Analysis and Review of Fabry Perot Resonator Antennas (FPRA)

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Abstract— A Fabry-Perot Resonator (FPR) antenna has found wide applications in microwave and millimetre waves and recently attracted considerable interest. In this paper, research progress on FPR antenna, a literature review on FPR antenna has been discussed. Further paper describes introduction, basics of Fabry perot cavity and PRS(Partially Reflective surface)& its applications, structure of FP cavity (FPC) model &finally improvement of gain bandwidthusing various methods are illustrated.

Keywords-*Fabry-Perot resonator antenna, PRS (Partially Reflective surface), Frequency Selective surfaces (FSS), Periodic structures, high gain, wide bandwidth.*

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I. INTRODUCTION

In recent times, thedemand for highly directive antennas are becomingmore and more stringent, especially in upper microwave and millimetre-wave regions.[2] So, high gain antennas are important components for manycommunication systems, such as radar, satellite and mobile communication systems. Traditional high-gain antennas are array antennas, reflector and lens antennas, and horn antennas. The Fabry-Perot resonator antennas (FPRAs), also called EBG resonator antennas or Fabry-Perot cavity antennas, were developed as high-gain antennas not long ago. Withtheir advantages of structural simplicity, low cost, and ease of fabrication and mounting, they have the potential to replace the traditional high-gain antennas in many communication systems. [4]

Fabry-Perot (FP) cavity is an attractive and well-known technique to increase the antenna gain.[5] A Fabry-Perot resonator (FPR) antenna generally consists of a primary radiator backed with a metal ground plate and a partially reflective covered plate(Trentini, 1956). The general configuration of FPRA is shown in fig.1. When the spacing between theseplates is about an integer multiple of $\lambda/2$, the forwardradiation can be enhanced remarkably by means ofin-phase bouncing. The single-feed system allows thegain to be increased with low complexity, as comparedto the feeding networks used in conventionalantenna arrays, and has drawn more and more attention.Various configurations like planar and cylindrical type FPRA's have been designed in the past years and produced high directivities atbroadside that are shown in Fig.2(a-b). Trentini (1956) first used FPR structure excited by a single source to produce a high directivity at broadside.[1][6]

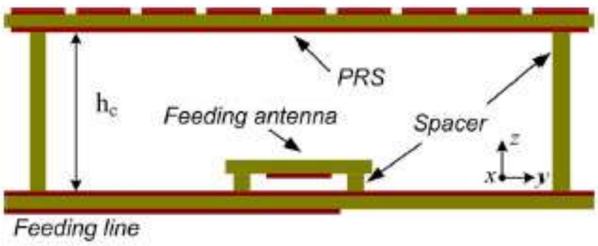

Figure 1. Geometry of conventional FPRA [2]

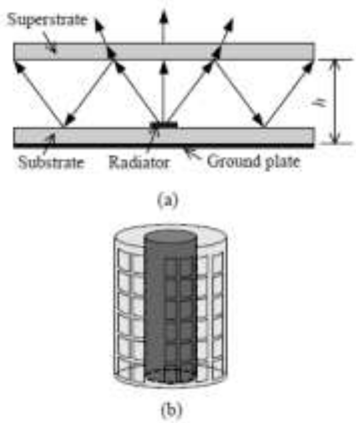

Figure 2(a). Geometry of planar type FPRA (b) Geometry of cylindrical type FPRA [1]

II. BASICS OF FABRY-PEROT CAVITY (FPC)

In optics, Fabry Perot interferometer or 'etalon' is made of transparent plate with two reflecting surfaces or two parallel highly reflecting mirrors. It is named after Charles Fabry and

Alfred Perot (1899).Fig 2(a)shows the geometry of the basic FPR,which consists of a primary radiator backed with a metal ground plate and a leaky reflective covered plate. The distance between two parallel plates, with reflective coefficient phases $\phi1$ and $\phi2$ respectively, is '*h'*. From the ray viewpoint, an electromagnetic (EM) wave excited by the source is bounced in the FP cavity. In order to superpose in phase, the phase shift of the EM waves each return is an integer multiple of 2π which can be written as -

$$-4\pi h / \lambda + \phi1 + \phi2 = N \cdot 2\pi, N = 0,1,2... \qquad (1)$$

The resonant frequency is determined by

$$f = [(\phi + \phi) / (2\pi) - N] \cdot c / (2h), N = 0,1,2.. \qquad (2)$$

where 'c' is the velocity of light in the vacuum

Different types of analytical models like FP Cavity model, leaky wave model, transmission line model & EBG defect model, Extended transmission line method are used to analyse FPRA analytically and numerically [13]. In which FP cavity model is very easy to understand the structure of FPRA from the ray viewpoint and transmission line model is important from the circuit viewpoint which is used to provide quick initial design guidelines.[1] Summary of all four types of models is given in following table.

TABLE 1- SUMMARY OF ANALYTICAL MODELS FOR FPRA

Sr.No	Name of the model	Purpose
1	FP Cavity model	Used to analyse FPRA from ray view point
2	EBG Defect model	It generates accurate results.
3	Transmission Line model	Used to analyse FPRA from circuit view point & provides quick design guidelines
4	Leaky wave model	It offers a novel mechanism of FPRA

III. BASICS OF PARTIALLY REFLECTIVE SURFACE (PRS)

The PRS composed of metallic periodic structure is often placed at approximately half a wavelength about a ground plane containing radiation source, and hence a Fabry-Perot (F-P) cavity is constructed. [14] The design of PRS is the key to achieve desired goals. The key part of high gain cavity resonance antenna is its highly reflective superstrate surface. The multiple reflections occurred between ground and PRS is shown in fig.3.

The main characteristics of antenna such as its operating frequency, directivity, gain, bandwidth and radiation patterns are determined by the property of the PRS. [2] The operating frequency depends on the following equation -

$$f = (c/4\pi h) (\phi H + \phi L - N \cdot 2\pi), N = 0,1,2..... \qquad (3)$$

where ϕH and ϕL are the reflection phases of the PRS and ground plane respectively, while 'h'is the distance between PRS and ground plane. With the increase of the reflectance of the PRS, a higher directivity can be generated, but the radiation bandwidth, for example, the 3 dBgain bandwidth, will become smaller due to the high Q-factor of the resonator. So there is a trade off between Q-factor and bandwidth of FPRA. [2]

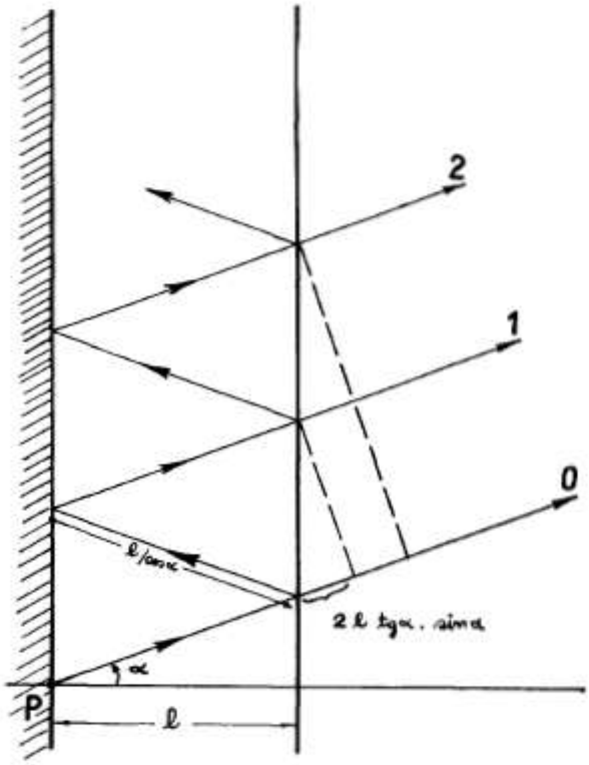

Figure 3. Multiple reflections between PRS and ground plane [6]

There are many structures available that can be used as a PRS in design of FPRA like Frequency Selective Surfaces (FSS), dielectric layers. EBG (Electromagnetic Bandgap) materials are also used as PRS to build an EBG resonator antenna. EBG materials are periodical structures composed of metallic or dielectric elements [10].

IV. BASICS OF FREQUENCY SELECTIVE SURFACE (FSS)

"A periodic surface basically an assembly of identical elements arranged in one dimension or two dimensional infinite array".

Frequency selective surfaces (FSS) are essentially array structure which consists of a plurality of thin conducting elements, often printed on dielectric substrate and the behave as passive electromagnetic filters. [20]

FSS is a good candidate as alternative to dielectric cover for directivity enhancement because they have provided high reflection coefficient and much easier to fabricate using etching processes.In addition, the use of FSS superstrate makes the antenna more compact in terms of thickness. So, because of plenty of advantages of FSS layer mostly it is used as a PRS in FPRA. We can excite FSS layers in two different ways namely by using individual generators and by using plane wave excitation that are briefly described by Ben.A.Munk. [21].
There are many different configurations of FSS available for various applications like Band-pass & Band-stop type FSS (See Fig.4(a-b)), thick and thin screen FSS, pure metallic and dielectric type FSS. Band-pass and band stop characteristics of EM filter can also characterized by slot type element and patch type element respectively.
Other one variation is aperture or slot type FSS and patch type FSS layers. These all configurations has been discussed by Ben.A.Munk. [21]

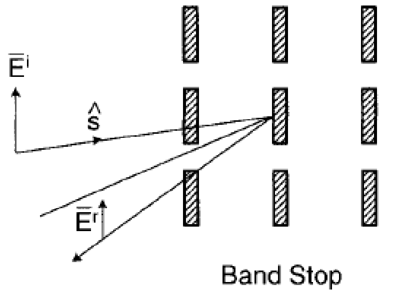

Figure.4(a) - Band stop type FSS [21]

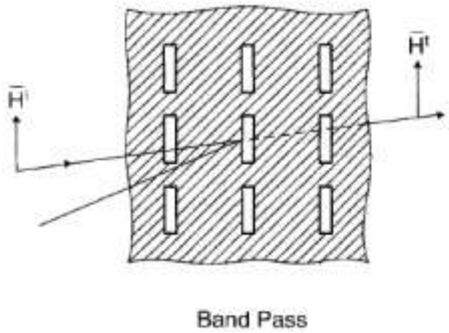

Figure.4(b) - Band pass type FSS [21]

Many times, metallic sheets perforated with either rectangular or circular apertures (holes) are used to form reflector surfaces, band pass filters and Fabry perot interferometers. M.Bozzi et al described that metal screen perforated periodically with apertures of various shapes are widely used as FSS in mm-wave and sub-mm-wave region. [18] Thick perforated metallic sheets are more preferred in many cases in order to enhance the strength and hardness of the structure, to improve band pass filter characteristics or to avoid radiation hazards due to leakage from microwave sources. [18] Thick screen aperture type FSS is shown in Fig-5.

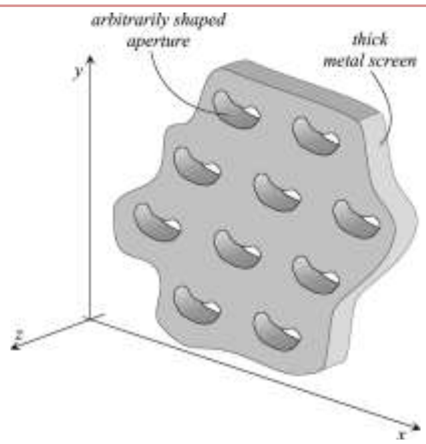

Figure.5- Thick perforated metal screen with arbitrarily shaped aperture [18]

The shape of apertures, their size and spacing and the thickness of metal screen determines the frequency behaviour of FSS. [18] There are various parameters that will affect the resonant characteristic of FSS namely Angle of incidence of an EM wave, Effective aperture size of the FSS, Grating Lobes, Periodicity of cells, Substrate that supporting FSS element (Dielectric or Metallic), Inter-element spacing and Arrangement of elements.

Analysis of FSS can be done using various numerical methods which includes the most popular Finite Difference Time Domain method (FDTD), Finite Element Method (FEM), and Integral Equation Method (IEM). From the review of literature one can conclude that FDTD and IEM methods are quite slow. And IEM is applicable for particular aperture shapes only. The great solution has been found for this problem and it is Boundary Integral Resonant Mode Expansion Method (BI/RME). This approach resulted in a fast and flexible computer code which performs the wideband analysis of FSS with arbitrarily shaped apertures in tens of seconds on a standard PC. This method is very fast and efficient. It allows calculating a large number of modes of an arbitrarily shaped waveguide in a few seconds [18].

There are two major techniques of fabrication of FSS are Photolithography and galvanizing growth on a base substrate. [18]

V. BASICS OF FPRA

A conventional FP resonator antenna is formed by placing an EBG structure as a partially reflective surface (PRS) at a proper distance from a ground plane, which creates an air-filled cavity between the PRS and the ground plane (PEC), and fed by a small antenna or an array. [2] The conventional FPRA structure made from highly reflective ground plane or PEC or wholly reflective surface (WRS) and Partially reflective surface (PRS) is shown in Fig.6.The EBG antenna is constructed by placing EBG superstrates as PRS above the ground plane and fed by feed antenna at the center to form air-filled cavity [12].

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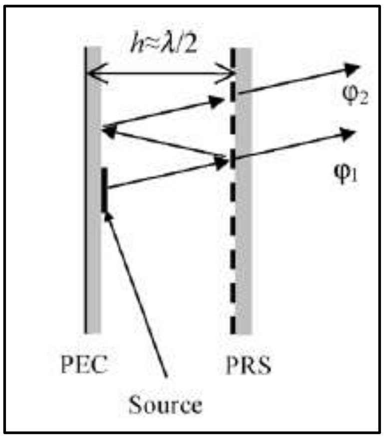

Figure.6-FPRA formed by PEC and PRS [17]

VI. Gain Enhancement in FPRA

FPRA is an attractive and well known technique to increase antenna gain [5]. The methods to improve the gain of FPRAs including those using multiple superstrates and feeding array have the challenges in either impedance matching or complexity reduction as they affect the gain bandwidth [4]. An early version of EBG resonator antennas uses appropriately spaced multiple dielectric layers to achieve a high gain [8].The broadside directivity of simple primary radiator with a ground plane can be greatly enhanced by placing planner PRS [9].

The gain of a physically small aperture feed element can be enhanced by using coherent multiple reflections between partially reflecting surface (PRS) and ground plane of FPRA.We can use dielectric and metallic type Frequency Selective Surface (FSS) layer is used as a PRS and waveguide horn as feed element.

Higher gains come with narrower bandwidths. On the other hand, surface-mounted short horns were recently applied to enhance the gains of small antennas successfully without changing other performance, parameters and increasing system complexity [4].

After designing the low-profile FPRA with small footprint, we can apply a surface-mounted short horn to further enhance the gain. And also a horn antennas provides ease of excitation, versatility & large gain [19]. Based on the previous research work, it has been seen that the FPRA with a conical short horn gives a higher gain and wider gain bandwidth [4].

VII. Bandwidth Enhancement in FPRA

According to the ray theory analysis, a PRS structure with a linearly increasing phase response versus frequency is needed to yield a wideband EBG resonator antenna. Unfortunately, conventional EBG structures composed of 1-D dielectric slabs, 2-D printed FSSs or 3-D woodpile structures, normally are with negative reflection phase slopes [4][8].

Fabry Perot resonator antennas (FPRA), which have advantages of simple structure, simple feeding mechanism and hence low cost, attracted much attention among antenna researchers recently. However, an inherent disadvantage of this kind of antennas is the narrow bandwidth due to their typically narrow band resonant cavity structure [8]. To overcome this, we can enhance bandwidth by using multiple layers of PRS and using multiple feed network. So the use of multiple sources to excite an PRS structure allows an increase in gain/bandwidth product [7].

Other one studied method of bandwidth enhancement is using tapered size elements of reflecting sheet to achieve a tapered index PRS [9].

One method to enhance radiation bandwidth of FPRA is the use of dielectric PRS and for that a thick dielectric substrate is required (around half a wavelength at fr) which may not be easily available [3].

The antenna performance is related to the reflection characteristics of the PRS array using a simple ray-optics model. According to this model, maximum directivity at bore sight is obtained when constructive interference occurs, that is, when the resonance condition given in is satisfied, where φ is the phase of the reflection coefficient of the PRS, ‘h’ is the distance between the ground plane and the screen.

$$\phi = (4\pi h/c)f - (2N-1)\pi, \quad N = 0,1,2\ldots \quad (4)$$

It indicates that the FPRA will produce a wideband resonance by using a PRS whose reflection phase increases with frequency. So, we can achieve wide bandwidth using a PRS which shows positive reflection phase gradient versus frequency. Such phase behaviour restores resonant condition of maximum broadside radiation over a wider bandwidth [9][16]. So we can achieve increasing reflection phase behaviour using multi-layer PRS’s for broadband applications of FPRA’s. A.P.Feresidis et al described this method by using three layers of PRS, in which patch type FSS is used to design three different layers of PRS. [16] We can obtain two resonances from three layered PRS. At each resonant frequency, the magnitude of reflection has a minimum and phase increases for a frequency range around resonance. To achieve broadband phase increase, the two resonances have to be brought close together but not overlap. [16] Fig-7 shows an expected reflection phase behaviour and a normal reflection phase behaviour of PRS.

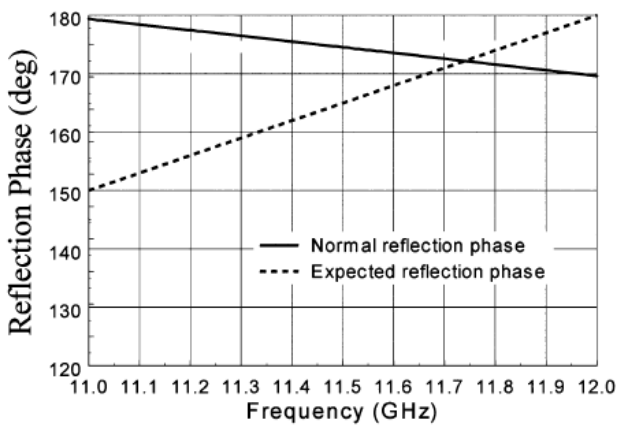

Figure.7- Normal & expected phase behaviour of PRS [15]

For that design of a PRS with required phase properties must be simulated by several parameters related to unit cell element of PRS such as length and width [9]. That's why it is a simple method for obtaining wider BW by positive reflection phase PRS which can be used in low profile, wide band EBG antenna [15].

So, bandwidth enhancement can be done by using multi-layer PRS structure and multi-feed FPC feed cluster for multi-beam reflector antenna antennas.

VIII. Advantages and Applications of FPRA

There are many advantages of fabry perot cavity based resonator antenna like High directivity and lower side lobe levels (SLL), good Q factor, high radiation efficiency, Small size & compact structures, ease of fabrication and mounting and low cost. Due to its numerous of advantages FPRA's are widely used in many applications. This type of satellite antennas are successfully used for many communication applications [11].Parabolic reflectors with groups of feeds in the focal plane are the most suitable antennas for multi-beam generation due to superior performances. [11]

IX. Conclusion

In this review paper, the basics of Fabry perot resonator antenna (FPRA) with its important characteristics have been studied. Also the application of Frequency selective surfaces as PRS in FPRA has been discussed . In this paper, various configuration of FPRA structures and different types of analytical models have been discussed.From the survey carried on FSS and FPRAwe can conclude that FSS layer can be used as a PRS to provide high Q factor and high directive properties of FPRA. By reviewing the literature on FSS, methods of numerical analysis of FSS layer are also included in this paper. Further various techniques of bandwidth enhancement and gain enhancement are also discussed in this paper.

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