A Novel Zigzag Line-based EBG Structure for the Simultaneous Switching Noise Suppression

Qiannan Xue [1,2*], Ziyuan Wang [2], Yi Tian [2], and Peng Wang [2]

[1] State Key Laboratory of Precision Measuring Technology & Instruments
College of Precision Instrument and Opto-electronics Engineering, Tianjin University, Tianjin, China

[2] Tianjin Key Laboratory for Civil Aircraft Airworthiness and Maintenance
Civil Aviation University of China, Tianjin 300300, China
*qiannanxue@163.com

Abstract **─** Simultaneous switching noise (SSN) generated between the power supply and the ground plane of a high-speed digital circuit is considered to be one of the most important factors affecting the signal integrity of a circuit system. In order to suppress the simultaneous switching noise, a new coplanar electromagnetic band-gap structure is proposed in this paper. Based on the zigzag line and square patch bridge, the inductance between the neighboring units can be enhanced. The results showed that the bandwidth of the band-gap is 0.1 ~ 12.6GHz when the depth of the new electromagnetic band-gap (EBG) structure is -30 db. Compared to the same parameter of the L-bridge structure, the relative bandwidth is about 48.7% and the cut-off frequency of the stop-band lower limit is reduced by 600MHz. The simultaneous switching noise on the power supply plane can be suppressed in all directions, and the signal integrity is less affected when the signal is transmitted by the differential line.

Index Terms **─** Coplanar electromagnetic band-gap, electromagnetic band-gap structure, high-speed digital circuits, simultaneous switching noise.

I. INTRODUCTION

With the rapid development of modern high-speed digital circuits [1], the operating frequency of the system clock is getting higher and higher. And according to the requirements of high power and low supply voltage, how to provide a clean power for the circuit system has become a major challenge in high-speed digital circuit system design [2]. On the interconnection, the high-speed signal transmission will be unstable caused by some noise, affecting the signal integrity (SI) [3, 4] and resulting in electromagnetic interference (EMI) [5]. Simultaneous switching noise (SSN) [6] problem not only reduces the noise tolerance of digital circuits, but also reduces the performance of analog circuits in mixed-signal systems. Conventional methods commonly used in the suppression of SSN circuit were that increasing the decoupling capacitors, power supply segmentation or designing through-hole location. Because of limited scope of application or the method too complex, these methods have not been widely used. In recent years, people gradually pay attention to use Electromagnetic band-gap structure (EBG) [7, 8] or SSN suppression.

EBG structure is a periodic structure that can control the propagation of electromagnetic waves. By correctly selecting the size, material and shape of the scattering medium, electromagnetic waves can be propagated in some frequency bands. The structure was first proposed to be used in the antenna to suppress the surface wave. The EBG structure could better inhibit the spread of electromagnetic waves in a certain frequency range. So it has been used in high-speed printed circuit board (PCB) [9] for SSN suppression. Several structures of the electromagnetic band-gap were designed, such as mushroom-liked electromagnetic band-gap structure [10], Fork-like EBG [11], FTS-EBG and so on. The structure of the mushroom-liked electromagnetic band-gap has prominent advantages in suppressing simultaneous switching noise. However, complex fabrication procedure, increasing cost and reliability associated with the printed circuit board and the narrow frequency of suppressing synchronous switching limit the application in high-speed digital circuits. Therefore, there are more and more researches focused on coplanar electromagnetic band-gap structures. This paper reported a new coplanar EBG structure which is based on the L-bridge EBG [12] structure. The zigzag line and the square patch bridge are used to construct the unit lattice to realize the new electromagnetic band-gap structure, which make the inductance between the neighboring units lattices enhanced. It could be expected to achieve better suppression characteristics for simultaneous switching noise in a high-speed digital circuit.

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II. STRUCTURE DESIGN OF NEW COPLANAR EBG POWER

The planar electromagnetic band-gap structure proposed in this paper is designed based on local resonance principle. Local resonant electromagnetic band-gap structure of the principle, mainly through the electromagnetic band-gap itself to form a periodic structure of local resonance band-gap, inhibit the propagation of electromagnetic waves nearby, which can inhibit the simultaneous switching noise. The new coplanar EBG structure (marked as NW-EBG) mainly increases the equivalent inductance L by increasing the bridge wire on the EBG structure, which could reduce the stop-band center frequency of the EBG structure, increase the stop-band width of the EBG structure and finally improve the suppression effect of the EBG structure on the SSN.

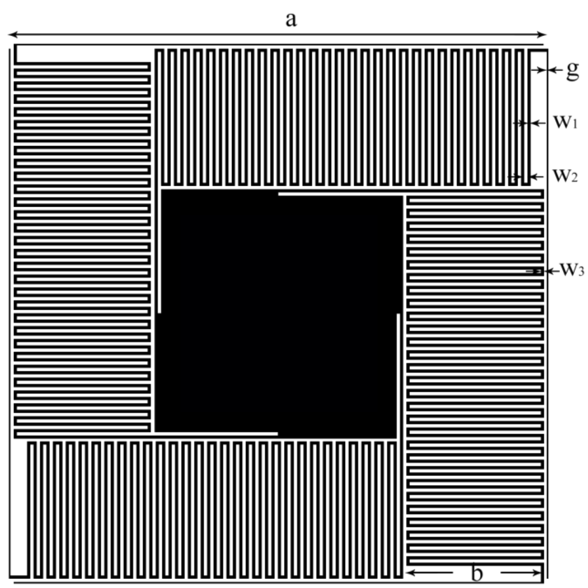

Fig. 1. The new structure design.

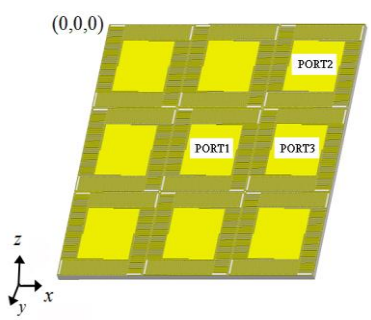

Fig. 2. The 3D view of simulation model.

The new structure consists of the center square and four side outwardly extending conductor lines. Four conductor lines are extended outwardly from the midpoint of the four corners of the center square, and the four conductor lines are bent around the center square with zigzag structures.

NW-EBG structure design size shown in Fig. 1, where a = 30mm, b = 5.2mm, w1=w2=w3=0.2mm, g = 0.1mm, line spacing are 0.2mm.

The circuit was fabricated by printed circuit board process. A double-layer PCB with 3 × 3 cell array was designed, and the EBG structure was embedded in the plane of the power plane. The total area of the new power layer structure designed in this paper is 81 cm^2, which is designed in the form of 3 × 3, each cell 9cm^2. The new coplanar EBG structure was simulated by the Ansoft HFSS, and three lumped ports were set up as shown in the Fig. 2. Port 2 and port 3 were set as output ports and port 1 was set as the input port.

III. DATA ANALYSIS AND SIMULATION VERIFICATION

A. Comparison with typical L-bridge type EBG structure characteristics

The L-bridge EBG structure is a typical electromagnetic band-gap structure. Draw a dashed line parallel to the horizontal axis at the position where the depth (longitudinal axis) is -30db. There are multiple intersections between dashed lines and curves. The adjacent intersection points with the largest difference in abscissa will be selected. The intersection point with small abscissa value is the lower limit. The intersection point with large abscissa value is the upper limit. As can be seen from the Table 1 and Fig. 3, L-bridged –EBG of low limit frequency is 0.7GHz, upper limit frequency is 4.7GHz, middle frequency is 2.7GHz, stop-band bandwidth is 4GHz, and relative band-stop bandwidth is 148.1%. The NW-EBG of low limit frequency is 0.1GHz, upper limit frequency is 12.6GHz, middle frequency is 6.35 GHz, stop-band bandwidth is 12.5 GHz, and relative band-stop bandwidth is 196.9%. Figure 4 shows the histogram of the middle frequency of the two EBG structures.

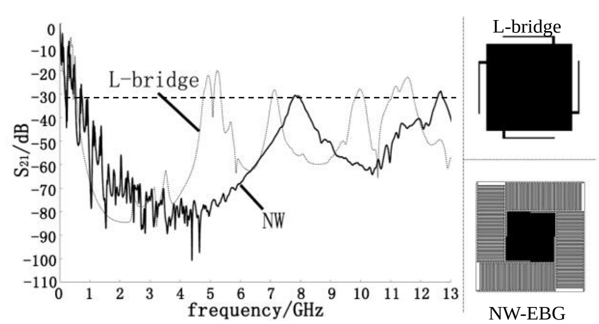

Fig. 3. Comparison of characteristic curve.

Table 1: Comparison of high frequency characteristics

EBG Type	L-Bridged-EBG	NW-EBG
Low limit frequency (GHz)	0.7	0.1
Upper limit frequency (GHz)	4.7	12.6
Middle frequency (GHz)	2.7	6.35
Stop-band bandwidth (GHz)	4	12.5
Relative band-stop bandwidth	148.1%	196.9%

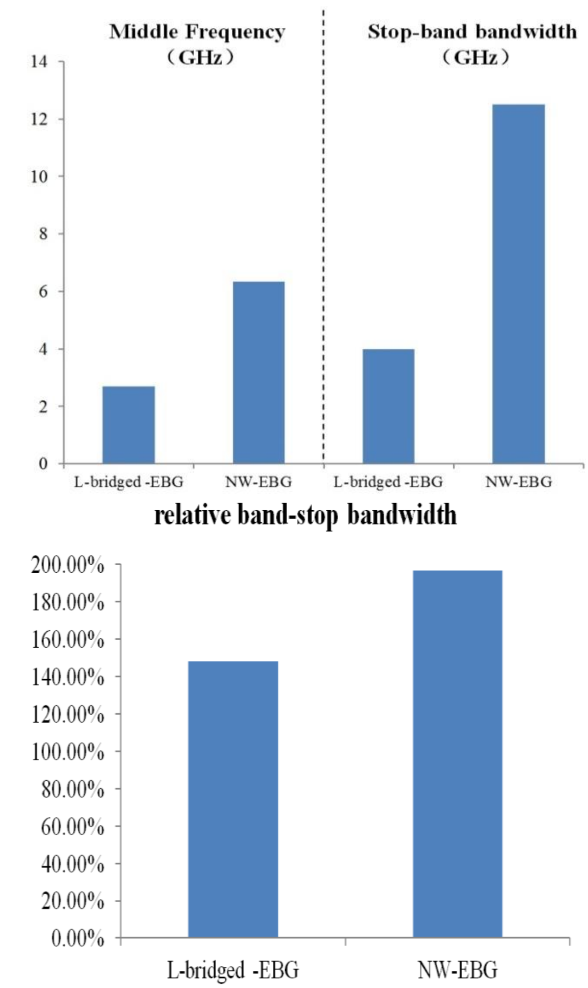

Fig. 4. Middle frequency, stop-band bandwidth and relative band-stop bandwidth of the two EBG structures.

We have compared the band-gap characteristics of NW-EBG and L-bridge-EBG. The suppression frequency of NW-EBG is 0.1-12.6GHz, the band-stop bandwidth is 12.5GHz and the relative band-stop bandwidth is 196.9% when the suppression depth is -30dB. Compared with L-bridge-EBG, the lower cut-off frequency of NW-EBG structure decreases from 700MHz to 100MHz, and the relative stop-band bandwidth increases from 148.1% to 196.9%, and the bandwidth is 48.8% of the 4GHz expanded to 12.5GHz. It can be seen that the NW-EBG structure can suppress the SSN at a lower operating frequency, and the inhibition range is wider than the L-bridge-EBG.

Figure 4 shows the histogram of stop-band bandwidth and relative band-stop bandwidth of the two EBG structures.

B. Omnidirectional suppression performance of a new planar EBG structure

By comparing the basic trend of the S21 and S31 characteristic curves, it is proved that the electromagnetic band-gap structure can suppress the simultaneous switching noise (SSN) between the power supply layer and the ground. Figure 5 shows the loss characteristics of port 2 and port 3 in the NW-EBG structure under different port outputs. It can be seen that the curves of S21 and S31 are basically consistent when the suppression depth is -30dB, which indicates that the NW-EBG structure can suppress the SSN in all directions.

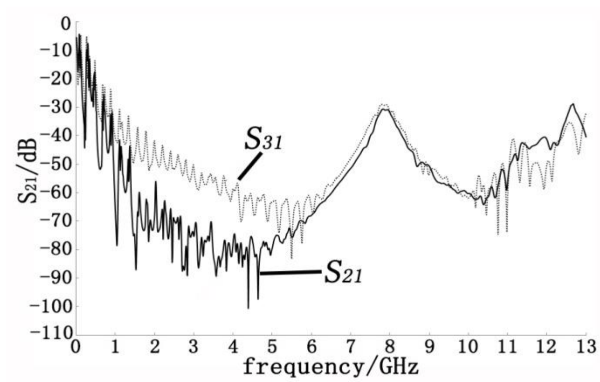

Fig.5. Comparison of S21 and S31 characteristic curve of NW-EBG.

C. Comparison of suppression characteristics of test and simulation

It can be seen from Table 2 that the difference between the test curve and the simulation characteristic parameters of the simulation curve is very small. It is further explained that the coplanar EBG power supply layer with a metal connection width of 0.2mm can fully detect the simultaneous switching noise of the high-speed printed circuit board. To the suppression, the most suitable for high-speed printed circuit board design and production.

Table 2: Comparison of suppression characteristics parameters of test and simulation

EBG Type	Test	Simulation	Recovery
Middle Frequency (GHz)	7.12±0.06	6.35	89.19%
Stop-band bandwidth (GHz)	12.88±0.07	12.5	97.05%
Relative band-stop bandwidth	189.97%±0.85%	196.9%	109.41%

IV. CONCLUSION

In this paper, a novel coplanar EBG structure is proposed, which is applied to the plane of PCB power supply. The unit cell is composed of a combination of zigzag line and square patch, which could enhance the inductance between the neighboring units. Compared with the traditional L-bridge structure, the band-stop bandwidth is increased by 48.7% as shown from the simulation results. The novel coplanar EBG power supply layer structure has a lower suppression frequency, a wider suppression bandwidth, and can effectively suppress simultaneous switching noise on the high-speed circuit all-directionally.

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