Design of Scan-capable Febry Perot Resonator Antennas

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Abstract

Fabry-Perot (FP) resonator antennas with scan capabilities are described in this paper. The proposed antennas, excited by a thinned array, not only achieve higher directivities but also improve suppression of sidelobes relative to that of the thin array alone. We also investigate the use of artificial magnetic conductor (AMC) for the purpose of size reduction of the FP antenna.

Keywords :, Directivity, superstrate, sidelobe level suppression, grating lobe, artificial magnetic conductor, FDTD

1. Introduction

While antennas based on FP resonators have been studied extensively, their investigations have been limited primarily to the case where a single feed, such as a microstrip patch antenna, has been utilized to excite the resonator. In this paper, we present the results of an extensive study of FP resonator-type antennas that utilize array feeds for excitation in order to provide scan capability, and not just the suppression as in [1] and [2]. It is often desirable to scan the FP antenna, even over a limited range of angles. This has prompted us to investigate the possibility of using an array excitation for the FP antenna. With this goal in mind, we investigate the use of a thinned array, with element spacings that are an the order of 1 λ or even higher, to excite the resonator, but show that the designed antenna with this type of feed does not suffer from grating-lobe problems, as the array itself would in the absence of the superstrate. We show that the number of elements in the array feed can be reduced significantly without introducing grating lobes, even though the separation distance between the elements is greater than 1 λ.

We proceed next to introduce an AMC for the ground plane in order to reduce the total height of the resonator antenna by almost a factor of two from its original value of 0.5 λ, which is typical for FP antennas. We then investigate the performance of the FP antenna with an AMC for the lower conductor and compare the same with that of the original design with the conventional PEC ground plane. We investigate the scan capability of both of these designs and present the results in this paper.

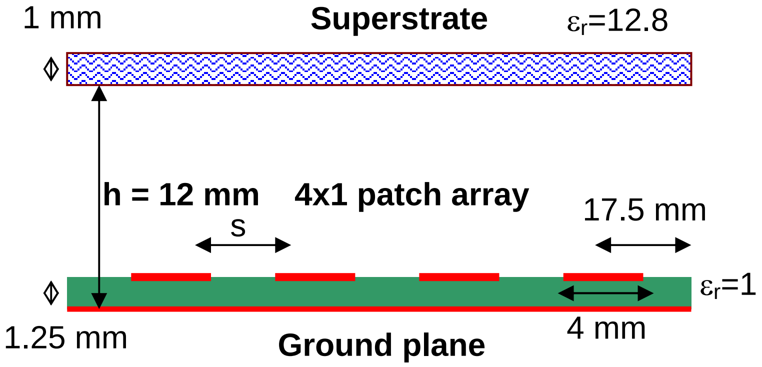
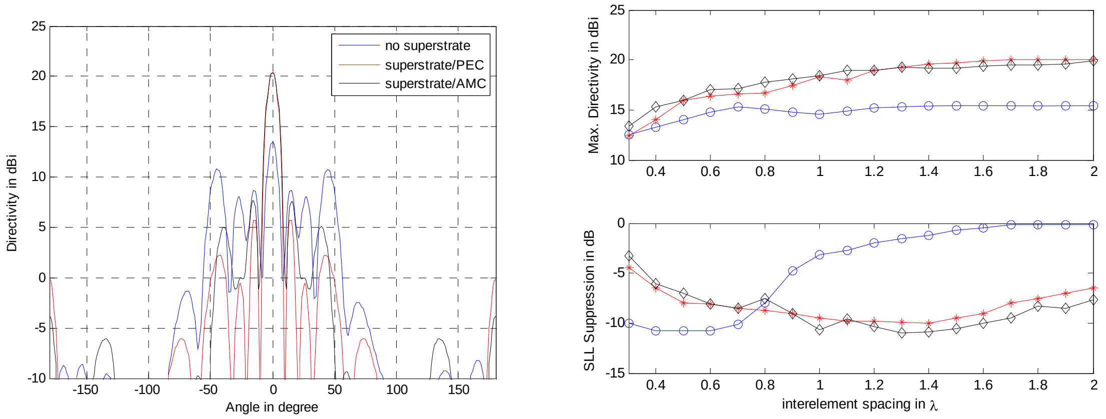


Fig. 1. Geometry of 4x1 patch array inside a superstrate/PEC composite

2. Design of Scanned Array by Superstrate/PEC Composite

The schematic view of a 4x1 array antenna composite, with a dielectric slab as a superstrate, is shown in Fig. 1. We study the performance of a uniform microstrip patch array as the excitation for the FP resonator at the operating frequency of 12.0 GHz, with the patch array located at a height of

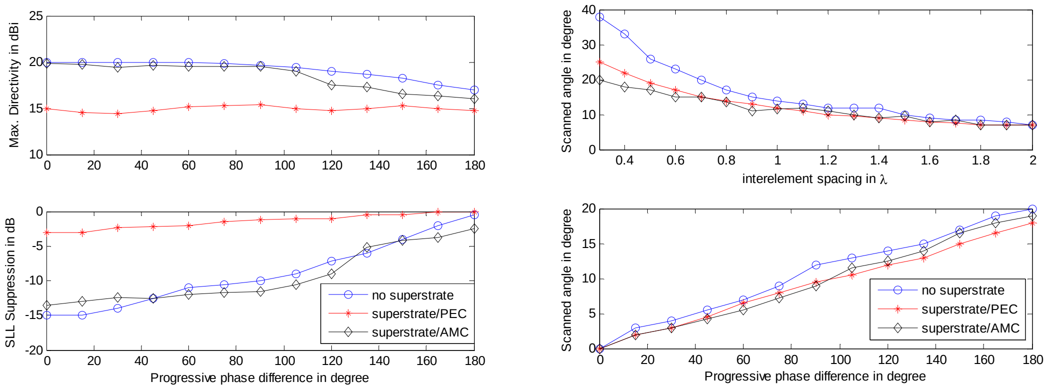
1.25 mm above the ground plane. The high-permittivity superstrate, which has ε_r=12.8 and a thickness of 1.0 mm, is placed at a height of half-wavelength above a patch antenna. High reflectivity values (~0.5 dB) were obtained for a broad range of frequencies around 12.0 GHz. The superstrate is located at a height of 12.0 mm (~0.5 λ) above the ground plane, where λ is the free space wavelength at 12 GHz. The inter-element spacing (s) is one of our design variables for the performance analysis of the array structure. We use a microstrip patch antenna whose dimensions are 10.7 x 4.0 mm^2. It is probe-fed at an offset position of 1.8 mm from the center of the patch, to realize a good impedance match. The FP antenna comprising of a uniform 4x1 patch array feed located inside a superstrate/PEC composite is designed by using the Finite Difference Time Domain (FDTD) method [3]. Fig. 2(a) shows the radiation patterns of the 4x1 array for an inter-element spacing of 1.4 λ_0 (35mm). The results of the superstrate/AMC composite, described in the next section, are also shown together in Figs. 2 and 3. The superstrate/PEC composite array shows a maximum directivity of 20.3 dBi, approximately 6 dBi higher than that of the patch array alone. The higher directivity is realized because of an increase in the effective size of antenna aperture at resonance. The sidelobe level of 2.4 dB is quite high for the array alone and is attributable to the grating lobes occurring when its inter-element spacing is large. On the other hand, when the superstrate is placed above the array, a sidelobe suppression of 15 dB is obtained. In order to investigate the effect of the inter-element of the feed for the superstrate/PEC composite array, maximum directivities and sidelobe level suppressions are investigated as the function of the inter-element spacings ranging from 0.3 to 2.0 λ_0 (see Fig 4(b)), under the condition of the progressive feed phase step of 90°. As the inter-element spacing is progressiely increased to~1.2 λ_0, the directivity also increases, at first, and then saturates at about 20 dBi. It is important to note, however, that the grating lobes do not occur in the array/superstrate composite despite the large inter-element spacing because of the suppression provided by the FP resonator configuration.



(a) (b)

Fig. 2. (a) Radiation patterns, (b) Maximum directivities and sidelobe level suppressions.

Next, the radiation characteristics of the proposed scanned array are investigated by varying the excitation phase of each input port for the 4x1 array antenna. Directivities and sidelobe levels are computed as the feed phase step from element to element is progressively increased from 0° to 180° for the inter-element spacing of 1.4 λ_0. The results are presented in Fig. 3(a), which shows the maximum directivities and sidelobe levels. We note that the directivity enhancement as well as sidelobe level suppression is achieved for the design of the superstrate/PEC composite, although a small performance degradation is seen. We also note that no grating lobes are generated except for the case of large phase tapers with an increment of 180°. Fig. 3(b) shows the maximum tilt angles as functions of the distance and feed phase increment. The superstrate/PEC composite has some reduction in the maximum scanned angle for small inter-element spacing, although this case is not of interest to us in this work. We find that the maximum scan angles of the superstrate/PEC composite are only about 1° lower than that of the no-superstrate case. This is a relatively small expense to pay for achieving high directitivity that we have realized in the thinned array case, with a compact size but with no grating lobes.

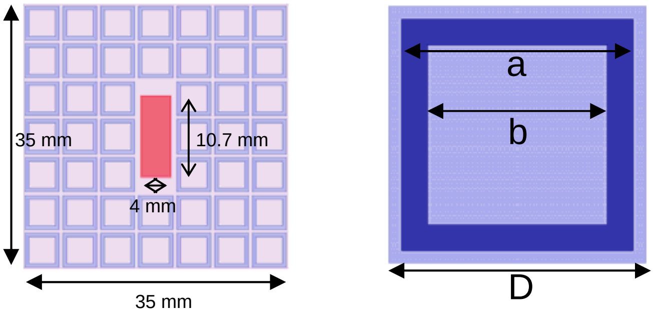


(a) (b)

Fig. 3. (a) Maximum directivities and SLL vs. feed phase difference, (b) Scanned angles vs. inter-element spacing and feed phase difference

3. Design of Scanned Array by Superstrate/AMC Composite

Next, we investigate the use of an artificial magnetic conductor (AMC) for the purpose of height reduction to achieve a low-profile design. An AMC for the ground plane is designed in order to reduce the total height of the resonator antenna by almost a factor of two from its original value. A patch radiator surrounded by AMC cells is shown in Fig. 4(a). The AMC cells are placed at the same height level as that of the 4x1 patch array in the geometrical view of Fig. 1.



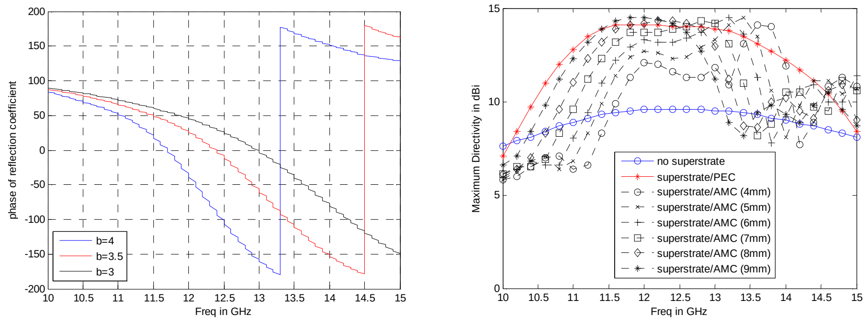
(a) (b)

Fig. 4. (a) patch radiator surrounded with AMC cells, (b) AMC unit cell

The square ring as an AMC unit cell is located at a height of 1.25 mm above the ground plane, as shown in Fig. 4(b). The advantages of the square loop element, as compared to other types of element geometries, such as a strip or a patch, are its symmetry, compact size and the possibility of using several concentric loops for greater flexibility of design. The reflection phase response of the unit cell, simulated by using the FDTD method, is shown in Fig. 5(a). The AMC plane is designed to achieve a phase of 0° for the reflection coefficient at normal incidence at the operating frequency of about 12.0 GHz. A broadband AMC operation has been obtained with a +90° to -90° reflection phase bandwidth of more than 30% (~4.0 GHz) by choosing its optimum geometrical parameters of D=5.0 mm, a=4.5 mm and b=3.5 mm.

Directivities of a microstrip patch antenna of superstrate/AMC composite type are investigated next, in the frequency band of 10.0-15.0 GHz (see Fig. 5(b)), to find the optimum height between the superstrate and the AMC surface at 12.0 GHz. An aperture size of 35.0 x 35.0 mm2 (1.4 λ0 x 1.4 λ0) is chosen for the superstrate and the same size is used for the corresponding array feed structure as well as the AMC surface. Directivities of the patch alone without the superstrate, and of the patch with superstrate located at a height of 12.0 mm above the patch (superstrate/PEC composite) are both shown in Fig. 5(b) for the sake of comparison. Directivity enhancement of about 5.0 dB is achieved by the addition of the superstrate layer over the patches in both the cases of superstrate/PEC and superstrate/AMC composites.

Fig. 5(b) shows the parameter analysis of the height (4.0 to 9.0 mm) between the superstrate and the AMC surface in the frequency band of 10.0 to 15.0 GHz. With an increase of the height of the superstrate/AMC composite, the frequency bands with the best directivity move to lower regions. Also, the directivity bandwidths of the superstrate/AMC composite are narrower than that of superstrate/PEC composite. We choose a height of 7.0 mm, which is a little larger than half of 12.0 mm for the superstrate/PEC composite case. The existence of the patch antenna increases the height, as compared to the case when the entire plane is covered with AMCs. We note that a reduction of the antenna height by approximately a factor of two has been achieved by employing the AMC ground plane.



(a) (b)

Fig. 5. (a) Reflection phase of AMC unit cell, (b) Directivity analysis for the distance variation between superstrate and AMC surface.

A 4x1 patch array using a height of 7.0 mm between the superstrate and the AMC surface has been analyzed in this work, while only a single patch located inside superstrate/AMC composites was investigated in [4] and [5]. Its radiation characteristics have been investigated for the variation of inter-element spacing and progressive feed phase difference. Its directivities, sidelobe levels, and tilt angles are found to be similar to those of the 4x1 superstrate/PEC composite array, as shown in Figs. 2 and 3.

4. Conclusion

Array type of feeds that provide scan capability, which cannot be conveniently realized by using a single feed for the resonator antenna, have been investigated. We show that the number of elements in the array feed can be reduced significantly without introducing grating lobes, even though the separation distance between the elements is greater than 1 λ. The paper has also presented the results of an investigation of the use of artificial magnetic conductors (AMCs) for the purpose of size reduction, so obtaining an antenna height of 7 mm, about quarter wavelength at 12 GHz.

Acknowledgments

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References

[1] Y. Lee, S. Jeong, W. Park, J. Yun, and S. Jeon, “Multilayer spatial angular filter with air-gap tuners to suppress grating lobes of 4 x 1 array antenna,” Electron. Lett., vol. 39, pp. 15–17, Jan. 2003.

[2] Y. J. Lee, J. Yeo, R. Mittra, and W. S. Park, “Application of Electromagnetic Bandgap (EBG) Superstrates With Controllable Defects for a Class of Patch Antennas as Spatial Angular Filters,” IEEE Trans. of Antennas and Propagation, Vol. 53, No. 1, pp. 224-235, 2005

[3] General Electromagnetic Simulator (GEMS), Computer and Communication Unlimited (2COMU), State College, PA, USA: http://www.2comu.com

[4] A. Pirhadi, M. Hakkak, F. Keshmiri, and R. K. Baee, “Design of Compact Dual Band High Directive Electromagnetic Bandgap (EBG) Resonator Antenna Using Artificial Magnetic Conductor,” IEEE Trans. of Antennas and Propagation, Vol. 55, No. 6, pp. 1682-1690, 2007

[5] A. P. Feresidis, G. Goussetis, S. Wang, and J. C. Vardaxoglou, “Artificial Magnetic Conductor Surfaces and Their Application to Low-Profile High-Gain Planar Antennas,” IEEE Trans. of Antennas and Propagation, Vol. 53, No. 1, pp. 209-215, 2005