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# Passive Decoupling Techniques in Ultra-High Field MRI

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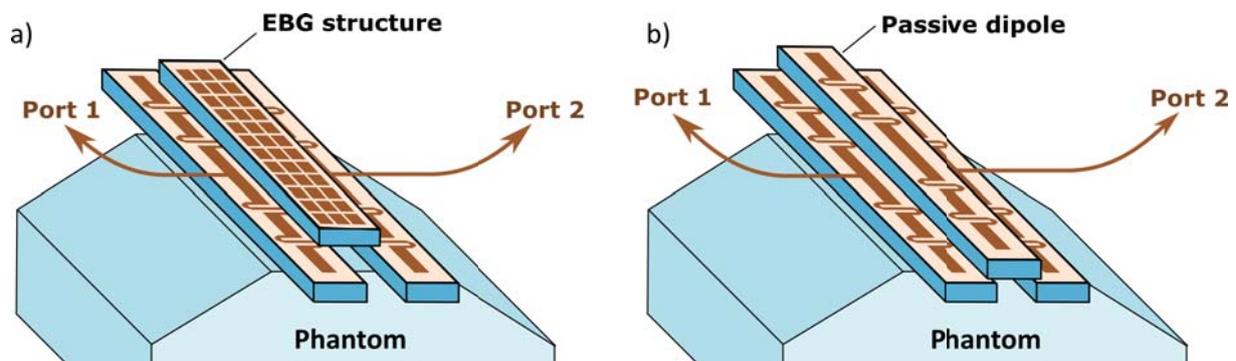
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**Abstract.** In this work a comparison of two passive decoupling techniques for ultra-high field magnetic resonance imaging (MRI) is presented. An electromagnetic band-gap (EBG) structure and a single passive dipole are compared in terms of their capabilities to decouple two active dipole body array elements at 7 Tesla at an extremely short inter-element distance. Decoupling band as well as distribution of circularly polarized radiofrequency magnetic field inside a homogeneous phantom provided with these two techniques are compared.

## 1. Introduction

Ultra-high field (UHF) MRI (over 7 Tesla) is an extensively developed tool for medical diagnostics and preclinical biomedical research. UHF imaging provides enhanced spatial resolution of images, thanks to the improved signal-to-noise ratio (SNR) ensured by extremely high static magnetic field. A complex MRI system comprises multiple blocks each one affecting SNR of images. Moreover, SNR is known to depend on the static magnetic field intensity. A radiofrequency (RF) block of an MR scanner contains so-called coils – RF antennas used for nuclei excitation and MR signal detection. In low- and high-field MR scanners volumetric coils are mostly used for excitation since they provide homogeneous RF magnetic field distribution over the whole human body. At the same time, for reception local coils are used providing high SNR over the particular region of interest (ROI). In ultra-high field MRI this strategy of using volumetric coils for transmission and local dedicated coils for reception is not feasible anymore. Due to the elevated RF signal frequency (298 MHz at 7 Tesla for instance), the wavelength inside a high-permittivity human body becomes comparable to its size (around 10 cm at 7 Tesla), which causes interference artifacts - signal voids. Therefore dedicated surface coils are used in UHF for transmission as well, mostly combined in coil arrays providing RF transmit magnetic field homogeneity over targeted ROI via parallel transmission. In this technique constructive interference of RF signal, created by multiple local RF coils is provided by the input signal phase manipulation of each coil element. Importantly all the elements of a coil array should be isolated one from another, i.e. should have a negligible mutual impedance, which is mostly not the case due to short distances between neighboring antennas. The way of mutual coupling suppression in coil arrays to be chosen mostly depends on the type of antennas comprising an array. For the magnetic-loop coil mutual inductance compensation can be achieved simply by overlapping





**Figure 1.** Two considered techniques for passive decoupling of dipole coil arrays operating at 7 Tesla: a) EBG structure ; b) passive dipole

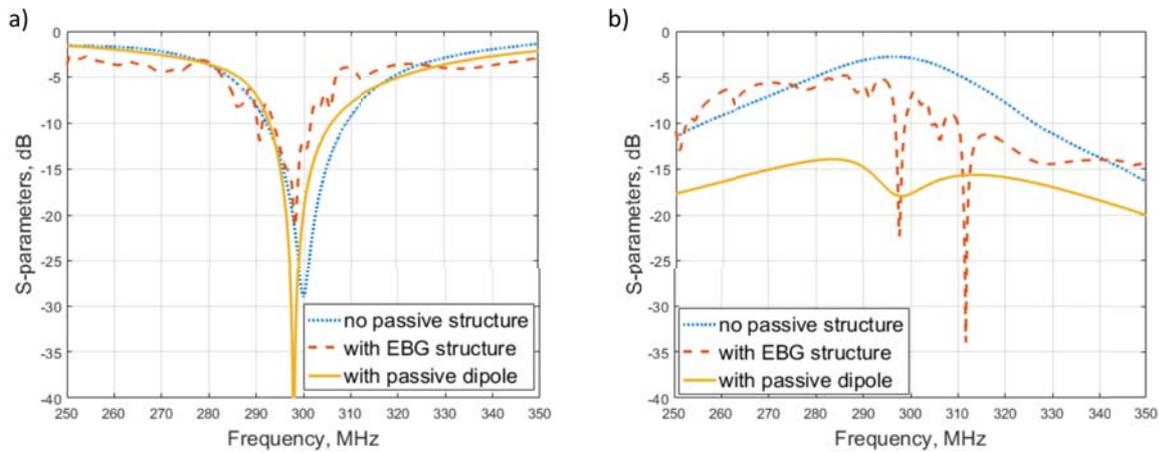
neighboring elements of an array [1]. Other passive decoupling techniques are available for loop coils such as: passive resonant loop [2], stacks of miniaturized resonators comprising so-called magnetic wall structures [3] for mutual inductance reduction. In [4] decoupling of TEM elements of head coil array by stacked magnetic resonators was demonstrated.

In this work recently demonstrated [5],[6] methods of decoupling of dipole antennas in arrays for parallel transmission at 7 Tesla are compared. A relative frequency band of decoupling as well as the intensity and homogeneity of a created circularly polarized RF transmit magnetic field ( $B_1^+$ ) are studied.

## 2. Mutual coupling reduction by EBG structure

A comprehensive analysis of using EBG structures for mutual coupling reduction of dipoles body array elements at 7 Tesla MRI was demonstrated in [5]. The employed EBG structure comprised a block of coupled periodically arranged unit cells of "mushroom" type: with a metal square patch connecting to the ground plane by a thin metal wire. Sub-wavelength operation of the EBG structure (containing  $3 \times 15$  unit cells) was provided by an additional layer of patches introducing high capacity and tuning the unit cell at the operational frequency near 298 MHz while having a period of EBG structure equal to 20 mm. One of eigenmodes of the finite structure was used for decoupling. An experimental sample of the EBG structure was build and its decoupling capabilities were tested using two fractionated dipoles [7] located over the homogeneous liquid phantom with the permittivity of 45 and conductivity of 0.25 S/m. The axes of the dipoles were separated by the distance of 30 mm. S-parameters of two dipoles were measured by the vector network analyzer. Experimental setup is depicted in Fig. 1a and its detailed description is given in [5].

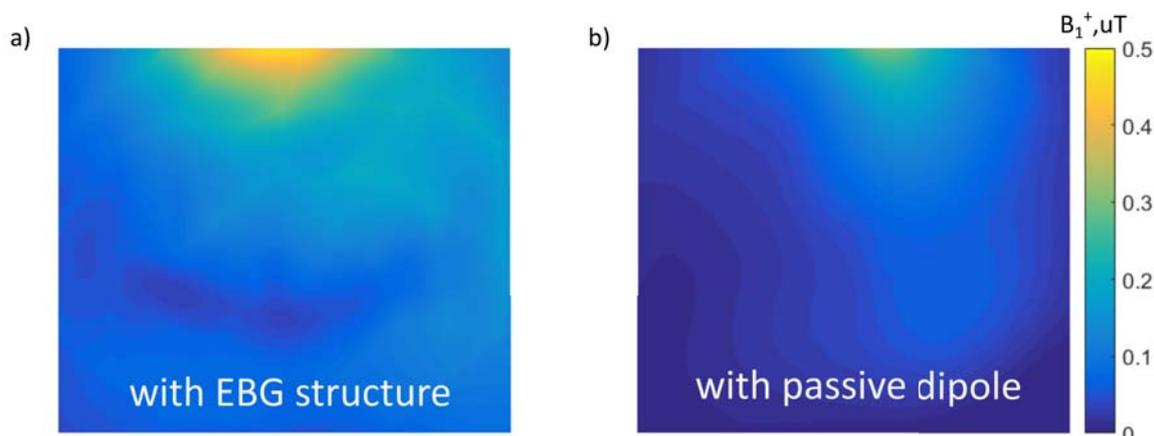
The frequency dependent reflection coefficient of two passive dipoles equipped with the EBG structure is depicted in Fig. 2a by the dashed line, while their transmission coefficient is plotted in Fig. 2b by the dashed line as well. Matching network was attached to both antennas to tune their input impedance in presence of the decoupling structure to 50 Ohm at the resonance frequency of 298 MHz. The transmission coefficient curve reveals that the relative decoupling band, where transmission coefficient is below -16 dB, is equal to 0.8 MHz. A single-frequency simulation of the above described setup was performed in CST Microwave Studio in order to evaluate the field created by the dipoles in the phantom in the presence of the EBG structure. Fig. 3a shows the transverse plane distribution of the circularly polarized magnetic field  $B_1^+$  created in the transmit mode inside the homogeneous phantom normalized to 1W of accepted power.



**Figure 2.** S-parameters of two active dipoles in the vicinity of passive decoupling structures: a) reflection coefficient; b) transmission coefficient

### 3. Mutual coupling reduction by a single passive dipole

In [6] another passive decoupling structure was studied analytically, numerically and experimentally. An analytical expression was derived using the electromotive force method determining the condition of full decoupling (for any combination of currents) of two active dipoles by a passive one, located in a middle between them. Using the aforementioned condition and analytical expressions for self- and mutual impedances of resonant dipoles, it was shown that full decoupling can be achieved within their resonance band. In this work we extended this study onto the pair of active fractionated dipoles equipped with the passive one located between them as depicted in Fig. 1b. This setup was studied numerically in CST Microwave Studio. S-parameters of the two dipoles in the frequency range of 250 – 350 MHz were calculated. The reflection coefficient of the dipoles in the presence of a passive one is depicted in Fig. 2a by the solid line, while the transmission coefficient is plotted in Fig. 2b by the solid line as well.



**Figure 3.** Transverse plane  $B_1^+$  distribution normalized to 1W of accepted power of an active dipole in the vicinity of second active dipole and a passive decoupling element (area dimensions 350 by 200 mm, frequency 298 MHz) a) EBG structure b) dipole

Both active antennas were matched virtually at 298 MHz using the schematic toolbox of CST. Regarding to the  $S_{12}$  curve the relative decoupling band is 11 MHz, where the transmission coefficient stands below -16 dB. The field  $B_1^+$  emitted by active dipoles at 298 MHz was also calculated and its transverse plane distribution normalized by 1W of accepted power is depicted in Fig. 3b.

#### 4. Discussion and conclusion

Our comparative study of the two considered decoupling techniques revealed benefits and drawbacks in both of them. The relative decoupling frequency band determined by the level of  $S_{12}$  below -16 dB is 0.8 MHz for the EBG structure, while for the passive dipole approach it is 14 times broader. Though the band provided by both the techniques is sufficient for the application in MRI. The wider band of the single dipole can be more stable with respect to variation of the phantom properties. On the other hand the numerical study of the created field in the phantom revealed the benefit of the EBG structure in terms of its effect on the level and homogeneity of  $B_1^+$ . Since unit cells of the EBG structure are extremely miniaturized (much smaller than the operational wavelength) they do not produce high scattered radiative field and therefore do not create any destructive interferences of  $B_1^+$  inside the phantom. This can be concluded from Fig. 3a, where the field produced by a dipole is similar to one produced in the absence of a decoupling structure. For the passive dipole the situation is opposite: the resonant passive dipole is an effective scatterer and creates destructively interfering fields in the bulk of the phantom reducing the efficiency of active dipoles. As can be seen in Fig. 3b this leads to a reduced level of  $B_1^+$  and a distorted field distribution with worse homogeneity. Therefore choosing the decoupling strategy is a trade-off between the bandwidth stability of radiative elements and their transmission efficiency (magnetic field magnitude normalized by an accepted power).

In this work two passive decoupling techniques were comparatively studied: the EBG decoupling structure and the passive dipole decoupling technique. Their decoupling bands as well as their impact on the transmission efficiency of active dipoles were studied. Comparative study revealed that the choice of decoupling strategy for each particular case is a trade-off between these two aspects.

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