IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 9, Issue 2, Ver. II (Mar - Apr. 2014), PP 01-07
www.iosrjournals.org

Omnidirectional Cylindrical Microstrip Patch Antenna versus Planar Microstrip Antenna - A Parametric Study

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Abstract: *The Industrial, Scientific and Medical (ISM) radio bands i.e. 2.4 GHz, are the radio bands reserved internationally for the use of radio frequency (RF) energy for industrial, scientific and medical purposes. Despite the intent of the original allocation, in recent years the fastest-growing uses of these bands have been for short-range, low-power communication systems. Cordless phones, Bluetooth devices, NFC (Near-Field Communication) devices, and wireless networks.*

Omnidirectional antennas are required to maintain an ease (proper) communication link. Conformal antennas follow the shape of the surface on which they are mounted and generally exhibit a very low profile. When these types of antenna are mounted on aircraft, missiles and instrumented artillery shells, they reduce turbulence effects in flight, because of their low profile. Low profile conformable antenna on a regular surface viz. cylindrical surface is easily achievable by conforming microstrip patch antenna on the surface. Design procedure involves parameters related to cylindrical microstrip elements to realize the desired resonant frequency, input impedance, radiation patterns etc. A radiating microstrip patch antenna mounted, as considered in this paper, on a cylindrical surface is chosen because major real world shapes can be approximated by cylindrical surface or cylindrical sector and uniformity in a plane provide ease of analysis. A microstrip line has been chosen to feed the patch antenna as this feed design provides very small stray radiation from the feed and is simplest geometry for theoretical analysis & practical manufacturing. Computer aided design of microstrip antennas and its analysis are based on efficient and accurate numerical methods using IE3D software.

This paper presents microstrip patch antenna with the effect of design parameters such as substrate thickness and dielectric constant of the substrate on the design frequency of cylindrical patch antenna and compare the results with planar microstrip antenna. Considering the effect of design parameters, a method for accurately determining the resonant/design frequency of such structures have been obtained. Antenna efficiency and Radiation efficiency of the antenna were obtained. The graphs were studied to see their conformance with theoretical performance.

Keywords*: Corporate Feed, Dielectric Constant, Omnidirectional Cylindrical Patch Antenna, Resonance Frequency, Return Loss (RL) Bandwidth.*

I. Introduction

Planar microstrip antenna by and large can be considered to have reached its maturity. Development of conformable antennas on non planar surfaces lags behind vis-à-vis planar microstrip antennas [4]. Relatively non planar or microstrip antennas conformable to non planar surfaces are at present topic of research. Specifically, theoretical works reported in literature pertain to conformable microstrip antennas on non-planar regular surfaces like cylinder, sphere and cone [7]. The need for conformal antennas is more pronounced for the large sized apertures that are necessary for functions like military airborne surveillance radars. A conformal microstrip antenna on a cylindrical surface with low profile has distinct advantage for applications related to fighter aircraft and spacecraft. Techniques exist to analyze conformable microstrip antennas on electrically small cylindrical surfaces [1].This paper is devoted to design and simulation of microstrip patch antenna on cylindrical surface as well as planar microstrip antenna and study the effects of design parameters on their resonant frequency. A relationship showing effect of substrate thickness and dielectric constant of substrate on the resonant frequency has been analysed.

II. Design of Omnidirectional Cylindrical Patch Antenna

The antenna shown in Fig.1 is designed to give omnidirectional linear (axial) polarization coverage [5]. In the structure of the conformal microstrip antenna, the surface of the metal cylinder is used as curved ground plane.

The design for the wraparound patch antenna operating at frequency 2.4 GHz is compared with planar antenna at same frequency.

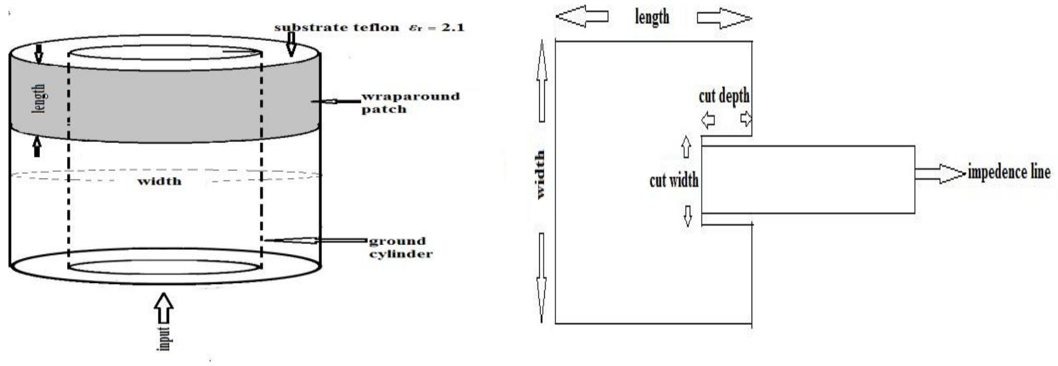

Fig.1: Printed circuit board design of cylindrical antenna and planar antenna

III. Design of Planar Microstrip Antenna

There are many different analysis techniques that have been developed for analyzing the microstrip antennas. However, the most popular ones can be separated into five groups: transmission-line circuit model, multimode cavity model, moment method, finite-difference time-domain (FDTD) method, and finite-element method [4]. Rectangular patch can be accurately analyzed and designed using Full - Wave Moment Method.

IV. Result and Discussion

IV.I Effect of Substrate Thickness on design Frequency and Return Loss (RL) bandwidth (Impedance Bandwidth) of Cylindrical and Planar Microstrip Antenna

An important factor in the antenna performance is the substrate thickness. Already small differences can affect considerably the bandwidth while the radiation patterns are nearly not affected. The thickness of the substrate is critical for the conformal antenna manufacture since the flexibility of the material is worse for thick substrates and very thin materials may be too fragile to bend. As for planar antennas [6], the Return Loss Impedance bandwidth is increased when the substrate thickness is increased, as shown in Fig.2 respectively. It can also be seen from Fig.2 that varying the thickness causes a shift of the resonance frequency and the resonance frequency increases with increase in substrate thickness.

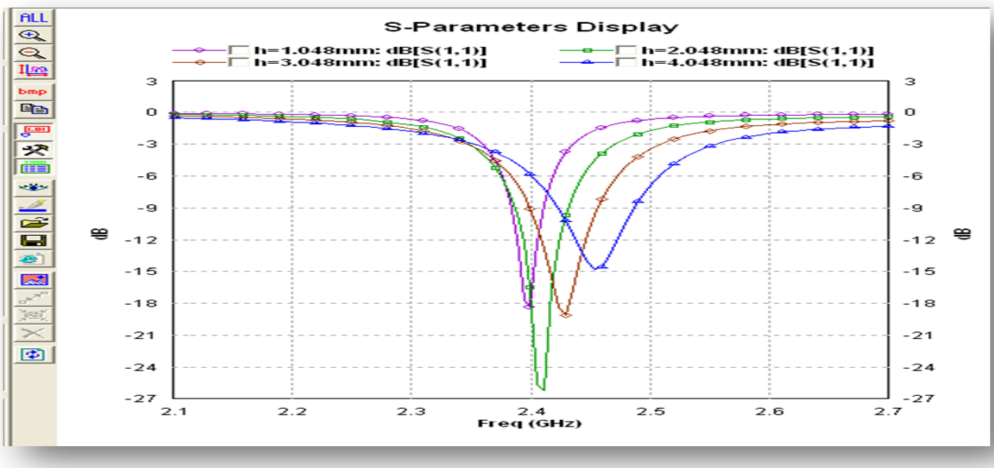

Fig.2: Return Loss for Different Substrate Thickness of planar microstrip antenna

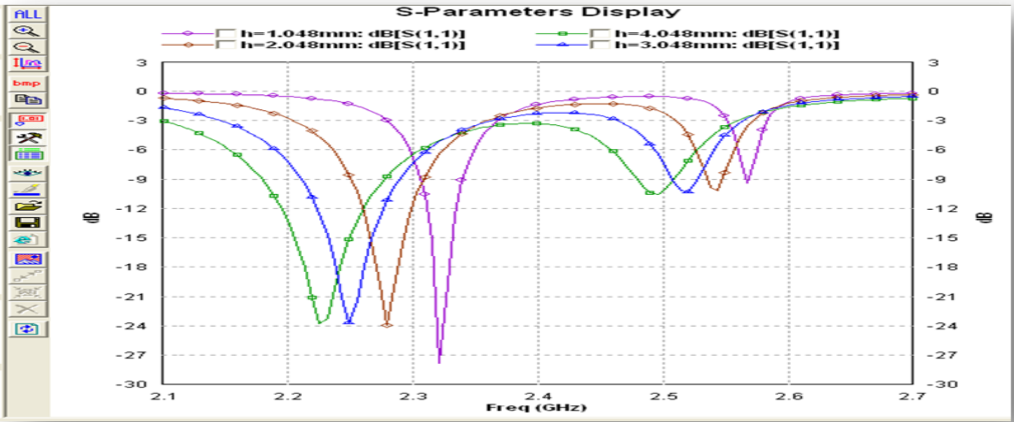

Fig.3: Return Loss for Different Substrate Thickness of cylindrical microstrip antenna

However, from Fig.3, we can see that as the substrate thickness increases, the impedance bandwidth is increased but the design frequency of cylindrical microstrip antenna decreases.

TABLE

DESIGN PARAMETER	PLANAR MICROSTRIP ANTENNA			CYLINDRICAL MICROSTRIP ANTENNA		
Substrate Thickness (h , mm)	**Design Freq (GHz)**	**S_{11} (dB)**	**BW (GHz)**	**Design Freq (GHz)**	**S_{11} (dB)**	**BW (GHz)**
h = 1.048	2.398	-18.23	0.02495	2.32	26.57	0.029
h = 2.048	2.41	-26.14	0.04034	2.28	23.92	0.050
h = 3.048	2.42	-19.01	0.04955	2.24	23.45	0.068
h = 4.048	2.45	-14.76	0.05307	2.226	23.80	0.085

The above table shows the variation of design frequency and RL bandwidth for cylindrical and planar microstrip antenna with changing substrate thickness. Also, return loss (S_{11}) is less than -10dB for all the cases.

IV.II Effect of Substrate Thickness on Radiation Efficiency (RE) of Cylindrical and Planar Microstrip Antenna

Conductor and dielectric loss is more important for thinner substrates. Conductor loss increases with frequency (proportional to $f_r^{1/2}$) due to the skin effect. Conductor loss is usually more important than dielectric loss. Hence, for planar microstrip antenna, radiation efficiency increases with substrate thickness [3]. Surface-wave losses increase for thicker substrates [2]. (The surface-wave power can be minimized by using a foam substrate). Therefore, for substrates of larger thickness, radiation efficiency decreases as shown in Fig.4.

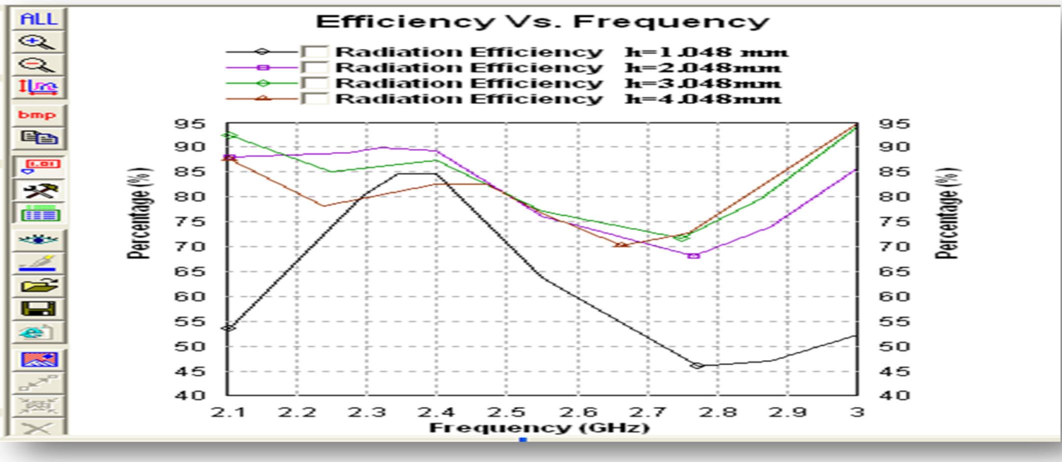

Fig.4: Radiation Efficiency for Different Substrate Thickness of Planar Antenna

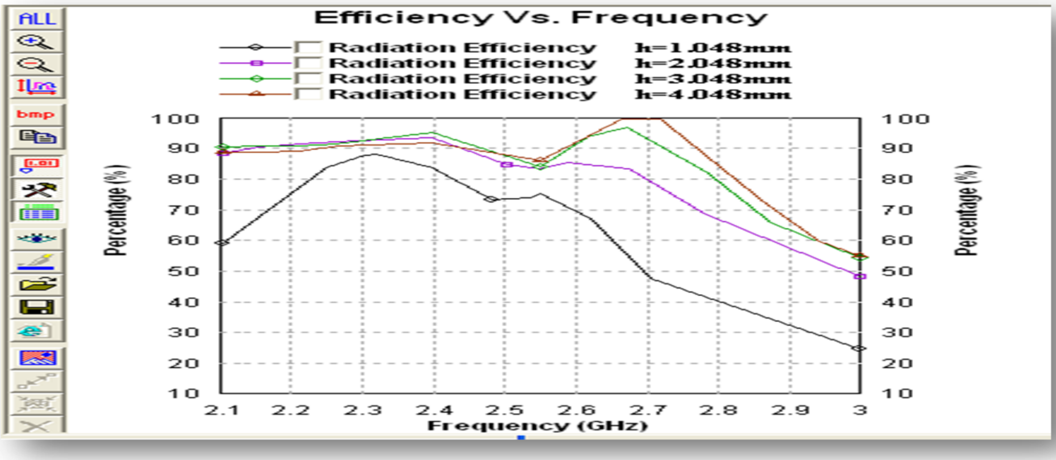

Fig.5: Radiation Efficiency for Different Substrate Thickness of cylindrical microstrip antenna

Also , radiation efficiency in case of cylindrical microstrip antenna follows the same trend as shown in Fig.5. It increases with substrate thickness however, it decreases for substrates of larger thickness.

TABLE

DESIGN PARAMETER	**PLANAR MICROSTRIP ANTENNA**	**CYLINDRICAL MICROSTRIP ANTENNA**
Substrate Thickness (h , mm)	**Radiation Efficiency (%)**	**Radiation Efficiency (%)**
h =1.048	84.5755	83.98
h =2.048	89.404	93.24
h =3.048	87.2698	94.80
h =4.048	82.3527	91.69

The above table shows the variation of Radiation Efficiency for cylindrical and planar microstrip antenna with changing substrate thickness.

IV.III Effect of changing Dielectric Constant of substrate on design Frequency and Impedance bandwidth of Cylindrical and Planar Microstrip Antenna

The following results are obtained by simulations varying the relative permittivity of the substrate. As known from non-conformal antenna design, for low relative permittivity the RL bandwidth is larger, and when the substrate permittivity increases the resonance frequency decreases [6, 8], as illustrated in Fig.6. Thus, low relative permittivity materials like foams are often employed in multilayer antennas. These foams tend to be fragile, difficult to glue and difficult to bend which might cause problems for the manufacturing. Therefore, not only the performance must be taken into account in conformal antenna design but also the manufacturing.

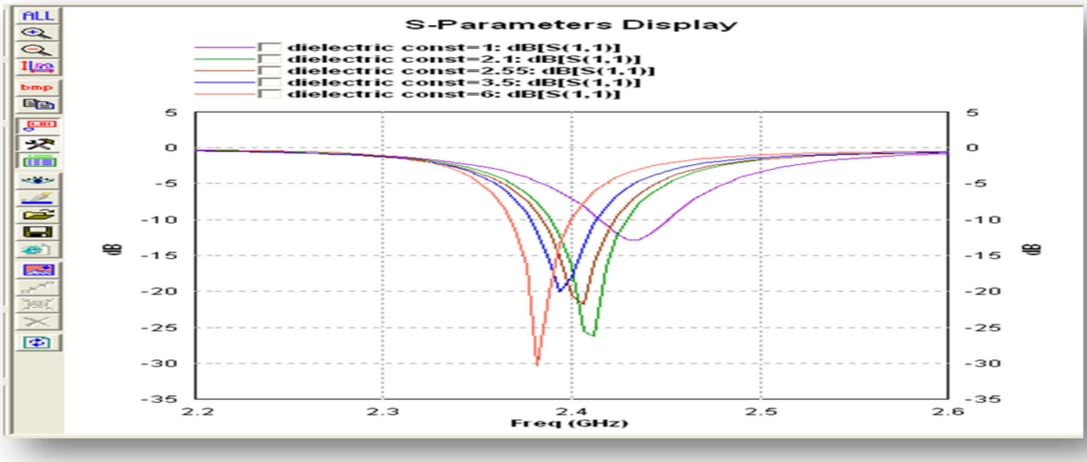

Fig.6: Return Loss for Different Relative Permittivities of planar microstrip

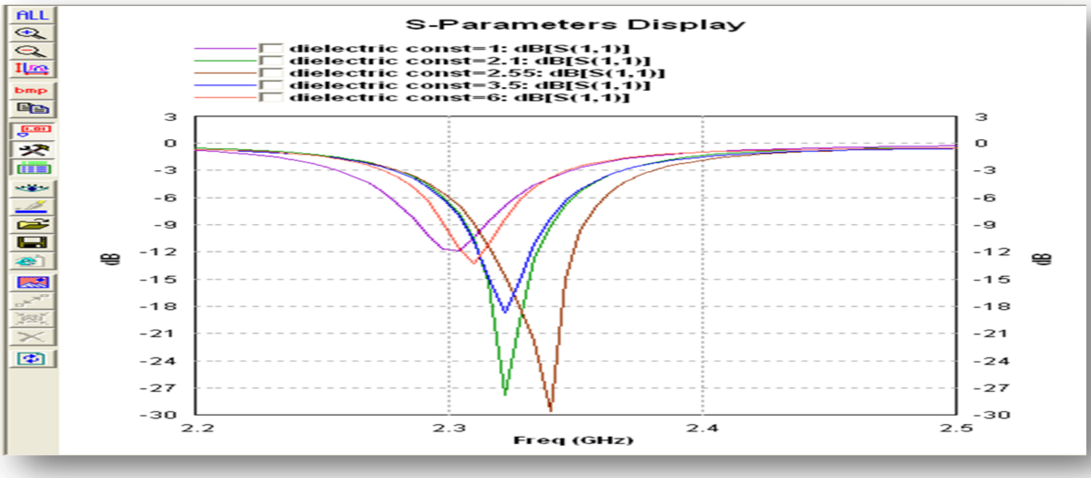

Fig.7: Return Loss for Different Relative Permittivity of cylindrical microstrip antenna

From Fig.7, it can be illustrated that, as the relative permittivity of the substrate increases, the resonance frequency of the cylindrical microstrip antenna first increases and then, decreases. The variation in Impedance bandwidth also follows a similar pattern, as it first increases and then, decreases with increasing relative permittivity.

TABLE

DESIGN PARAMETER	**PLANAR MICROSTRIP ANTENNA**			**CYLINDRICAL MICROSTRIP ANTENNA**		
Dielectric Constant (ε_r)	**Design Freq (GHz)**	**S_{11} (dB)**	**BW (GHz)**	**Design Freq (GHz)**	**S_{11} (dB)**	**BW (GHz)**
$\varepsilon_r = 1$	2.4312	-12.80	0.041	2.30	-11.82	0.01973
$\varepsilon_r = 2.1$	2.4114	-26.14	0.040	2.32	-26.57	0.02966
$\varepsilon_r = 2.55$	2.406	-21.74	0.038	2.33	-28.80	0.03877
$\varepsilon_r = 3.5$	2.3952	-19.68	0.035	2.32	-18.33	0.02798
$\varepsilon_r = 6$	2.3826	-29.24	0.032	2.31	-13.08	0.01795

The above table shows the variation of design frequency and Impedance bandwidth for cylindrical and planar microstrip antenna with changing dielectric constant of substrate. Also, return loss (S_{11}) is less than -10 dB for all the cases.

IV.IV Radiation Efficiency (RE) of Cylindrical and Planar Microstrip Antenna

For planar as well as cylindrical microstrip antenna, radiation efficiency decreases with increasing substrate permittivities as shown in Fig.8 and Fig.9, as surface-wave losses increases for large relative permittivities.

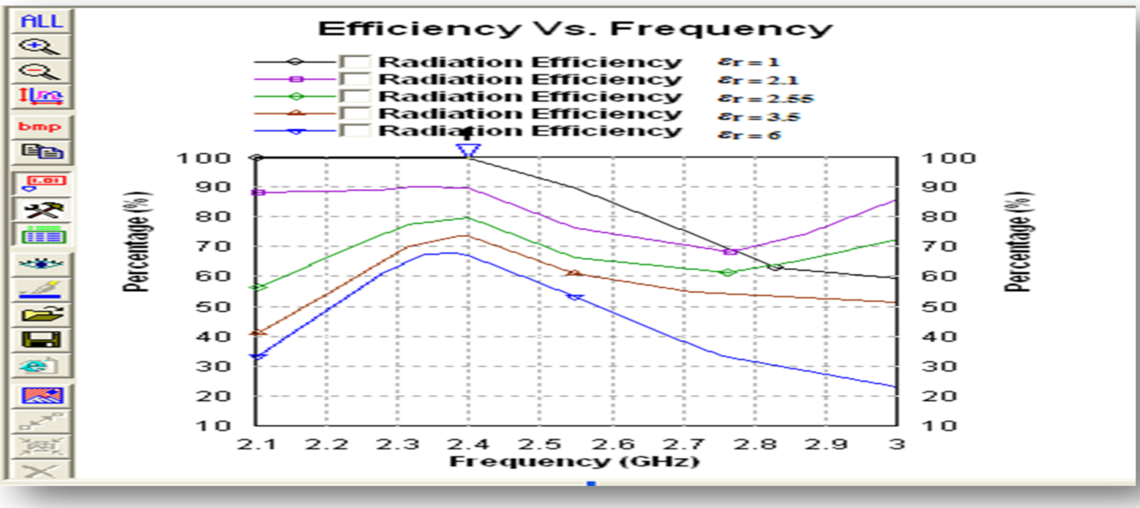

Fig.8: Radiation Efficiency for Different Relative Permittivities of Planar Antenna

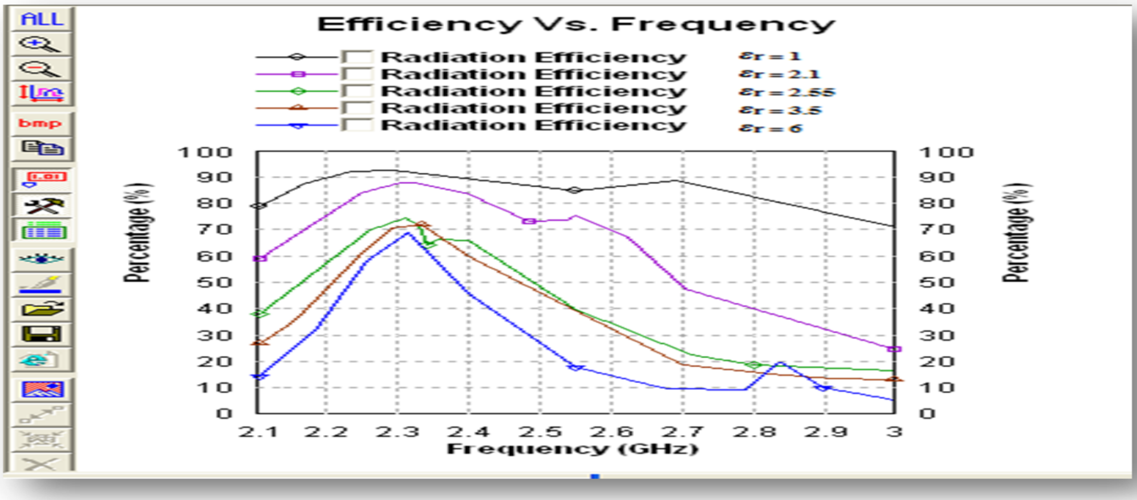

Fig.9: Radiation Efficiency for Different Relative Permittivities of cylindrical microstrip antenna

TABLE

DESIGN PARAMETER	PLANAR MICROSTRIP ANTENNA	CYLINDRICAL MICROSTRIP ANTENNA
Dielectric Constant (ε_r)	**Radiation Efficiency (%)**	**Radiation Efficiency (%)**
$\varepsilon_r = 1$	100	92.1859
$\varepsilon_r = 2.1$	89.3838	87.8906
$\varepsilon_r = 2.55$	79.4983	74.1803
$\varepsilon_r = 3.5$	73.4944	71.5245
$\varepsilon_r = 6$	67.283	68.8701

The above table shows the variation of Radiation Efficiency for cylindrical and planar microstrip antenna with changing dielectric constant of substrate.

V. Conclusion

Considering the effect of thickness and relative permittivity of substrate for accurately determining the resonant frequency of such structures has been reported. To overcome the time consuming and laborious accurate numerical methods a direct use in algorithm for the design of the antenna is suggested.

The design and simulation using IE3D shows that the resonance frequency of cylindrical antenna decreases while that of planar microstrip antenna increases, with increasing substrate thickness and impedance bandwidth follows a same pattern for both the antennas i.e. it increases with increasing substrate thickness. However, when the substrate permittivity is increased, the resonance frequency of planar microstrip antenna decreases, whereas, it first increases and then, decreases in case of cylindrical patch antenna. Also, Impedance bandwidth of cylindrical antenna first increases and then, decreases with increasing substrate permittivity while it follows an inverse relationship in case of planar microstrip antenna. Thus, considering the effect of design parameters, a method for accurately determining the resonant/design frequency of such structures have been obtained.

The variation of radiation efficiency follows the same trend for both cylindrical and planar microstrip antennas. It increases with increasing substrate thickness, however, for larger substrate thickness, it decreases. Also, radiation efficiency decreases with increasing substrate permittivity due to increase in surface-wave losses.

Further investigation can be done on the accuracy of resonance frequency with multi-dielectric microstrip antenna using super state layer.

Acknowledgement

We have taken efforts in this research. However, it would not have been possible without the kind support and help of many individuals and organizations. I would like to extend my sincere thanks to all of them. I am highly indebted to Dr. R S Gupta Professor, Department of Electronics and Communication Engineering, Maharaja Agrasen Institute of Technology, Delhi for his guidance and constant supervision as well as for providing necessary information regarding the research and also for his support in completing the research.

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