Electromagnetic Noise Suppression Technology Using Metamaterial - Its Practical Implementation

TOYAO Hiroshi, HANKUI Eiji, KOBAYASHI Hayato, ANDO Toshikazu

Abstract

The rapid size reduction of wireless equipment has led to a drop in the communication performance caused by the electromagnetic noise that is generated inside the equipment becoming an important issue. The electromagnetic bandgap (EBG) structure that is a kind of metamaterial is attracting attention as a new technology for reducing electromagnetic noise. This paper introduces a newly developed EBG structure, which is a technology developed originally by NEC. Wi-Fi home router products that apply this structure as a world first technology are also discussed.

Keywords

metamaterial, EBG structure, electromagnetic noise, electromagnetic interference, Wi-Fi, home router

1. Introduction

As a result of the recent reductions in size and increased communication speeds, wireless equipment has been increasingly affecting our daily lives. It is now becoming one of the critical issues that affect our social foundations.

On the other hand, the rapid reduction in equipment sizes has made electromagnetic interference inside equipment a non-ignorable issue. This issue is caused mainly in that chassis size reduction has increased the number of cases in which the antenna and wireless circuitry are being placed in close proximity to the digital circuitry. This causes a risk of reduced communication performance due to interference from the electromagnetic noise generated by the digital circuitry.

Fig. 1 shows a representative mechanism of generation and propagation of electromagnetic noise. The PC board on which LSIs and wireless circuitry are mounted has two conducting planes called the power plane and the ground plane that supply the power voltage to the LSIs. Since a large number of transistors perform switching simultaneously during operation of the LSIs, large voltage fluctuations are generated in the power and ground planes and consequently electromagnetic noise of some hundreds of MHz to a few GHz in the microwave band. Part of this electromagnetic noise is radiated at the openings and edges of the planes and this causes a drop in the receiving sensitivity and/or communication speed when it is caught by a nearby antenna.

This paper describes a new technology for suppressing electromagnetic noise, which is a kind of metamaterial referred to as the electromagnetic band gap (EBG) structure. Further-

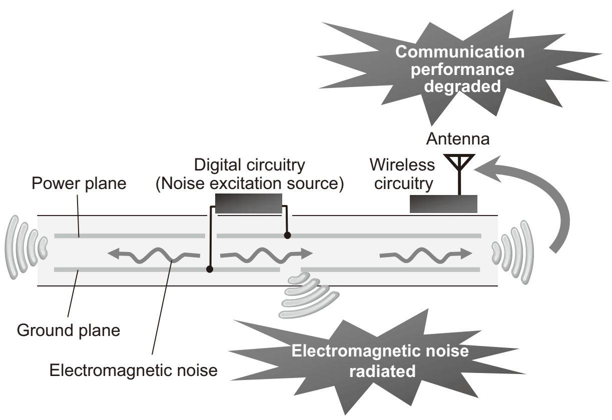

Fig. 1 Mechanism of generation and propagation of electromagnetic noise.

more, we also introduce the newly developed EBG structure, a technology developed originally by NEC, and the Aterm-WG1800HP/WG1400HP Wi-Fi home routers offering both significant size reduction and increased speed by adopting the newly developed EBG structure as a world first technology.

2. Metamaterial and EBG Structure

Since the early 2000's, research has been conducted on the idea of applying a kind of metamaterial called the EBG structure as a technique for preventing the propagation of electromagnetic noise.

The metamaterial technology is the one for forming an effectively homogeneous medium by arranging components such as metals at optimal intervals compared to the wavelength, etc. Proper design of the components and their placement can control the values of effective electric permittivity ε and the magnetic permeability μ in the metamaterial negatively as well as positively. So it is even possible to create a physical property that does not exist naturally. Interesting phenomena such as the negative refractive index that occurs in the domain where both the electric permittivity and the magnetic permeability are negative, has triggered the attention of researchers and worldwide interest in metamaterial.

On the other hand, in the domain where either the electric permittivity or magnetic permeability is negative, the propagation solution does not exist, so the propagation of electromagnetic waves is inhibited. The band in which the electromagnetic wave propagation is inhibited is called the electromagnetic band gap (EBG), and the structure that can implement it is called the EBG structure.

If an EBG structure can be formed in the layer between the power and ground planes of a PC board, it is expected that the propagation of electromagnetic noise can be restricted within the circuit board and radiation into space can be suppressed significantly. As the EBG structure can be formed by the copper foil etching process in the same way as the wiring of a PC board, it basically does not entail an additional manufacturing cost. Furthermore, it also presents an excellent noise suppression effect, even in high frequency bands such as the GHz band that is regarded as the limit for the chip components used traditionally as electromagnetic noise countermeasures. Because of these advantages, it is very much expected that the EBG structure will become the electromagnetic noise suppression technology of the next generation. Researches aiming at its practical implementation are being applied energetically.

3. Examples of EBG Structures - Their Issues

Two approaches are proposed for the implementation of the EBG structure. These are the ε-negative type achieving negative electric permittivity and the μ-negative type achieving negative magnetic permeability. **Fig. 2** shows the representative configurations of the two approaches.

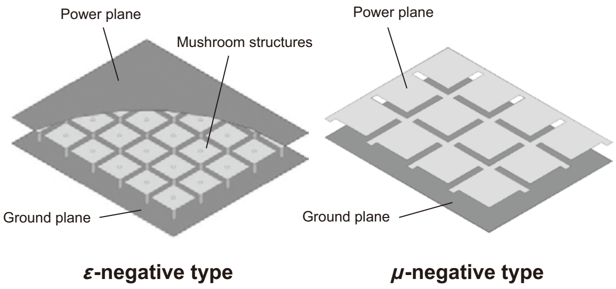

Fig. 2 Representative EBG structures.

The ε-negative type achieves negative electric permittivity in a specific frequency band by arranging resonators that interact with the electric field components of the electromagnetic wave. The known representative example is the configuration in which unit cells of the so-called mushroom structures are arranged between the power and ground planes.[1] The mushroom structures function as LC resonators at high frequencies, and these present negative electric permittivity at near resonance frequency that acts as an electromagnetic band gap.

On the other hand, the μ-negative type achieves negative magnetic permeability in a specific frequency band by arranging resonators that interact with the magnetic field component of the electromagnetic wave. The known representative example is the configuration in which periodic slits are formed on the planes themselves.[2] The periodic slits function as LC resonators at high frequencies, and present negative magnetic permeability at near resonance frequency that acts as an electromagnetic band gap.

Nevertheless, an issue has hindered practical implementations of both approaches, which is the size of the unit cell. Since large inductance and capacitance are required to suppress the electromagnetic noise that is the main cause of electromagnetic interference in the frequency bands from some hundreds of MHz to a few GHz, it is essential to increase the area of the LC resonators. For example, when the target is the 2.4 GHz Wi-Fi band, the required unit cell size becomes 8 mm or more for the ε-negative type and 30 mm or more for the μ-negative type. This means that it is difficult to implement the unit cells on the circuit boards of wireless devices that are continuously reducing in size.

4. NEC's Unique, Ultracompact EBG Structure

In order to respond to the need for unit cell size reduction, we propose a newly developed EBG structure based on a new concept.[3] This structure is an ε-negative type EBG structure that achieves negative electric permittivity by using a resonating structure called an open stub in place of the traditional LC resonators.

An open stub is a transmission line with open ends. It is capable of controlling the resonance frequency by "length" instead of area. To reduce the frequency of the band gap, the open stub should be increased in length but the area does not always need to be increased, which means that it enables a great reduction in the unit cell implementation area compared to previous designs. **Fig. 3** shows the evaluation board of the newly developed EBG structure for the 2.4 GHz band that we have prototyped and its unit cell. The spiral-shaped stub design permits implementation of the stub with a length of 18 mm, which corresponds to 1/4 of the wavelength at 2.4 GHz, and in the small unit cell size of 2.1 mm × 2.1 mm. This implementation area is less than 1/15th of the unit cell area of the EBG structures proposed hitherto.

The implementation of the ultracompact unit cell has for the first time made it possible to implement the EBG structure of complicated circuit boards at a complicated product level. **Fig. 4** shows the results of strength measurements of the magnetic fields leaked from the inside to the surface of the PC mother board prototypes with and without the newly developed EBG structure. The board without this structure leaks a strong magnetic field from the digital circuit region and board edges, while that with this structure can significantly reduce the leaked magnetic field. We have additionally evaluated the communication performance using a prototype equipped with wireless circuitry and an antenna. It is demonstrated thereby that the reception sensitivity deteriorated by the electromagnetic noise can be improved by up to 10 times with the use of the newly developed EBG structure.[4)]

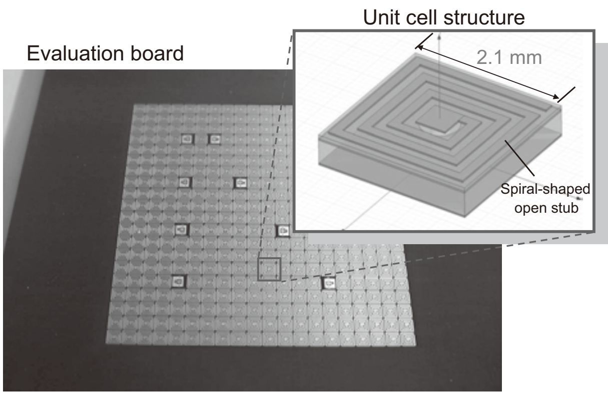

Fig. 3 The newly developed EBG structure evaluation board and unit cells.

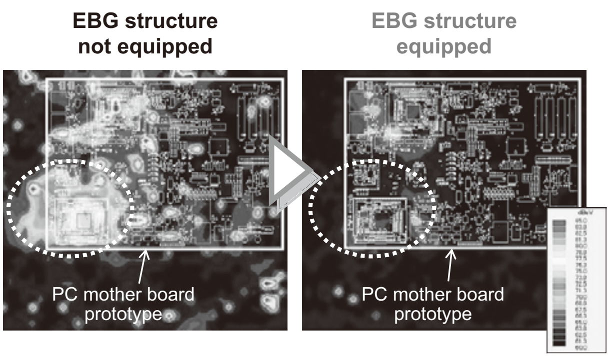

Fig. 4 Results of surface magnetic field strength measurements of the prototype.

5. World First for Wi-Fi Home Routers with EBG Structures

After the demonstration step using prototypes, we started shipment of the Wi-Fi home routers AtermWG1800HP/WG1400HP (**Photo**) based on the new EBG structure in April 2013 as products of NEC Access Technica, Ltd. These products are the world's first example of the practical implementation of the EBG structure.

Our products comply with the latest Wi-Fi standard IEEE 802.11ac (Draft), and the AtermWG1800HP achieves an ultra high speed communication rate of 1,300 Mbps (theoretical value) that is about three times that of the traditional standard. Furthermore, the suppression of electromagnetic noise by the new EBG structure has made it possible to place the digital circuitry and antenna at a shorter distance apart so that a significant size reduction is achieved. Ultra high speed communication performance is secured at the same time.

The advanced performance of these products has already been highly evaluated; The Grand Prix of the "Best of Show Award" for the Mobile & Wireless Category was awarded at Interop Tokyo 2013, which is the highest class network and computing event that is held in Asia.

Photo External views of AtermWG1800HP and WG1400HP, the new EBG structured unit cells on their boards

6. Conclusion

This paper has introduced the newly developed EBG structure, which is a new electromagnetic noise suppression technology that enables both size reduction and high communication speed for wireless equipment. Wi-Fi home router products that adopt this technology as a world first release are also described. This is a highly universal technology so it is expected to be disseminated in a very wide range of products. For the future, too, we intend to advance R&D of this technology with the aim of realizing a more familiar wireless society that will provide more comfort for humankind.

* Wi-Fi is a registered trademark of Wi-Fi Alliance.

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