Fabry-Pérot cavity antenna with multi frequency overlapping feeds

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***Abstract*—A wideband planar Fabry-Pérot cavity (FPC) antenna formed by an electrically thick partially reflective surface (PRS) with overlapping feeds is investigated. The two feeds operate at two different frequencies. Recent techniques for FPC wideband operation allow the reuse of the FPC at multiple frequencies, where each frequency has its own feed. The distance between two adjacent feeds is in the order of 1.2 wavelength.**

***Index Terms*—Fabry-Pérot cavity (FPC) antenna, leaky-wave antenna (LWA), partially reflecting surface (PRS), wideband antenna, overlapping feeds**

I. Introduction

Fabry-Pérot cavity (FPC) antennas have been highly investigated due to their high radiation efficiency, good pattern performances, low profile nature, simplicity of design, sound theoretical support and inexpensive fabrication [1]. Originally directive FPC antennas were narrow band, though allowing to obtain high gain [2], [3].Therefore, after the interesting note made in [3], where a greater bandwidth could be obtained if the PRS phase linearly increases with frequency, in the neighborhood of the operating frequency, a good analytical description to make FPC antenna wide band has been formulated in [4]. This wideband behavior for the FPC antenna is obtained by using an electrically thick partially reflective surface (PRS).

FPC antennas are a good answer to the need of high gain and wide bandwidth wireless communications that has grown significantly in the last decades with respect to alternative planar antennas characterized by low radiation efficiency and gain, significant intrinsic losses related to the material used.

Moreover, both directivity and side lobe level can be controlled by using multiple sources, [5],[6], by changing the distance between the radiating sources.

The goal of this work is to present a wideband FPC antenna excited by two patches as radiating sources working at two different frequencies. Each source is associated to a large aperture induced by the presence of the FPC that acts as a gain enhancer. The two apertures (working at two different frequencies) overlap. This antenna can also be used to generate ”overlapping feeds” for reflectors working at multiple frequencies. All simulations were performed by using CST Studio Suite.

II. Antenna analysis assuming an infinte lateral extent

The unit cell forming the periodic PRS of the FPC antenna has been designed in order to obtain a wideband operation around the 22GHz bandwidth. Its geometry is shown in Fig. 1, where $t = 0.64$mm, $s = 5$mm and $d = 3.1$mm and *RO3010* is employed as dielectric substrate, with $\varepsilon_r = 11.2$ and tan$\delta = 0.0022$.

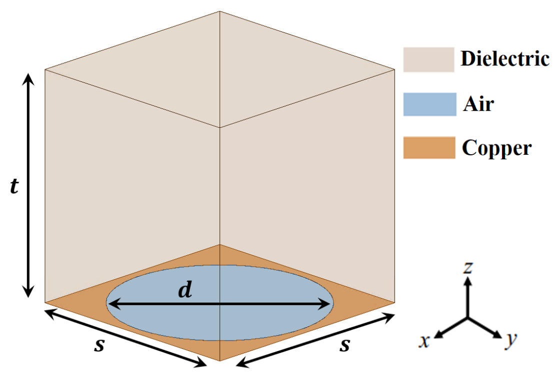

Fig. 1: Geometry of a PRS unit cell. Lateral side s, dielectric layer thickness t and the copper sheet at the bottom is patterned with a circular hole of diameter d.

A cavity height of approximately half wavelength is formed between the ground plane and the bottom part of the PRS, considering the central frequency band around $f = 22$GHz, leading to $h = \frac{\lambda_0}{2} \approx 6.8$mm. By using a patch as a feed, the cavity height of the FPC has to be varied because of the dielectric substrate that supports the patch, of thickness h_s. The cavity height is then designed as $h_c = h - \Delta - h_s$, where Δ is a correction factor, as detailed in [5], given by:

$$\Delta = \frac{\lambda_0}{2\pi} \arctan\left[\frac{1}{\sqrt{\varepsilon_s}} \tan\left(\frac{2\pi}{\lambda_0}\sqrt{\varepsilon_s} h_s\right)\right] - h_s\,, \qquad (1)$$

where ε_s is the relative dielectric constant of the substrate on which the patch is located. Solving Eq. (1) by using a *RO5880* substrate with $h_s = 0.787$mm, $\varepsilon_s = 2.2$ and tan$\delta = 0.0009$, $\Delta = 39.1\mu$m and $h_c \approx 6.7$mm.

Based on the theory shown in [4], the value of radiated intensity $U(\theta, \phi) = \frac{|E|^2}{2\eta}$, with $\eta = \sqrt{\mu_0/\varepsilon_0}$, normalized with respect to its maximum, is reported in Fig. 2. There are two peaks where the power is maximum: one at 20.4GHz and one at 23.8GHz. The -3dB bandwidth is limited below by 19.6GHz and above by 24.96GHz, leading to a total bandwidth of 5.3GHz. Note that the generated radiation intensity at the two frequencies is the same.

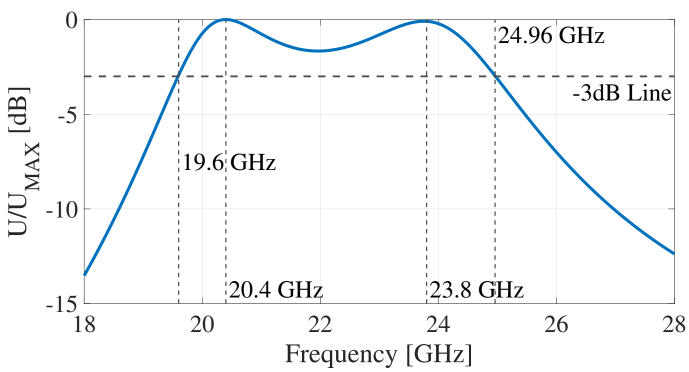

Fig. 2: Radiation intensity normalized to its maximum versus frequency considering a PRS with infinite extent.

III. Wideband FPC antenna of finite size

The FPC structure is analyzed here and it is composed by a PRS made of 14x14 unit cells shown in Fig. 1. The structure is reported in Fig. 3, where the FPC antenna is fed by two patches over a ground substrate (they are inside the cavity).

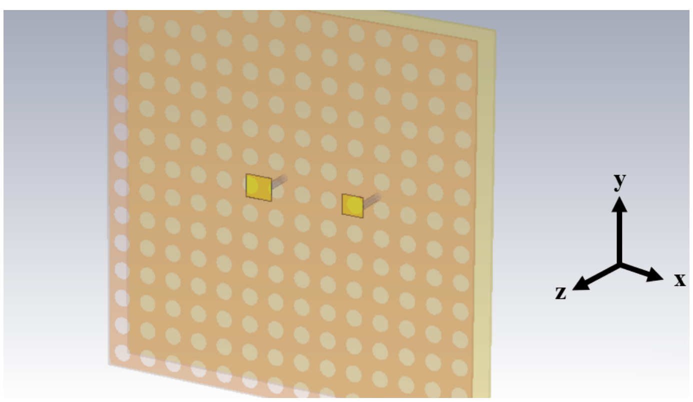

Fig. 3: FPC antenna with two patch feeds. The PRS is composed by 14x14 unit cells.

A good matching has been obtained at the two frequencies related to the peaks (not shown here). Two patches are fed such that the E and H planes are respectively the (z,y) and (z,x) planes. The patches are separated along the E plane. The patch resonating at 20.4GHz has a length $L = 4.1$mm and a width $W = 4.8$mm, and the distance from the patch edge to the coaxial cable pin is equal to 0.8mm. The other resonating at 23.8GHz has a length $L = 3.6$mm, width $W = 4$mm and the distance from the patch edge to the coaxial cable pin is equal to 0.7mm. The distance between the two patches (from edge-to-edge) is 11.6mm. The simulated gain versus frequency is shown in Fig. 4. The two peaks do not have the same level of gain, and depending on the application a further tuning of the cavity height may be needed.

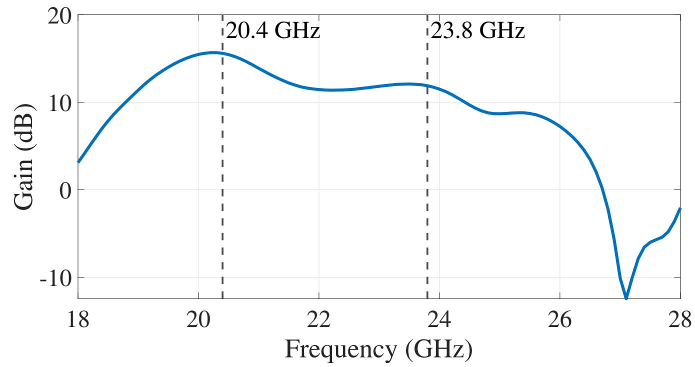

Fig. 4: Broadside gain of the double fed FPC antenna.

IV. Conclusion

A wideband FPC antenna with single PRS and two radiating sources is presented. The two sources operate at two distinct frequencies and they are close to each other. Therefore, this antenna can be useful as two overlapping apertures, operating at two different frequencies. The distance of the two centers of the two radiating apertures is smaller than the distance of two equivalent (in terms of the same directivity) horn antennas. Hence a possible application is the one of overlapping feeds for reflector antennas. Since now people have learned how to make wideband FPC antennas, various other applications are opening for this kind of antenna that is very simple to design and fabricate, and it offers also high radiation efficiency.

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References

[1] D. R. Jackson and A. A. Oliner, "A leaky-wave analysis of the high-gain printed antenna configuration", *IEEE Transactions on Antennas and Propagation*, vol. 36, no. 7, pp. 905-910, July 1988.

[2] A. Hosseini, F. Capolino and F. De Flaviis, "Gain Enhancement of a V-Band Antenna Using a Fabry-Pérot Cavity With a Self-Sustained All-Metal Cap With FSS", *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 3, pp. 909-921, March 2015.

[3] A. P. Feresidis and J. C. Vardaxoglou, "High gain planar antenna using optimised partially reflective surfaces", *IEEE Proceedings-Microwaves, Antennas and Propagation*, vol. 148, no. 6, pp. 345-350, December 2001.

[4] A. T. Almutawa, A. Hosseini, D. R. Jackson and F. Capolino, "Leaky-Wave Analysis of Wideband Planar Fabry-Pérot Cavity Antennas Formed by a Thick PRS", *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 8, pp. 5163-5175, August 2019.

[5] R. Gardelli, M. Albani and F. Capolino, "Array thinning by using antennas in a Fabry-Perot cavity for gain enhancement", *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 7, pp. 1979-1990, July 2006.

[6] R. Gardelli, G. Donzelli, M. Albani and F. Capolino, "Design of patch antennas and thinned array of patches in a Fabry-Perot Cavity covered by a partially reflective surface", *2006 First European Conference on Antennas and Propagation*, vol. 54, n. 7, pp. 1-5, 6-10 November 2006.