Electric and Magnetic One- and Two-Dimensionally Tuned Parameter-Agile SIW Components and Devices

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Abstract— **In this work, a novel magnetically tunable microwave components and devices are developed and demonstrated using SIW technology. The performances of the magnetically tunable devices were further enhanced by incorporating both electric and magnetic tuning on the single device. The designed tunable and non-reciprocal circuits, components and devices are very useful in the realization of high power communication and radar system designs design.**

***Index Terms*—Ferrite, half-mode substrate integrated waveguide (HMSIW), magnetic tuning, tunable filter**

I. Introduction

THE PRESENT wireless communication systems are becoming every day more complex in nature. New features are added into a single device to satisfy the growing customer needs. A small hand-held device is expected to have multiple functionalities with an excellent performance quality. In order to meet the growing complexities of RF front-end, its design must be adaptive and flexible in nature. An adaptive RF front ends can be realized by incorporating multi-band or multichannel circuits to satisfy the several wireless system standards. One way of realizing the multiband or multi-channel communication systems is by incorporating the tunable microwave components, circuits and devices into them. This not only will make the device operate in multiple frequency bands, but at the same time a single tunable device will replace the requirement of multiple devices to achieve the same functionalities. Moreover, the use of a single tunable device will also reduce the total size and the cost of the whole RF and microwave system.

The tunable devices for RF and microwave applications are realized by incorporating special type of tuning elements into them. The most widely and commercially used tuning elements include: semiconductors (varactor diodes, PIN diodes, and transistor), micro-electro-mechanical systems (MEMS), ferroelectrics materials, and ferromagnetic materials. Each of these tuning elements or techniques has their own advantages and disadvantages. Their use largely depends upon, the required type of tunability (discrete or continuous), operating power, design frequency, and also manufacturing complexity and total cost. In this Ph.D. thesis, using ferromagnetic material and substrate integrated waveguide (SIW) technology new types of tunable components and devices are proposed, developed and demonstrated. Originally, rectangular waveguides were used in order to realize number of ferrite based non-reciprocal devices including circulators and resonant cavities. There could have been several reasons, why metallic waveguides were always chosen to be used together with ferrite materials. Metallic hollow waveguides are well known for their low-loss and high power handling properties. Ferrite materials are also popular tuning elements for high power applications. Therefore, a combination of metallic hollow waveguide and ferrite material would have yielded very useful non-reciprocal and tunable devices especially for high power applications. Thus, development of low-loss high power devices could have been a fundamental reason to associate ferrite material with rectangular waveguide. Although, ferrite loaded metallic waveguides have many advantages including lower loss, high power handling capability, easy integration of ferrite and it’s biasing, but due to their 3-dimensional geometry they cannot be easily integrated into planar circuits. The modern day communication systems require RF and microwave circuits not only to be lighter in weight but also they are required to have planar form to be integrated with other circuitries. Therefore, it is a purpose of this thesis to realize a magnetically tunable ferrite loaded components and devices that inherit all the properties of rectangular metallic waveguide and also at the same it is planar in nature. Since, SIW is a planar or two-dimensional form of rectangular waveguide, it is chosen for the realization of magnetically tuned devices. Planar polycrystalline ferrite slabs are inserted or fitted inside the SIW devices to realize magnetically tunable planar microwave components and devices for high power applications.

In this work, number of microwave components and devices based on ferrite loaded SIW were presented. As a first step, a magnetically tunable ferrite loaded SIW cavity resonator was presented [1]. The design of magnetically tunable cavity resonator was very important in order to understand the behaviour of SIW when it is loaded with ferrite material. From both theory and measurement it was observed that, when the cavity loaded with ferrite material is applied with static magnetic bias, the resonant frequency of the cavity had a tendency of shifting towards higher frequency values. It was noticed that this shift was non-linear in nature. The measurements were performed for one, two and four-ferrite

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slabs loaded cavity resonators. The measurement results indicated increasing the effective area of the ferrite slab also increases the total frequency tuning range. For the four ferrite slabs loaded cavity resonator, the frequency up to 16% was measured. The design of the ferrite loaded cavity resonator provided valuable information about total losses, frequency tuning range and physical design requirements.

A cavity resonator is a basic building block of any microwave system design. It can be used as a foundational circuit, and all other system`s components and devices can be derived from it. In this work, the tunable SIW cavity resonator was further developed to realize other active and passive components and devices all working at 12 GHz. One of the devices designed on the basis of magnetically tunable cavity resonator was a tunable feedback-loop oscillator [2]. The oscillator consisted of ferrite loaded magnetically tunable cavity resonator, which was connected between input and output ports of an amplifier. The frequency of oscillation was tuned to higher frequency value by the application of DC magnetic bias on the ferrite loaded cavity resonator. A biasing mechanism was proposed, which consisted of a U-shaped soft iron metal connected between the two ferrite slabs. A similar soft iron metal plate was also soldered on the bottom of the substrate, to create a return path for the magnetic field. Copper solenoid was wounded around the metal core. To produce the magnetic field in the soft metal core, the two terminals of the wire was connected to the power supply. It was also demonstrated, that by replacing the DC current supplied on the metal core with AC, the oscillator output frequency was modulated by the frequency of the applied AC current source. The designed oscillator can be used as a signal generator for FMCW radar applications.

The proposed and demonstrated SIW based magnetically tunable devices exhibited very promising performances at the design frequency of 12 GHz. However, it was noticed that at highest value of applied magnetic bias ($H0$ = 0.4 T and beyond), their performances started to degrade gradually. In the case of cavity resonator, there was a significant reduction in the magnitude of the resonance peak values. In the case of tunable band pass filter, the total frequency tuning range was limited due to the degradation of the filter shape and bandwidth. In order to improve the performance of magnetically tunable devices, a new concept of simultaneous electric and magnetic two-dimensional tuning was introduced [3]. With the new concept of two-dimensional tuning, electric and magnetic field components are simultaneously tuned to achieve the highest performance quality. Again SIW cavity resonator was considered to demonstrate and validate the concept of two-dimensional tuning. Planar ferrite slabs were loaded along the sidewall slots of the cavity, while a lumped capacitance was placed near the central region of the cavity where the electric field strength is highest. It was demonstrated that with the simultaneously changing the values of applied magnetic bias and the capacitance, the total frequency tuning range of the cavity was increased by two-folds. The same concept was also implemented on a band-pass filter, which was realized by cascading the two cavities together. This time, varactor diodes were connected along the central region of the cavity to achieve the desired electrical tuning. With the simultaneously changing the electric and magnetic fields applied on varactor diodes and ferrite slabs, a frequency tunable constant bandwidth as well as constant frequency tunable bandwidth filters were realized and successfully demonstrated. The same concept was also applied to enhance the total frequency tuning range of a cavity backed antenna.

The magnetically as well as simultaneous magnetically and electrically tunable devices mentioned above do not display any non-isotropic properties. In this work, the non-reciprocal aspects of ferrite loaded SIW devices were also investigated [4]. To begin with, a simple nonreciprocal transmission line consisting of a single ferrite loaded SIW was demonstrated. Two-separate ferrite materials (Nickel ferrite and YIG) with different value of magnetization were considered to investigate the non-reciprocal behavior. It was noticed, that the material with the higher saturation magnetization produces higher value of differential phase shifts when applied with the same value of magnetic bias. With Nickel ferrite, a differential phase shift of 180° was obtained for an applied magnetic bias of 0.16 T, while with YIG a differential phase shift of only 50 could be achieved. Using Nickel ferrite a four-port circulator was successful fabricated and demonstrated. The four-port circulator consisted of ferrite loaded non-reciprocal phase shifter (gyrator) and two 3-dB couplers. Isolations for more than 15 dB between each of the four ports were obtained. As a final step, the concept of magnetic tuning was also implemented on HMSIW. From the geometry, HMSIW is symmetrically half of SIW. Therefore, it was interesting to compare the performance between magnetically tunable ferrite loaded SIW and HMSIW. From the measurement results, it was observed that HMSIW performance was very close and in some cases even better than that of SIW in terms of losses, switching, and tuning. Similar to SIW, using a principal of electric and magnetic tuning a bandwidth tunable band-pass filter was successfully demonstrated.

References

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