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A Highly-efficient Single-feed Planar Fabry-Pérot Cavity Antenna for 60 GHz Technology

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***Abstract*— A low-loss planar Fabry-Pérot cavity antenna fed by a planar feed, a CPW-fed slot dipole, is designed and fabricated for 60 GHz wireless systems. The antenna is fabricated on a planar substrate using standard lithography process. The measurement results of the fabricated antenna are in good agreement with simulation data and show a gain of 16.5 dB.**

I. Introduction

Recently, high-gain low-cost planar millimeter-wave (MMW) antennas have received attention due to the new generation of wireless local area network (LAN) systems operating at 60 GHz. Fabry-Pérot cavity (FPC) antennas have shown to be a promising candidates for MMW antenna designs [1- 3] for being highly-efficient and able to provide a highly directive radiation pattern while using a single feed along with its planar structure (desirable to be integrated with other parts of planar circuits). The history of this type of antennas goes back to 1950's when Von Trentini, [4], reported gain enhancement through placing a partially reflective surface (PRS) in front of an antenna. Leaky-Wave (LW) antennas, being able to provide high-gain radiation, were studied in separate book chapters by Tamir [5] and Oliner [6]. The gain enhancement methods were also reported by forming cavities covered by a PRS made of a dielectric slab [7], or multi-layer dielectric slabs [8], or periodic metallic slots or patches [9] (also known as a Frequency Selective Surface (FSS)). In this paper, using a low loss substrate, a new single-feed planar FPC antenna is designed with center frequency of 59.5 GHz and 3dB gain bandwidth of 1.4 GHz.

II. The Antenna Design

Figure 1(a) shows the structure of the designed FPC antenna. The antenna is fabricated using a dielectric slab as cavity covered by very thin layers of copper on both sides which is the typical arrangement for printed circuit boards. One side of the wafer is forming the FSS layer and the other side provides the ground plane. The two metallic layers are separated by a distance h (thickness of the dielectric slab) which is going to determine the resonance frequency (f_{res}) of the antenna. The transmission line (TL) model of the antenna [2-3, 9], is shown in Fig. 1(b). In this model, the cavity is modeled as a shorted transmission line having length h and characteristics impedance $Z_d = Z_0/\sqrt{\varepsilon_r}$ where $Z_0 = 120\pi\ \Omega$ and ε_r is the relative permittivity of the material inside the cavity. The air above the FSS is modeled as an infinite-length transmission line with characteristics impedance Z_0 .

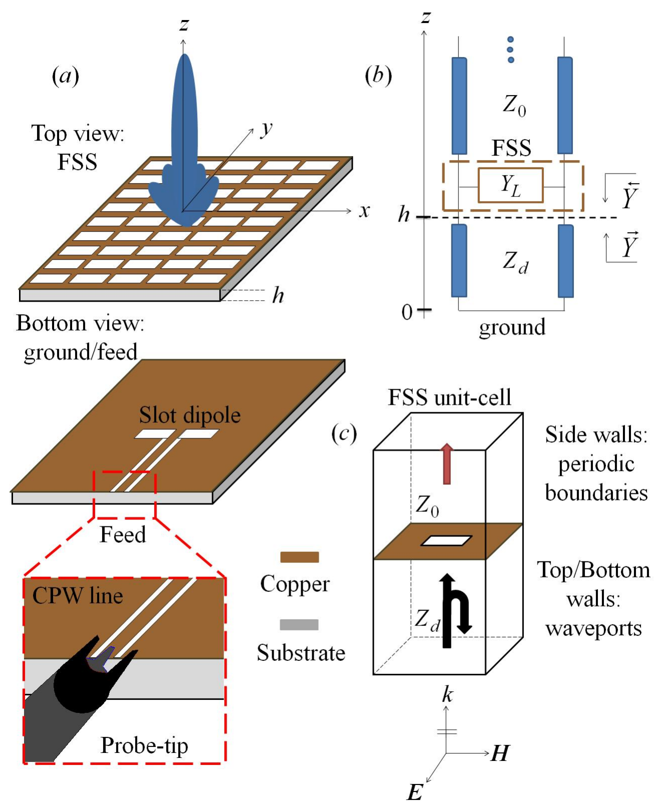

Figure 1. (a) top/bottom view of the proposed antenna, (b) the TL model of the antenna, (c) the FSS unit-cell.

Furthermore, the FSS can be modeled as pure imaginary admittance ($Y_L = jY_0\hat{b}$, where $Y_0 = 1/Z_0$) [9] and its susceptance $\hat{b}$ is found using numerical simulations of the FSS alone with a semi-infinite dielectric below and air above. This is accomplished by implementing a unit cell of FSS surrounded by periodic boundaries, equivalent to a 2D periodic FSS extended in the xy-plane, as shown in Fig. 1(c).

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In order to find the resonance frequency of the cavity, using the TL model, the imaginary part of the total admittance $B_{tot} = \mathrm{Im}\left(\vec{Y} + \overleftarrow{Y}\right)$ where the upward and downward admittances are defined as $\vec{Y} = Y_0 + Y_L$ and $\overleftarrow{Y} = -jY_d \cot\left(2\pi h f_{res}\sqrt{\mu_0 \varepsilon_0 \varepsilon_r}\right)$, respectively, is set to zero [2-3, 9], resulting in

$$f_{res} = \cot^{-1}\left(\hat{b}/\sqrt{\varepsilon_r}\right) / \left(2\pi h\sqrt{\varepsilon_0 \varepsilon_r \mu_0}\right), \qquad (1)$$

To calculate the theoretical maximum gain of the FPC antenna which occurs in proximity of its resonance frequency [2-3, 9], based on the TL model of the antenna, the formulas proposed in [8, Appendix A] are used. The design procedure of a FPC antenna is straight-forward [2-3, 9]. To feed the antenna, a coplanar waveguide on the opposite side of FSS is used; this type of feed was introduced in [3] for the first time.

A Rogers 5880 substrate (ε_r = 2.26, $\tan\delta$ = 0.0009 at 59.5 GHz, and copper thickness of 7 micron), with standard thickness of 1.575 mm, was used for the antenna design and fabrication. The entire fabrication process, including the lithography, double-side mask alignment on the substrate, and the acid-etching process of copper has been done in the dark-room/wet-lab at University of California, Irvine. The fabricated antenna with closed-views of the FSS slots, the slot dipole, CPW line and their dimension values are shown in Fig. 2(a). Fig. 2(b) shows the normalized broadside radiation gain of the antenna, a comparison between the simulation results (Ansys HFSS) and the measurement results. Maximum radiation gain of the antenna was measured approximately equal to 16.5 dB at 59.5 GHz. Moreover, based on both simulation and measurement results shown in Fig. 2(b), the 3dB gain bandwidth (defined as the frequency-range within which the broadside gain of the antenna remains in -3dB level of its maximum at 59.5 GHz) of the antenna is estimated equal to 1.4 GHz. The radiation pattern of the antenna in the H-plane (*zx* planes, Fig. 1(a)), at 59.5 is shown in Fig. 2(c). There is a very good agreement between the simulated and the measurement results. The simulated radiation efficiency of the antenna in its frequency band is around 93%.

III. Conclusion

A relatively simple planar antenna design operating at 59.5 GHz has been presented and tested. The measurement results are in a good agreement with the simulation results showing the feasibility of this highly-efficient high-gain planar antenna design for 60 GHz wireless systems.

Acknowledgement

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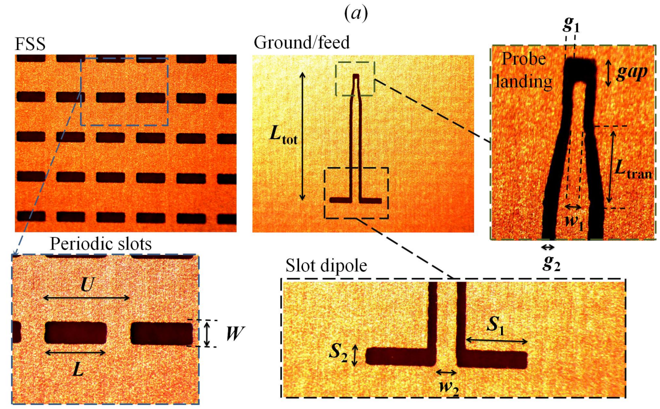
(*a*)



Parameters	Value (mm)	Parameters	Value (mm)
U	1.5	w_1	0.15
L	1.1	w_2	0.40
W	0.4	g_1	0.11
L_{tot}	7.975	g_2	0.175
L_{tran}	1	S_1	1.245
gap	0.3	S_2	0.35

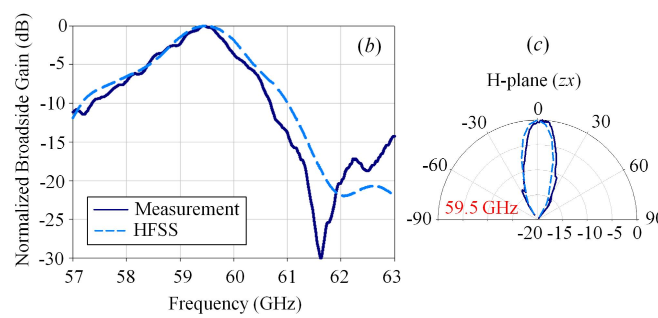


Figure 2. (a) The fabricated antena with the design details and parameters. (b) The broadside radiation gain of the antenna versus frequency, (c) the radiation pattern (H-plane)