A Wideband Low-Profile Fabry-Perot Antenna Employing a Multi-Resonant Metasurface Based Superstrate

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***Abstract*—A wideband, low-profile Fabry-Perot antenna with a multi-resonant metasurface superstrate is presented. The superstrate consists of a patch-type and an aperture-type metasurface printed on the top and bottom surfaces of a Rogers 5880 dielectric, respectively. A small-size version of a waveguide fed Fabry-Perot antenna achieved a measured 3-dB gain bandwidth of over 40% without resorting to multi-layered superstrates. In addition, a 1-dB gain bandwidth of 24% was also achieved. The aperture efficiency in both cases is 64% for an aperture size of 1.7λ_C x 1.7λ_C, where λ_C is the free space wave length at the central frequency of 11.8 GHz. Two prototypes were fabricated and tested to confirm the design concepts.**

Keywords*— *Bandwidth; metasurface; Fabry-Perot; multi-resonant; wideband; low profile.

I. Introduction

The quest for wideband low-profile Fabry-Perot antennas (FPA) is an ongoing endeavor. A typical FPA consists of a superstrate placed about half a wavelength above a metallic ground plane with a low directivity antenna or an array used to excite the resonant cavity created. These antennas are highly directive with simpler, less lossy, and cheaper feed networks compared to antenna arrays and reflector antennas for example [1], [2]. Due to their numerous advantages, FPAs find many applications in areas such as satellite communications, electronic warfare, sensor networks, and point-point- links. Although the directivity of FPA can be very high, the gain bandwidth (GBW) can be quite narrow due to the inverse relationship between the two, which poses a limitation on their applicability.

In this paper, another method is reported that enhances the 1-dB and 3-dB GBWs of FPAs. Unlike the usual method of bandwidth extension using multiple superstrate layers, this approach uses a single multi-resonant superstrate to create multiple resonances satisfying the resonance condition. This ensures substantial bandwidth extension without further increase in height. The superstrate shown in Fig. 1 consists of a patch-type and an aperture-type MS (PMS and AMS) placed on the top and bottom surfaces, respectively, of a Rogers 5880 dielectric. Using this method, two antennas were designed, fabricated and measured to test an alternative approach. For both designs, the total antenna size is 2.1λ_C x 2.1λ_C x 0.66λ_C at the central frequency (11.8 GHz) and the aperture efficiency at the peak gain is 64%. The aperture size for the stated efficiency is 1.7λ_C x 1.7λ_C. Because of the small foot print of the antenna, it is suitable for space limited applications or as an element in a sparse antenna array for further increased directivity.

This paper is organized as follows. Section II describes the multi-resonant FPA design, and our conclusions are presented in Section III.

II. Wideband Multi-resonant FPA Design

Two FPA designs focused on improving the 1-dB and 3-dB GBWs are presented in this section.

A. Antenna Structure

The proposed wideband FPA is shown in Fig. 2. It consists of a superstrate made up of 9 × 9 elements (43.2 mm × 43.2 mm) placed less than half a wavelength above a $D_x \times D_y$ ground plane with a standard WR75 waveguide at its centre. This aperture size was chosen to fulfill the minimum area required for a directivity improvement of 13.8 dB at 9 GHz. The maximum directivity obtainable with this aperture at the highest frequency (14.4 GHz) is 17.3 dB. This truncated aperture can be better illuminated for higher aperture efficiency and a reasonably good gain [3]. The total dimension of the antenna is 52.8 mm × 52.8 mm × 16.75 mm. A dielectric substrate is inserted into the Fabry-Perot cavity to reduce the overall antenna height and for greater flexibility in tuning the directivity and impedance matching. Both the dielectric insert, and the multi-resonant superstrate are made from Rogers RT/Duroid^{TM} 5880 with ε_r = 2.2 and tanδ = 0.0009.

B. Comparison and Discussion

The designed FPA antennas were fabricated and compared with previous designs using a new metric introduced here to account for the volume of the antenna in addition to its directivity or gain bandwidth product (i.e. DBWP or GBWP). This metric is the ratio of each BWP and the volume here designated as the DBWP/V or GBWP/V.

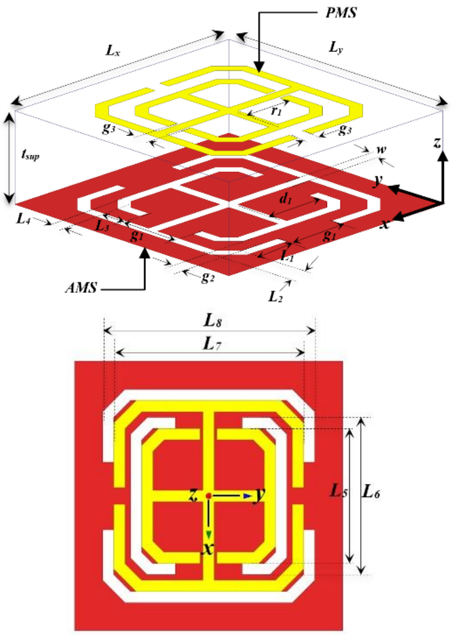

Fig. 1. The multi-resonant superstrate unit cell. (a) Perspective view with the top side showing the patch-type MS (PMS) and the bottom side showing the aperture-type MS (AMS). Dimensions are given in millimeters for resonance at 10 GHz. w = 0.2, t_{sup} = 1.5748, g_1= 1.2, g_2 = 0.3, g_3 = 0.3, L_1 = 0.9, L_2 = 0.4, L_3 = 0.5, L_4 = 0.3, L_x = L_y = 4.8, r_1 = 1.0, and d_1 = 1.2. (b) Top view with dimensions L_5 = 2.4, L_6 = 2.8, L_7 = 3.4, and L_8 = 3.8. The substrate is Rogers RT/Duroid™ 5880 with ε_r = 2.2 and tanδ = 0.0009.

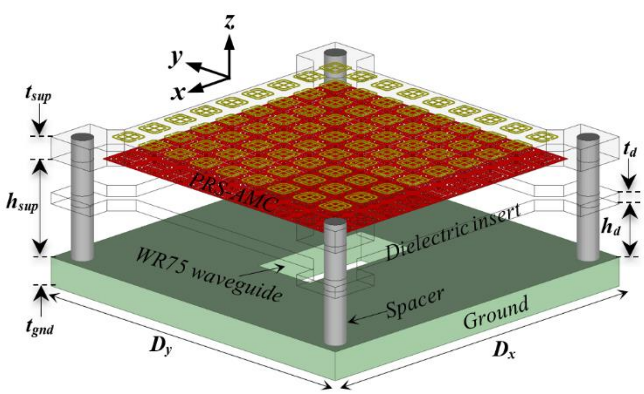

Fig. 2. FPA with a waveguide feed. Both the dielectric insert and the multi-resonant superstrate are made from Rogers RT/Duroid™ 5880 with ε_r = 2.2 and tanδ = 0.0009. WR75 dimensions = 19.05 mm × 9.525 mm. Teflon spacer radius = 1.5 mm

The DBWP/V and GBWP/V are calculated based on the largest antenna dimensions at the central frequency. A high value of DBWP or GBWP is desireable. The antenna height, *h*, is measured from the ground plane to the very top of the superstrate. Considering one of the two reported designs, its GBWP/V is higher than all the reported designs in table I except [4]. However, in [4], three layers of superstrate were required to achieve the stated performance with an aperture efficiency of only 38.4% as compared to the high value of 64% reported in this work.

TABLE I
FPAS PERFORMANCE COMPARISON

Ref.	G_{max}	*3dB-BW*	*V = A*h*	*GBWP*	*GBWP/V*	*Aper. eff.*
[5]	16.0	23.0	7.56*0.65	915.6	216.2	41.9
[6]	13.8	28.0	5.76*0.53	671.7	233.2	33.1
[4]	14.2	86.3	4.16*1.24	2269.9	439.9	38.4
This work	**14.3**	**40.0**	**4.31*0.66**	**1076.6**	**378.5**	**64.0**

Antenna volume, *V* = *A*h* = area * height.

III. CONCLUSIONS

An alternative method of improving the bandwidth of low profile FPAs s has been introduced and verified in this paper. This method uses a multi resonant metasurface based substrate. Two prototypes focused on improving the 1-dB and 3-dB gain bandwidths have been designed, analyzed, fabricated and tested. The first fabricated prototype achieved a measured 1-dB GBW of 24.0% and a 3-dB GBW of 42.1% with a peak gain of 13.4 dB. The second fabricated prototype achieved a measured 3-dB GBW of 40.0% with a peak gain of 14.3 dB. A high GBWP/V value was obtained for both designs coupled with superior aperture efficiency (64%) compared to similarly sized antennas described in the literature. The detailed design methodology and the measured results will be presented at the conference.

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