Soft Surface - EBG Structure to Improve the |H|/|E| Field Ratio of Stripline Coil for 7 Tesla MRI

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Introduction

The anti-phase currents in the metallic conductor (PEC) ground plane placed underneath the meander strip-line transmit coil element [1] for high field MRI, represents the main reason for the reduction in RF magnetic flux density above these coils (inside the phantom). The objective of this paper is to replace this PEC ground plane with a high impedance surface electromagnetic band gap EBG structure [2] to improve the efficiency of a well-established strip-line coil for 7Tesla MRI, by suppressing the anti-phase currents on the metallic ground plane. In this paper, a novel multilayer offset EBG structure is proposed to work as a soft surface [3] with low surface impedance in the transversal direction, to satisfy the perfect electric conductor PEC like condition (tangential electric field near to zero in the x-axis, cf. Fig. 2), and with higher surface impedance in the longitudinal direction to satisfy the artificial magnetic conductor AMC like condition (tangential magnetic field near to zero in y-axis, cf. Fig.2). Thereby, the magnetic flux density inside the patient's body is increased, which will further increase the signal-to-noise ratio and hence the contrast between the different tissues of the body and leads to improve the resolution and quality of the scanned images by MRI machines. EBG structures may be built to either stop the propagation of waves or to support a quasi-transverse electromagnetic wave along the surface. The former is called a soft surface, whereas the latter is a hard surface. The first application of high impedance surface EBG structures for MRI applications appeared in [4].

Materials and Methods

In this paper, a multilayer EBG structure is introduced, which consists of two arrays of metal patches diagonally offset from each other. The top layer consists of 4×3 patches each of 8% of $\lambda_{300\text{MHz}}$ in length and 3% of $\lambda_{300\text{MHz}}$ in width. These patches are connected to the metal backed dielectric substrate by vertical pins. The lower layer consists of solid patches and is floating. The HFSS full wave simulator (based on FEM) and the FDTD simulator EMPIRE XCcel were used to characterize and analyse the EBG structure. The geometry of the PEC and the proposed EBG structure together with a resonant meander dipole printed on FR4 substrate (ε_r=4.4, tan(δ)=0.02) with a dimension (100 mm × 250mm × 0.5 mm) is shown in Fig. 1 and 2 respectively. The physical dimensions of the proposed EBG structure are L=0.080 $\lambda_{300\text{MHz}}$, W=0.030 $\lambda_{300\text{MHz}}$, g = 0.002 $\lambda_{300\text{MHz}}$, t = 0.0064 $\lambda_{300\text{MHz}}$, r = 0.003 $\lambda_{300\text{MHz}}$ and ε_r = 10.9; where $\lambda_{300\text{MHz}}$ is the free-space wavelength at 300 MHz, which is used as a reference length. L is the patch length, W is the patch width, g is the gap width, and t is the thickness of two Arlon AR-1000 substrates, with a relative dielectric constant of 10.9. The spacing between the two layers of patches was chosen to be 0.0032 $\lambda_{300\text{MHz}}$ due to the availability of laminates of 3.2mm thickness. The length of the stripline coil is $\lambda_{300\text{MHz}}$/4 and the meanders used at both ends are similar to the ones proposed in [1]. A homogeneous phantom (ε_r = 40, σ = 0.8 S/m) is placed 2cm above the coil in order to emulate the human body at the MRI operating frequency of 300MHz. Two end capacitors are used at the end of the meanders to shift the resonance down in frequency to 300MHz. The entire height of the coil and the PEC or EBG structure is kept constant to 3.4cm.

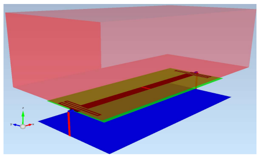

Fig. 1 stripline coil backed by a PEC

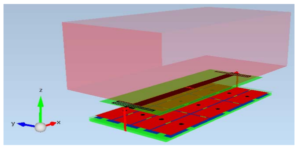

Fig. 2 stripline coil backed by 4x3 cells EBG structure, later 1x3 cells soft surface could be used

Results and Discussion

Fig. 3 shows the reflection phase coefficient of the proposed soft surface EBG structure. It is clear that for plane waves illuminating the EBG surface at oblique incidences, the reflection phase in the x-polarized direction corresponding to the MRI operating frequency, 300MHz, is about 40^0 which is still inside the useful in-phase band gap (± 90^0) reflection coefficient through which the structure works like an artificial magnetic conductor AMC. Thus, the proposed structure exhibits very high surface impedance in the longitudinal direction with a tangential magnetic field tending to zero. Similarly, the reflection phase corresponding to 300 MHz in the y-polarized direction is about 180^0 (see Fig. 3). Thus, the structure behaves similar to the PEC with very low surface impedance in the transversal direction, and hence the tangential electric field tends to zero. With respect to the dominant problem of SAR in high-field MRI, the performance of the original coil configuration based on a stripline coil over a PEC ground plane was compared in a fair manner to the performance of the design using the EBG structure as a ground plane by simulating the distribution of magnetic over electric field ratio 4cm inside a homogeneous the phantom. In Fig. 4, the stripline coil backed by the proposed EBG structure exhibits a stronger $|H|/|E|$ than the original design when the RF coil was backed by a PEC [1]. The maximal quantitative improvement in this ratio amounts to 58%. Fig. 5 and 6 show the normalized magnetic and electric field 4cm inside the phantom. These figures show the advantage of the proposed EBG structure to improve the magnetic field intensity inside the phantom while reducing the electric field. Thus the specific energy absorption rate SAR is maintained within the standard values.

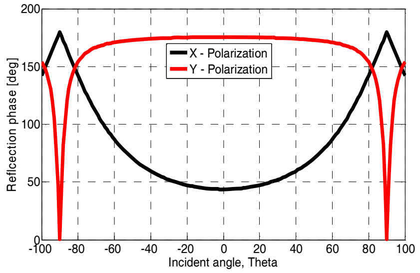

Fig. 3 Reflection phase characteristics of x- and y-polarized plane wave at oblique incidence, at 300MHz.

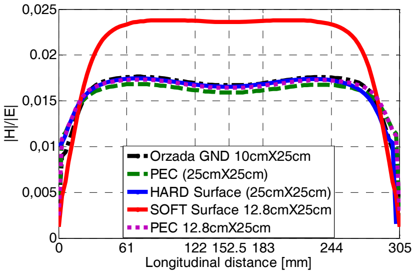

Fig. 4 The ratio of $|H|/|E|$ 4cm inside a homogeneous phantom

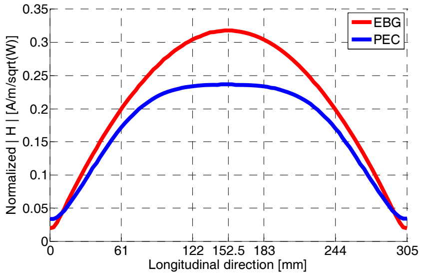

Fig. 5 Normalized $|H|$ [A/m/√W] 4cm inside the phantom

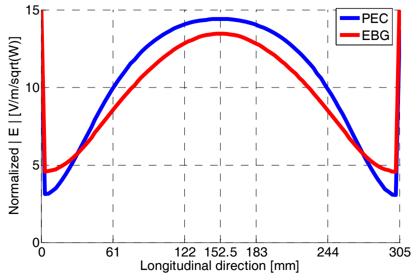

Fig. 6 Normalized $|E|$ [V/m/√W] 4cm inside the phantom

References

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