# Simultaneous switching noise mitigation in PCB using cascaded high-impedance surfaces

S. Shahparnia and O.M. Ramahi

A novel concept for ultra-wide-bandwidth suppression of simultaneous switching noise (SSN) in high-speed printed circuit boards (PCBs) is proposed and implemented. This method consists of cascading high-impedance surfaces (HIS) with different stop bands, creating rejection over a wide frequency region. A PCB with the cascaded HIS design has been successfully fabricated and tested.

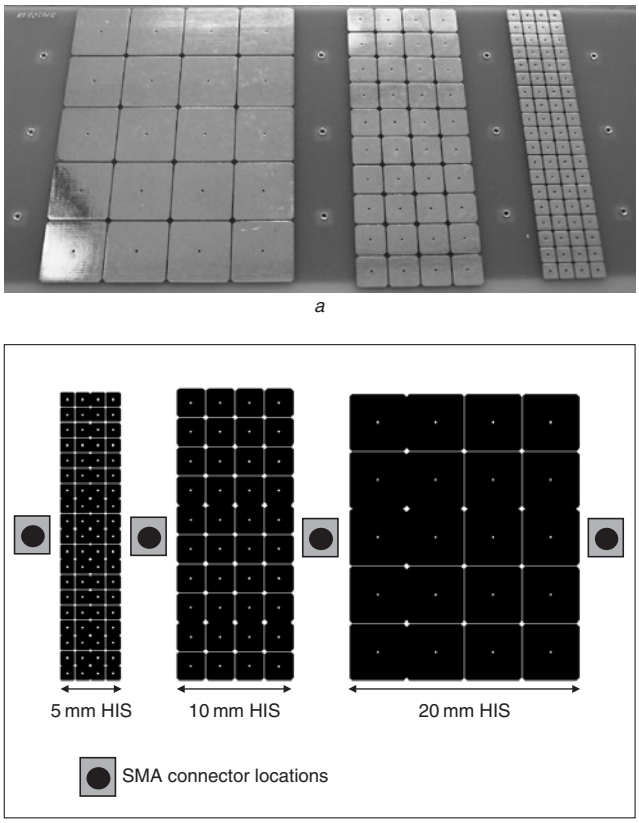
*Introduction:* Fast switching in digital circuits that use standard printed circuit board (PCB) technology creates simultaneous switching noise (SSN), also known as ground bounce or Delta-I noise. Switching noise, if undetected, can produce several low- and high-frequency anomalies, most important of which is the biasing of the power planes, which leads to logic errors in digital circuits. In fact, SSN is considered one of the bottlenecks in the design of high-speed PCBs and packages. With the fast increase of clock speed of digital circuits, the suppression of this noise becomes inevitable.

In previous work, different techniques were proposed to mitigate the SSN as much as possible. These techniques centred on adding decoupling capacitance to create a low impedance path at higher frequencies. Discrete decoupling capacitors and embedded capacitance were both used with limited success. Decoupling capacitors have limited effect on SSN owing to their finite lead inductance and, in general, these capacitors are not effective at frequencies higher than 500 MHz [1]. Embedded capacitance, however, is still in the development stage and can be impractical due to its cost limits.

In an earlier work, Kamgaing and Ramahi introduced the use of high-impedance surfaces (HIS) to mitigate SSN [2]. A similar concept was also introduced in [3]. In [2], SSN is suppressed by the introduction of a HIS between the power planes of the circuit board. The HIS suppresses surface waves within the structure. These structures support TM modes only at lower frequencies and TE modes only at higher frequencies. Between the lower and higher frequency regions, there is a transition band, where the HIS supports neither TE nor TM modes. For most effective use of HIS in suppressing the most dominant resonant peaks of a printed circuit board cavity, the bandgap of the HIS must overlap with the high transmission band of the simple parallel-plate waveguide.

In [2], a bandgap of 3.3 GHz was achieved using a combination of an inductance-enhanced HIS with a wall of RC pairs. In [3], a bandgap of 2.2 GHz was achieved by using the double-mushroom structure originally introduced in [4]. These two earlier works, which introduced the concept of suppression of SSN using a HIS structure, for the first time, suffered from two important drawbacks. The first drawback is manufacturing cost. In both cases, the new power plane structure has a total of four layers instead of the typical two. This leads to a substantial increase in fabrication cost. The second drawback is performance. In [2] and [3], a relatively short bandgap was achieved, capable of suppressing the dominant harmonic but not successive higher-order harmonics. The design presented in this Letter eliminates these two critical drawbacks.

*Design concept:* Based on filter theory and the fact that a HIS behaves like a band-stop filter, it is expected that, if several HIS surfaces were cascaded, the overall effect would be a filter with a stop-band equivalent to the superposition of the original individual filters. Each stage of the filter is composed of an independent periodic structure. In this work, for the HIS, we used the simplest structure that was originally proposed in [4], which consists of a rectangular patch with a via post positioned in its centre (see Fig. 1). Approximate models were primarily used to have an initial estimate of the location of the bandgap. Full-wave numerical simulations were used to validate the design before fabrication. Three structures were designed. Board thickness, board material, via and also gap sizes were kept constant among different structures. The only variable was patch size. Patches of 5, 10 and 20 mm were considered, and we expected to have resonance frequencies of 5.93, 2.97 and 1.48 GHz, respectively. Each of these frequencies is the location of one of the zeros in the transfer function of each filter stage, although this location is usually within the corresponding gap.




*a*

*b*

**Fig. 1** *Proposed wideband/multiple band structure (gap size = 0.4, via diameter = 0.8 mm, board thickness = 1.54 mm and $\varepsilon_r = 4.1$). Top view of middle layer of PCB and measurement points*

*a* Fabricated cascaded structures
*b* Schematic of overall filter

*Fabrication, measurements and results:* After initial design using the simplified model, the cascaded structure was implemented with commercial PCB technology on FR4 laminates as a two-layer board. Fig. 1*a* shows the fabricated two-layer structure in detail. A separate one-layer board was mounted to the top of the initial two-layer board as a second power plane. Finally the whole structure was pressed to remove any air gaps between the boards. The overall dimension of the PCB was $10 \times 30$ cm. A top view of a schematic of the middle layer is shown in Fig. 1*b*, where each HIS section and the SMA connector locations are clearly indicated.

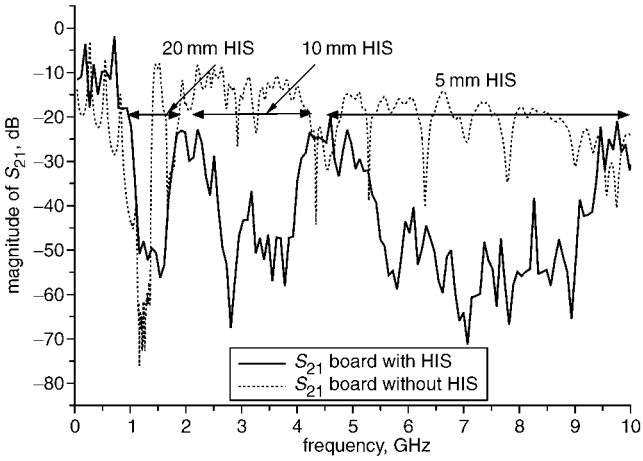



**Fig. 2** *Measured $S_{21}$ of fabricated PCB employing cascaded HIS configurations*

$S_{21}$ measured between farthest SMA connectors as shown in Fig. 1*b* using vector network analyser

Fig. 2 shows the experimental results from the fabricated boards. The three designed bandgaps are located at 0.8–1.8, 2.2–4.2 and

4.5–10 GHz. They have been designed without overlap to show the flexibility of the superposition effect. Of course the design parameters can also be modified such that the suppression bands overlap, expanding the suppression region from 800 MHz to 10 GHz.

*Conclusions:* A novel design concept to mitigate simultaneous switching noise in printed circuit boards is presented. This technique consists of cascading different configurations of HIS with different stop-bands, creating rejection over a wider frequency region. The cascading can be performed in series as demonstrated in this work, or can be made in a variety of arrangements such as concentric islands, where each island is a different HIS with its unique stop-band. To demonstrate the validity of our proposed design, a prototype was fabricated and tested that consisted of three different HIS designs (equivalent to three different stop-band filters). Experimental measurements yielded highly satisfactory results confirming that our proposed technique can lead to significant SSN suppression over an ultra-wide bandwidth. This bandwidth includes the dominant clock frequency and its subsequent harmonics.


*22 November 2003*
*Electronics Letters* online no: 20040077
doi: 10.1049/el:20040077

S. Shahparnia and O.M. Ramahi (*Electrical and Computer Engineering Department, A. James Clark School of Engineering, University of Maryland, College Park, MD 20742, USA*)

E-mail: oramahi@calce.umd.edu

S. Shahparnia: Also with Mechanical Engineering Department at University of Maryland

O.M. Ramahi: Also with Mechanical Engineering Department and CALCE Electronic Products and Systems Center, at University of Maryland

**References**

1 Xu, M., Hubing, T.H., Chen, J., Van Doren, T.P., Drewniak, J.L., and DuBroff, R.E.: 'Power-bus decoupling with embedded capacitance in printed circuit board design', *IEEE Trans. Electromagn. Compat.*, 2003, **45**, (1), pp. 22–30
2 Kamgaing, T., and Ramahi, O.M.: 'A novel power plane with integrated simultaneous switching noise mitigation capability using high impedance surface', *IEEE Microw. Wirel. Compon. Lett.*, 2003, **13**, (1), pp. 21–23
3 Abhari, R., and Eleftheriades, G.V.: 'Metallo-dielectric electromagnetic bandgap structures for suppression and isolation of the parallel-plate noise in high-speed circuits', *IEEE Trans. Microw. Theory Tech.*, 2003, **51**, (6), pp. 1629–1639
4 Sievenpiper, D.F.: 'High-impedance electromagnetic surfaces'. PhD thesis, Department of Electrical Engineering, UCLA, Los Angeles, CA, 1999