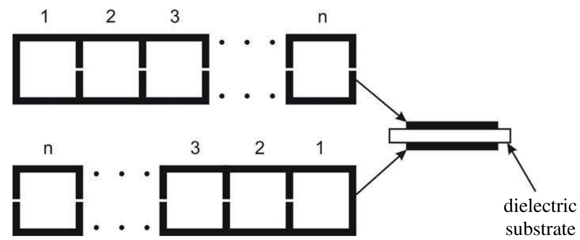


Figure 3: Design of the double QPR structure.

Figure 2 shows distribution of normalized magnetic flux density B_n on the cross-section of the QPR structure. It is evident from the figure the gradient character of the B_n.

It is possible to use this gradient magnetic field in special applications. However, the creation of highly homogenous magnetic field is necessary for standard MR imaging techniques. This problem was solved using the concept shown on Fig. 3.

As is apparent from Fig. 3 that double QPR structure is designed as two QPR structures mutually rotated by 180 degrees and separated by dielectric substrate. Fig. 4 shows B_n on the cross-section of the double QPR structure. The rather homogenous character of the B_n is evident from the figure.

From distribution of B_n is evident that the double QPR structure radiates magnetic field with very high homogeneity in compare to common planar RF coils. Hence, this concept fits for quality improvement of RF field in MR tomography. However, design of above described QPR and double QPR structures consider only excitation by plane electromagnetic wave and the generated field pattern corresponds to the geometry of the structure. However, it is necessary to create the magnetic field pattern which is suitable distributed in defined volume. The creation of convenient magnetic field pattern is reached by usage concept shown on Fig. 5.

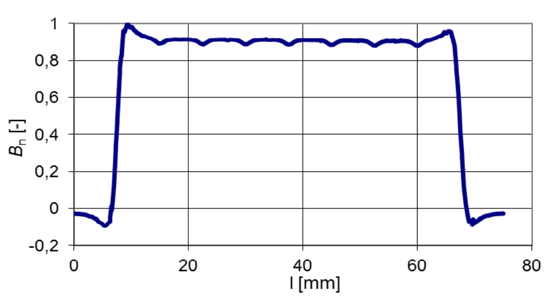


Figure 4: B_n on the cross-section of the double QPR structure.

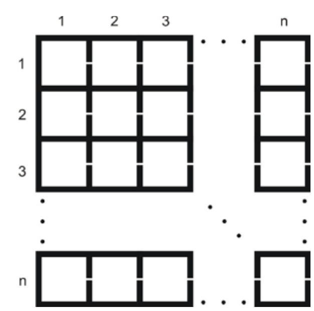


Figure 5: Design of the GQPR structure.

Figure 5 shows system of QPRs where single linear components are connected and creates grid QPR (GQPR) structure. Fig. 6 shows result B_n of numerical analysis of the GQPR structure which is excited by the planar single loop coil. It is evident from B_n distribution that the GQPR structure generate non homogenous magnetic field in combination with one-loop coil. This effect is caused by rotation of the electric field intensity vector around excitation coil. Because of this reason, only correctly oriented resonators resonate. In order to solve this problem two GQPR structures, mutually rotated by 180 degrees,were used. Thus, a double GQPR structure is created. The resultant magnetic field is formed as superposition of magnetic fields created by individual GQPR structures.

Figure 7 shows geometry of numerical analysis of the double GQPR structure and result of the B_n. Double GQPR structure has 5×5 cells and it is tuned on 200 MHz. Distribution of magnetic field is shown on the imaging cut plane. It is apparent from the results that this configuration creates highly homogenous magnetic field.

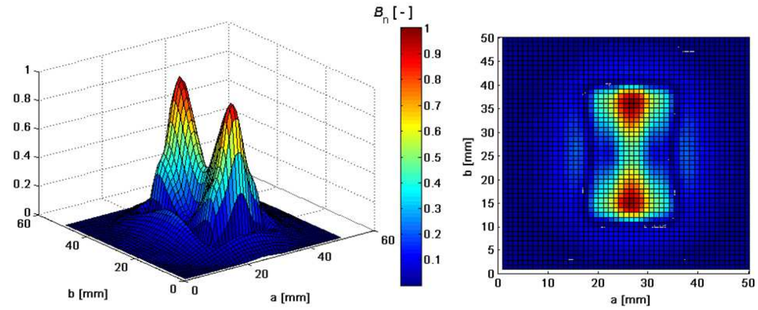


Figure 6: B_n of the GQPR structure excited by one-loop coil..

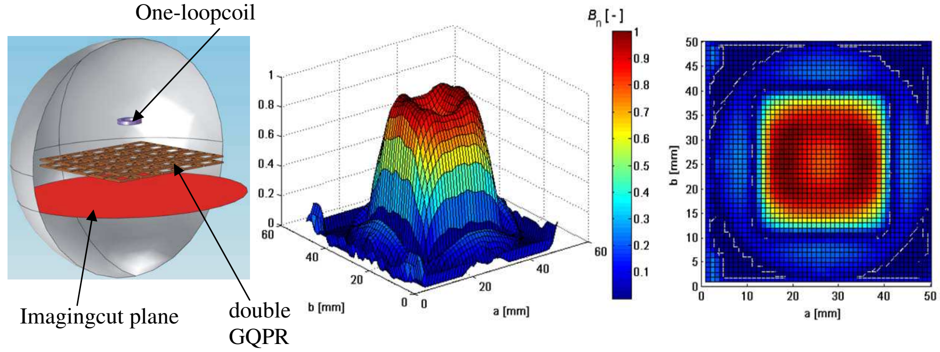
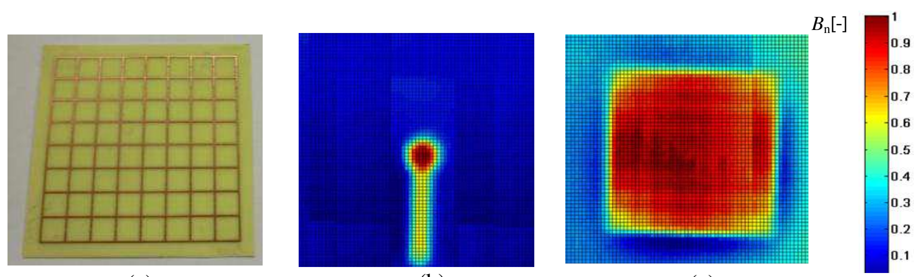


Figure 7: B_n of the GQPR structure excited by one-loop coil.



(a) (b) (c)

Figure 8: B_n of the GQPR excited by one-loop coil.

3. CALCULATION OF EFFECTIVE PERMEABILITY

The effective permeability μ_{ef} was calculated from the results obtained by the numerical analyses. The μ_{ef} can be determined using the relation:

$$\mu_{ef} = \frac{\iint B_{n2} dS}{\iint B_{n1} dS}, \tag{1}$$

where B_{n1} is normalized flux density of the geometry where acts only excitation coil and B_{n2} is normalized flux density of complete geometry containing excitation coil and double GQPR structure. Therefore, it is necessary to perform two numerical analyses. The first with only excitation coil present and the second with the overall assembly. Then, it is necessary to choose integration area of the B_n. For the results given above,the integration area was selected. The area has the same size asthe area where B_n was greater than or equal to 0.7. Resulting μ_{ef} then reached the value of -28.8.

4. MEASUREMENT OF GQPR STRUCTURE

The realization of complete GQPR structure is shown in Fig. 8(a). Structure was fabricated using wet etching on FR4 substrate. Fig. 8(b) shows B_n distribution around the excitation coil. Fig. 8(c) shows B_n distribution of the overall assembly.Measurement was carried out using half-automatic measuring station [5].

5. CONCLUSION

As is apparent, that the results obtained from measurement are consistent with the results obtained from numerical analyses. These results prove correctness of designed structures and realized numerical models. It is also evident from the results that B_n radiated by GQPR structure reach very highhomogeneity. Therefore, this concept fits for quality improvement of RF field in MR tomography. The work will continue with real validation in MR system. The examination of the influence on image quality will be performed.

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