A New Electromagnetic Bandgap Power Plane with super-broadband suppression of Ground Bounce Noise in High Speed Circuits

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Outline

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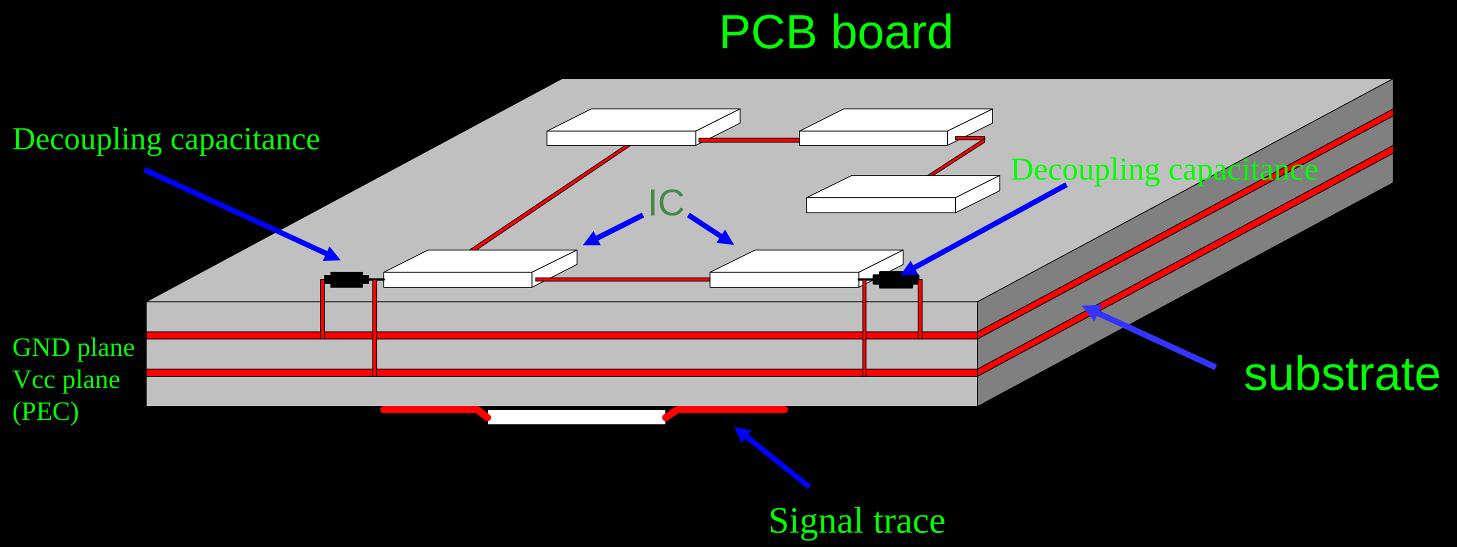
- Stopband Model for the EBG Power Planes
- Signal integrity for L-bridge EBG power plane
- EMI for L-bridge EBG power plane
- Conclusion

Introduction

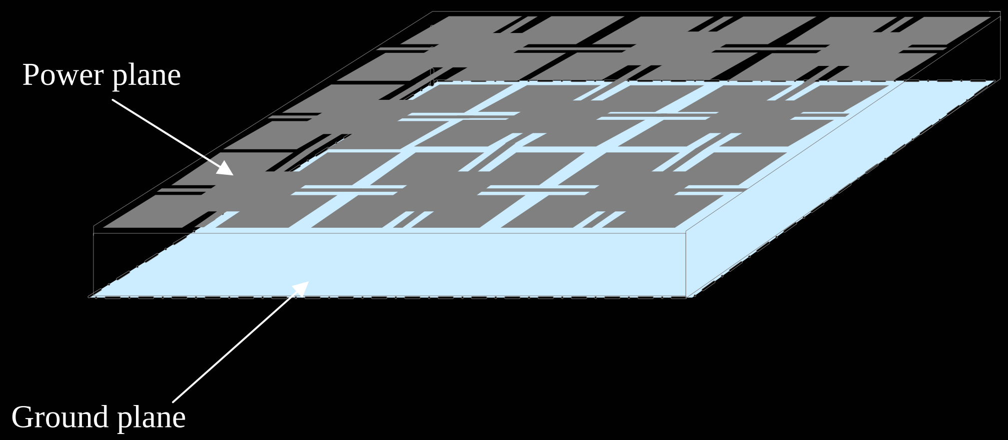
- Ground bounce noise (GBN) on the power/ground planes is becoming one of the major concerns for the high-speed digital computer systems.
- Adding decoupling capacitors to suppress the GBN[7] is not effective at frequencies higher than 600MHz due to their finite lead inductance.

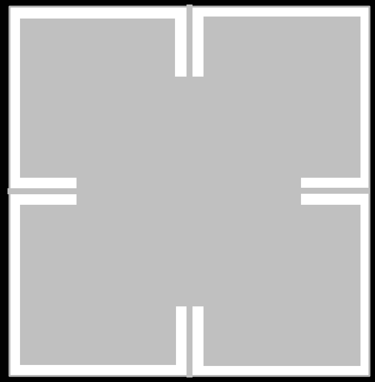


[7] Tzong-Lin Wu, Yen-Hui Lin, Jiuun-Nan Hwang and Jig-Jong Lin, " The effect of test system impedance on measurements of ground bounce in printed circuit boards" *IEEE Transactions on Electromagnetic Compatibility*, vol. 43 ,No. 4 ,pp. 600 – 607, Nov. 2001

Introduction

- A new idea for eliminating the GBN is proposed by designing electromagnetic bandgap (EBG) structure on the power or ground plane.
- The first EBG power/ground plane design[5], [8] was demonstrated with 1.7GHz stop-band bandwidth centered at 3.77GHz.





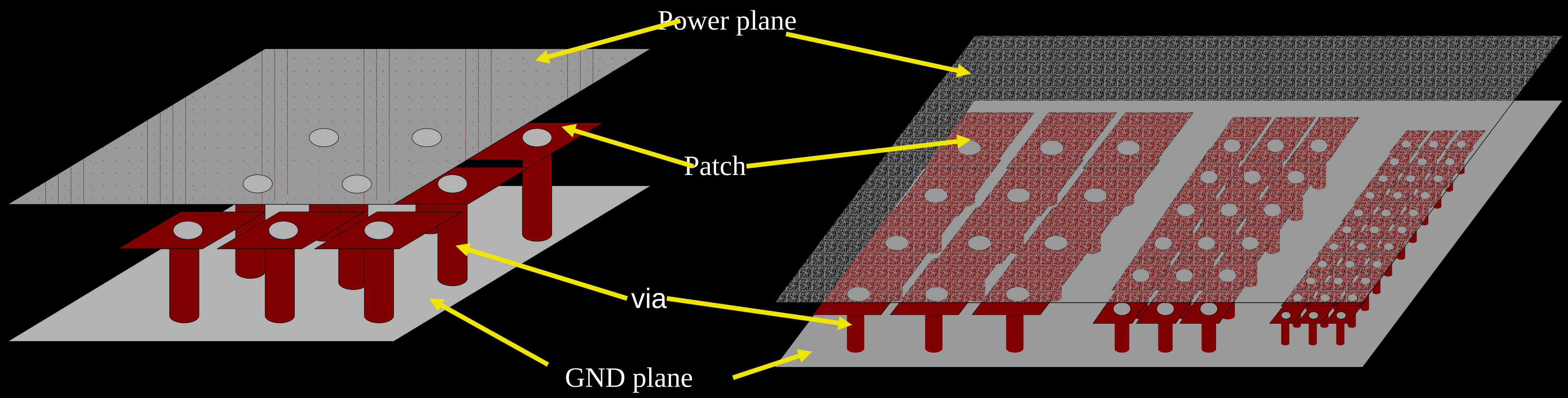
Unit cell

[5]F. R. Yang, K. P. Ma, Y. Q. and T. Itoh, "A uniplanar compact photonic-bandgap (UC-PBG) structure and its applications for microwave circuit," *IEEE Trans. Microwave Theory & Tech*., vol. 47, no. 8, pp. 1509-1514, August 1999.

[8] Tzong-Lin Wu, Yen-Hui Lin, and Sin-Ting Chen, " A novel power planes with low radiation and broadband suppression of ground bounce noise using photonic bandgap structures" *IEEE Microwave and Wireless Components Letters*, vol 14, No. 7, pp. 337 – 339, July 2004

Introduction

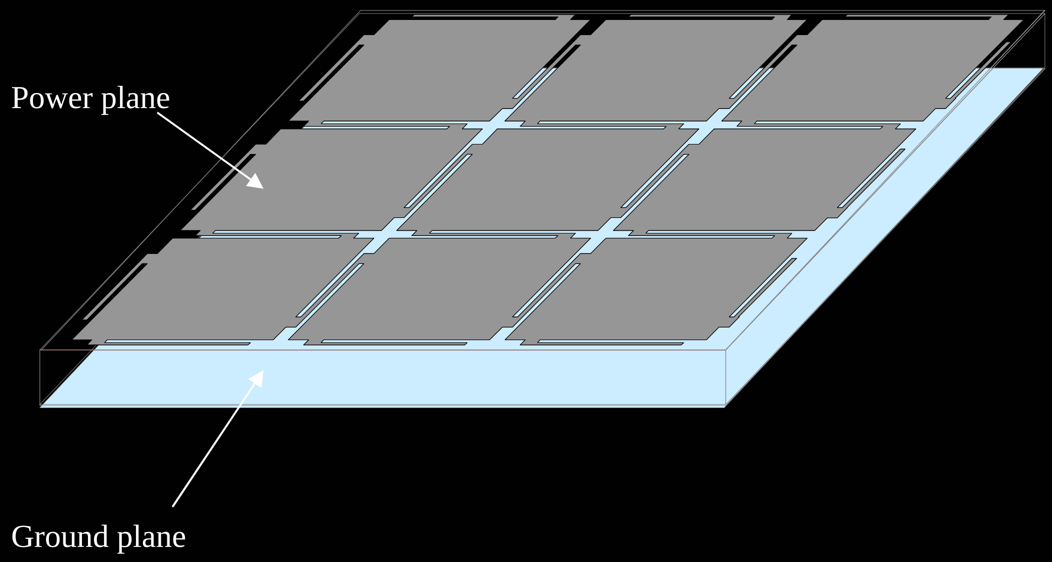
- Although a design of the inductance-enhanced high impedance surface (HIS)[2] and the concept of cascading EBG structure with different stop-bands were proposed to achieve wider bandgap bandwidth, there are some drawbacks.

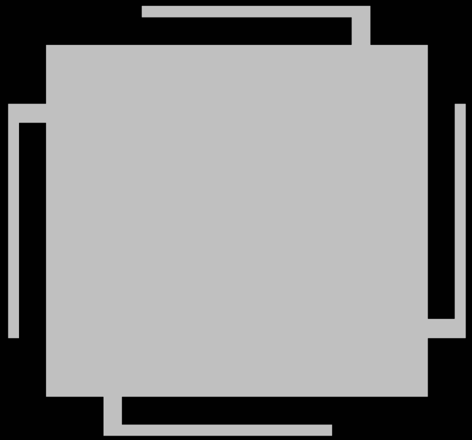


[2] T. Kamgaing, and O. M. Ramahi, "A novel power plane with integrated simultaneous switching noise mitigation capability using high impedance surface," *IEEE Microwave and Wireless Components Letters* , vol. 13 no. 1 pp. 21-23, January 2003

Introduction

- A Novel power plane designed with a coplanar EBG structure is proposed in this work with 4GHz stop-band covering from 600MHz to 4.6GHz.

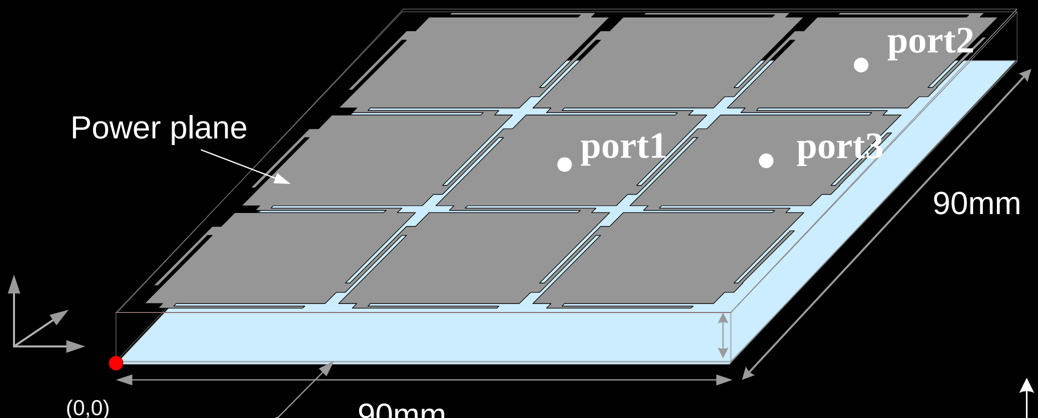




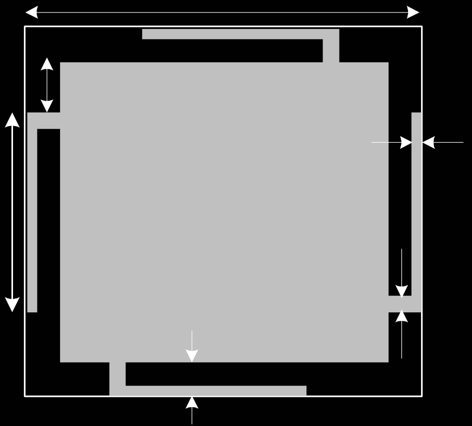
Unit cell

L- bridge EBG design concept

L-bridge EBG structure



Nine cell L-bridge EBG



Unit cell

$a = 30mm$

$w = a/4 = 7.5mm$

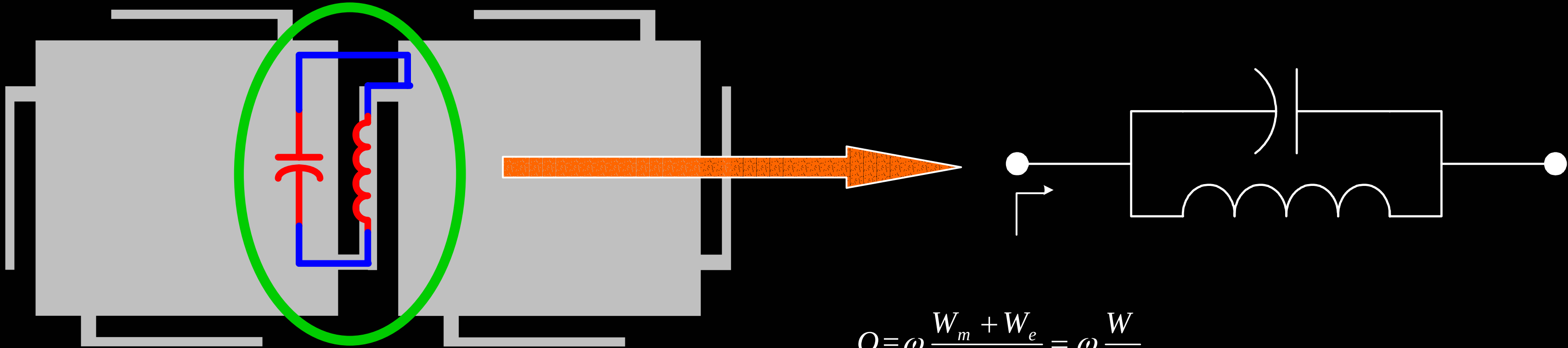
$g1 = 0.1mm$

$g2 = 0.2mm$

$g3 = 0.65mm$

$L = 15.2mm$

L- bridge EBG design concept



$$Z_{in} = \frac{1}{j\omega C} \parallel j\omega L = \frac{j\omega L}{1-\omega^2 LC}$$

When $\omega = \omega_0 = \frac{1}{\sqrt{LC}}$ $\quad Z_{in} \to \infty$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \omega\frac{W_m + W_e}{P_L} = \omega\frac{W}{P_L}$$

W:total time average energy in a cavity resonator

W_e:the energy stored in the electric fields

W_e:the energy stored in the magnetic fields

P_L : time-average power disspated in the cavity

at resonant frequency $W_e = W_m$

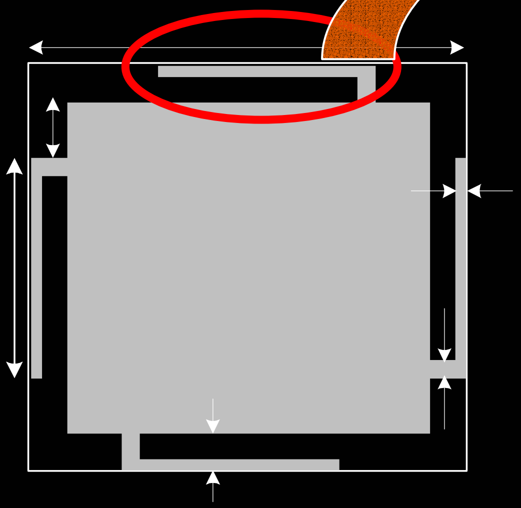
$$Q = \omega_0\frac{2W_e}{P_L} = \omega_0\frac{2\cdot\frac{1}{4}C|V|^2}{\frac{1}{2}\frac{|V|^2}{R}} = \omega_0 RC = R\sqrt{\frac{C}{L}}$$

$$BW = \frac{1}{Q} = \frac{1}{R}\sqrt{\frac{L}{C}} \propto \sqrt{\frac{L}{C}}$$

Cg L

L- bridge EBG design concept

Design concept : $f_0 \ \alpha \ \frac{1}{2\pi\sqrt{LC}}$ $BW \ \alpha \ \sqrt{\frac{L}{C}}$

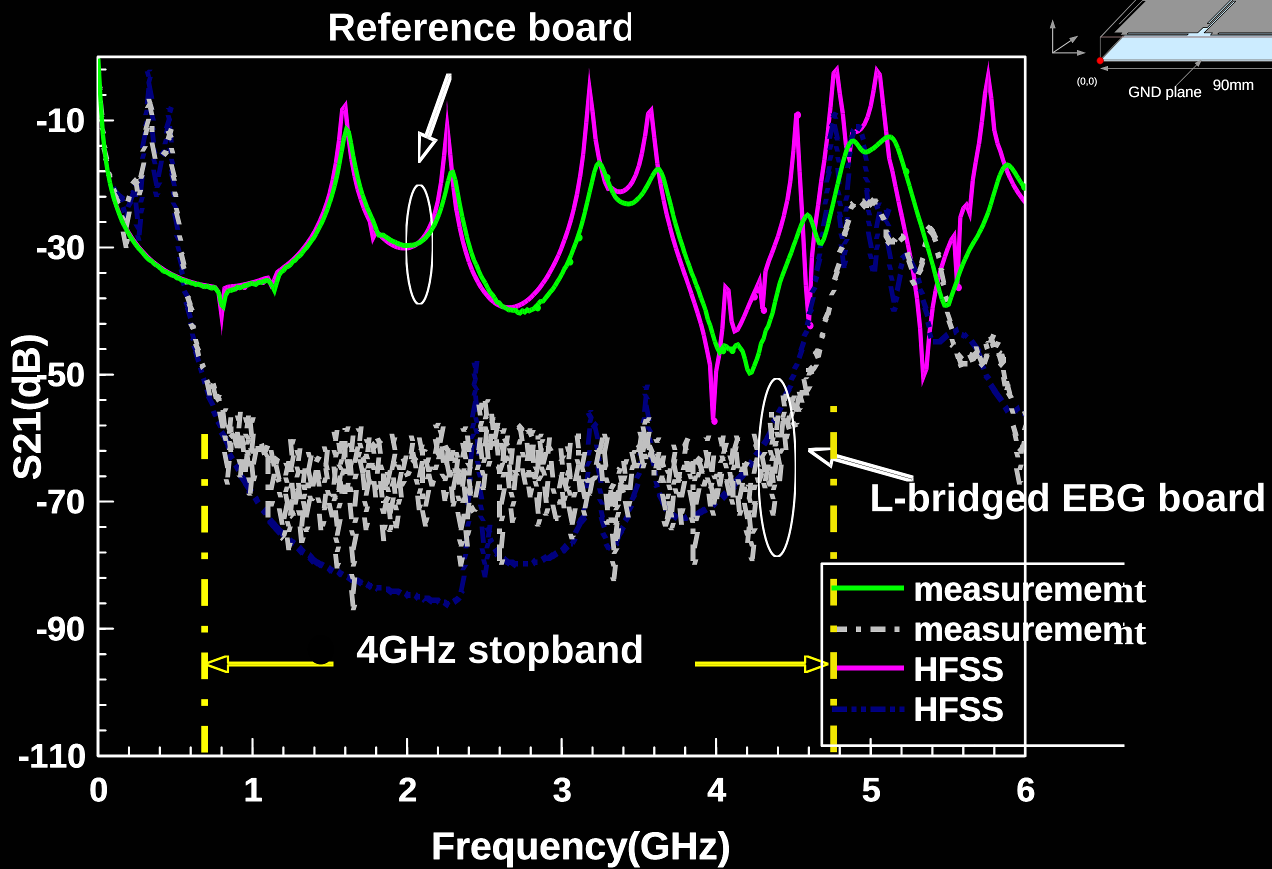


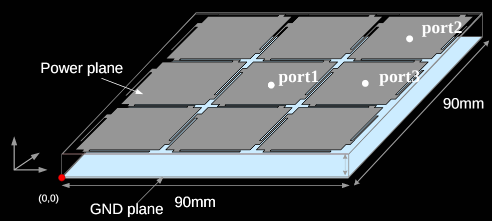
- Increase the effective inductance between adjacent cells and thus increase the stop-band bandwidth
- Ease the damage of the imperfect power plane to the signal quality.

Unit cell

The simulation and measurement result

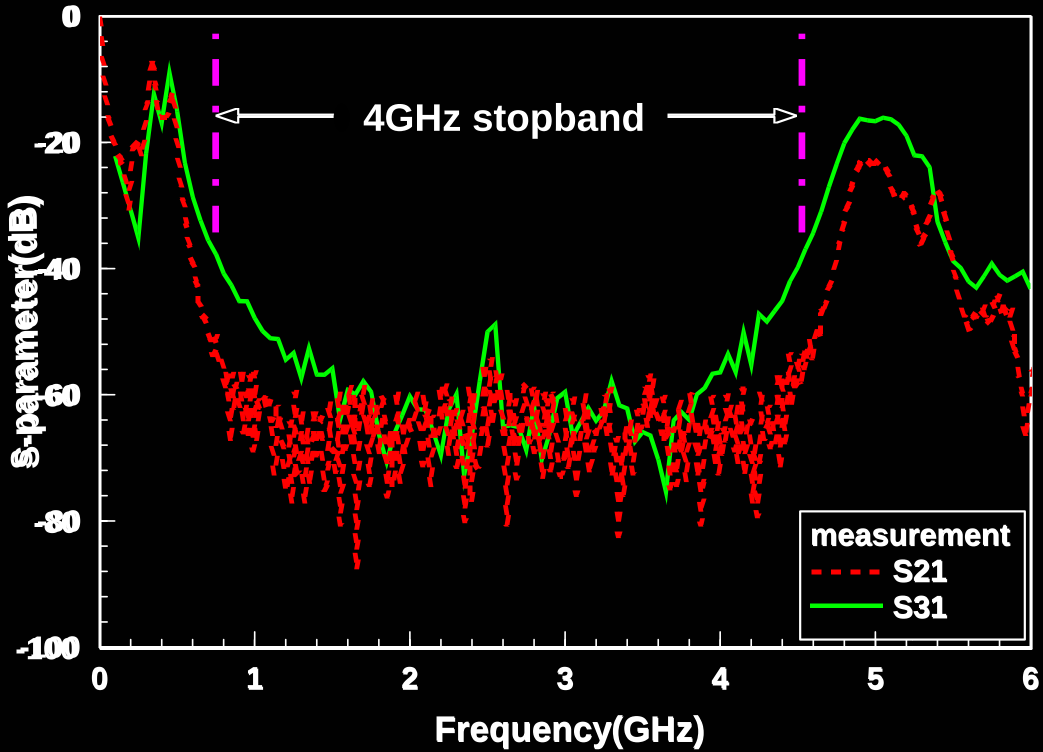
Broadband GBN suppression

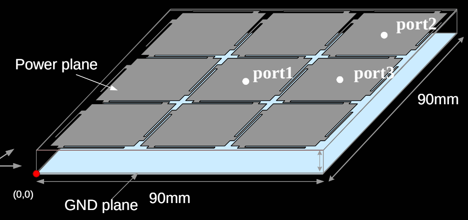




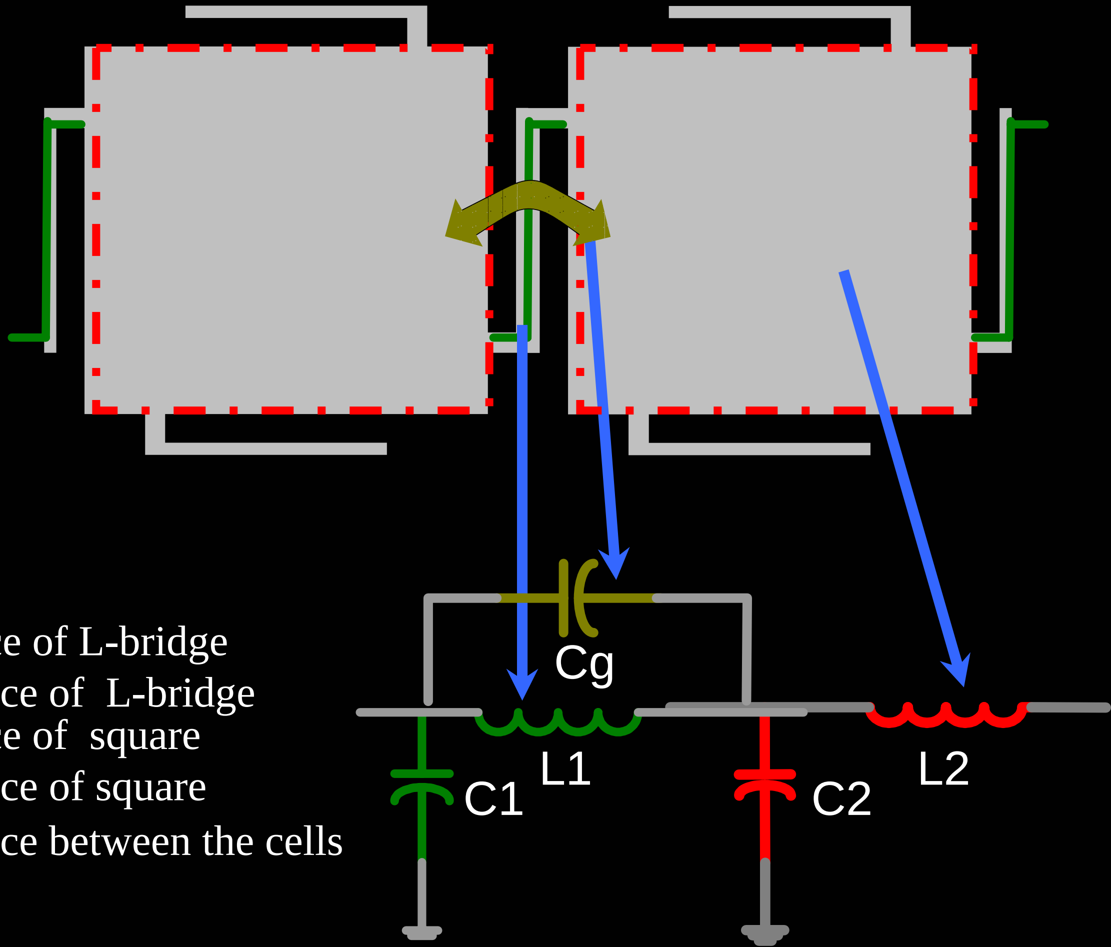
The simulation and measurement result

Broadband GBN suppression



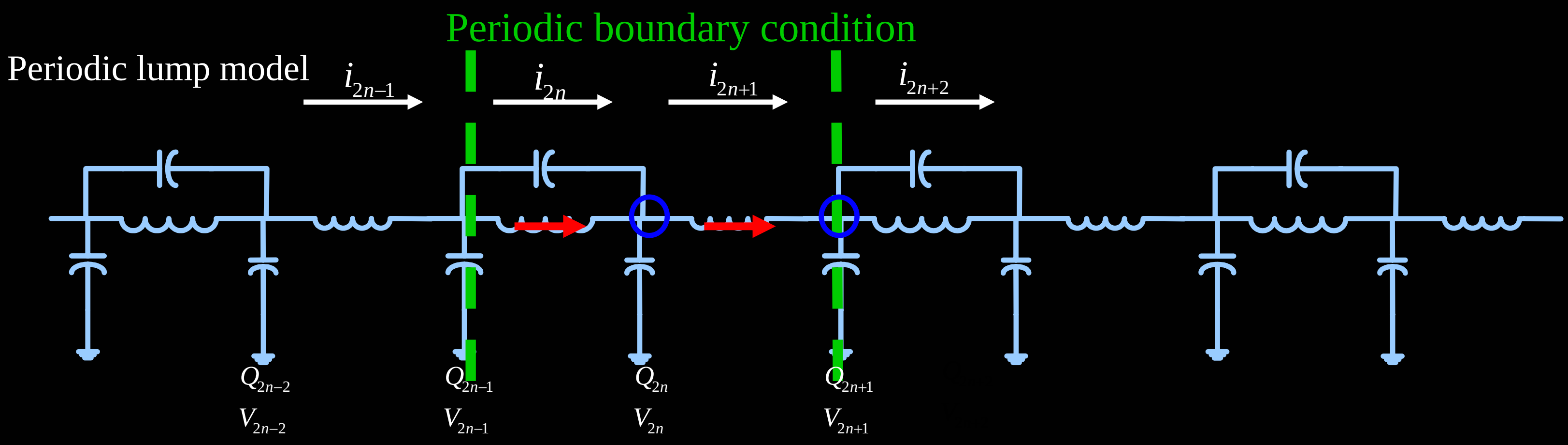


Stopband Model for the EBG Power Planes



L1 : the inductance of L-bridge
C1 : the capacitance of L-bridge
L2 : the inductance of square
C2 : the capacitance of square
Cg : the capacitance between the cells

Stopband Model for the EBG Power Planes



$$\begin{cases} L_1 \dfrac{d\dfrac{i_{2n}}{1-w^2 L_1 C_g}}{dt} = V_{2n-1} - V_{2n} = \dfrac{Q_{2n-1}}{C_1} - \dfrac{Q_{2n}}{C_2} \\ L_2 \dfrac{di_{2n+1}}{dt} = V_{2n} - V_{2n+1} = \dfrac{Q_{2n}}{C_2} - \dfrac{Q_{2n+1}}{C_1} \end{cases}$$

$$\begin{cases} i_{2n} - i_{2n+1} = \dfrac{dQ_{2n}}{dt} \\ i_{2n+1} - i_{2n+2} = \dfrac{dQ_{2n+1}}{dt} \end{cases}$$

Stopband Model for the EBG Power Planes

$$\begin{cases} L_1 \dfrac{d^2 \dfrac{i_{2n}}{1-w^2 L_1 C_g}}{dt^2} = \dfrac{i_{2n-1}-i_{2n}}{C_1} - \dfrac{i_{2n}-i_{2n+1}}{C_2} \\ L_2 \dfrac{d^2 i_{2n+1}}{dt^2} = \dfrac{i_{2n}-i_{2n+1}}{C_2} - \dfrac{i_{2n+1}-i_{2n+2}}{C_1} \end{cases}$$

assume

$$\begin{cases} i_{2n} = A_2 e^{i(\omega t - 2nk_1)} \\ i_{2n+1} = A_1 e^{i(\omega t - (2n+1)k_1)} \end{cases}$$

$$\begin{cases} \left(\dfrac{-L_1 w^2}{1-w^2 L_1 C_g} + \dfrac{1}{C_1} + \dfrac{1}{C_2} \right) A_2 + \left(\dfrac{1}{C_2} e^{-ik_1} - \dfrac{1}{C_1} e^{ik_1} \right) A_1 = 0 \\ \left(-L_2 w^2 + \dfrac{1}{C_1} + \dfrac{1}{C_2} \right) A_1 + \left(\dfrac{1}{C_2} e^{ik_1} - \dfrac{1}{C_1} e^{-ik_1} \right) A_2 = 0 \end{cases}$$

Stopband Model for the EBG Power Planes

$$\left\{ \left(\frac{-L_1 w^2}{1 - w^2 L_1 C_g} + \frac{1}{C_1} + \frac{1}{C_2} \right) \left(-L_2 w^2 + \frac{1}{C_1} + \frac{1}{C_2} \right) - \left(\frac{1}{C_2} e^{-ik_1} + \frac{1}{C_1} e^{ik_1} \right) \left(\frac{1}{C_2} e^{ik_1} + \frac{1}{C_1} e^{-ik_1} \right) = 0 \right.$$

$$\Longrightarrow \quad w = f(k)$$

Stopband Model for the EBG Power Planes

L_C estimation

$$l, w$$

↓

$$Z_0 , K\_eff$$

↓

$$V_p = \frac{C}{\sqrt{K\_eff}} , \quad L_0 = \frac{Z_0}{V_p} , \quad C_0 = \frac{1}{Z_0 V_p}$$

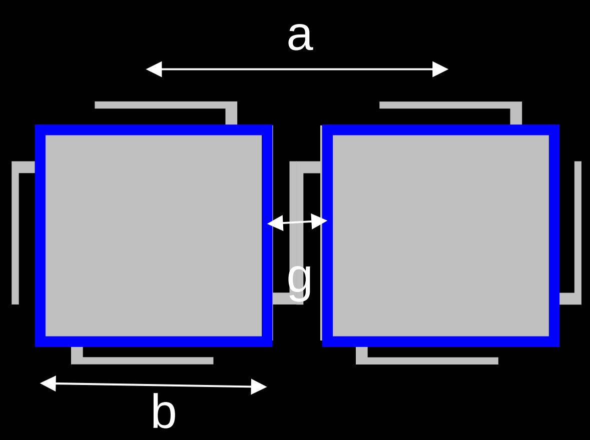
↓

$$L = L_0 * l , \quad C = C_0 * l$$

Stopband Model for the EBG Power Planes

Cg estimation

$$C_g = b\frac{\varepsilon_0\left(1+\varepsilon_r\right)}{\pi}Cosh^{-1}\frac{a}{g}$$

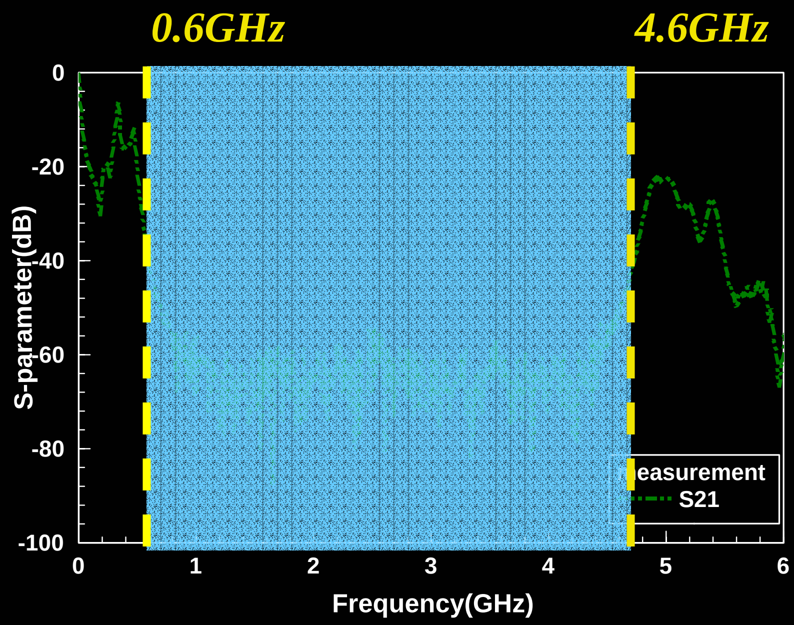


a = 30mm b = 28.5mm g = 1.5mm

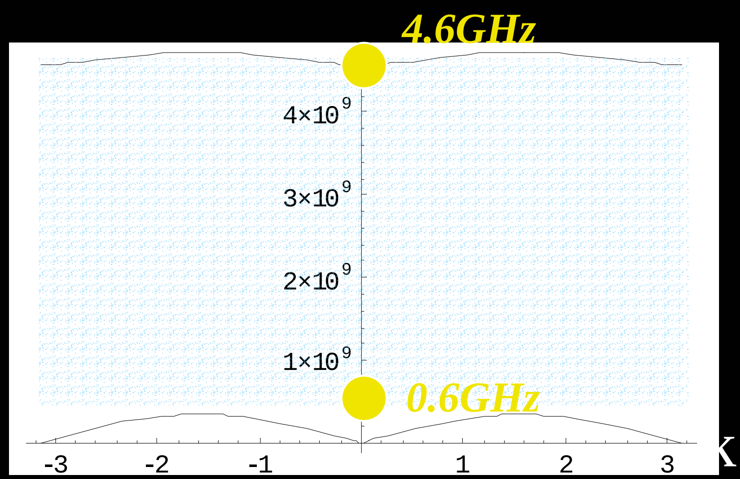
$\varepsilon_r = 4.4$

$$\Rightarrow C_g = 1.59757\,pF$$

Stopband Model for the EBG Power Planes



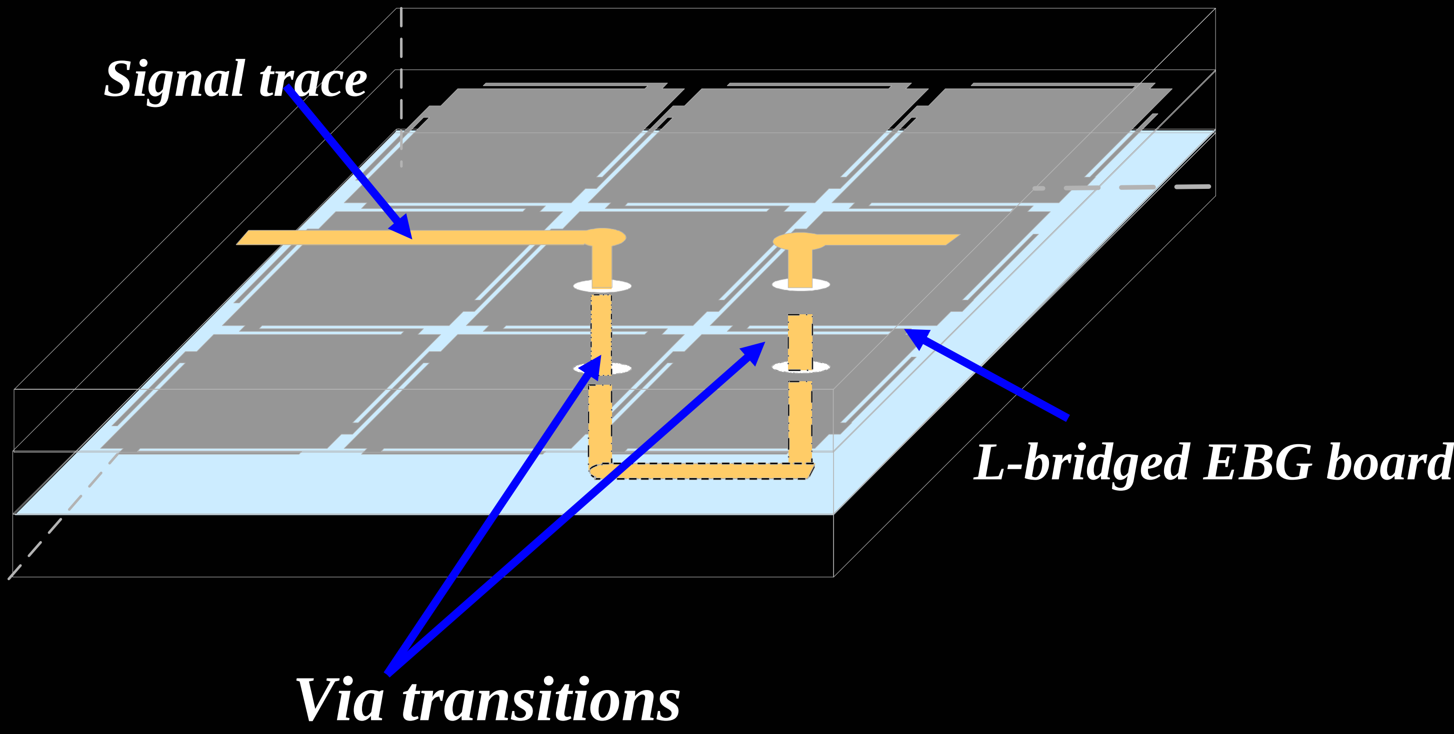
measurement



Dispersion diagram

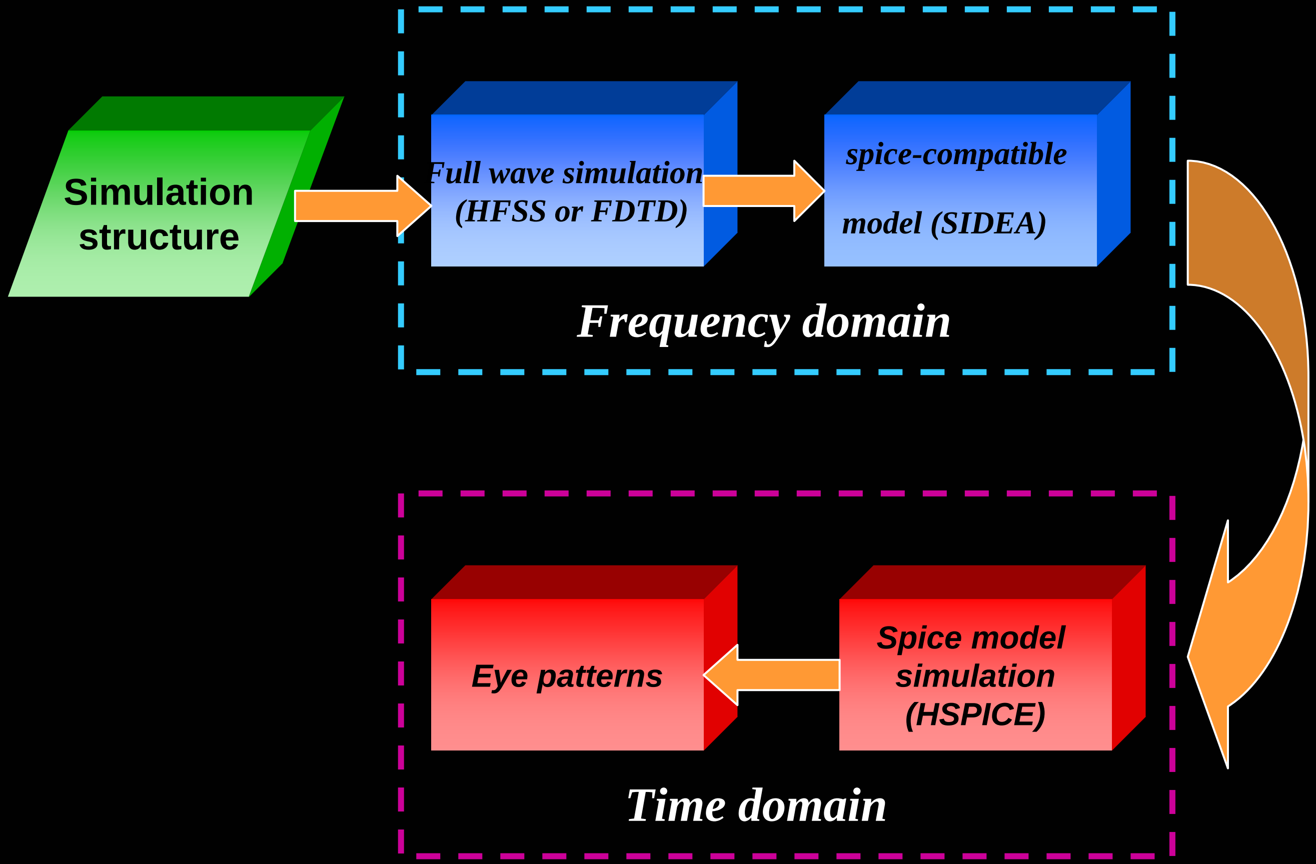
Signal integrity for L-bridge EBG power plane

Simulation structure



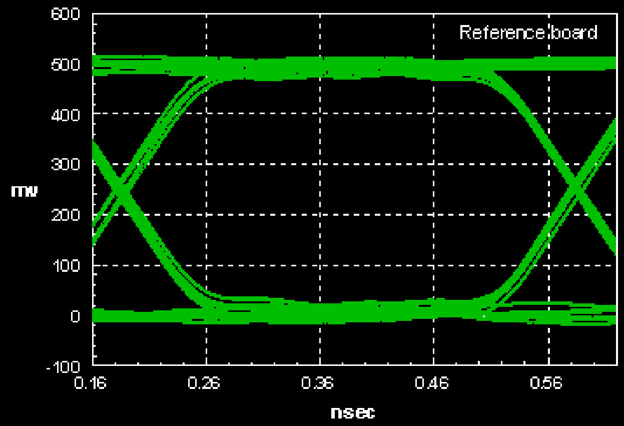
Signal integrity for L-bridge EBG power plane

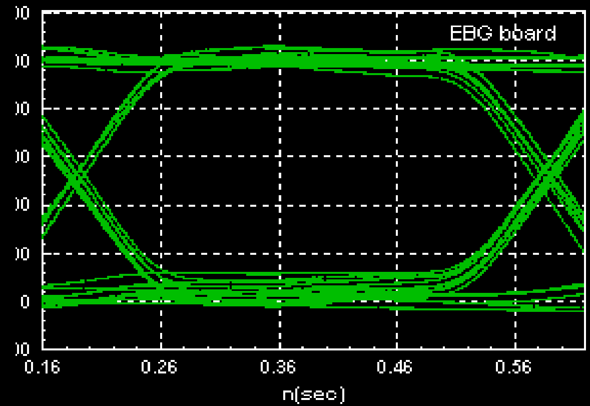
Flowchart



Signal integrity for L-bridge EBG power plane

Source : 2^7-1 PRBS, NRZ, coded at 2.5Gb/s, bit sequence swing is 500mv, rising/falling time 120ps

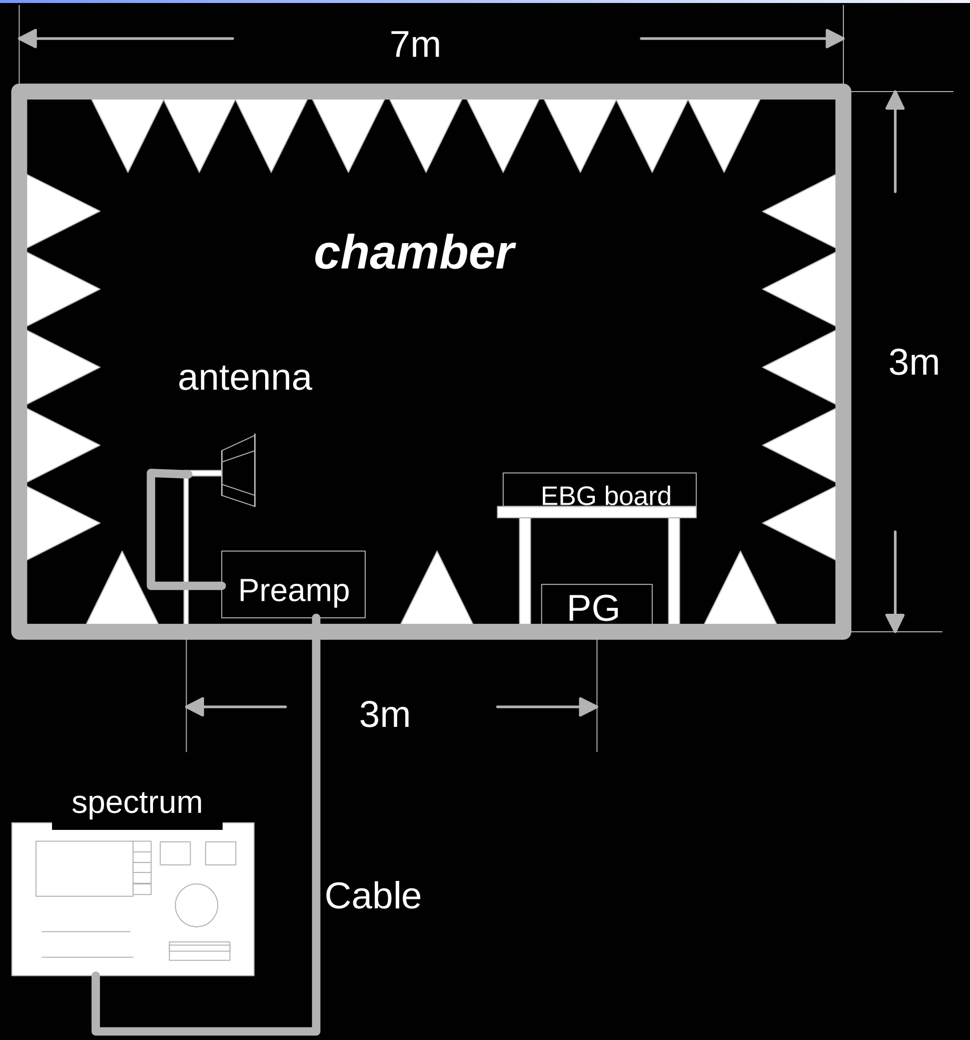




	Maximum eye opening (mv)	Maximum eye width (ps)
NO EBG	448.8	390
EBG	412.3	382

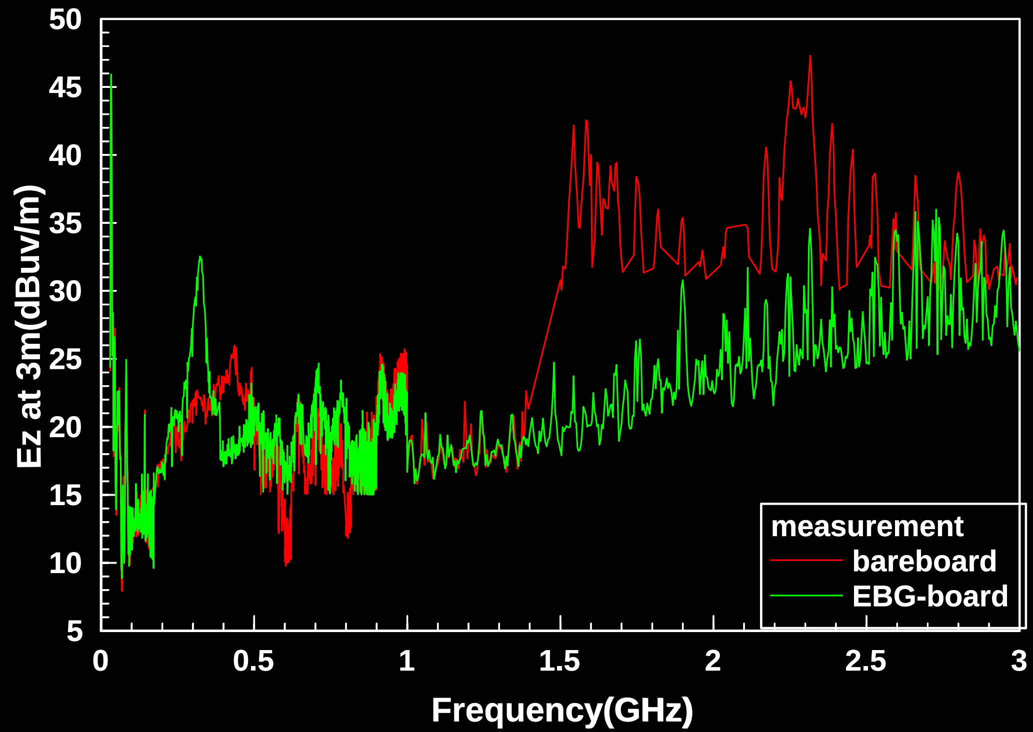
EMI for L-bridge EBG power plane

Set up



EMI for L-bridge EBG power plane

Measurement result



Conclusion

- A novel L-bridged EBG power plane is proposed in this paper with super-wideband suppression of the GBN from 600MHz to 4.6GHz.
- Compared with previous designs, this novel structure provides three advantage.
  a. The L-bridged power plane broadens the stop band bandwidth to 4GHz and can cover to the low frequency range of 600MHz.
  b. The signal quality is still kept acceptably good for the signal referring to the perforated EBG power plane
  c. It is cost effective because only two layer metals are needed to design this novel power/ground plane structure.
- The excellent performance of the low-period PBG power planes is investigated both by measurement and simulation. Good agreement is seen.

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