Non-Foster loaded periodic structures for fast and slow wave propagation

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Abstract—**This research project is to investigate the broadband applications by integrating non-Foster circuits into current periodic structure designs. Two studies have been carried out. The first study demonstrates the possibility of the broadband dispersionless fast wave propagation, where a 1-meter-long superluminal non-Foster circuit loaded transmission line has been fabricated and measured, showing a superluminal square pulse propagation with negligible distortion. Furthermore, it is mathematically proved such superluminal propagation based on Kramers-Kronig relations. The second study is about broadband slow surface wave application. Particularly, by loading a non-Foster circuit, -2.8 pF ‖ -3.6 nH, to conventional impedance surface, a broadband slow surface wave with index of 1.5 is demonstrated over the bandwidth of 450-800MHz.**

Index Terms—**periodic structure, superluminal propagation, non-Foster circuit, metasurface, impedance surface.**

I. INTRODUCTION

MODERN microwave technology requires more and more bandwidth. Since non-Foster circuit has shown its potential in broadband antenna designs [1-2]. It is thus expected that the non-Foster circuits can also be helpful in broadband guided wave designs, especially for the guided waves that are intrinsically dispersive. As for two typical example of dispersive waves, one is the fast wave and the other is the surface wave. Thus this research project is divided into two parts, for the broadband fast wave propagation and slow surface wave propagation, respectively.

For the study on the fast wave propagation, a discrete transistor based negative capacitor circuit has been proposed and integrated into a microstripline. A three-unit-cell loaded microstripline has been successfully fabricated and tested [3]. The retrieved effective material parameters from the measured S-parameters identify an effectively uniform medium with a constant phase velocity of 1.2c over a bandwidth of 60-120 MHz. Furthermore, the measurement results have been verified by Kramers-Kronig relations and the measured near field distribution along the microstripline, which demonstrate that the accomplished waveguide can be regarded as a stable, causal, and homogeneous material rather than a lumped element, showing the possibility of cascading multiple unit

cells with transistor based non-Foster circuits to achieve an effectively homogeneous material that supports broadband fast wave propagation. This study is extended by implementing a longer transmission line supporting the superluminal pulse transmission, which is observed by a time domain approach [4]. The found result is demonstrated by the mathematical proof based on Kramers-Kronig relations.

For the slow surface impedance study, this research focuses on realizing a broadband impedance surface with a constant propagation index [5-6]. To achieve such goal, the non-Foster loading approach is adopted, demonstrating that a frequency-dependent non-Foster type impedance is able to accomplish a low-profile artificial impedance surface and also reduce the dispersion of the well-bounded surface wave propagation. Starting from a conventional 5-mm-thick impedance surface resonating at over 1 GHz, an optimized non-Foster type frequency-dependent impedance, which is capable of producing a constant surface wave propagation index, is synthesized. The required non-Foster load, a shunt combination of -2.8 pF ‖ -3.6 nH, is designed and integrated with the thin artificial impedance surface. The near-field measurement of the non-Foster impedance loaded surface presents a constant surface wave index of 1.5, corresponding to a 420 jΩ surface impedance, over 450-800 MHz, a fractional bandwidth of 56%. By varying the biasing voltage of the non-Foster circuit, the achieved surface impedance can be tuned from 250 jΩ to 420 jΩ, while maintaining the low dispersion and the same bandwidth.

II. PROJECT OUTCOMES

A. Non-Foster Loaded Superluminal Pulse Propagation

The concept of boosting the phase velocity with a non-Foster impedance is illustrated in Fig. 1(a). When a typical non-Foster impedance, for example a negative capacitor, is loaded to a conventional transmission line, the capacitance per unit length is decreased by the loaded negative capacitor. The overall phase velocity, which is inversely proportional to the square root of the capacitance per unit length, is thus increased. By properly choosing the capacitance, it is possible to make the net capacitance per unit length less than the threshold value that produces the light phase velocity. In such case, the fast wave propagation can be obtained. Moreover, since the microstripline preserves the quasi-TEM wave mode, the non-Foster approach does not produce additional dispersion to the propagation. Therefore, it is possible to realize a non-dispersive broadband fast wave propagation [3]. It is noted
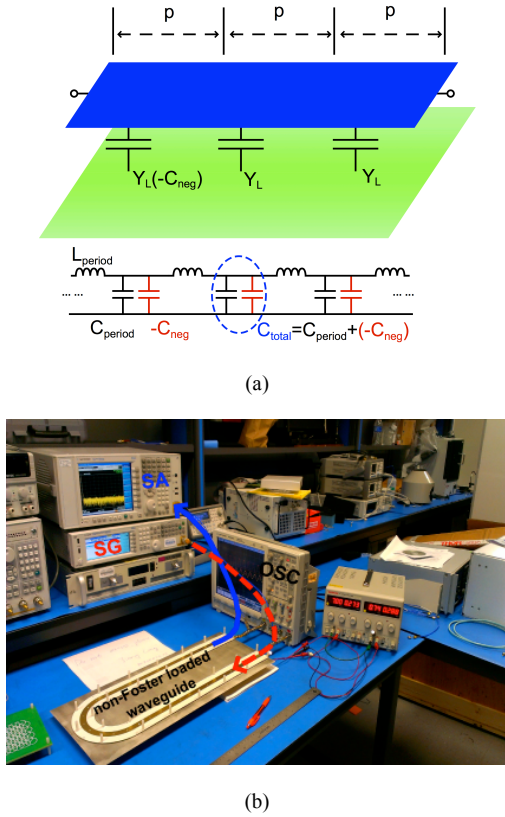
(a)

(b)

Fig. 1. Non-Foster loaded fast wave application. (a) The principle of the non-Foster loaded waveguide. (b) superluminal pulse transmission measurement system with the fabricated 38-unit-cell non-Foster loaded waveguide.
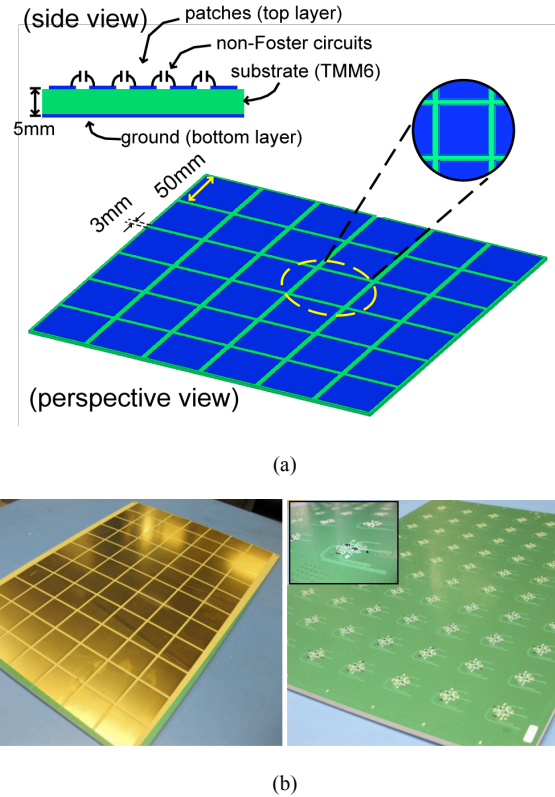

(a)

(b)

Fig. 2. Non-Foster loaded impedance surface. (a) a schematic of the non-Foster loaded impedance. (b) a fabricated sample (left: top view; right: bottom view).

that when the dispersion is negligible, the group velocity converges to the phase velocity, thus resulting in broadband superluminal propagation. With such principle, we first demonstrated a 3-unit-cell non-Foster loaded waveguide, and eventually implemented a 38-unit-cell waveguide with a total length of 1 meter. Time domain measurement approach, as shown in Fig. 1(b), is adopted to measure a transmitted superluminal square wave pulse with an index about 0.8, which is double confirmed by the frequency domain measurement. Furthermore, it is mathematically proved that the superluminal pulse transmission is limited by the distortion, when the stable system is enforced by Kramers-Kronig relations [4].

B. Non-Foster Loaded Impedance Surface

For slow surface wave application, it is demonstrated that non-Foster circuits are capable of producing broadband slow surface wave and control the surface impedance [5-6]. To demonstrate this conclusion, we started from a conventional impedance structure, as shown in Fig. 2(a), loaded it with synthesized non-Foster circuit. The fabricated impedance surface is shown in Fig. 2(b), where it is clear to see all the non-Foster circuit are populated on the backside of the impedance surface. The initial simulated result can be found in [5]. The measurement results show a constant slow index of 1.5 is obtained over a broad frequency range from 450-800 MHz [6].

III. Career Plan and Fellowship Impact

Thanks to the MTT-S fellowship which has encouraged and facilitated me to complete this research. It provided me not only the financial support during my PhD study, but also the opportunity to IMS 2015 in Phoenix to share my research with prestigious fellows, which inspired me for my future studies. Keep learning and innovating is my long term goal. I will keep myself open to all kinds of innovation and technology in both industry and academia. For my immediate goal, I plan to gain more practical experience in industry.

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