Rotation Sensor Based on Horn-Shaped Split Ring Resonator

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Abstract—This paper presents a rotation sensor based on a modified split ring resonator (SRR) coupled to a coplanar waveguide. It is shown that compared with previous SRR-based rotation sensors, the proposed sensor benefits from a higher dynamic range and superior linearity. It is shown that the geometry of the SRR can be optimized to compensate for the non-uniformity of the magnetic flux through the SRR, in order to suppress the unwanted frequency shift in the resonance. This is a significant improvement because the sensor can be operated as an inexpensive single frequency system. The concept and simulation results are validated by experimental measurements.

Index Terms—Microwave sensors, metamaterials, rotation sensor.

I. INTRODUCTION

BEYOND the initial goals of creating artificially engineered materials with electromagnetic constitutive parameters not available in nature, such as double-negative materials, metamaterials have opened new perspectives for other novel applications such as high-quality resonators [1] and compact filters [2]. Also, it has been shown that metamaterial-inspired resonators such as split ring resonators (SRRs) are ideal structures for the design of high sensitivity and high resolution sensors because of their high quality factor resonance, subwavelength dimensions, as well as sensitivity to changes in surrounding materials and physical dimensions [3]–[8].

Recently, displacement and rotation sensors based on symmetry properties of SRRs have been published in [9], [10]. As explained in detail in [9], [10], a displacement or rotation of an SRR coupled to a coplanar waveguide (CPW) produces a notch in the transmission coefficient of the structure, when the SRR is displaced from the symmetry plane of the CPW. Since the depth of the notch is dependent on the displacement or rotation of the SRR, this spectral feature can be used to sense the amount of the displacement or rotation. Sensors of this type are more robust to changes in ambient conditions such as temperature and humidity, since they operate based on the change in the depth of notch rather than shift in the resonance frequency. However, one limitation of the sensors is that a change in displacement or a rotation not only changes the depth of resonance, but also causes a shift in the resonance frequency. Thus, their operation requires a frequency sweeping microwave source such as an expensive network analyzer. In a previous work [11] the authors showed that the shift in the resonance frequency in the displacement sensor based on uniform rectangular SRR is due to the non-uniformity of the magnetic flux passing through the SRR surface. Thus, the frequency shift can be suppressed by modifying the shape of the SRR to compensate the non-uniformity of the SRR’s magnetic coupling by precisely adjusting its electric coupling.

In the present letter we show that a similar approach, based on the modification of the SRR shape, can be used to design a rotation sensor that not only operates at a single fixed frequency but also benefits from a higher dynamic range and superior linearity.

II. ROTATION SENSOR BASED ON HORN-SHAPED SRR

The proposed rotation sensor is composed of a CPW loaded with a horn-shaped SRR as illustrated in Fig. 1. The design starts by changing the rectangular SRR to a trapezoidal SRR, which increases the dynamic range [11]. Next, the SRR sides are curved (as a 3-point spline) and the curvature is optimized to achieve a linear response. Finally, the length of the SRR’s split is adjusted to achieve a fixed operating frequency. The geometric dimensions of the optimized structure are listed in the caption of Fig. 1 and are scalable to achieve a desired operation frequency.

Figure 2 compares the simulated transmission coefficients of the proposed sensor (solid lines) with those of a rectangular rotation sensor similar to the rotation sensor in [9] (dashed lines) for a rotation of the SRRs from \( \theta = 0^\circ \) to \( 6^\circ \) in steps of \( 2^\circ \). The figure clearly shows that while there is an angle-dependent shift in the resonance frequencies for the rectangular SRR, in the case of the optimized horn-shaped SRR all notches are at a fixed frequency \( f = 1.38 \text{ GHz} \).
The comparison also shows that the proposed sensor operates at a fixed frequency, and thus does not need a frequency sweeping microwave source, but can be operated as an inexpensive single frequency system. The proposed sensor benefits from superior linearity and around 40% higher dynamic range. More importantly, it has been shown that the unwanted frequency shift in the characteristic of the previous rotation sensor can be suppressed by precisely adjusting the length of the SRR’s split. This is a significant improvement since the sensor does not require a frequency sweeping microwave source, but can be operated as an inexpensive single frequency system. The proposed sensor is possibly of greater interest in a scaled down structure using MEMS technology.

III. CONCLUSION

A rotation sensor based on a horn-shaped SRR has been presented. Compared to previous SRR-based rotation sensors, the proposed sensor benefits from superior linearity and around 40% higher dynamic range. More importantly, it has been shown that the unwanted frequency shift in the characteristic of the previous rotation sensor can be suppressed by precisely adjusting the length of the SRR’s split. This is a significant improvement since the sensor does not require a frequency sweeping microwave source, but can be operated as an inexpensive single frequency system. The proposed sensor is possibly of greater interest in a scaled down structure using MEMS technology.

REFERENCES