

주파수 선택도를 가지는 메타재질구조를 이용한, 선로상의 전류펄스에 의한 불요방사 억제기법

A Method to Suppress the Spurious Radiation due to the Current Pulse on the Cable using the Frequency Selective Metamaterial Structure

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Abstract - The spurious electromagnetic radiation is generated due to the RF unbalanced current on a conductive cable connecting an electronic device to another. A metamaterial-based filtering geometry with frequency selectivity is suggested to reduce the radiation with a bandgap structure, where the right-handed inductance and capacitance stem from the transmission-like configuration between the cable and the metal protrusion, and the left-handed components come from the narrow cavities. The effect of the structure on the unbalanced current pulse and its spurious radiation is presented in the FDTD-method frame work.

Key Words : EMI filter, Metamaterial, Spurious electromagnetic radiation, EMP filter

1. Introduction

Cables and conductive wires are essential apparatus to electric and electronic equipment. They connect a part to another in a device, and link one device to another through apertures of an enclosure. When an RF current is transferred on the cable, if it goes through an aperture, the change in the electromagnetic field distribution and impedance results in the unbalanced current such as common-mode current, and becomes a source of unwanted radiated emission. Specifically, as the clock speed of signal increases and PCBs of a device are densely populated with traces and components in a electronic system, it is more likely that an increasing number of EMI sources are much related to the occurrence of the unbalanced current on the cable. Researchers paid more attention to the shielding and coupling mechanism of the cables and internal PCBs [1], [2]. They addressed that the unbalanced current induced on the cable degrades the equipment performance due to the EMI, ground-bounce, etc. Alternatively, ferrite beads have been adopted to weaken its common-mode current

[3-5]. However, ferrite products wrapping the cables are not printable, and the use of magnetic material beads will end up with a higher cost.

This paper presents a method to effectively lower the magnitude of the unbalanced current with the help of a bandgap geometry fitting the cable through an aperture, when it is attached to the enclosure. It suppresses much of the EMI causing current, working as a stopband filter. To validate this technique, numerical experiments are conducted with the FDTD method [6], [7] to present the effective drop of the unbalanced current, and it is shown that the spurious electromagnetic emission is avoided by a remarkable margin.

2. Problem Statement and the Design of a Bandgap Structure

As was mentioned previously, a cable runs through an aperture in an electronic system, and a current pulse generated from an RF driver in the circuit, which draws attention from the system developers and circuit designers. This stems from the fact if the current is unbalanced including the common-mode component, it will end up with an impedance hike in the cable and an unwanted electromagnetic radiation. In particular, though the balanced RF current is injected to the cable, as the usual way of making the aperture causes the electromagnetic field distribution of the current to change and impedance mismatch, the current becomes unbalanced and its common-mode component tends to create radiated emission other than being guided. This is simply illustrated in Fig. 1, and related to the RE like Appendix.

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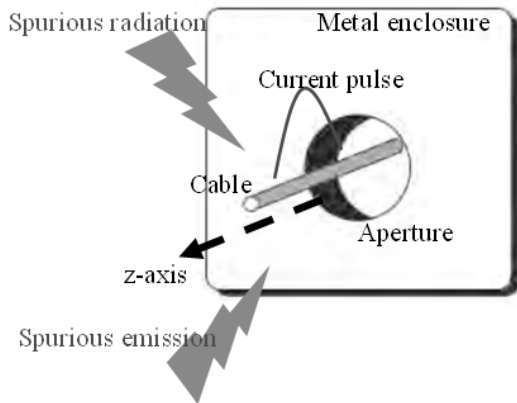


Fig. 1 A cable conveying an RF current through a slot and the radiated emission will occur

The current pulse is the excitation source of this conduction and scattering problem. It is modelled as sinusoidally modulated Gaussian pulse in the finite-difference time-domain(FDTD) electromagnetics simulation. In this paper, the conditions of the pulse are set for the frequency range from 100 MHz to 1 GHz. This test case is chosen due to the fact that commercial electronic products and communication systems usually have the clock speed of the frequency range including f 450 MHz. Now, a bandgap structure is proposed to reduce the unbalanced current and its resultant radiated emission. Its 3-dimensional shape is shown in the following figure where it is relatively easy to install as attached to the metallic enclosure around the aperture.

In Fig. 2(a), a straight cable goes through the enclosure to which a flat round PEC cylinder is mounted. The inside of this 3D geometry is peeped as Fig. 2(b) and it consists of concentric metal rings with different sizes. It is now called a ring stack. Before the design procedures, the FDTD as the analysis method running the program SEMCAD and the inputs should be addressed. For convenience, the thickness of all the grooves and teeth of the ring stack is set as 10mm, considering EMI filters for power-supplies. Besides, the grooves and teeth start from a point in the radial direction, as the radius of the aperture(R_{apr}) on the enclosure(20mm). Here, the number and radii of grooves and Z_{stk} are adjusted, while Z_{w-out} , Z_{w-cnt} , Z_{w-in} and wire radius are fixed as 1350mm, 1060mm, 350mm and 20mm, respectively. The gap source is positioned at -150mm from xy -plane and occupies 20mm as the Δz for the FDTD simulation. The source is the sinusoidally modulated Gaussian pulse with the bandwidth of 500 MHz, 3 dB time-width of 10^{-9} , as the unit gap voltage source. The cylindrical coordinates are used, since the problem can be simplified to 2-D(R, Z), and $\Delta z = \Delta R = 20$ mm leads to time step $\Delta t = 4.81 \times 10^{-12}$ s by the Courant

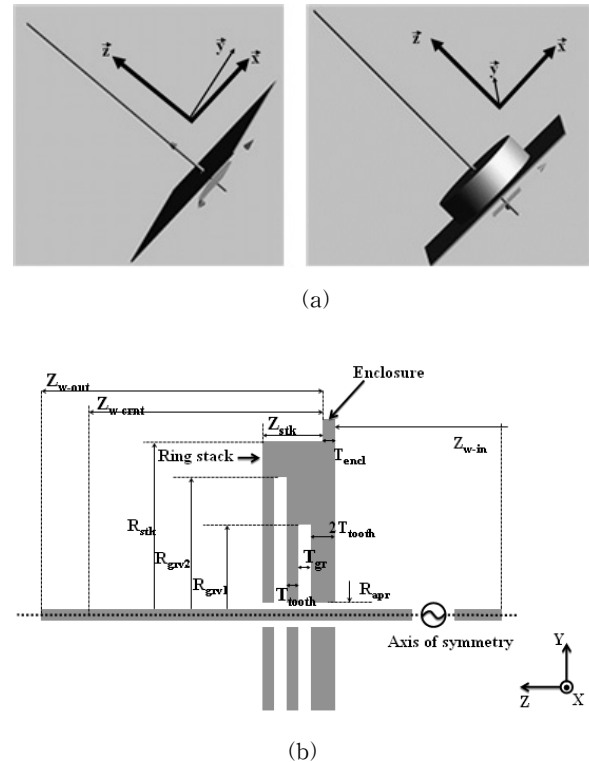


Fig. 2 Proposed structure reducing the unbalanced current (a) before and after our structure (b) 2D view

stability condition. In addition, 8 PMLs are adopted and each of the layers has reflection coefficient 10^{-6} to form the ABC(Absorbing boundary condition) of the simulation space. By adjusting the physical dimensions, a bandgap needs to be created to cause effective attenuation where the unbalanced current is transmitted between input and output ports. Therefore, either a stopband filter or a lowpass filter is required to have the stopband fall on the suppression frequency region that is beyond 450 MHz.

The geometry is suggested based on the filtering properties analogous to a composite right- and left-handed circuit which enables the frequency response to have a stopband as shown in [8-10]. The cable and the teeth of the inner rings form an ordinary transmission line with the right-handed capacitance and inductance. This right-handed part is connected to the left-handed structure-type circuit elements such as a series capacitance over the narrow groove and a shunt inductance due to the surface current on the wall of a groove to the bottom PEC. Therefore, when the right- and left-handed parts are cascaded, a CRLH circuit is made as shown on the right side of Fig. 3(a). Then, the geometrical parameters for the aforementioned circuit elements are varied until the frequency response of the filter has the stopband from 450 MHz beyond 1 GHz. Three grooves are used with thicknesses of 40mm, 37mm, and 30mm, and radii of 250mm, 200mm, and

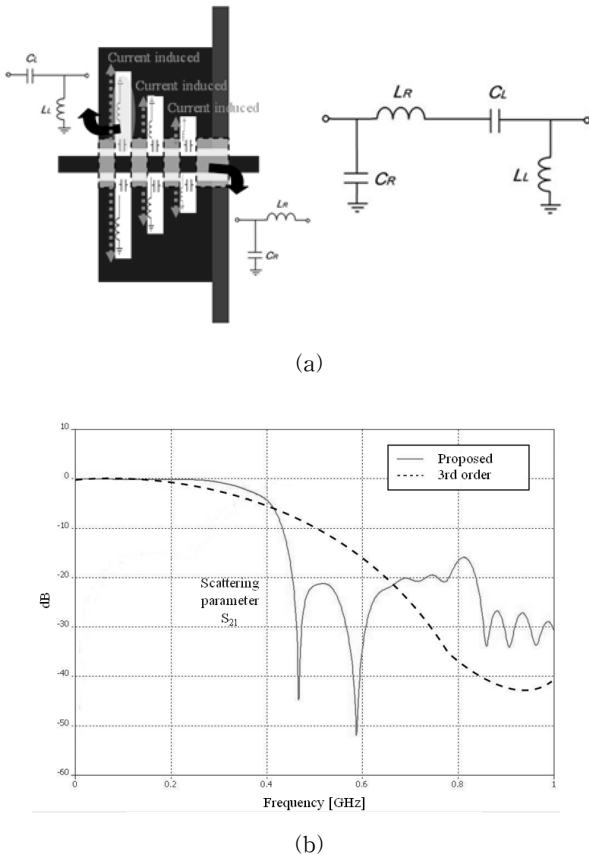


Fig. 3 Proposed structure analogous to a Metamaterial bandgap and frequency response (a) CRLH equivalent circuit analogy (b) Steep and wide stopband performance

140mm in order, spaced with the two teeth of 15mm, and 10mm, as the initial step for the unbalanced current choke, the s-parameter S_{21} is obtained as Fig. 3(b). Obviously, the stopband is created from 410 MHz as the cut-off above 1 GHz, and steeply attenuates the conduction noise due to the unbalanced current from 450 MHz to 1 GHz. This bandgap and filtering structure is applied to the spurious radiation as well as the common-mode current in the following section.

3. The Bandgap Structure to Reduce the Spurious Radiation

The stopband filter is adopted to a test case of the unbalanced current pulse excitation. The FDTD simulation uses the sinusoidally modulated Gaussian pulse as described previously. The structure with the initial geometrical values is adjusted to have the right result. Extra optimization renders the following physical dimensions: $R_{grv1}=120$ mm, $R_{grv2}=170$ mm, $R_{grv3}=220$ mm, $R_{grv4}=270$ mm, and $R_{grv5}=320$ mm, with the other

parameters remaining the same. This case is compared with other experiments of different number of grooves.

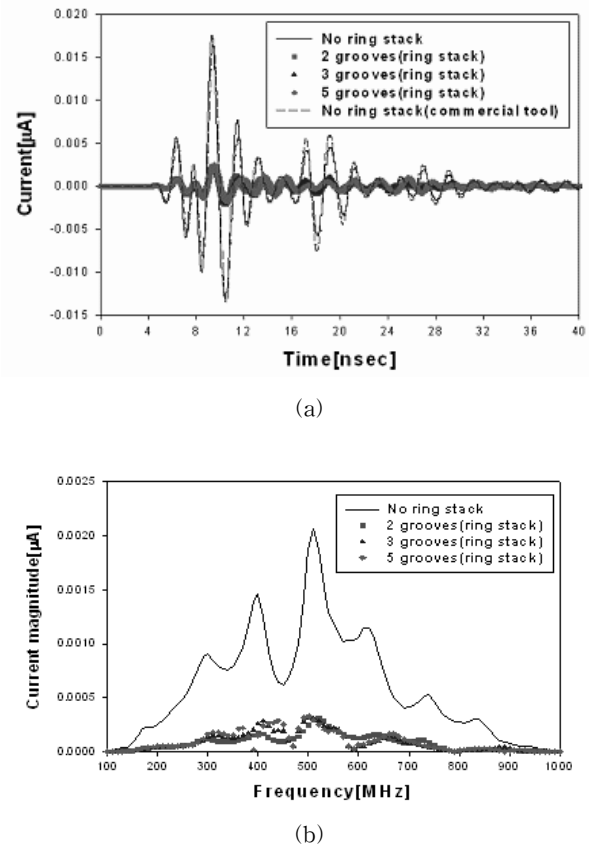


Fig. 4 Effect of suppressing the unwanted current pulse (a) Time-domain observation (b) Frequency-domain observation

The three-groove case is compared with the ordinary case, and the geometry with one groove or two. For a note, the FDTD simulation by the SEMCAD as the commercial tool is compared to the in-house FDTD code with regard to the case with no rings, and they are in good agreement. Apparently in Fig. 4(a) as the time-domain observation, the ordinary case 'no ring stack' has the highest level of the unbalanced current pulse, and the current pulse becomes weaker with the introduction of the bandgap structure. Also, as the number grows from 1 to 3, the noise suppression effect is maximized and convergent. The time-domain result is transformed to the frequency-domain in Fig. 4(b). The solid line as the current before taking a measure is the biggest. By adopting the stopband filter, the unbalanced current is noticeably suppressed. The effectiveness of this method will be verified by examining the radiated waves reduced by the structure.

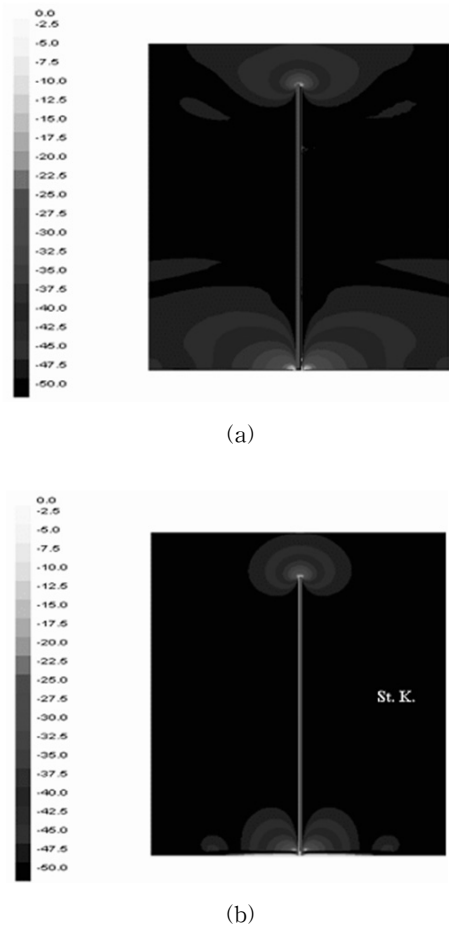


Fig. 5 Effect of suppressing the spurious radiation (a) with no bandgap structure (b) with the bandgap structure

In Fig. 5(a), the electromagnetic wave is distributed and wide-spread due to the radiation from the stronger unbalanced current at the bottom. This will make the electronic product fail in passing the EMI test and interfere with the nearby equipment. However, the ring stack as the bandgap filter attenuates the level of the unbalanced current and finally reduces the radiated emission level as shown in Fig. 5(b). So, the proposed method can be used in similar designs and EMP suppression.

4. Conclusion

A metamaterial-based filtering geometry with frequency selectivity was proposed to reduce the radiation with a bandgap structure, where the right-handed inductance and capacitance stem from the transmission-like configuration between the cable and the metal protrusion, and the left-handed components come from the narrow cavities. The effect of the structure on the unbalanced current pulse and its spurious radiation was presented in the FDTD-method frame work.

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Appendix

In this section, electromagnetic radiation can be generated by the unbalanced current in PCB transmission line structures. The common-mode current is such an unbalanced phenomenon caused by the impedance mismatch near a geometrical or material discontinuity, or geometrical asymmetry between the signal trace and the ground. Regarding an asymmetric transmission line, the common-mode current can be suppressed if the return current path is secured and the return current has the same velocity as the injected signal current. However, if the transmission line is placed near a discontinuity like

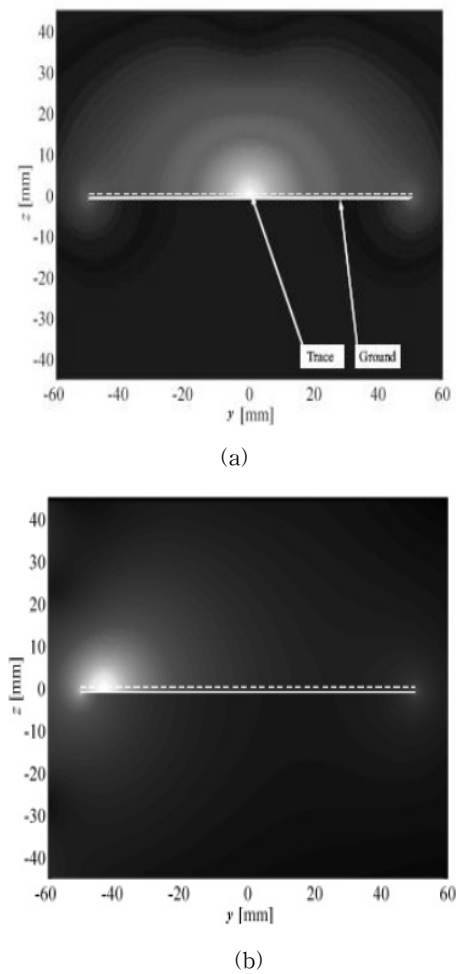


Fig. A-1. Magnetic field distribution over the transmission line structures (a) Signal trace away from an edge (b) Current paths near the edge.

an edge, the reflected electromagnetic field from the edge will cause an intolerable difference between the velocities of the main and return currents of the system, and disrupt the original impedance. As a result, the impedance of the ground will increase due to the elongated path of the return current and increasing the series inductance. This ends up with the break-off of the conduction current to the displacement current from the edge to the external space of the transmission line structure. This is verified by the following test where two transmission lines will have different field distributions without and with the generation of the imbalance between the main and return currents.

The magnetic field is visualized by FDTD simulations with respect to the planar microstrip transmission structures. When the signal trace is located at the center of the front-view of the transmission line, most of the magnetic field is concentrated in the middle of the plane as shown in Fig. A-1(a). Though the field is spread to the edges, it results from the finite-sized ground, and the strength of the field is very weak under the ground. However, the trace is moved to the vicinity of the left edge, the magnetic field exists strongly almost every point of the space as shown in Fig. A-1(b). Obviously, the reflection at the edges is intense, which

results from the mismatched impedance of the transmission line. Therefore, the unbalanced current will cause the unwanted radiation to the neighboring devices and make the prototype not meet the requirement on the radiated emission.

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