Suppression of the Mutual Coupling Between Two Adjacent Miniaturized Antennas Utilizing Printed Resonant Circuits

Young Jun Song* and Kamal Sarabandi
Radiation Laboratory
Department of Electrical Engineering and Computer Science
University of Michigan, Ann Arbor, MI, 48109-2122
{yjsong, saraband}@eecs.umich.edu

Introduction

The isolation between antennas is a critical parameter in many practical applications such as antenna arrays, multiple input and multiple output (MIMO) communication systems, and integrated antenna systems. However, the close spacing between each of antennas generates the cross talk factor, and it restricts the integration of antenna system. Various methods have been studied to improve the mutual isolation. Mainly these can be divided by two approaches. The first method is to use the artificial material to change the property of material. For example Mushroom-like structure can suppress the mutual coupling by introducing the negative refractive index [1], [2]. However, this type of approach needs a large dimension of structure and a large number of periodicity, therefore it is difficult to suppress the coupling of small system which operates at low frequency. Another approach is to put the metamaterial insulators to block the EM energy from being transmitted across the insulation boundary [3]. This metamaterial insulator consists of magneto-dielectric embedded circuits which can be modeled as a resonant circuit (parallel LC). Since the inductance is determined by the loop area, the dimension of this metamaterial insulator can be reduced to $\lambda_0/20$. However, this structure involves an intricate fabrication process to be embedded on the substrate [3]-[5]. To address this problem, a new type of approach is proposed in this paper. By using the printed circuit technology and vertical vias, we can decrease the complexity of fabrication process. Furthermore, by utilizing the parallel resonant circuits, this proposed approach can achieve the improvement of isolation between two closely spaced miniaturized antennas with a small dimension of structure and small number of periodicity. The response of the proposed structure is demonstrated through extensive numerical simulations using a commercial finite element method (FEM) solver.

Operation Mechanism

In this paper, we place the resonant coupled elements between two adjacent antennas to create an additional coupling to suppress the wave propagation through the substrate. These elements consist of the array of closely spaced single pole resonant cells. The geometry of the proposed unit cell is shown in Fig. 1.

978-1-4244-3647-7/09/$25.00 ©2009 IEEE

According to the image theory on the ground plane, the unit cell acts like a square loop as shown in Fig. 2. Assuming the fundamental mode of waves propagates from one antenna to the other antenna, the electric current is induced due to the magnetic flux linked by the loop. This electric current generates a magnetic field which is perpendicular to the loop, therefore we can put a Perfect Magnetic Conductor (PMC) planes on the sides of the unit cell when the spacing between loops is small. According to the image theory, the loop in the PMC walls generates an infinite array which resembles an infinite toroid with $1/d$ turns per meter, where d is the spacing between each cells, and it behaves as an inductor. By connecting the capacitor to the inductor, the array behaves like a parallel LC resonant circuit and suppresses the wave propagation form one antenna to the other antenna. Since the operation frequency of the array is determined by the resonant frequency, it is strongly sensitive to the variation of inductance and capacitance. Instead of using a lumped capacitor, we can utilize the printed interdigital capacitor to decrease the variation of parameters and the fabrication complexity.

Design and Results

Based on the qualitative description provided in the previous section, we can derive the inductance of the loop and capacitance of the interdigital capacitor. The self inductance of the square loop as shown in Fig. 2 can be obtained from [6]

$$\mathrm{L_s} = \frac{\mu_r \mu_0 \mathrm{A_{loop}}}{d} \tag{1}$$

where $\mathrm{A_{loop}}$ is the internal area of the loop, and d is the spacing between each cells. The capacitance per unit length of two thin co-planar strips can be obtained from [6]

$$\mathrm{C} = \frac{\varepsilon_r \varepsilon_0 K\left(\sqrt{1-g^2}\right)}{K(g)} \tag{2}$$

where $g = h/(h+w)$, h is the half of the spacing between two strips, w is the width of the strip, and K is the complete elliptic integral defined by

$$K = \int_0^{\pi/2} \frac{d\phi}{\sqrt{1-\mathrm{g}^2 \sin^2\phi}} \tag{3}$$

Hence, the self capacitance can be calculated from $\mathrm{C_s} = \mathrm{C} l_{\mathrm{cap}}(\mathrm{n}+1)$, where l_{cap} is the overlapped length of two strips, and n is the number of branches of interdigital capacitor. The parameters' values for a proposed design are shown in Table 1. Using these design parameters, FEM simulations are performed.

Table 1 Design parameters

h_{loop}	l_{loop}	d	h	w	l_{cap}	n
62 mil	246 mil	32 mil	4 mil	4 mil	151 mil	2

For the fabrication, we used the printed circuit technology to implement the interdigital capacitor and vertical via holes which are plated with copper on the commercial dielectric substrate (62-mil-thick Rogers RO-5880). The length and height of one unit cell are $\lambda_0/20 \times \lambda_0/75$ (6.2mm × 1.6mm) respectively, and the corresponding inductance and capacitance of the unit cell are 15.2132 nH and 0.3098 pF respectively. The array of resonant elements is placed between two closely spaced antennas and the overall geometry is shown in Fig. 3. The array incorporates twenty five elements of the unit cell.
To test the isolation capabilities of the proposed design, a commercial FEM solver (HFSS ver. 11) was employed. Without the array of resonant elements, the closely spaced antennas cause extremely strong mutual coupling due to the substrate trapped waves. When the array of resonant elements is inserted to this simulation, a 40 dB of isolation is observed in the power transfer parameter S21 as shown in Fig. 4. The proposed array of resonant elements achieves the 30 dB of improvement of isolation over the entire band of interest.

Conclusion

In this paper, a new array of coupling elements to enhance the isolation between two miniaturized antennas is presented. The dimension of the unit cell is $\lambda_0/20 \times \lambda_0/75$, which can be incorporated with the closely spaced antenna system. Furthermore, the interdigital capacitor and vertical vias solve the fabrication complexity by using the printed circuit technology.
Simulations indicate that with Rogers RO-5880 dielectric substrate, this array can achieve the -40 dB of isolation between two antennas at the resonant frequency and improve the isolation level of mutual coupling to -30 dB. Although the array and miniaturized antennas have been physically fabricated and verified, there is a mismatch problem on the antenna. Once this matching has been solved, the final array can be measured for presentation at conference.

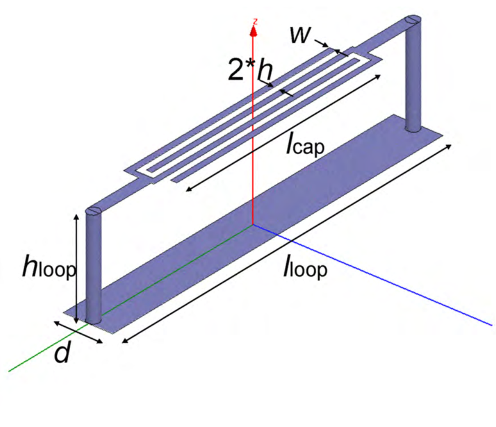

Figure 1 Unit cell of the proposed resonant elements on the ground plane and design parameters.

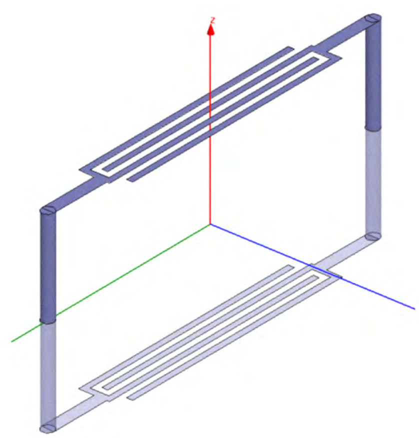

Figure 2 Unit cell structure composed of a square loop and interdigital capacitors after applying the image theory.

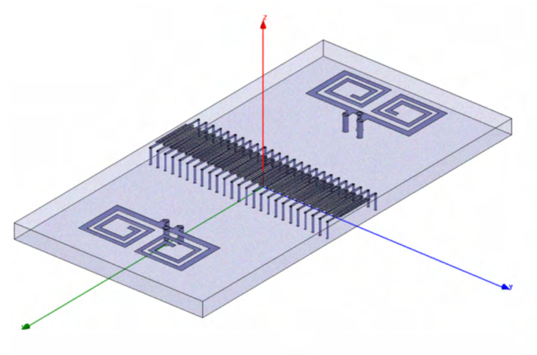

Figure 3 Proposed design incorporated with two adjacent miniaturized antennas.

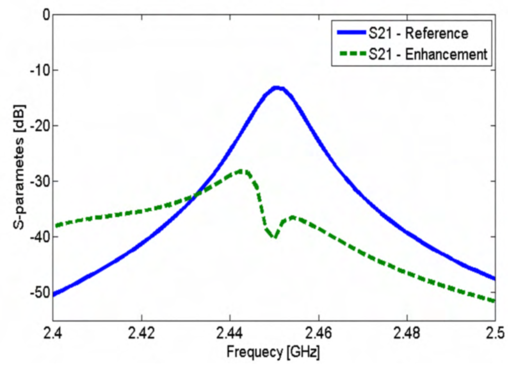

Figure 4 Enhancement of isolation between two adjacent miniaturized antennas.

References

[1] D. Sievenpiper, L. Zhang, R. F. J. Broas, N. G. Alexopolous, and E. Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band." *IEEE Trans. Microwave Theory Tech.*, vol. 47, no. 11, pp. 2059-2074, Nov. 1999.

[2] F. Yang and Y. Rahmat-Samii, "Microstrip Antennas Integrated With Electromagnetic Band-Gap (EBG) Structures: A Low Mutual Coupling Design for Array Applications," *IEEE Trans. Antennas Propag.*, vol. 51, no. 10, pp 2936-2946, Oct. 2003.

[3] K. Buell, H. Mosallaei, and K. Sarabandi, "Metamaterial Insulator Enabled Superdirective Array," *IEEE Trans. Antennas Propag.*, vol. 55, no. 4, pp 1074-1085, Apr. 2007.

[4] K. Sarabandi and H. Mosallaei, "Novel artificial embedded circuit meta-material for design of tunable electro-ferromagnetic permeability medium," *IEEE Int. Microwave Symp.,* Philadelphia, PA, Jun. 8-13, 2003.

[5] K. Buell, H. Mosallaei, and K. Sarabandi, "A Substrate for Small Patch Antennas Providing Tunable Miniaturization Factors," *IEEE Trans. Microwave Theory Tech.*, vol. 54, no. 1, pp. 135-146, Jan. 2006.

[6] H. Mosallaei and K. Sarabandi, "Design and Modeling of Patch Antenna Printed on Magneto-dielectric Embedded-Circuit Metasubstrate," *IEEE Trans. Antennas Propag.,* vol. 55, no. 1, pp. 45-52, Jan. 2007.