Titre: Title:	High gain slot array with Fabry-Perot cavity feeding circuit
Auteurs: Authors:	Halim Boutayeb, & Mourad Nedil
Date:	2016
Type:	Article de revue / Article
Référence: Citation:	Boutayeb, H., & Nedil, M. (2016). High gain slot array with Fabry-Perot cavity feeding circuit. International Journal of Antennas and Propagation, 2016, 1-5. https://doi.org/10.1155/2016/9674742

Titre de la revue: Journal Title:	International Journal of Antennas and Propagation (vol. 2016)
Maison d'édition: Publisher:	Hindawi
URL officiel: Official URL:	https://doi.org/10.1155/2016/9674742
Mention légale: Legal notice:	

Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2016, Article ID 9674742, 5 pages
http://dx.doi.org/10.1155/2016/9674742

Research Article

High Gain Slot Array with Fabry-Perot Cavity Feeding Circuit

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Received 11 January 2016; Accepted 13 June 2016

Academic Editor: Paolo Burghignoli

A new approach for designing slot arrays using a Fabry-Perot cavity for the feeding circuit is presented. Th proposed array has simpler and smaller feeding circuit compared to conventional feeding networks that have multiple dividers or combiners. Th dividers and combiners are usually sources of losses. In addition, the profile of the proposed array is not limited by the half-wavelength resonance condition that exists for Fabry-Perot resonator antennas based on partially refle ting surfaces. The operating frequency is not sensitive to the profile of the antenna. A small profile can be achieved without the utilization of an artificial magnetic conductor or a substrate with high dielectric constant. To validate the proposed approach, full-wave numerical results are presented at 5.8 GHz showing good impedance matching, a high gain of about 22 dB, and an efficie y of 76%.

1. Introduction

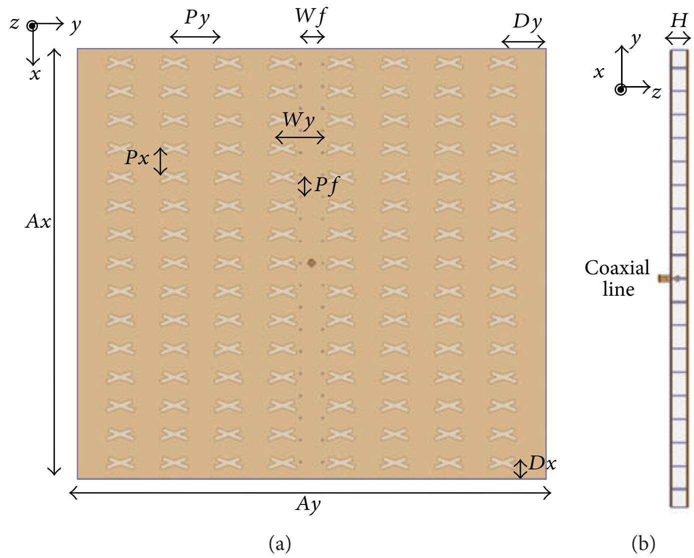
Low-cost single-feed directive antennas are essential to several wireless communication systems, such as satellites, various point-to-point links, and high-speed wireless LANs. Thei single-feed system allows increasing the gain with low complexity and less loss compared to feeding networks used in conventional antenna arrays.

Among single-feed directive antennas, Fabry-Perot resonator antennas have attracted significant attention, in the past few years, in microwave and millimeter wave domains. Thi is because these antennas have a number of interesting properties, such as low profile, low complexity, low loss, high directivity, and conformal deployment capability [1–4]. These types of antennas can be analyzed using different models: ray tracing/ray launching, Electromagnetic Band Gap (EBG) defect, leaky-wave, transmission line, and refractive lens models [5–7].

In a Fabry-Perot resonator antenna, the cavity can be mainly fi led with air [8–11], or it can be fully filled with a planar single-layer dielectric slab [12–14]. Th latter structure with full dielectric integration poses several design challenges, particularly for high-permittivity substrates, including increased dielectric loss, lowered directivity caused by small-volume antennas, poor surface-wave efficie y, and narrow 3 dB gain bandwidth compared with the air-filled Fabry-Perot resonator antenna. Nevertheless, such an antenna configur tion is still considered a promising candidate, due to its smaller volumetric occupation compared with other substrate-lens designs [15]. It also presents a number of other advantages, such as low profile and low cost, mechanical robustness, good integration, and stable fabrication and installation. Fabry-Perot cavity antennas with a very small distance between the planar feed and the partially refle ting surface (PRS) have been reported in [16, 17]. However, the design suffers from a tiny gap between the two closely apprised substrates, and a resonance frequency shift could thus present an ineluctable problem. In [18], a Fabry-Perot resonator cavity antenna made of a high-permittivity substrate and excited by a planar leaky-wave slit has been proposed as an alternative.

Another interesting solution for designing a high gain antenna without a feeding network consists in using a single patch having a rectangular profile and a genetic algorithm optimization to replace the array [19, 20].

In this work, a new technique for designing high gain antenna is proposed. The excitation structure is composed of a Fabry-Perot cavity and the radiators are slots. The proposed



Figur e 1: Slot array excited by using a Fabry-Perot cavity feeding circuit: (a) top view; (b) side view.

array has simpler and smaller feeding circuit compared to conventional feeding networks that have multiple dividers or combiners, which are causing losses. Also, the profile of the array is not limited by the half-wavelength resonance condition that exists for Fabry-Perot resonator antennas based on partially refle ting surfaces. A small profile can be achieved without the utilization of a high-permittivity substrate or an artifici l magnetic conductor.

The paper is organized as follows. First, the actual prototype of the antenna is described. Second, full-wave numerical results are presented to validate the design. Finally, concluding remarks are given.

2. Antenna Design

Figure 1 presents the main views of the antenna array that is used to validate the proposed concept. This antenna is made of a parallel plate waveguide excited by a probe connected to coaxial line; cross-slots are on one wall of the parallel plate waveguide and a Fabry-Perot cavity made of metallic wires is used in order to distribute the fields equally in phase and amplitude in the radiating slots disposed in the same column.

The following are the main parameters of the array. Wf is the width of the Fabry-Perot cavity and Pf is the period for the metallic wires. Wy is the distance between two adjacent cross-slots that are on each side of the cavity. Py is the periodic distance in y direction between other adjacent cross-slots. Px is the period between adjacent cross-slots in x direction. Dy and Dx are the positions of short-circuits of the waveguide in y and x direction, respectively. Ax and Ay are dimensions in xy plane. H is the height of the parallel plate waveguide.

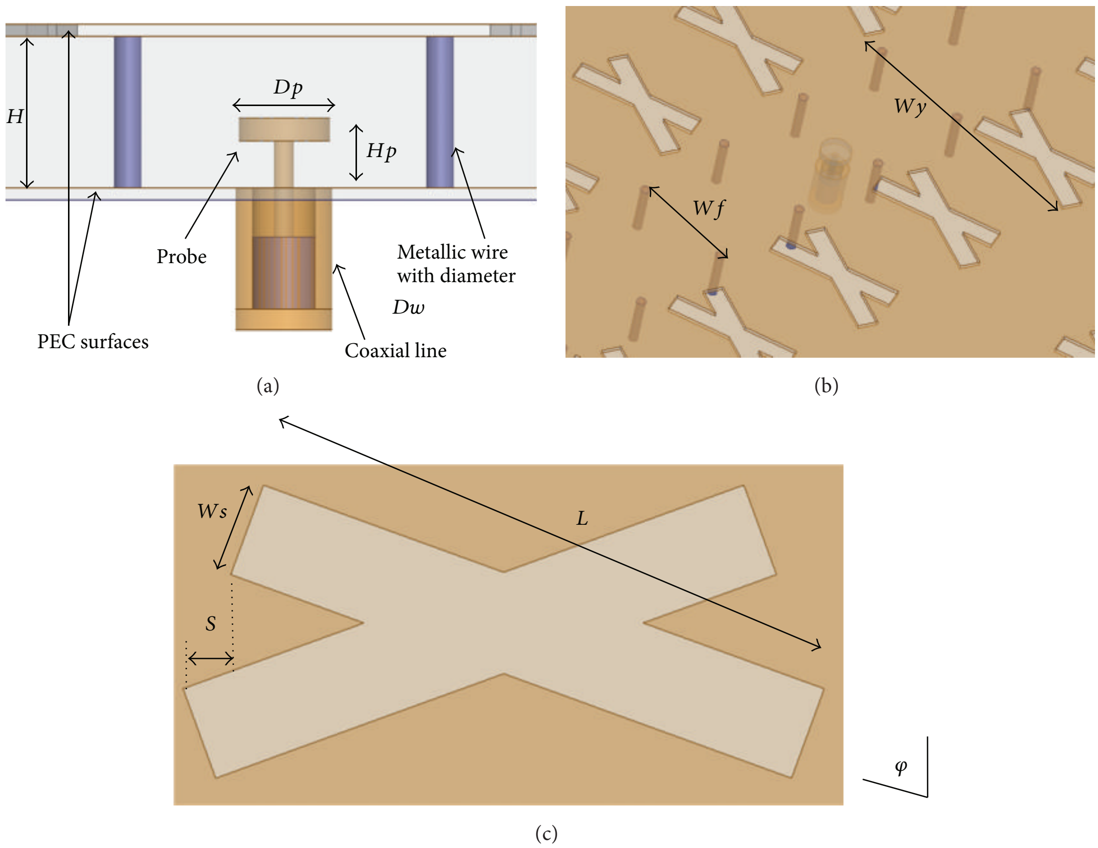
Figure 2 presents in more detail the probe excitation, the position of the cross-slots, and the cross-slots parameters. Dw is the diameter of the wires of the Fabry-Perot cavity. Dp and Hp are the diameter and the height of the probe, respectively. L is the length of the slots, Ws is the slot width, φ and $-\varphi$ are the angles of rotation of the slots, and S is the shift distance between two rectangular slots that belongs to the same cross-slot.

Wf controls the resonance of the Fabry-Perot cavity (about half wavelength), whereas S plays a role in the cross-polarization discrimination. Py is about one wavelength distance and Px is about half wavelength. At the resonance of the Fabry-Perot cavity, cross-slots that are in the same y coordinate receive fields with the same phase [5]. Th wavelength size of Py allows for the radiating slots to radiate field at the same phase when the wave propagates in the y direction, such as a traveling wave antenna array. The dimensions of the antenna parameters were obtained using a quasi-Newton optimization algorithm for maximising the gain with good impedance matching.

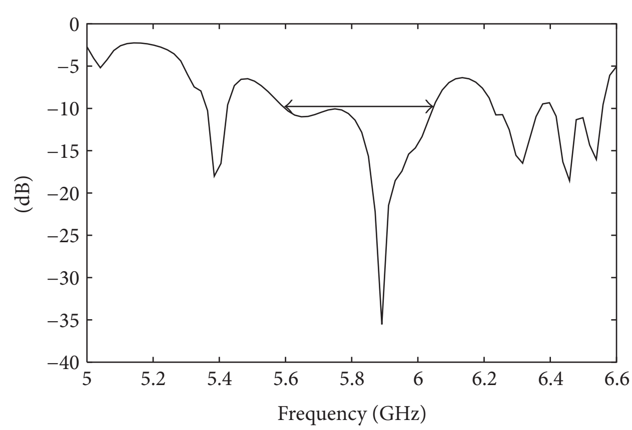
3. Full-Wave Numerical Results

Th proposed antenna was simulated with a full-wave simulator (ANSYS HFSS). The following are the chosen values of the antenna parameters for operating at 5.8 GHz: $H = 10$ mm, $Ay = 437$ mm, $Ax = 400$ mm, $Dw = 1$ mm, $Dp = 6$ mm, $Hp = 4.6$ mm, $Wf = 20.5$ mm, $Wy = 54$ mm, $Pf = 20.5$ mm, $Py = 50$ mm, $Px = 26.5$ mm, $Dx = 14$ mm, $Dy = 41.5$ mm, $L = 25$ mm, $S = 2$ mm, $Ws = 4$ mm, and $\varphi = 70^\circ$.

Figure 3 illustrates the simulated refle tion coeffici t of the antenna. A matching bandwidth ($S11 < -10$ dB) from 5.6 GHz to 6.04 GHz (a fractional bandwidth of 7.6%) is achieved. The simulated broadside gain versus frequency of the antenna is shown in Figure 4 for x-polarization and y-polarization. A maximum gain of 22 dB is achieved around 5.85 GHz (the radiation efficie y is about 76%). The 3 dB gain bandwidth is about 2.05%. This bandwidth needs to be increased to obtain a broadband high gain antenna. For this, different approach will be discussed later. Th maximum



Figur e 2: Details of the proposed antenna: (a) probe excitation; (b) Fabry-Perot cavity and position of cross-slots; (c) cross-slot design details.



Figur e 3: Simulated return loss of the antenna array. Bandwidth for $S11 < -10$dB is shown.

cross-polarization gain of the antennas is approximately 45 dB below one of the copolarization values.

Th 3D pattern of the simulated antenna gain at 5.85 GHz is shown in Figure 5, whereas Figures 6 and 7 show the gain patterns at 5.85 GHz of the antenna, in *xz* and *yz* planes, respectively. In *yz* plane, the directivity is due to the travelling wave radiation, whereas in *xz* plane, the directivity is due to the Fabry-Perot cavity.

To illustrate further the directivity mechanism, Figure 8 shows the electric current distribution at the surface of the slots. From this figure, it can be seen that the current distribution along *xz* plane is similar to the field distribution observed in a PRS of a Fabry-Perot resonator antenna [7].

In *xz* planes the field distribution is due to the functionality of the Fabry-Perot cavity with a quasi-uniform distribution. In the *yz* plane, the energy is radiated by

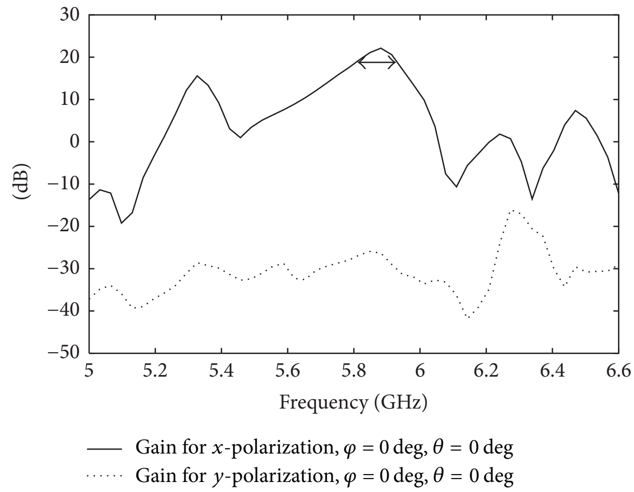


Figure 4: Simulated x-component (copolarization) and y-component (cross-polarization) of total gain versus frequency. 3 dB gain bandwidth is shown.

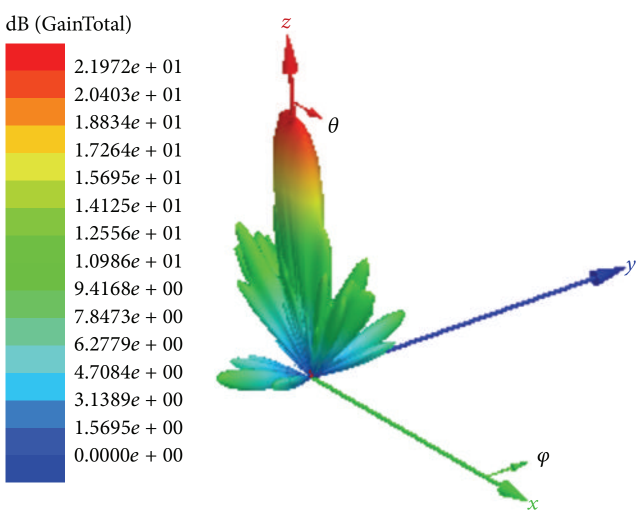


Figure 5: Simulated 3D total gain pattern of the antenna at 5.85 GHz.

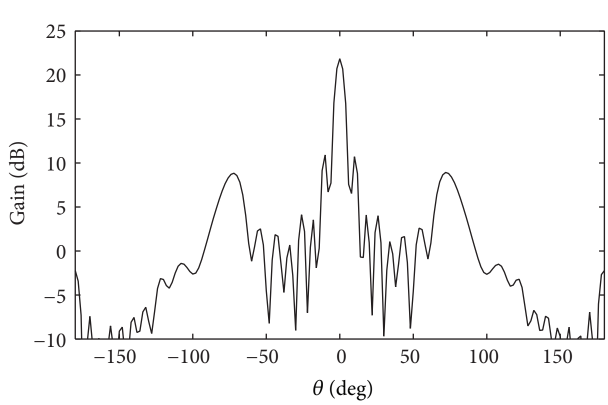


Figure 6: Simulated gain in yz plane at 5.85 GHz.

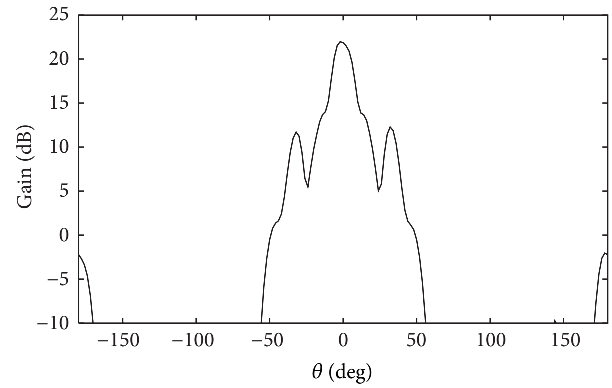


Figure 7: Simulated gain in xz plane at 5.85 GHz.

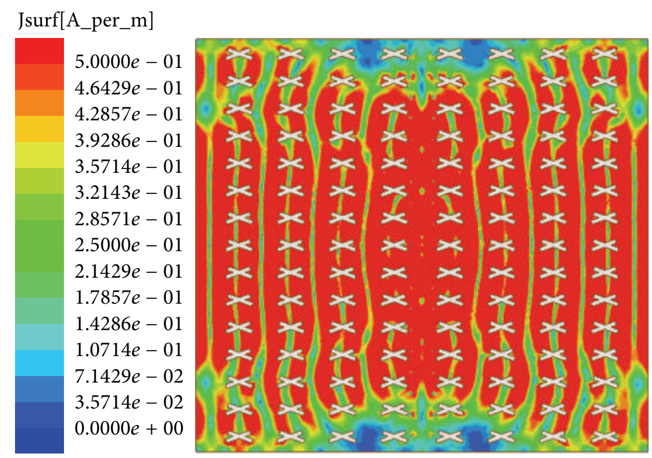


Figure 8: Electric current distribution at the surface of the slot array at 5.85 GHz.

the slots in the manner of a travelling wave antenna except there is no metallic wall like in usual waveguides. By using different synthesis techniques, the field distribution could be optimized for reducing the side lobes observed in both planes (Figures 6 and 7).

It should be noted that the proposed concept can be used with other types of sources, for example, a substrate integrated waveguide with a transition from a microstrip line, in order to design the antenna with a single layer. Furthermore, the same principles as those used in [21–23] for a nonperiodic PRS or with multiple PRSs could be used for feeding a slot array. The e techniques could be used to increase the gain bandwidth and the efficiency of the antenna. Finally, the slots along the y direction can be designed using more advanced techniques that are usually used for travelling-wave antennas, such as in [24].

4. Conclusion

A new slot array with a Fabry-Perot cavity feeding circuit has been proposed and analyzed. Th proposed concept has been validated with full-wave simulations. This type of antenna can be integrated with other printed and/or lumped passive and active components on the same board and therefore proposes a promising solution for RF/microwave and millimeter wave technologies.

Competing Interests

The authors declare that they have no competing interests.

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