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Cover Page Footnote
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ELECTROMAGNETIC INTERFERENCE REDUCTION OF HIGH-SPEED DIGITAL AND ANALOG CIRCUITS USING ENGINEERED ELECTROMAGNETIC BANDGAP STRUCTURES

Brandon S. Ramos
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ABSTRACT

In this paper, we will discuss the concerns of a microstrip two patch antenna system. Coupling of the two-port system can be miniaturized using Electromagnetic Bandgap Structures (EBG) or Defected Ground Structures (DGS) centered between the two patch antennas half a wavelength in size. Different miniaturization methods were used in the design of the antenna system to change the properties of the signal. Changing via locations that are not found on EBG strips themselves, rather found on interleaved ledges between EBG strips allowed for further change in shifting the signals frequency.

INTRODUCTION

Electromagnetic radiation of high-speed digital and analog circuits is considered one of the most critical challenges to the electromagnetic interference (EMI) compatibility and reliability of electronic systems. The continuous decrease in power supply in digital circuits increases their vulnerability to external electromagnetic interference. At the same time, the increase in speed in digital and analog circuits increases the potential of the circuit to radiate, thus compromising its compatibility potential while also increasing its security vulnerability. Switching noise due to EMI is one of the major concerns for electromagnetic compatibility (EMC) engineers in modern designs.

Electromagnetic interference is a complex mechanism that takes place at different levels including the chassis, printed circuit boards (PCBs), components, and finally, the device level. Radiation sources typically include trace coupling, cables attached to the boards, components such as chip packages and heat sinks, power busses and practically anything that can provide a low impedance current path at the low impedance the current is high leading to a higher EMI.

As the speed of modern high-performance digital circuits increases rapidly, their energy consumption increases as well. The required energy is provided by power planes embedded in the multilayer structure of the board. These power planes induce radiation in a manner highly analogous to the way antennas radiate. For example, in patch antennas and in printed circuit boards, radiation is induced by a time-varying fringing electric field at the edges of the board. There are studies that describe this phenomenon [1] and others characterize this phenomenon analytically and through numerical simulations [2].

Using a microstrip antenna can be an advantage since they are able to radiate well due to its thin substrate and resonance frequency. As the substrates’ thickness decreases, the patch antenna tends to radiate less due to image cancellation. The numerical analysis method used for modeling
computational electrodynamics is called the Finite Difference Time Domain [3] (FDTD) method used in the Computer Simulation Technology (CST) software.

1. MATERIALS AND FIRST MODEL

Materials and Laminates are received from Rogers Corporation and Given on the Data Sheet for the RO3000 Series Circuit Materials, The RO3006 Laminate [4] was the sheet used in prototyping. The Dielectric Constant, $\varepsilon_r$ Design of 6.50 and a standard thickness of 1.28mm. Changing the width and length of our patch antennas, we can produce a matching at 5.8GHz (WIFI frequency) using the equations [5]

$$Width = \frac{c}{2f_0}\sqrt{\frac{\varepsilon_r + 1}{2}}$$

$$Length = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right)\left(\frac{W}{\varepsilon_{eff} + 0.3} + 0.264\right)$$

In the equation, an infinite ground plane is considered. Adjustments in the parameters must be taken into consideration in order to produce accurate results in our matching parameters. For the model, we give a ground plane and substrate length of (10cm) squared. A rectangular patchs’ bandwidth is directly proportional to the patch width. Whereas the bandwidth is inversely proportional to $\varepsilon_r$. To avoid problems with the (0,2)mode, $W<2L$. The feeding method will be a direct coaxial feed from the ground, through the substrate. Using this method is directly compatible with the coaxial cable and it is easy to acquire an input match by shifting the feed position across the x-axis. Initially, keeping in mind $\varepsilon_{r,f,h}$ we find $W$ to be 13.35mm and $L$ to be 9.788mm. The feed is centered in the middle of the patch which little to no resonance. By conducting a parametric sweep with the port from 0mm to 2mm as a shift away from the center. The results are shown in Figure 1.
Figure 1. Single patch antenna on a grounded dielectric slab.

Figure 2. Comparison of the $S_{11}$ where the direct feed from the ground to plane is shifted.

Shown in the Figure 2, the matching is around 4.2GHz. In order to shift the frequency to 5.8GHz, we decrease $W$ that in return changes the e-fields increasing frequency. By leaving the feed to be shifted at 1.5mm, we conduct a parametric sweep from 9.2mm to 9.8mm. The matching aligns with 5.8GHz when we are close to 9.44mm as shown in Figure 3. Scattering Parameters. At the center frequency, we obtain a 1% bandwidth.
To best optimize the single patch antenna design, we do a parametric study to find the best matching between the antennas. After the study it was found to have great and precise matching with feed_x at 1.6mm and w_strip to be 9.44mm we get Figure 4.

Figure 3. Scattering Parameters of the width of patch

Figure 4. The Scattering Parameter of S_11 of a single port network where feed_x=1.6mm and the matching exceeds -10dB threshold for communication.
2. TWO PATCH ANTENNA

Next model shown in Figure 5, is remodeled from the single patch antenna to a two-port network. Keeping \( \frac{1}{2} \lambda_0 \) from each patch, we find the wavelength from \( \lambda_0 = \frac{c}{f_c} \) where we acquire the wavelength in free space to be 51.68mm. From the center points of each patch, the space between the antennas will be approximately 26mm not including the width of the patches. Including the patches width, there will be 16.50mm of space, taking into consideration that limited amount of space will be available due to later compact EBG structures [6] That in mind, the closer the structures are to the patches, the more of an interference there becomes with the radiation patterns of free space. Below is the two-patch antenna design with a 16.5mm free gap.

![Two-Patch planar antenna printed on a dielectric slab](image)

Figure 5. Two-Patch planar antenna printed to a dielectric slab.

Looking at its scattering parameters of the two-patch antenna in Figure 6, we can see that we have good matching below the -10dB matching threshold. The coupling from the second port is expected, with surface and linear waves propagating from the antenna, there will be significant coupling which is unwanted. This is where the EBG structures can be effective in the antenna design.

![Scattering Parameter of two-port network](image)

Figure 6. Scattering Parameter of two-port network. Significant coupling can be seen radiating though S_21 where S_11 has a 1% relative bandgap occurring at \( f_c \)
3. EBG CHARACTERIZATION METHODS

To begin the implementation of the EBG structures, we simulate the results of the structures outside of the antenna model. This saves the cost of simulation time. First model that is made is a periodic strip of metal inside of a cell as shown in Figure 7. That cell is transformed on the x-axis both ways by 3 cells for a total of 7 strips. Using methods by moving the vias in the x-axis we move the via onto the edge of the metal strips [7]. This not only provides miniaturization methods, but also proposes an increase in bandwidth. As shown in Figure 7, we have two waveguided ports on each end of the x-axis. The extensions are determined by the variables $f, \varepsilon_r$ and the constant $c$. 

$$\lambda_0 = c/f \Rightarrow \lambda_g = \lambda_0/\sqrt{\varepsilon_r}$$

In this case the extension comes to 20mm. An increase of the extension by 10mm is expressed to be cautious that the substrate extension was greater than $\lambda_g$.

Figure 7. Characterization of EBG structure in a waveguided port: strips with no ledges but vias are shifted towards the edge of the strips.

Another proposal for an EBG structure is one with interleaved ledges alongside each strip periodically as shown in Figure 9. Starting off the model as one single cell and transposed in both directions three times and vias shifted onto those ledges allows for further miniaturization of not only the width of the strips, but also the antenna model in later designs.

Figure 8. EBG structure with no ledges containing a 3% relative bandgap at $f_c$ below threshold.
Figure 9. EBG structure with ledges on the edge of the strips. Allows for further reduction of the strip width.

Figure 10. $S_{11}$ and $S_{21}$ from the interleaved ledged EBG structure. Receiving a relative bandwidth of 6% at $f_c$.

4. IMPLEMENTATION OF EBG STRUCTURES

First model shown in Figure 11 is the EBG structures that has been shown in Figure 7. Implementation of EBG structures has shown to reduce coupling in other studies [8] Where the $w_{\text{strip}}=4.8\text{mm}, \text{gap}=1.5\text{mm}$ leaving no room for a third EBG strip for filtering coupling. Shifting of the vias can only be moved at most towards the edge of the strips.
By comparing the coupling from the two-patch antenna model in earlier simulations, there is shown to be a -17dB decrease at $f_c$ using an EBG structure with two metal strips with vias shifted off from the center. Coupling shown in Figure 12 drops down to -32dB with matching reaching -27dB. Complete communication transfer below -20dB can be seen using periodic EBG structures [9].

The second model shown in Figure 13 is the EBG structure demonstrated in Figure 9. Rather than an increased strip width we deduct the strips width by the usage of the miniaturization methods [10] This brings the width of the strip to be 2.9mm in size and a bandwidth percentage of 2%. What can also be seen in the model is more space for additional strips to be added for filtering. However, in order to minimize the size of the patch antenna and to prevent interference with the radiation patterns, we keep only 2 structures and later reduce the distance between the two-patch antennas.
Figure 13. Two-Patch antenna with two interleaved EBG strips.

Figure 14. $S_{21}$ reduction of relative coupling reduces to -19dB, a -4dB decrease while keeping the distance between patches 26mm.
Reduction of the relative coupling at the center frequency in Figure 14. shows that the coupling from $S_{21}$ did not reach the -20dB threshold. However, the -1dB difference will not be significant considering that the EBG structure has a -4dB decrease already apart from not using structures shown in Fig. 6. This gives a relative bandwidth of 2% when integrated to the model.

As said before, keeping the two strips instead of three leaves more space between the patches and the EBG structures. Keeping a close eye on radiation patterns, decreasing the distance between the patches from 26mm to 20mm. The reason for watching radiation patters is because where the antenna radiates is where the information from the antenna is transmitted to. If radiation patterns are distorted, this could decrease the antennas ability to transmit information. The reduction in distance to less than half a wavelength in size will have different effects on the model. Minimizing the structure will allow for the use of a more compact design but the tradeoff is that it will have more communication interference with itself. The EBG structure can reduce relative coupling of the system. This can be described by the characterization of the EBG structures alone and then simulated when it has been integrated onto the patch antenna.

Comparing the model that has 26mm to the 22mm model shows that the EBG structure does have its own unique reduction of -4dB, Fig. 15. shows that $S_{21}$ for 26mm has a greater decoupling than $S_{21}$ for 22mm. This can be deceiving because the two-patch antenna with 26mm of spacing looks as if it does a better job decoupling. Considering that both models are using the same EBG structure and the only variable that changed was the distance between the two patches, we can safely conclude that it is because of more interference. The closer the two patches are to each other, the greater the $S_{21}$ coupling will be between them. Using the EBG structure does help but only to its specified reduction size.

![S-Parameters](image)

Figure 15. Comparison with both $S_{11}$ and $S_{21}$ of the distance between patches 26mm and 22mm.
5. DEFECTED GROUND STRUCTURES (DGS)

Another approach to reducing the coupling of our two-patch antenna model if using Defected Ground Structures (DGS) [11] instead of the implementing EBG structures on the surface of the soft surface planar. The EBG structure can be engraved onto the ground plane of the structure. This is a method that reduces surface waves without implementation of vias. The negative image of the EBG structure on the ground plane can be seen in Fig. 16. By watching the interference with the radiation patterns in the model, instead of how close the strips are to the patches, we observe how close they are to the ports in reference to the ground plane. Three strips were used in Figure 16.

Figure 16. Defected Ground Structure with negative image of EBG on ground plane.
When looking at the results of the DGS model, relative coupling reduction wasn’t significantly reduced below the -20dB threshold. Instead, what is shown is a merely -1dB decrease in the scattering parameters. When the \( w_{\text{strip}} = 2.6\text{mm} \) as shown in Fig. 17, relative bandgaps cannot be immediately seen around \( f_c \) besides what can be seen around \( 6.3\text{GHz} \). Increasing \( w_{\text{strip}} \) of the model would normally shift the bandgap over to the center frequency, but when DGS was used in the two-patch antenna system the bandgap disappears when it gets close to \( 5.8\text{GHz} \). Reducing the \( w_{\text{strip}} \) increases coupling around the center frequency and does not produce any relative bandgap.

**CONCLUSION**

In this paper we have discussed different methods of DGS and EBG structures that can reduce relative coupling of a two-patch antenna system. Our results show that we can decrease coupling down to -32dB with shifting vias towards the edge of the strips. Using miniaturization methods along with shifting the port horizontally best fits the antenna design at \( 5.8\text{GHz} \). Interleaved ledges allow for wide strips of metal yet being able to be in a compact form to reduce the overall size of the EBG on the model. This allows for the distance between the two patch antennas to be reduced to less than half a wavelength in size. When using DGS on the two-patch antenna model, little to no reduction of relative coupling was shown in the scattering parameters. Bandgaps were seen around \( 6.3\text{GHz} \), but when shifting the width of the DGS strips, bandgaps were unable to shift towards the center frequency of the model.

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