Concurrent Multi-Mode Ferrite-Loaded SIW Components

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***Abstract*—Next generation of wireless systems aim toward multi-functionality based on multi-band and multi-mode components. This brief aims to report on our latest developments in integrated multi-mode ferrite-based nonreciprocal components. Moreover, we have reported novel and innovative approaches for exploiting nonreciprocity through mode compared to conventional approaches using amplitude and phase in isolators and phase shifters, respectively. In particular, the proposed dual-mode circulator can address a paradigm shift in designing a full-duplex transceiver front-end using a dual-mode circulator and dual-polarized antenna to achieve ultra-high isolations.**

***Index Terms*—circulator, ferrite, mode conversion, nonreciprocity, substrate integrated waveguide (SIW), TE_{20} mode, Full-duplex.**

I. Introduction

NONRECIPROCITY is a crucial property in many RF systems, including communication, radar, measurement, etc. Ferrite-based components are a popular approach to attain nonreciprocity for their passiveness, which results in high linearity and low noise performance at RF front-ends. Further, ferrite components are inherently tunable, which is desired for new wireless systems. Traditional ferrite components are bulky and non-integrated, though ferrite-loaded SIW devices offering integrated and compact solutions are suitable approaches to exploit ferrite nonreciprocity.

On the other hand, multi-function and multi-mode components are emerging and ubiquitous in new RF and microwave systems. However, ferrite components have rarely been extended into multi-mode configurations. Therefore, the lack of a general approach to developing and implementing multi-mode ferrite components suitable for 5G and future wireless systems is evident.

Hence, in our Ph.D., we proposed and developed a general approach to implement multi-mode ferrite components for the first time. Moreover, we introduced the concept of modal nonreciprocity, which can be used to exhibit nonreciprocity through mode compared to conventional approaches that use amplitude (isolator) or phase nonreciprocity (phase shifter).

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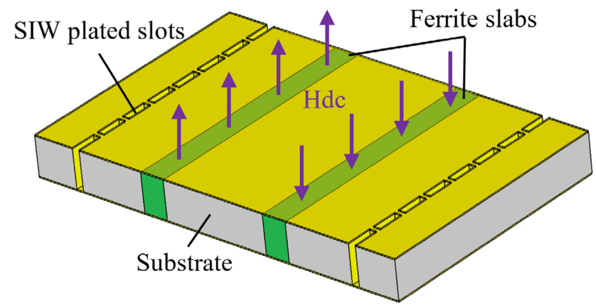

Fig. 1. Perspective view of a section of an anti-symmetrically twin-slab ferrite loaded SIW [4].

II. Nonreciprocal multi-mode ferrite loaded SIW components

The schematic of a twin-ferrite-loaded SIW is depicted in Fig. 1. This is the general topology for realizing a concurrent dual-mode ferrite device. In this configuration, SIW is oversized to propagate the first two dominant waveguide modes. Ferrites can be biased in the same direction for reciprocal behavior or in the opposite direction for nonreciprocal behavior. The lateral position of ferrite slabs significantly impacts propagation constant and electromagnetic field patterns within the structure. In [1, 2], the structure was investigated for the particular case where ferrite slabs are in contact with SIW walls. Then it was shown that for a specific range of magnetic bias having ferrites with high saturation magnetization, it is possible to create very different electromagnetic field patterns for forward and reverse directed waves with substantial difference in their phase constant. In the proposed component, in one direction electric field pattern is similar to normal waveguide modes with the electric field maximum at the center of the waveguide. In contrast, the electric field pattern is hyperbolic with maxima at ferrite edges in the reverse direction with a substantially higher phase constant. Therefore, the structure is exploited to create a modal nonreciprocity, where for one direction, TE_{10} mode is converted to TE_{20} mode, while for the reverse direction, the mode is preserved, as illustrated in Fig. 2(a-b). As shown in this picture, introducing a bend in the structure causes modal nonreciprocity.

In [3, 4], we have proposed and developed another approach to design a nonreciprocal mode converter waveguide suitable for materials with lower saturation magnetization. In this work,

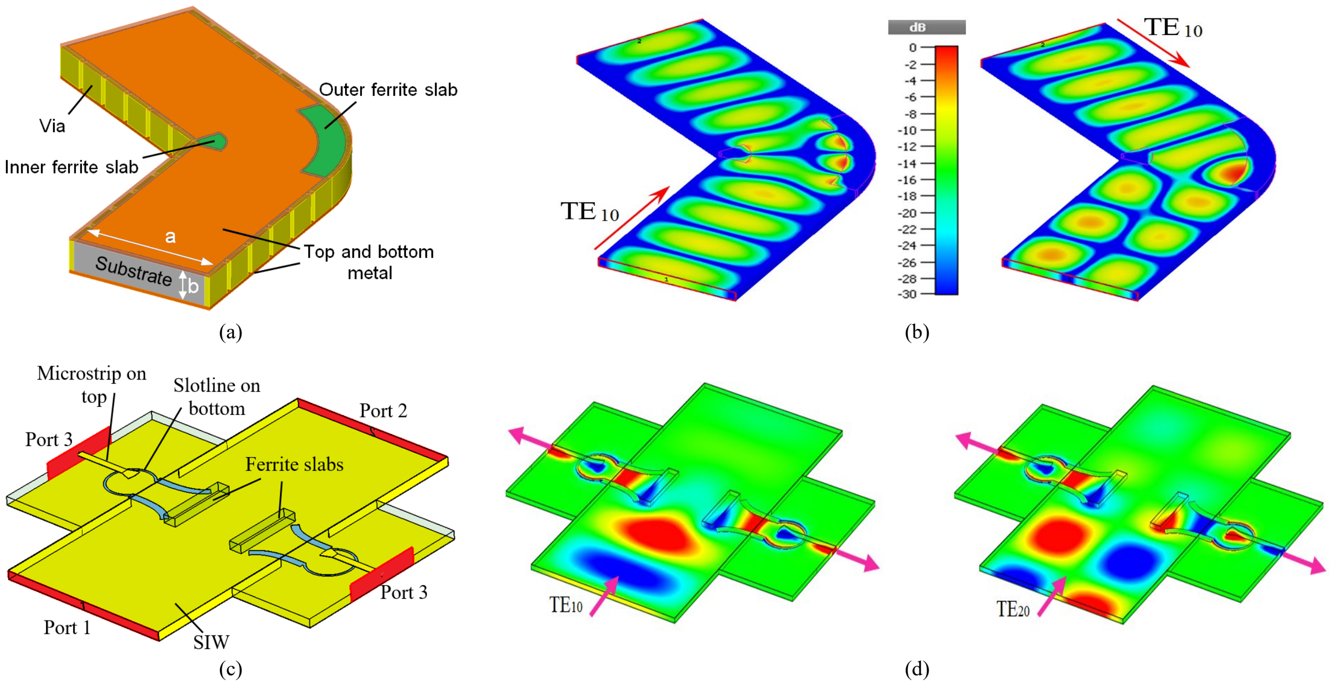

Fig. 2. (a) Schematic of the nonreciprocal mode-converting waveguide in [2] and (b) the electric field pattern in forward and reverse directions for TE_{10} mode. (c) Schematic of the proposed dual-mode circulator in [5] and (d) the electric field pattern for both TE_{10} and TE_{20} modes for port one feeding.

we investigated the structure in Fig. 1 for the general case where ferrite slabs are positioned at arbitrary distances from SIW walls. It was revealed that for a proper magnetic bias that derives ferrite permittivity into the negative region, two distinct and separate channels are created within the ferrite-loaded SIW for forward and reverse-directed waves. One channel propagates fields between two pieces of ferrite at the center of the waveguide, while the other channel is created in the reverse direction at the sides of the SIW and between the ferrite slabs and the SIW walls.

This nonreciprocal SIW was also exploited to design and develop a dual-mode circulator for the first time in [5], which simultaneously circulates both TE_{10} and TE_{20} modes. This work showed that a dual-mode SIW loaded by twin-ferrites with negative permittivity that are far from each other and SIW walls can construct a dual-mode circulator. For the design of the circulator, additional ports must feed the structure from the sides of the SIW to create a resonance junction. The field pattern of such a dual-mode circulator is shown in Fig. 2 (c-d) for TE_{10} and TE_{20} modes feeding one of the SIW ports.

III. Conclusion and Future Work

We presented and showcased our latest publications concerning developing novel nonreciprocal and multi-mode ferrite-loaded components in this brief. These works unveil the potential for exploiting ferrite materials for novel applications and in distinctive and innovative approaches. More importantly, it is demonstrated that ferrite components can be deployed in multi-mode configurations suitable for 5G and future multi-function wireless systems. In this regard, we have submitted a paper in the review process, which demonstrates that this approach can be expanded and extended to higher-order modes by employing more ferrite pieces within an oversized SIW. Finally, we believe dual-mode circulators can be employed in future wireless systems connected with dual-polarized antennas to achieve ultra-high and wideband isolation for Full-Duplex applications, which is the subject of our future work.

IV. Career Plan

Now, I am writing my thesis to finish my doctoral studies. After graduation, I will start a postdoctoral position to develop a full-duplex transceiver based on proposed ferrite components. I would also like to pursue an academic career as a faculty member in the future. Receiving the IEEE MTT-S graduate fellowship for 2020 has encouraged me to stay in the academic environment and contribute to the MTT society. I look forward to participating in future events hosted by the IEEE MTT-S society.

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