SIW-Fed Thin Fabry-Pérot Cavity Antenna

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***Abstract*—The resonant characteristics of the substrate integrated waveguide (SIW) slot in the fully dielectric-filled thin Fabry-Pérot cavity (FPC) antenna are studied. The FPC antenna fed by a pair of proposed SIW slots with an aperture of 66 mm × 66 mm and a cavity thickness of 1.93 mm (λ_0/15) achieves a high gain of 15.5 dBi at 9.8 GHz.**

I. INTRODUCTION

Fabry-Pérot cavity (FPC) antennas have attracted increasing attention for their merits of high gain and simple feeding network. A conventional FPC resonant antenna is with half-wavelength thickness [1]. In order to lower down the cavity thickness, numerous techniques have been developed such as utilizing high impedance surface and planar artificial magnetic conductor with a near zero reflection phase [2]. Recently the substrate integrated FPC antennas have been presented to achieve low profile as well as mechanically robustness for low-cost mass production [3].

In this paper, we investigate the resonance characteristics of the substrate integrated waveguide (SIW) slot in the dielectric-filled FPC using full-wave simulations first. Then, the initial values of the slot parameters are extracted for the impedance matching of the SIW-slots fed fully substrate integrated FPC antenna, and verified by an antenna prototype operating around 10 GHz.

II. CHARACTERISTIC OF SIW SLOT WITH FPC

Fig. 1 illustrates the analysis model of the SIW longitudinal slot within the dielectric-filled FPC. Rogers RO4003C (ε_r = 3.38, tanδ = 0.0027) is used here. Copper square patch array and square aperture array are patterned onto the opposite sides of a 0.813 mm-thick RO4003C to form the partially reflecting sheet (PRS). The PRS unit (p = 6mm, w = 5.48mm, and l = 2.43mm) together with the filled dielectric in the cavity achieves the optimal reflection amplitude of 0.95 and excites the FPC mode at 10 GHz. The FPC with a thickness of d = 1.93 mm is composed of a PRS with 11×11 unit cells (66mm × 66mm) and a ground plane of 92.4mm × 92.4mm. The longitudinal slot in the SIW with/without the dielectric-filled FPC can be modeled as a shunt element in terms of its admittance Y on a transmission line with the characteristic admittance Y_0 [4]. The dielectric-filled rectangular waveguide with the cross section of W_{wg} × H_{wg} = 13mm × 0.813mm is adopted to represent the SIW for simplicity. The slot width is fixed at 0.4 mm. The reference planes at the two ports are shifted inward the center of the slot to remove the transmission line effects.

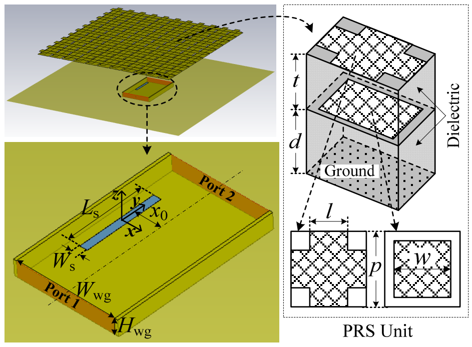


Fig. 1. Analysis model for a single waveguide slot element in the dielectric-filled FPC.

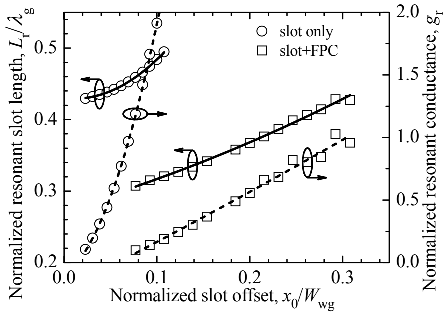


Fig. 2. Normalized resonant slot length and conductance.

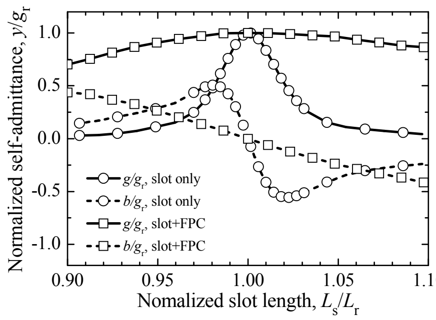


Fig. 3. Normalized admittance (slot only: x_0 = 0.9 mm, slot + FPC: x_0 = 3.0 mm).

The normalized self-admittance ($y = Y/Y_0$) can be computed from the simulated reflection coefficient as following:

$$y = g + jb = -\frac{2S_{11}}{1+S_{11}}. \qquad (1)$$

For each slot offset x_0, the corresponding resonant slot length L_r and the normalized resonant conductance g_r are determined by locating the zero-crossing of the normalized self-susceptance.

With the increasing slot offset, both the resonant slot length and normalized resonant conductance increase as shown in Fig. 2. To achieve the same resonant conductance, the slot offset increases significantly and the slot length decreases in the presence of the covered dielectric-filled FPC. The normalized resonant slot length (L_r/λ_g, where λ_g is the guided wavelength in the waveguide) and the normalized resonant conductance (g_r) of the FPC covered slot set are data-fitted as functions of the normalized slot offset (x_0/W_{wg}) over the range of $0.08 < x_0/W_{wg} < 0.31$, with the second-order polynomials as following:

$$\frac{L_r}{\lambda_g} = 0.2746 + 0.37578\frac{x_0}{W_{wg}} + 0.46181\left(\frac{x_0}{W_{wg}}\right)^2 \qquad (2)$$

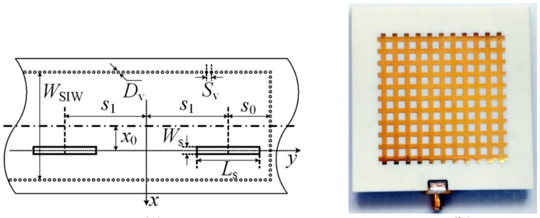
$$g_r = -0.2189 + 3.76923\frac{x_0}{W_{wg}} + 0.77957\left(\frac{x_0}{W_{wg}}\right)^2. \qquad (3)$$

For the feeding SIW with the same effective width W_{wg} of 13 mm and height of 0.813 mm, the values of the longitudinal slot length and offset can be calculated for the required resonant conductance of the SIW-slot fed FPC antenna using the characteristic functions given in (2)–(3).

In order to show the resonance characteristics, the normalized self-admittance is normalized again for the normalized slot length (L_s/L_r). The components of the renormalized self-admittance (y/g_r) are hardly affected by the change of the slot offset for the cases with and without the covered FPC. Therefore, only the renormalized slot admittance for the slot offset of 0.9 mm and 3.0 mm are presented in Fig. 3, respectively. Due to the occurrence of the covered FPC, the renormalized slot conductance (g/g_r) and susceptance (b/g_r) are less sensitive to the slot length. It is also found from Fig. 2 that the slot resonant conductance varies much more slightly with the slot offset in the FPC covered SIW slot. It suggests that the covered FPC will not only increase the antenna gain, but also reduce the fabrication tolerance requirement of the SIW slot. Moreover, the covered FPC lowers the slot resonant conductance such that a large number of slots can be arrayed in a single SIW section for high-gain applications.

III. Antenna Results and Discussion

To verify the analysis, double longitudinal slots on the SIW (W_{SIW} = 13.2mm, D_v = 0.3mm, S_v = 0.6mm) are used in the prototyped FPC antenna as shown in Fig. 4. The slot width W_s is fixed at 0.4 mm. As the effective width of the SIW is about 13 mm, the initial slot length and offset values are calculated to be 7.53 mm and 2.4 mm from (2)–(3) for the required normalized resonant conductance g_r of 0.5. The optimized parameters are: L_s = 7.6, x_0 = 3.0, W_s = 0.4, s_0 = 5.18, and s_1 = 10.05 (all in mm). The $|S_{11}|$ and boresight gain of the antenna are shown in Fig. 5. Good impedance matching has been achieved except the slight frequency shift between the simulation and measurement. The frequency shift is attributed to the actual dielectric constant deviated from the value for simulation as well the tolerance of fabrication and assembly. The measured *E*- and *H*-plane radiation patterns at 9.8 GHz with a maximum gain of 15.5 dBi are plotted in Fig. 6.



(a) (b)

Fig. 4. (a) Configuration of SIW slot feed, (b) photo of the antenna prototype.

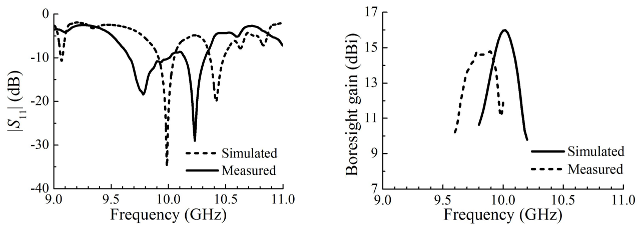


Fig. 5. $|S_{11}|$ and boresight gain of the antenna.

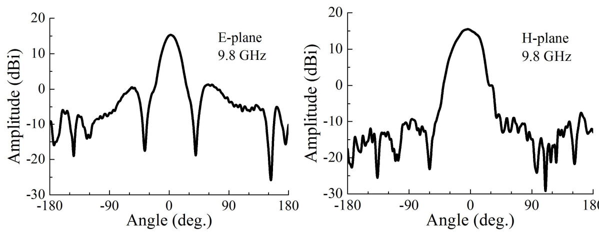


Fig. 6. Measured radiation patterns of the antenna at 9.80 GHz.

IV. Conclusion

The characteristics of the longitudinal SIW slot in the dielectric-filled thin FPC have been analyzed. The FPC antenna fed by a pair of SIW slots with a small cavity thickness of $\lambda_0/15$ has demonstrated a measured high gain of 15.5 dBi.

References

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