Active Negative Impedance Loaded EBG Structures for the Realization of Ultra-Wideband Artificial Magnetic Conductors

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Abstract

A new design methodology is introduced for an ultra-wideband Artificial Magnetic Conductor (AMC) that is based on loading the elements of Electromagnetic Bandgap (EBG) structures with active devices. The types of active loads used for this application belong to the class of devices known as Negative Impedance Converters (NICs). NICs are active two-port networks for which the impedance looking into one port is the negation of the impedance connected to the other port scaled by the impedance conversion coefficient of the device. Several design examples will be presented that demonstrate the considerable enhancement in bandwidth that can be achieved, compared to conventional passive AMC surfaces, by using EBG structures actively loaded with NICs.

I. Introduction

EBG structures represent an important class of metamaterials, primarily because it has recently been shown that they can be designed to exhibit AMC properties [1,2]. However, it is a well-documented fact that the desirable AMC properties of these high-impedance surfaces only exist over a narrow frequency range in the neighborhood of the resonance. This narrowband limitation can severely restrict the number of useful applications for conventional passive AMC surfaces, especially when considered for antenna applications. Active impedance loading such as the NIC offers a method to overcome these bandwidth limitations, which makes possible the ability to engineer active metamaterials that exhibit electromagnetic activity over a much broader frequency range.

For the designs to be presented here, the usable bandwidth of an AMC is considered to be the frequencies between which the phase of the reflection coefficient is bounded by ± 45 degrees, and will be given as percent bandwidth with respect to the center frequency. Moreover, it will be shown that NIC active loads provide a means for increasing the AMC bandwidth from a typical unloaded value of about 10% to as much as 200% or more. AMC surfaces that exhibit such ultra-wideband properties are attractive for use in the design of low-profile multiband or broadband antenna systems. They may also be used for situations that require several low-profile antennas that operate simultaneously at different frequencies or cover different bands.

II. Negative Impedance Loading

Active NIC loads have been recently considered for use in a number of electromagnetic metamaterial applications [3,4]. Here we consider a new application of NIC loads involving their use in the design of ultra-wideband AMC surfaces. A specialized two-port active network consisting of an amplifier and load impedance configured to provide positive feedback is used to implement the negative impedance load. The ideal NIC device is an active two-port network having a driving point impedance looking into one terminal pair exactly equal to the negative of the impedance connected across the other

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terminal pair. A schematic diagram of one possible configuration for a NIC is shown in Fig. 1.

III. Results

A typical unloaded high impedance EBG structure consisting of square metal patches connected by a center via to the ground plane is shown in Fig. 2. In this case, the EBG is designed to act as an AMC with center frequency at 25 GHz. The analysis of these structures is performed using a parallel LC circuit model to describe the resonant high-impedance behavior of the EBG surface [1,2].

To improve the bandwidth of such a structure, negative impedance parallel capacitor and inductor loads are added to the EBG surface as shown in Fig. 3. By varying the values of the negative capacitor and inductor, denoted by C_{neg} and L_{neg}, respectively, the AMC bandwidth can be increased considerably. The reflection coefficient phase curves are shown in Fig. 4 for an unloaded EBG and three loaded EBG structures with different values of negative impedance. By simultaneously increasing the overall inductance and decreasing the overall capacitance, the EBG response obtains the same resonant frequency with an increased bandwidth. Furthermore, by dramatically altering the original inductance and capacitance values of the structure, an ultra-wide bandwidth can be achieved.

The unloaded EBG shown in Fig. 4 has a bandwidth of only 4.4%, while the next two loaded cases yield a bandwidth of 35.2% (for L_{neg} = -0.222 nH and C_{neg} = -0.18 pF) and 70.8% (for L_{neg} = -0.210 nH and C_{neg} = -0.19 pF), respectively. Finally, the reflection coefficient phase of the EBG structure for the ultra-wideband case is shown as the solid curve in Fig. 4, with a bandwidth of 175% and a center frequency maintained at 25 GHz. The ultra-wideband EBG requires a negative inductance value of L_{neg} = -0.204 nH and a negative capacitance value of C_{neg} = -0.196 pF.

IV. Conclusions

The design examples presented here demonstrate the ability for a NIC active load to considerably improve the bandwidth of a standard EBG structure designed to act as an AMC. Specifically, it was found that by increasing the overall inductance while simultaneously decreasing the overall capacitance of the AMC structure by the same factor allows an ultra-wideband response to be achieved. By correctly designing a stable NIC circuit with the appropriate values of negative inductance and capacitance, EBG structures with operating bandwidths of 175% or more are possible. Since the NIC active load is theoretically independent of the operating frequency, it should be possible to design an ultra-wideband AMC surface with nearly any desired center frequency and bandwidth, provided the NIC remains stable.

Acknowledgement

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References

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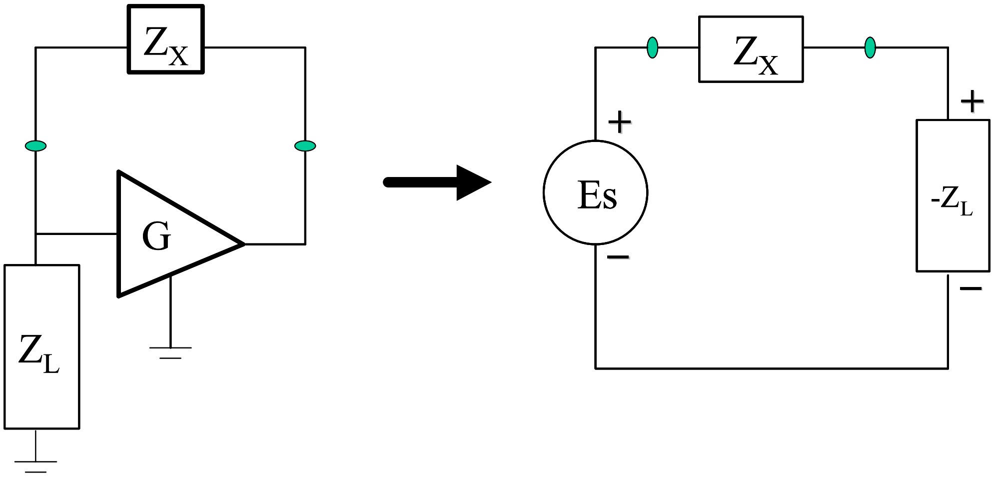


Fig. 1: Schematic diagram of NIC configuration and its equivalent circuit model.

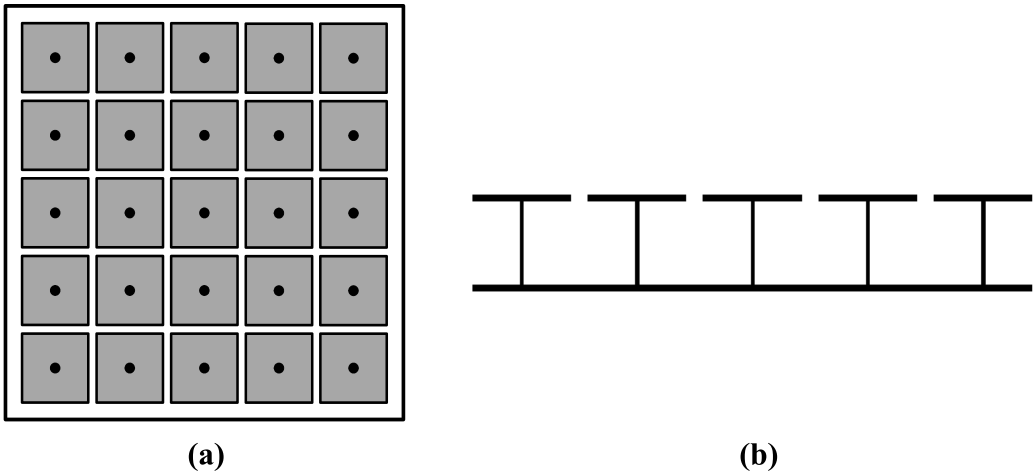
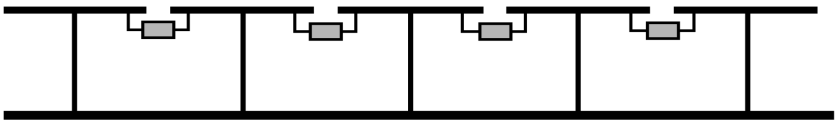
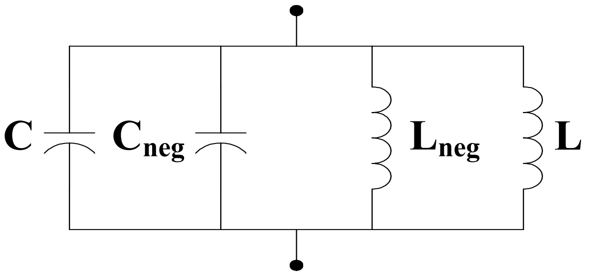


Fig. 2: Unloaded high impedance EBG structure. Top view (a), and side view (b).



(a)



(b)

Fig. 3: EBG with active loads. Side view of EBG with active load configuration (a), and equivalent circuit model of EBG structure with NIC (b).

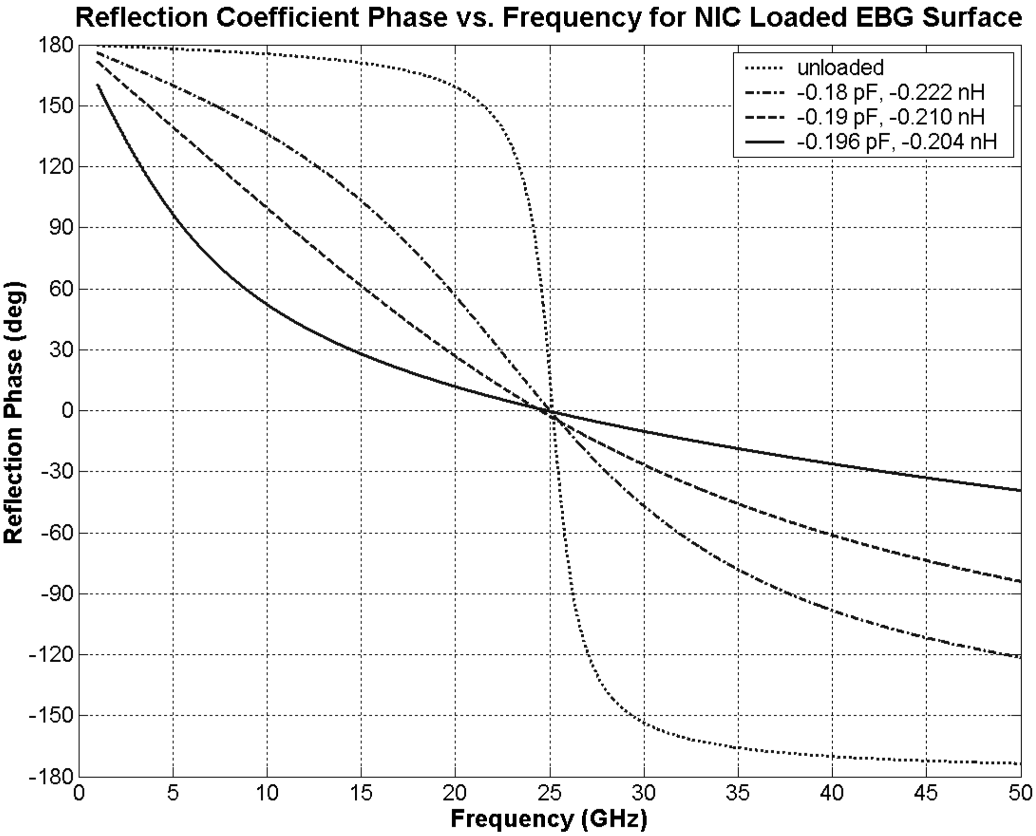


Fig. 4: Reflection coefficient phase curves for an unloaded EBG surface and three loaded EBG structures with different values of negative inductance and capacitance. The solid curve represents the ultra-wideband EBG design.