Parasitic Element Based Decoupling Network for a Two-Element MRI Phased Array

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***Abstract*—A parasitic-element based Decoupling Network (DN) for 7-Tesla Magnetic Resonance Imaging (MRI) phased arrays is presented to compensate for the effect of mutual coupling between array active elements. The DN network consists of an open circuited parasitic element in parallel between a two-element MRI array, each element in the array is a rectangular loop-shape microstrip transmission line Radio Frequency (RF) coil. L-shaped tunable matching network is integrated, the whole structure is optimized to operate at the resonant frequency of the 7-Tesla MRI system. Numerical modeling of the whole structure is carried out using CST to characterize and verify the performance of the open circuited parasitic element based decoupling network for a two-element MRI array.**

***Index Terms*—Decoupling network, MRI phased array, parasitic element, RF coil, and tunable matching network.**

I. Introduction

Phased arrays in MRI is an important issue due to the rapid development in the parallel MRI techniques [1], and [2], by which the imaging time becomes shorter and the signal-to-noise ratio is enhanced over a wider coverage area. Phased arrays in MRI suffer from the effect of mutual coupling between array elements same as antenna arrays used in wireless communications. In [3-5], a reactive-element based Decoupling Network (DN) to compensate for mutual coupling was presented for two-, three- and four-element arrays based on the theory of the eigenmodes. To decouple an N-element array, matching all eigenmodes admittances is required. In [6], perfect decoupling between two arbitrary spaced antennas has been proposed using a reactively loaded parasitic element in between the array two active elements. Tuning the reactive load of the parasitic element in addition to the dimensions of active and parasitic elements has provided good port isolation over a narrow frequency band. In [7], good port isolation over a wider frequency band is obtained by replacing the reactively loaded parasitic element in [6] with short circuited parasitic elements. By optimizing the whole structure, good port isolation over a wider frequency range is obtained for a given array elements spacing without extending the overall area. However, phased arrays in MRI are a little bit different from antenna arrays in wireless communications, such as their near-field and their very small element spacing (approximately 0.1 wavelength compared with 0.5 wavelength in wireless communication arrays). Therefore, MRI phased arrays are more sensitive to mutual coupling effect in comparison of communication arrays. In MRI phased arrays, the mutual coupling increases as the separation between array elements decreases [8]. In [8], a reactive elements based decoupling network was presented for a two-element MRI array, where each element in the array is a rectangular loop-shape microstrip transmission line RF coil. The reactive elements are chosen to be two inductors inserted in parallel between the two RF coils. A return loss of -31.46 *dB* at 298.08 MHz is obtained and an isolation of more than 23 *dB* is obtained over a frequency band [297.93 MHz-298.23 MHz].

In this paper, the concept of parasitic decoupling elements is applied to the two-element MRI array to obtain good port isolation between the two array active elements. Instead of reactively loaded parasitic element [6], an open circuited parasitic element is proposed. By proper choice of parasitic element position and dimensions in addition to the active elements dimensions, port isolation is obtained for a given array elements spacing without extending the overall area. In a two-element MRI array, each active element in the array is a rectangular loop-shape microstrip transmission line RF coil consists of four microstrip lines connected in a rectangular shape through lumped capacitors in serial on the top layer of a grounded dielectric substrate [9].

II. Design Of A Parasitic Element Based Decoupling Network

Consider an array of two active elements and one open-circuited parasitic element in between. The two active elements of the array are identical and each element is a rectangular loop-shape RF coil. The RF coil dimensions are 13 cm × 13 cm. The RF coil is modeled as copper with the conductivity of 5.8×10^7 S/m. The coil was built for 7 Tesla MRI, corresponding to the resonance frequency of 298.3 MHz. The substrate is polytetrafluoroethylene (PTFE), which has ($\varepsilon_r = 2.1$, dielectric loss tangent <0.0002 and dielectric thickness$=1.2$cm. The microstrip line width = 1.2 cm. The two RF coils are separated by 1 cm (0.01 λ). The lumped capacitors are C_1, C_2 and C_3. Each RF coil is connected to the tunable L-shaped lumped elements matching network to match to the source impedance of 50 Ω. The L-shaped matching network consists of series and shunt capacitors (C_{serial}, and C_{shunt}). The RF coils are excited by microstrip line feed. Between the two RF coils, an open circuited microstrip transmission line of length 17 cm and width 0.5 cm is inserted as a parasitic element to compensate for the effect of mutual coupling between the array two active elements. The active elements for MRI system are RF coils. The structure of the two-element MRI array with a parasitic element based decoupling network and an L-shaped matching network is shown in Fig.1. The whole structure is designed and simulated using CST.

The terminal currents and voltages are related through the admittance matrix as [10]

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} & y_{13} \\ y_{21} & y_{22} & y_{23} \\ y_{31} & y_{32} & y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \quad (1)$$

The open circuited condition for the parasitic element implies that $I_2 = 0$, and due to reciprocity, $y_{ij} = y_{ji}$, where $i \neq j$, $\{i, j = 1,2,3\}$. Substituting into (1) and rearrangement, the voltages and currents of array active elements are related as

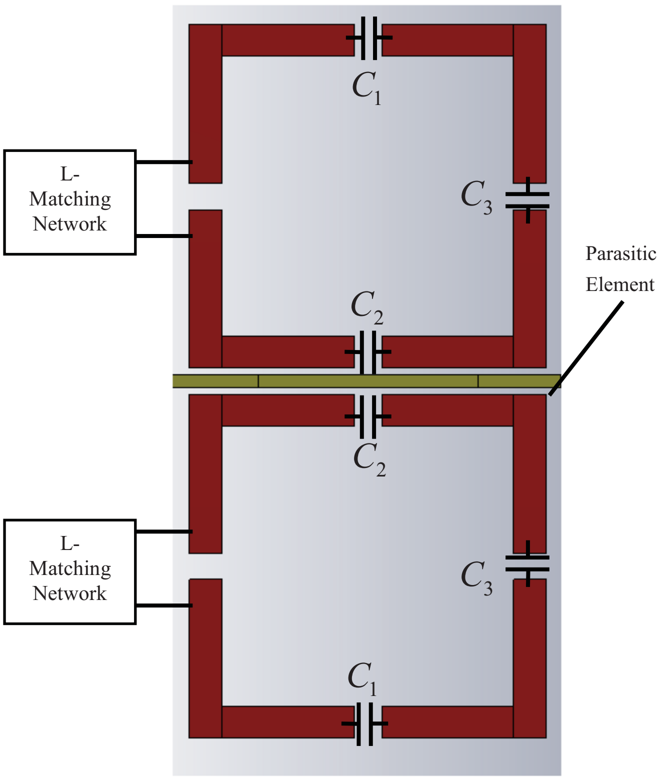


Fig. 1. Schematic diagram of a two-element MRI array with a parasitic-element based decoupling and matching network.

$$\begin{bmatrix} I_1 \\ I_3 \end{bmatrix} = \begin{bmatrix} y'_{11} & y'_{13} \\ y'_{13} & y'_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_3 \end{bmatrix} \quad (2)$$

where,

$$y'_{11} = y_{11} - \frac{y_{12}^2}{y_{22}}$$
$$y'_{33} = y_{33} - \frac{y_{23}^2}{y_{22}} \quad (3)$$
$$y'_{13} = y_{13} - \frac{y_{12}y_{23}}{y_{22}}$$

for identical array elements

$$y_{12} = y_{23}$$
$$y'_{11} = y'_{33} \quad (4)$$
$$y'_{13} = y_{13} - \frac{y_{12}^2}{y_{22}}$$

Now the impedance matrix and the admittance matrix are related as

$$\begin{bmatrix} z'_{11} & z'_{13} \\ z'_{13} & z'_{11} \end{bmatrix} = \begin{bmatrix} y'_{11} & y'_{13} \\ y'_{13} & y'_{33} \end{bmatrix}^{-1} \quad (5)$$

For decoupled ports the condition $Z'_{13} = 0$ should be satisfied which implies that y_{13} should equal to y_{12}^2 / y_{22}. Tuning the parasitic element position and dimensions, the lumped capacitors $C_1, C_2,$ and C_3 connected between the cascaded microstrip line elements and the serial and shunt capacitors of the tunable L-shaped matching network will compensate for the mutual coupling between array active elements for good matching at the resonant frequency of 7-Tesla MRI system.

All optimized values are summarized in Table I. The scattering parameters of the two-element MRI array with the decoupling matching network are simulated using CST. A return loss of -22.669 dB and an isolation of 18.531 dB are obtained at 298.28 MHz, as seen in Fig.2.

For comparison, the scattering parameters of the two-element MRI array without the parasitic element based decoupling network are shown in Fig.3. Without a decoupling network, a return loss of -19.707 dB and an isolation of less than 7 dB are obtained at 298.18 MHz. By inserting a parasitic element between the two RF coils of the MRI array as shown in Fig.1, the isolation between the ports is enhanced by more than 11 dB. In addition, the return loss is better matched at the resonant frequency of 7-Tesla MRI system.

TABLE I
LUMPED CAPACITORS, AND DECOUPLING AND MATCHING NETWORK OPTIMIZED VALUES

Lumped Capacitors			*L-Matching Network*		*Decoupling Network*	
C_1	C_2	C_3	C_{series}	C_{shunt}	L	W
4.82 pF	4.22 pF	5.54 pF	3.1 pF	12.2 pF	17 cm	0.5 cm

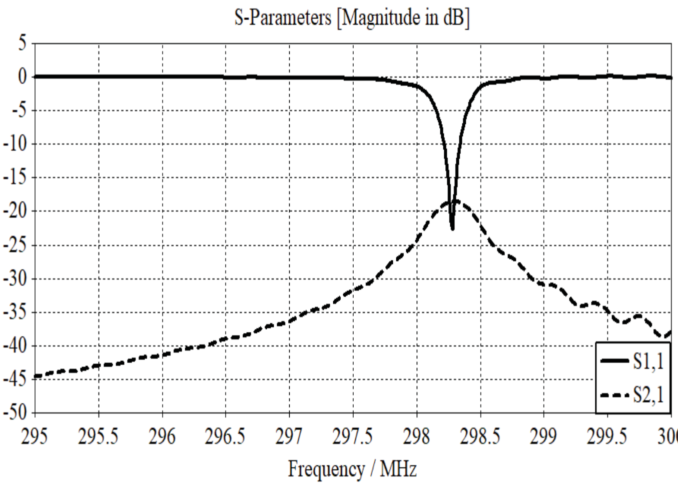


Fig. 2. Scattering parameters of the two-element MRI array with a parasitic-element based decoupling and matching network.

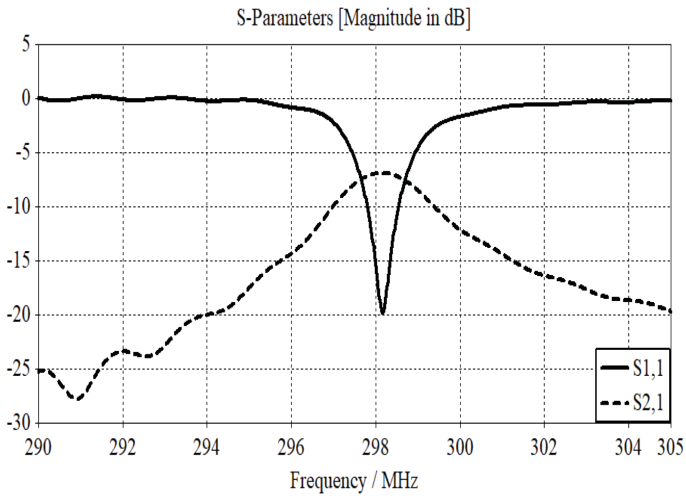
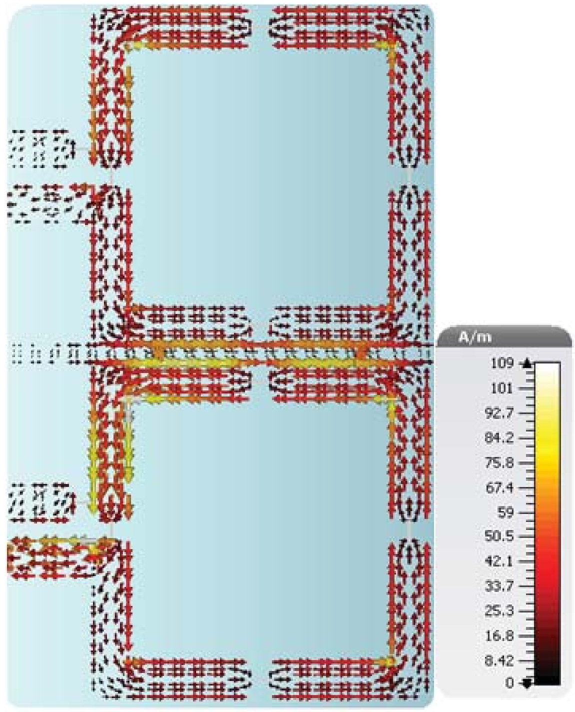
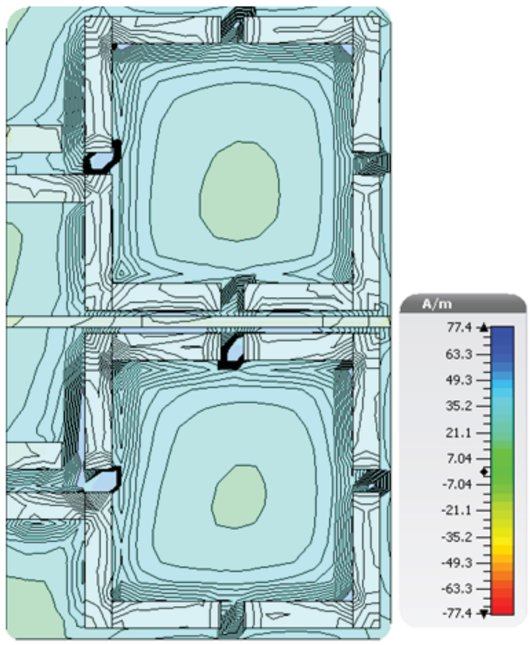


Fig. 3. Scattering parameters of the two-element MRI array without a decoupling network.

The maximum surface current and magnetic field for the two-element array with a parasitic element based decoupling and matching network are also simulated using CST and demonstrated in Fig.4 at 298.28MHz. As it can be seen in Fig.4(a), the current magnitude is uniformly distributed along the RF coil without phase shift. Fig.4 (b) shows the distribution of the magnetic field which has a constant instantaneous amplitude distribution along the RF coil.



(a)



(b)

Fig. 4. Simulated maximum (a) surface current, and (b) magnetic field at 298.28MHz.

III. CONCLUSION

In this work, a parasitic-element based decoupling network is designed and simulated in CST to decouple a two-element MRI array. Each element in the array is a rectangular loop-shape RF coil. The parasitic element is a microstrip line with length 17 cm and width 0.5 cm. The parasitic element is inserted between the two RF coils without direct connection to the array elements as in the case of the reactive element based decoupling network. By optimizing the decoupling network and the L-shaped matching network, a return loss of -22.669 dB at 298.28 MHz is obtained and an isolation of more than 18 dB is obtained over a narrow frequency band [298.21 MHz-298.34 MHz] compared to the isolation of less than 7 dB for the case of the two-element MRI array without a decoupling network.

The maximum surface current and magnetic field for the two-element array with a parasitic element based DN are also simulated using CST. Results show a uniform current distribution along the RF coil and this current produces a uniform magnetic field.

REFERENCES

[1] Sodickson D.K., Manning W.J., "Simultaneous Acquisition of Spatial Harmonics (SMASH): Fast Imaging with Radiofrequency Coil Arrays", *Magn. Reson. Med.*, pp. 591–603, vol. 38, no. 4, Oct. 1997.

[2] Roemer P.B., Edelstein W. A., Hayes C.E., Souza S.P.,and Mueller O.M., "The NMR Phased Array", *Magn. Reson. Med.*, pp. 192–225, vol. 16, no. 2, Nov.1990.

[3] Coetzee J.C., and Yu Y., "Closed-form design equations for decoupling networks of small arrays", *Electronics Letters*, vol. 44, no. 25, Dec. 2008.

[4] Chua P.T., and Coetzee J.C., "Microstrip decoupling networks for low-order multi-port arrays with reduced element spacing", *Microwave and Optical Technology Letters*, pp. 592-597, 2005.

[5] Salama S., and Solbach K., "Design of decoupling network for monopole four sqaure array antenna for multi-beam applications," LAPC 2013, Loughborough, UK, Nov. 2013.

[6] B. K. Lau, and J. B. Andersen, "Simple and efficient decoupling of compact arrays with parasitic scatterers," IEEE Transactions on Antennas and Propagation, Vol. 60, No. 2, February 2012.

[7] S. Salama, and K. Solbach, "Parasitic Elements Based Decoupling Technique for Monopole Four Square Array Antenna", European Microwave Conference EuMC2014, Rome, Italy, October 2014.

[8] S. Salama,"Reactive-Element Based Decoupling Network for a Two-Element MRI Phased Array",Journal of King Saud University-Engineering Sciences JKSU, May 2018. (accepted)

[9] Salama S., "Design of a Rectangular Loop-Shape RF Coil for 7-Tesla Magnetic Resonance Imaging," APMC 2017, Kuala Lumpur, Malysia, Nov. 2017.

[10] David M. Pozar. Microwave Engineering. Hoboken, NJ, USA: Wiley, 2005.