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An experimental study of rectangular microstrip antenna on a curved surface in simulated plasma medium

Prem Bhushan Mital

Department of Electronics & Communication Engineering, CR State College of Engineering,
Murthal (Sonepat) 131 039

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The effect of plasma on the radiation characteristics of rectangular microstrip antenna on curved surface is studied by means of a new plasma simulation technique. The relative refractive index less than unity has been obtained by representing free space with a high dielectric constant sodium chloride powder, and plasma by a medium of lower dielectric constant (air). Wide range of dielectric constants of simulated plasma could be possible with this technique using solid dielectrics instead of liquids. It is observed that when the dimensions of patch are fixed, the resonant frequencies of TM modes are not affected by the curvature. However, radiation patterns are significantly affected.

1 Introduction

In many applications, antennas conforming to a non-planar surface are required, viz. in satellites, missiles and space crafts. Such antennas are flush mounted on curved surfaces to reduce aerodynamic drag. Microstrip antennas belong to this category, since, they are easily conformed to the surfaces on which they are mounted. The experimental study of a rectangular microstrip antenna on a curved surface in simulated plasma conditions is described in this paper.

2 Design and fabrication of rectangular microstrip antenna on a curved surface

The geometry and coordinate system of a rectangular patch antenna on a curved surface is shown in Fig. 1. The dimension of the straight edge is $2b$, while that of the curved edge is $2(a+h)\,\theta$, where a is the radius of the cylindrical ground plane and 2θ is the angle subtended by the curved edge. The resonant frequency of the structure is given as:

$$f_{\mathrm{mn}} = \frac{c}{2\sqrt{\varepsilon_{\mathrm{r}}}}\left[\sqrt{\left(\frac{m}{2(a+h)\,\theta}\right)^{2} + \left(\frac{n}{2b}\right)^{2}}\right]$$

where,

c Velocity of light
h Thickness of substrate
ε_{r} Relative permittivity of substrate

For TM modes, the following parameters have been used in designing the antenna:

Resonant frequency = 8.2 GHz (X-band)
Dielectric substrate: RT Duroid
$\varepsilon_{\mathrm{r}} = 2.2$
$h = 0.0795$ cm
$a = 1$ cm
$2b = 1.24$ cm

The antenna is fed by coaxial feed.

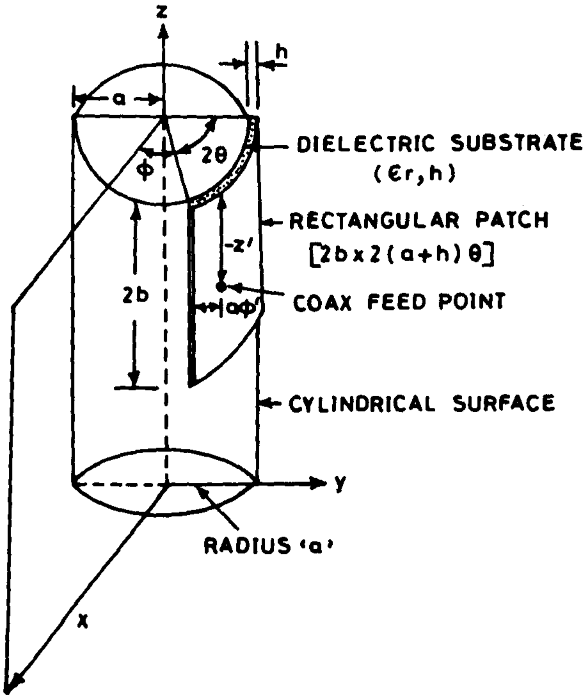

Fig. 1—Geometry of rectangular microstrip antenna on a curved surface

3 Experimental set-up

The details of experimental set-up are shown in Fig. 2. Unlike previous simulation technique[1,2] the relative refractive index less than unity is obtained by using two contiguous real dielectric media. Free space is represented by the high dielectric constant material (sodium chloride powder, $\varepsilon_r = 5.9$ at 8.2 MHz and a loss tangent $\delta = 5 \times 10^{-4}$) and plasma by a medium of lower dielectric constant (air). Since closely packed powder retains its position, the use of acrylic box as a separator between the two media is not required.

The value of the simulated plasma dielectric constant is given by

$$\varepsilon(\text{simulated plasma}) = \frac{\varepsilon\ (\text{air})}{\varepsilon\ (\text{sodium chloride})}$$

$$= \frac{1}{5.9} \approx 0.17$$

The horn antenna is fed by an EC sweep generator (Model UM-400) and is used as transmitting antenna, whereas rectangular microstrip antenna (MSA) on a curved surface as receiving antenna, the distance between them being greater than $2D^2/\lambda$. The transmitting antenna is fixed in position and rectangular microstrip antenna on a curved surface is rotated in azimuthal plane. To avoid reflections from the plasma simulation chamber, microwave absorbers are used all around the inner surface of the box.

4 Limitations of simulation of plasma medium

Due to complicated structures of the plasma, it is difficult to create exact plasma in an experiment. A variety of devices have been suggested and used in plasma simulation, viz. lumped electric elements, mechanical analogs and artificial dielectrics. These simulation techniques have limited applications. For example, (i) an artificial medium made of metal spheres or consisting of holes in plates or dishes may have a propagation constant equivalent to that of a plasma but a relative magnetic permeability that differs from unity. (ii) A conductive solution of an acid of salt may have the proper attenuation constant, but a refractive index greater than unity. Therefore, the degree of applicability of these simulation techniques is limited, since only one or two of the scalar parameters of a plasma are simulated. All the parameters necessary to simulate the plasma are not available.

The difficulty in plasma simulation techniques is that the real part of the plasma dielectric constant is less than unity, i.e. $(\varepsilon_p/\varepsilon_a) < 1$, where ε_p is plasma dielectric constant and ε_a is the dielectric

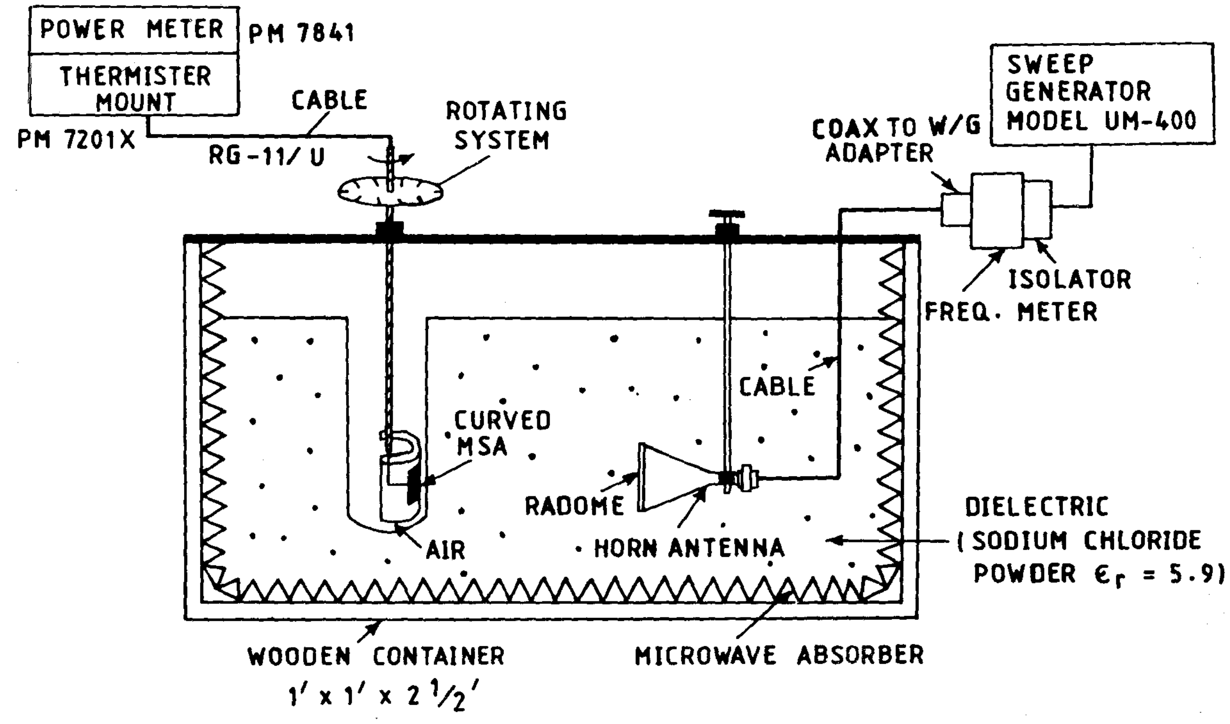

Fig. 2—Experimental set-up for pattern measurement of curved MSA in simulated plasma media.

constant of free space. If however, $(\varepsilon_p/\varepsilon_a)=(\varepsilon_{ps}/\varepsilon_{as})<1$, where subscripts 'ps' and 'as' denote plasma simulation and air simulation, respectively. It is seen that a simulated plasma environment depends on the ratio of the dielectric constants and not on their absolute values. Thus, an artificial plasma environment can be created by covering a radiator under investigation with a medium having a dielectric constant less than that of free space simulator.

Here we have simulated the condition of plasma actually encountered in the atmosphere (air-plasma-air). The relative refractive index less than unity between the plasma and free space is maintained by using two contigious (adjoining) real dielectric media. Since, real dielectrics cannot be substituted directly for the plasma in a simulation experiment, double substitution technique is used in which the free space region is represented by a liquid of high refractive index and plasma by a medium of low refractive index like air.

Such techniques for simulation of plasma have already been applied by many researchers[1,2] while studying the radiation properties of microstrip antennas in plasma.

5 Pattern and VSWR measurements

An EC sweep generator model (UM-400) has been used as a microwave signal source. The desired frequency range is obtained from its RF plug in units XA-400 A. The far field radiation patterns of rectangular microstrip antenna on a curved surface were obtained for free space and for plasma medium taking plasma parameter $A=1$ and $A=0.41$, where the plasma parameter is defined as

$$A=\sqrt{\varepsilon}=\sqrt{1-\frac{\omega_p^2}{\omega^2}},$$

ω_p and ω being the plasma frequency and source frequency, respectively. The pattern factor in EM mode is computed for different values of plasma parameters, i.e. $A=1$ for free space and $A=0.41$ for plasma. The results are plotted in Figs 3 and 4 for $\theta=90°$ and $\phi=90°$ in TM modes.

The VSWR of rectangular microstrip antenna on a curved surface was measured in free space as well in plasma medium. The values of VSWR in free space and plasma medium are given in Table 1. It is seen that the minimum value of VSWR is 1.2 and 8.25 GHz which is near the design frequency of 8.20 GHz.

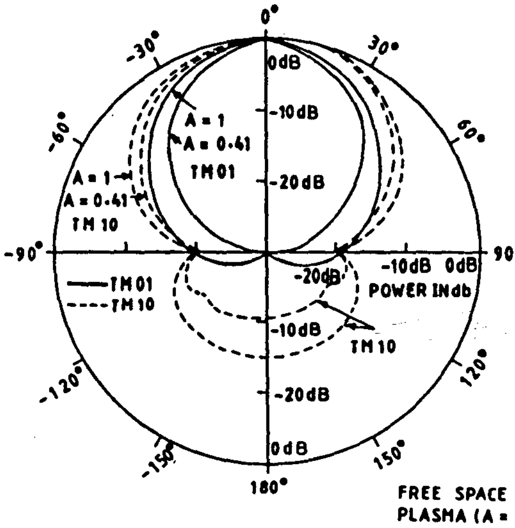

Fig. 3—The EM mode shown represents electromagnetic component of the far field (H plane)

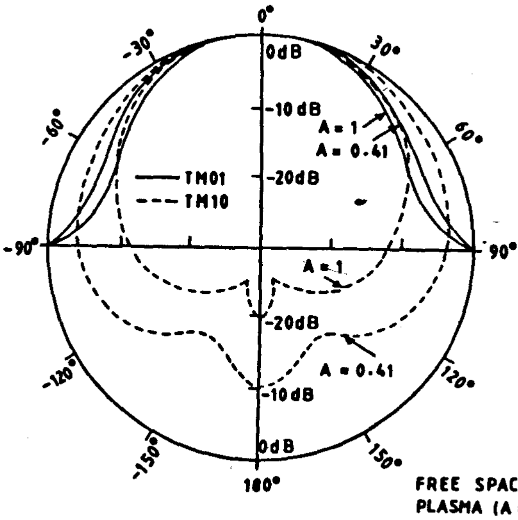

Fig. 4—The EM mode shown represents electromagnetic component of the far field (E plane)

Table 1—Variation of VSWR with frequency in free space and plasma for rectangular microstrip antenna on curved surface

Frequency GHz	VSWR	
	Free space	Plasma
7.80	1.8	2.1
7.90	2.4	1.7
8.00	1.5	1.6
8.10	1.3	1.5
8.25	1.2	1.4
8.30	1.4	1.8
8.40	1.6	2.0
8.50	1.6	2.5
8.60	2.0	2.2

6 Conclusions

From the experimental study of rectangular microstrip antenna on curved surface in simulated plasma medium, it is observed that when the dimensions of the patch, i.e. $2(a+h)\,\theta$ and $2b$ are fixed, the resonant frequencies of TM modes are not affected by the curvature. This is valid for thin substrates ($h \leq a$), i.e. substrate thickness is much smaller than the wavelength. However, the radiation patterns are significantly affected. The variation in beam-width with the plasma parameter is not uniform in E and H planes. In H plane the beam-width decreases as plasma parameter increases, whereas in E plane beam-width increases as plasma parameter decreases. The results have also been compared when antenna is placed in free space[3,4].

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