Ring Resonances in Groove Gap Waveguides with Application to Slot Array Antennas

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***Abstract*—This paper describes a simple procedure to create a compact resonance effect in the context of new contactless gap waveguide structures. The resonance is achieved shortening a given nail in the textured surface and can be used to feed slots in a slot array. In the following, the resonance effect is explained and a basic radiating cell with two slots is designed to illustrate the potential of the resonant device.**

I. INTRODUCTION

Recently, a new type of waveguiding structure called gap waveguide was proposed in [1]. The structure is able to propagate fields in the air gap between two metal plates. These plates are not required to be in electrical contact to confine the field. One of the plates is textured with a bed of nails, a quarter of a wavelength in height, creating a high-impedance environment. Between these two plates, a wideband cut-off condition will exist, provided the gap between the upper plate and the tops of the nails is narrower than $\lambda_0/4$, being λ_0 the wavelength in the vacuum. Then, this cut-off condition can be exploited for guiding waves by opening a path among the nails. This path can be in the form of a groove or a strip. Numerous examples have already been published demonstrating the concept [2] and showing its applicability for antennas and circuits [3].

In this paper a convenient way to create compact cavity resonances and integrate them in the bed of nails is described. The resonance occurs as a magnetic field loop around a nail. Typical nail periodicity exhibits enough room for such a resonant field loop to be excited, just by shortening the selected nail with respect to the surrounding ones.

This ring resonance can be used in a number of ways. In this paper in particular it will be used to excite slot antennas so that they will be able to radiate all the incoming power. In the following, the working principle will be explained in detail. Later, a basic cell with 2 slots will be described to illustrate its potential use for larger arrays.

II. RING RESONANCE

The basic geometry of the field loop comprises a groove gap waveguide [4] where one of the nails is shortened with respect to the surrounding ones. This nail must be adjacent to the groove so that the field can excite the cavity. An example is shown in Fig. 1.

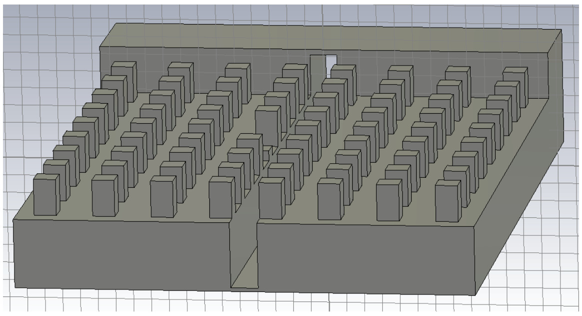
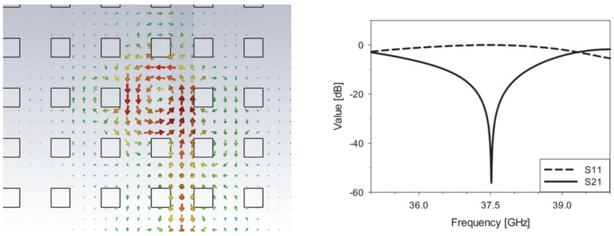


Fig. 1. Groove gap waveguide with a shortened nail.



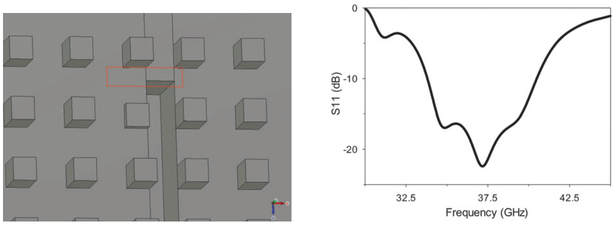
(a)

(b)

Fig. 2. Ring resonance simulation results. a) Magnetic field b) S-parameters

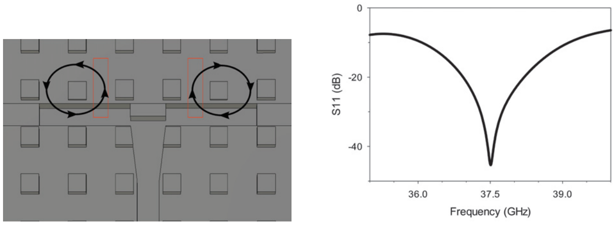
The structure is designed for a frequency of 37.5 GHz and the amplitude of the ring resonance is maximized when the shortened nail is 0.55 mm in height. The nails periodicity is $p = 0.4\lambda_0$. The size of the nails is $0.38p$ and their height $\lambda_0/4 = 2$ mm. The gap between the tops of the nails and the top metal plate is $\lambda_0/20$. Unless otherwise specified, these values are not varied throughout the article. The magnetic field for the resonant frequency is shown in Fig. 2.

As seen in Fig. 2a, the field loop is originated around the nail whose height is reduced. The direction of the magnetic field is always tangent to the loop. Therefore, there is a 180-degree phase difference at opposite sides of the nail. Another property is that the field loop acts as a trap for the field traveling along the groove. The field loop prevents the wave from being transmitted forward causing a high reflection backwards. Interestingly, the frequency for which the field loop is originated varies with the nail height. The taller the nail, the lower the working frequency, up to a given height where the effect is lost.



(a) (b)

Fig. 3. Slot over a ring resonance. a) Slot position b) Reflection



(a) (b)

Fig. 4. Two-slot basic cell. a) Magnetic field b) Reflection

III. PLACING A SLOT OVER THE RESONANCE LOOP

In Fig. 3 the new embodiment is seen. Now, a slot is cut out the top metal layer so that it radiates the input power. The mode supported by the groove is similar to a TE_{10} mode in a rectangular waveguide. Notice that observing Fig. 1, the groove dimensions are such that the electric field is oriented horizontally, therefore the covering plate plays the role of the narrow wall in a rectangular waveguide, and a slot perpendicular to the direction of propagation does not naturally radiate. To achieve radiation the ring resonance originated by a shortened nail will be used to stimulate the slot without resorting to any tilting. In addition, the waveguide is short-circuited in order to achieve a higher power radiation.

The position of the slot can be seen in Fig. 3a. Its length, 4 mm, is equivalent to half the wavelength in the vacuum. The slot width is 1 mm. In order to radiate more power, the waveguide is short-circuited 0.92 mm after the centre of the ring resonance. The nail height is also slightly decreased to 0.5 mm. The result is shown in Fig. 3b.

As seen, the reflection is below -10 dB for a bandwidth of 6.7 GHz, which is a large bandwidth considering that the radiating element is a slot.

IV. BASIC CELL OF TWO SLOTS

Now a basic two-slot cell is designed. To feed both slots with the same phase, the embodiment shown in Fig. 4a is generated. A T-junction power divider modified with a linear tapered impedance transformer and a reactive metal step is used. One characteristic of this power divider is that the phase difference between the outputs is 180 degrees. There are different manners to solve this problem. In this case, the resonance fed from the left arm of the power divider is placed on the right side of the groove, while the ring resonance fed from the right arm of the power divider is placed on the left side of the groove. Then, the slots are cut out on the side of the resonance which is nearer to the other resonance. Therefore, the distance ”between” the slots is twice the nails period, i.e. $0.8\lambda_0$. This arrangement of resonances succeeds in feeding the slots in phase while keeping the structure symmetric. The heights of the shortened nails are 0.67 mm now and the short-circuits are positioned 1.60 mm away from the centre of the ring resonances. The reflection factor of the structure is shown in Fig. 4b.

As can be seen, the bandwidth is now 3.05 GHz. This is a lower value than for the case with only one ring resonance and a slot, but it is still a good value. To prove that both slots are in phase, the radiation pattern of the two-slot array is shown in Fig. 5.

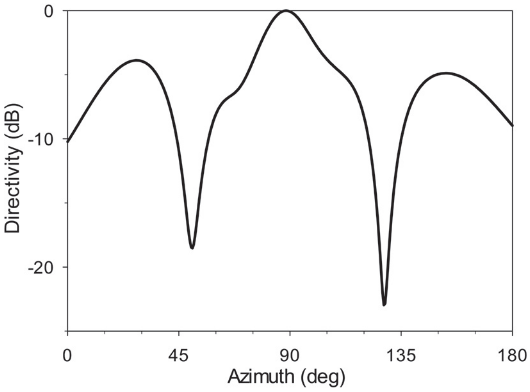


Fig. 5. Two-slot linear array directivity.

V. CONCLUSION

The generation of a ring resonance in a bed of nails by shortening one of the nails has been characterized. In addition, the resonance has been used to feed a slot and a basic cell with two slots, demonstrating how the ring resonance phenomenon eases the process of getting a coherent radiation in broadside direction. Simulation results are encouraging, and the concept is currently being extended to larger slot arrays. It is expected that this new concept will be the basic building block to more complex single-layer corporate-fed slot arrays.

ACKNOWLEDGEMENTS

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