Extraordinary transmission frequency tuning based on meander hole arrays

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Abstract

In this work, we present some modifications in the topology of typical subwavelength hole arrays to tune the frequency of the resonant peak associated to extraordinary transmission phenomena. By substituting the straight line between holes by a meander line it is possible to move the extraordinary transmission peak downward which also brings about an enlargement of the fractional bandwidth. This phenomenon is theoretically analyzed from an equivalent circuit perspective and demonstrated experimentally at the millimetre-wave regime. A wide range of applications may benefit from this, since now the extraordinary transmission happens far away from the onset of higher order diffracted modes.

1. Introduction

Metamaterials are artificial structures designed to have special electromagnetic properties that materials found in nature could not obtain. One of the most relevant unconventional properties is extraordinary transmission (ET). This phenomenon allows obtaining a narrow and strong peak of transmission through an opaque screen perforated periodically with small holes. It was thoroughly studied by Ebbesen *et al* [1] at optical frequencies and called extraordinary optical transmission and subsequently was also demonstrated at millimetre-wave frequencies [2]. There is still some controversy about the origin of ET, but the role of complex surface waves is undoubtedly crucial. However, what is undeniable is the numerous applications derived from ET [3].

In this paper, we propose a new way to control Extraordinary Transmission in metallic slabs perforated with rectangular holes, adding a meander line between holes without changing the dimensions of the structure or holes.

2. Subwavelength hole array based on meanders

Periodic and guiding structures at microwave frequencies have been studied for more than a century due to important applications such as impedance matching, antennas design and filter optimization among others. One of these structures is meander lines whose properties and behaviour are well known [4]. From a typical subwavelength hole array structure and adding meanders between holes we are able to select the resonant frequency and the bandwidth of the ET peak.

Fig. 1 depicts a simulation that shows how the proposed meander modification affects the transmission coefficient. The term "wires" identifies the structure without meanders between adjacent holes. The size of the unit cell is fixed to in-plane dimensions d_x = 1.5 mm and d_y = 3 mm; the plate thickness is equal to 6 μm; the hole size is 0.9 x 0.9 mm; the line width of the meander is fixed to 5 μm with a separation between adjacent meanders of 0.1 mm and the length of the elbow bend equal to 0.2 mm.

Simulations have been performed with CST Microwave Studio^{TM} frequency solver imposing periodic boundary conditions to the above defined unit cells and exciting the structure with a TEM wave with the polarization shown in Fig 1.

In the wire case, the ET peak appears at 97.3 GHz, which is really close to the Wood's anomaly located at 100 GHz. However, for the smart meander design (blue line), the resonance is located at 56.04 GHz, meaning a frequency tuning of 42.4 %. The increased fractional bandwidth is also notable having an increment of 55.2 %.

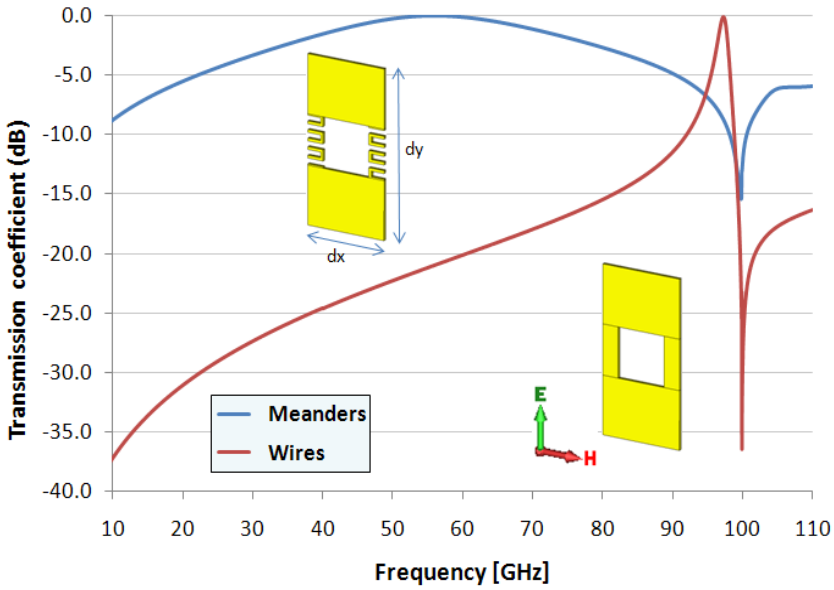

Fig. 1: Simulated transmission coefficient of a hole array structure in a typical configuration (red line) and meander configuration (blue line). Insets: unit cells.

As expected the frequency tuning depends basically on meander parameters: width, length and number of meanders. Therefore, we have simulated several cases to achieve different pass bands and to understand meander behaviour.

3. Equivalent circuit perspective

The behaviour of this structure can be also explained using an equivalent circuit model. All obstacles in waveguides can be characterized from an equivalent circuit perspective as seen in [5]. For example, a rectangular aperture in a rectangular waveguide has a resonant behaviour modelled with a shunt inductance and capacitance.

The equivalent circuit of a meander line has been reported already [6,7]. It consists of several circuit elements in series and shunt configuration depending on the number of meanders. However, when the wavelength is large enough compared to the meander size, it is possible to simplify it into a lumped inductive element. Meander lines involve adding an extra path to the current, so the inductance is enlarged too. In our case, meander and unit cell are of the order of some microns and millimetres, respectively, that allows us to consider the meanders as a single inductance. Therefore, the inclusion of the meander can be interpreted as an extra shunt inductive element that increases the total inductance of the structure. Hence, ET peak is moved toward lower frequencies because of the 1/L dependence [5].

4. Measurement results

Similar structures to the aforementioned have been measured employing an AB Millimetre^{TM} quasioptical vector network analyzer in the frequency range of 40 up to 75 GHz. Prototypes have been made over a substrate rather than free-standing to make fabrication process easier. Substrate thickness is h = 1.1 mm and permittivity ε_r = 1.35. Fig 2 depicts transmission coefficient simulated and measured for both cases: structure with wires 2(a) and meanders 2(b). They show good agreement between simulated and measured results demonstrating the frequency tune of the structure.

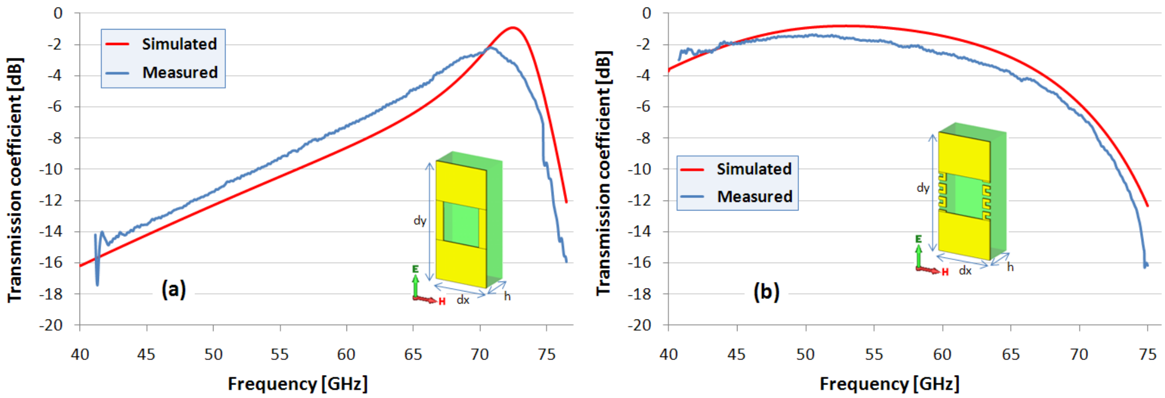

Fig. 2: Transmission coefficient: simulated (red) and measured results (blue) of subwavelength hole array with wires (a) and meanders (b).

4. Conclusion

In this work, we have presented a novel way to tune extraordinary transmission through sub-wavelength hole arrays adding meander lines. We have checked how meanders move ET peak toward lower frequencies achieving a frequency tune of 42.4 % and increase the fractional bandwidth of the resonance (55.2 %). Attending to meander design the conclusions reached are the followings:

- The wider the meander, the higher the frequency of resonance.
- Increasing meander length supposes to move peak toward higher frequencies.
- Varying the number of meanders over two almost does not change frequency.

From a circuit theory perspective we have clarified how meander structures modify the total inductance of the aperture making it possible the tune frequency effect. Furthermore, several prototypes have been fabricated to check the behaviour of a real structure with good agreement between simulated and measured results.

References

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