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High Gain Slot Array with Fabry-Perot Cavity Feeding Circuit

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A new approach for designing slot arrays using a Fabry-Perot cavity for the feeding circuit is presented. The 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 reflecting 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 efficiency 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. The 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. These single-feed systems allow increasing the gain with low complexity and less loss compared to feeding networks used in conventional antenna arrays.

The proposed array has simpler and smaller feeding circuit compared to conventional feeding networks that have multiple dividers or combiners. The 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 reflecting 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 efficiency of 76%.

In this work, a new technique for designing high gain antennas 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 antennas is proposed. The excitation structure is composed of a Fabry-Perot cavity and the radiators are slots.
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 reflecting surfaces. A small profile can
be achieved without the utilization of a high-permittivity
substrate or an artificial 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. $W_f$ is
the width of the Fabry-Perot cavity and $P_f$ is the period for
the metallic wires. $W_y$ is the distance between two adjacent
cross-slots that are on each side of the cavity. $P_y$ is the
periodic distance in $y$ direction between other adjacent cross-
slots. $P_x$ is the period between adjacent cross-slots in $x$
direction. $D_y$ and $D_x$ are the positions of short-circuits of
the waveguide in $y$ and $x$ direction, respectively. $A_x$ and
$A_y$ 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. $D_w$
is the diameter of the wires of the Fabry-Perot cavity. $D_p$ and
$H_p$ are the diameter and the height of the probe, respectively.

$L$ is the length of the slots, $W_s$ is the slot width, $\varphi$ 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.

$W_f$ controls the resonance of the Fabry-Perot cavity
(about half wavelength), whereas $S$ plays a role in the cross-
polarization discrimination. $P_y$ is about one wavelength
distance and $P_x$ 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]. The
wavelength size of $P_y$ 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

The proposed antenna was simulated with a full-wave simu-
lator (ANSYS HFSS). The following are the chosen values of
the antenna parameters for operating at 5.8 GHz: $H = 10$ mm,
$A_y = 437$ mm, $A_x = 400$ mm, $D_w = 1$ mm, $D_p = 6$ mm, $H_p =
4.6$ mm, $W_f = 20.5$ mm, $W_y = 54$ mm, $P_f = 20.5$ mm, $P_y =
50$ mm, $P_x = 26.5$ mm, $D_x = 14$ mm, $D_y = 41.5$ mm, $L =
25$ mm, $S = 2$ mm, $W_s = 4$ mm, and $\varphi = 70^\circ$.

Figure 3 illustrates the simulated reflection coefficient
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 efficiency 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. The maximum
cross-polarization gain of the antennas is approximately 45 dB below one of the copolarization values.

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

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

Fig. 6: Simulated gain in $yz$ plane at 5.85 GHz.

Fig. 7: Simulated gain in $xz$ plane at 5.85 GHz.

Fig. 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.

References


