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# Single Passive Scatter Decoupling Technique For Ultra-High Field Magnetic Resonance Imaging Application

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Abstract—In this report, decoupling conditions between two dipole antennas, created by adding either a single passive dipole or single passive split-loop resonator (SLR), for ultra-high field magnetic resonance imaging (MRI) are compared. In contrast to our previously reported work, the decoupling granted by the dipole is advantageous. We numerically and experimentally demonstrate that parasitic impact of the passive dipole on distributed magnetic field inside the phantom is smaller than that of the passive SLR.

*Index Terms*—decoupling, dipole antenna, magnetic resonance imaging.

## I. INTRODUCTION

In ultra-high field magnetic resonance imaging (MRI), due to some dimensional restrictions the distance between transceiver antennas (RF coils) can be as small as  $\lambda/30$  ( $\lambda$ is operational bandwidth). This closeness between antennas implies a very high coupling between them resulting in interchannel scattering and cross-talk between the antennas. Several researchers have presented novel decoupling techniques to reduce this decupling for two antennas in MRI application [1-7]. However, none of these techniques works properly when the distance between dipole antennas is smaller than  $\lambda/10$  (the situation for prostate ultra-high field MRI).

In our previous works, we have reported passive decoupling technique by adding a passive scatter between two diploe antennas with the gap of  $\lambda/33$  (practical distance in ultra-high field MRI) in free space [8,9]. In these works we have proved that a adding a passive resonant dipole or a passive split-loop resonator (SLR) satisfies the decoupling condition, resulting in decupling between two closely located dipole antennas. In free space, the decoupling band created by adding the passive resonant dipole. However, in MRI application, only a narrow decoupling band is satisfactory and the main goal is to reduce the parasitic magnetic field created by the scatterers.

In this report, we aim to compare parasitic magnetic fields created by added passive dipole and passive SLR inside the phantom when the distance between the dipole antennas is  $\lambda/33$ . It will be numerically and experimentally shown that compared to SLR, adding the passive resonant dipole entails



Fig. 1. Schematic view of active dipoles decoupled by a passive dipole and by a passive SLR in the presence of the phantom.

less parasitic effect on the distributed magnetic field inside the phantom.

## II. EFFECTS OF PHANTOM AND SCATTERER

In references [8,9] we have proved the deep decoupling between two closely located dipole antennas by adding a passive resonant scatterer (dipole or SLR) to the structure in free space. It was shown that the passive scatterer should be exactly located between the dipole antennas to decouple them. However, the presence of the phantom in this report kills the symmetry in the mentioned structures. Consequently, in order to keep the decoupling condition satisfied, we need to shift the passive scatterer to a distance  $h_1$  from the plane of antennas. In this situation, the dimer of the real scatterer and its quasi-static image in the phantom enable the needed symmetry again. Fig. 1 shows this situation.

Besides the need of the scatterer shift, the presence of the phantom affects the decoupling performance. Similarly, the presence of the scatterer affects the distributed magnetic field, created by antenna 1, inside the phantom. In the following we will discuss these effect separately.

#### A. Impact of Phantom on Decoupling Performance

The presence of a phantom with high permittivity (in our case  $\epsilon_r = 78$ ) in the near-field zone of the antennas and the scatterer will shift the resonance frequency of them to a lower frequency. Moreover, the phantom increases the radiation resistance of the antennas resulting in the broader bandwidth for both matching and decoupling compared to free space. In this situation, the increase of the radiation resistance cancels the advantage of the SLR compared to the dipole scatterer. Consequently, the SLR will not be advantageous over dipole scatterer for decoupling anymore (compared to the situation in free space).

## B. Impact of Scatterer on Distributed Magnetic Field Inside the Phantom

The main goal of decoupling for MRI application is to achieve the distributed magnetic field created by antenna 1 in the presence of antenna 2 inside the phantom as close as the case when antenna 2 is absent. Although the added scatterer decouple antenna 1 and 2 from each other, this scatterer also creates an arbitrary distributed magnetic field inside the phantom. In fact, the induced current over the scatterer relates to currents of both antennas [8]; so, the distributed magnetic field by the scatterer relates to antenna 2 which makes it arbitrary. Fortunately, in order to obtain decoupling in the presence of the phantom, the scatterer has to be shifted up which implies its magnetic field is not as high as magnetic field by antenna 1. All the same, the parasitic magnetic field is still significant and we have to numerically and experimentally investigate the effect of which scatterer (resonant dipole or SLR) is lower.

### **III. NUMERICAL AND EXPERIMENTAL VERIFICATIONS**

In order to prove the reliability of our method, we numerically verified our model by carring out CST Microwave Studio simulation and experimentally verified by measuring S-parameters and distributed magnetic field of a fabricated prototype. Fig.2 shows the fabricated prototype. In the simulation and measurement we used the same parameters used in references [8,9] for the antennas and the scatterers; the parameters of the phantom are tabluated in the Table; reletive permittivity and conductivity of the phantom are  $\epsilon_r = 78$  and  $\sigma = 1.59$  S/m, respectively.

<b>Hadres</b> surged of the geometric parameter	Table:	Values of	of the	geometric	parameter
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Parameter	Value (mm)	Parameter	Value (mm)
$L_W$	500	$h_p$	360
$L_1$	290	$h_o$	50
$L_p$	400	$W_p$	600
h	7	d	30
$h_d$	20	g	20

For the reference case – antennas 1 and 2 are present and the scatterer is not employed – transmission coefficients between antennas is -4 dB in the matched regime (both simulation and



Fig. 2. Schematic view of active dipoles decoupled by the passive dipole and by the SLR in the presence of the phantom.



Fig. 3. Simulated and measured result of S-parameters for the reference case.

measurement, shown in Fig. 3), and the distributed magnetic field of the goal case (antenna 2 and the scatterer are absent) at the observation point  $h_o = 50$  mm is 0.15 A/m and 0.008 A/m in simulation and measurement, respectively (we used a practical case  $h_o = 50 \text{ mm} - \text{used}$  in prostate scanning). After employing the scatterers, we preformed the simulation of S-parameters gradually increasing  $h_1$ . The optimal values of  $h_1$  for decoupled structure by passive dipole and SLR are 20 mm and 10 mm, respectively. Simulation and measurement results of S-parameters with optimal value for  $h_1$  are shown in Fig. 4 in the mached regime. For matching the structure, we used schematic tool box of CST Studio to prevent fabrication of a tunable matching circuitry for different  $h_1$  values. As shown in Fig. 4, there is a good agreement between simulation and measurement results which proves the decouling between antennas. In this situation, the decoupling band created by both scatterer are almost equal in length which shows high effect of the high permittivity phantom beneath the antennas - broader decoupling bandwidth of structure by SLR is cancelled by high permittivity of the phantom.

After finding the exact decoupling frequencies for both case, we simulated and measured distributed magnetic field inside the phantom and compared it with the goal case – only antenna 1 is present and antenna 2 and the scatterer are absent. Figs. 5



Fig. 4. Simulated and measured result of S-parameters for the decoupled structure with a passive dipole at height  $h_1 = 20$  mm and a passive SLR at  $h_1 = 10$  mm.



Fig. 5. Simulation of distributed magnetic field inside the phantom: (a) using the paasive dipole for decoupling, (b) using the passive SLR for decoupling. The value of the signal at the observation point is marked.



Fig. 6. Measurement of distributed magnetic field inside the phantom: (a) using the passive dipole for decoupling, (b) using the passive SLR for decoupling. The value of the signal at the observation point is marked.

and 6, respectively, show simulation and measurement results of distributed magnetic field (in the decoupled frequency) produced by antenna 1 when antenna 2 is connected to a match load. Figs. 5 and 6 demonstrate that the value of distributed magnetic field at the observation point in the case of using the passive dipole is closer to the goal case compared to the case of using the passive SLR (the same referes to the whole scanning area) The magnitutde of simulated distributed magnetic field at the observation point in the case of the passive dipole and the passive SLR are 0.17 A/m and 0.1 A/m, respectively (the goal value is 0.15 A/m). The magnitutde of measured distributed magnetic field at the observation point in the case of the passive dipole and the passive SLR are 0.008 A/m and 0.004 A/m, respectively (the measured goal value was 0.008 A/m). Mostly, this advantage of the passive dipole is due to its higher distance to the body compared to the case of the passive SLR.

## IV. CONCLUSION

In this report, passive decoupling between two closely located dipole antennas by adding either a passive resonant dipole or an SLR in presence of a phantom has been studied numerically and experimentally. In the presence of the phantom, the scatterer has been shifted up to satisfy the decoupling condition. We have compared the performance of the dipole and the SLR and in order to choose the better of two decoupling scatterers the main attention is paid to the magnetic field inside the phantom, distorted by the decoupling scatterer. From this perspective, the passive dipole is more advantageous than the SLR. The main reason for this advantage is that the decoupling condition holds for higher shift of the dipole than for the SLR, resulting in lower magnetic field inside the phantom due to the scatterer.

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