OPEN ACCESS
International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-1, Issue-6, January 2013

Design and Comparative analysis of a Metamaterial included Slotted Patch Antenna with a Metamaterial Cover over Patch

Surabhi Dwivedi, Vivekanand Mishra, Y.P.Kosta

Abstract: A metamaterial is introduced into the cover of a patch antenna and its band structure is analyzed. The metamaterial cover with correct selection of the working frequency increases the patch antenna's directivity. Based on the methodology, optimization of structure is proposed for the application of metamaterials as antenna substrate to primarily enhance directivity by minimizing its refractive index. The experimental results are presented thoroughly and compared with the analytic calculations. This paper aims to review and critically discuss the comparision of a metamaterial included patch and metamaterial cover over the patch. An analytical method is used to predict the features of the simulation results, implying that within a certain frequency range, comparision can be made between these two models. The S-parameters as a performance matrix are obtained from antenna simulations carried on CADFEKO Silverlite version 5.5. Simulations have been carried out for different shapes of microstrip patch antenna in the microwave regime. © 2010 ISRO – Indian Space Research Organisation

Index Terms: Microstrip antenna (MSA), Antennas, Patch cover, Directivity, Negative refractive Index (NRI), metamaterials.

I. INTRODUCTION

Metamaterials are a broader class of materials which enables us to manipulate the permittivity and permeability for optimizing physical properties of radiating patch primarily for improvement in radiation from antenna. Recently, there has been growing interest in both the theoretical and experimental study of metamaterials. Many properties and potential applications of left-handed metamaterials have been explored and analyzed theoretically [10]. Emission in metamaterials using an antenna was presented in 2002 by Enoch et al. [8]. An MSA in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side [7]. The top and side views of a rectangular MSA (RMSA) are shown in Figure 1.1. Radiation from the MSA can occur from the fringing fields between the periphery of the patch and the ground plane. In 1953, Deschamps first proposed the concept of the MSA [1].

Revised Manuscript Received on 30 January 2013.
* Correspondence Author
Surabhi Dwivedi*, ECED, SVNIT, Surat, India,.
Dr. Vivekanand Mishra, ECED, SVNIT, Surat, India.
Dr. Yogesh P. Kosta,, Marwadi Education Foundation's Group Of Institutions, Rajkot, India

Practical antennas were developed by Munson [2, 3] and Howell [4] in the 1970s. The numerous advantages of MSA led to the design of several configurations for various applications, which includes its low weight, small volume, and ease of fabrication [5, 6]. With increasing requirements for personal and mobile communications, the demand for smaller and low-profile antennas has brought the concept of MSA.

Another objective of this paper is to develop a methodology to analyze, design and compare a metamaterial substrate for a microstrip antenna with a patch cover. We will use numerical simulation and theoretical studies first to design a metamaterial structure that is suitable for the antenna substrate; then use experiments to prove our prediction for the comparison purpose.

II. THEORETICAL BACKGROUND

A. Metamaterials

A metamaterial (or meta material) is a material which gains its properties from its structure rather than directly from its composition.

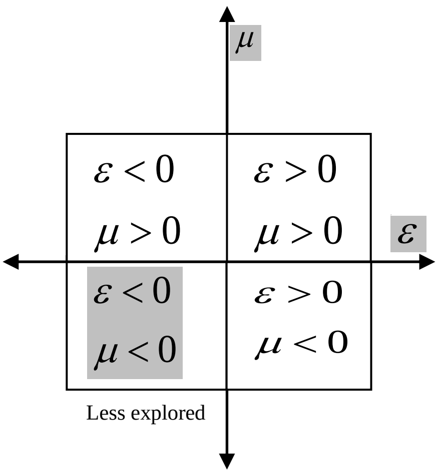

Fig 1 Permittivity- permeability graph

B. Types of Metamaterial:

TABLE I . FOUR TYPES OF METAMATRIALS

Permittivity	Permeability	Abbreviation
>0	>0	DPS
<0	>0	ENG
>0	<0	MNG
<0	<0	DNG

Where,

- DPS- Double Positive material
- ENG- ε (Electrically) negative material
- MNG- μ (Magnetically) negative material
- DNG- Double Negative material

C. Patch Antenna

MSAs are manufactured using printed-circuit technology, so that mass production can be achieved at a low cost.

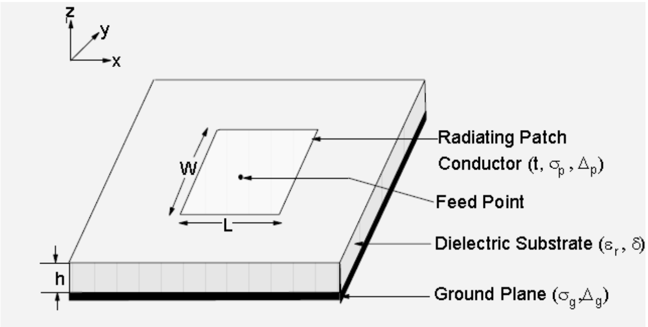

Fig 2 Basic structure of a rectangular microstrip patch antenna

ε_r =relative permittivity, δ =loss tangent, σ =conductivity, Δ =surface roughness

III. FIGURES

A. Simple Patch with generalized dimensions

Substrate dimensions: 52.4mm x 36.2mm x 1.56mm Patch dimensions: 40mm x 20mm

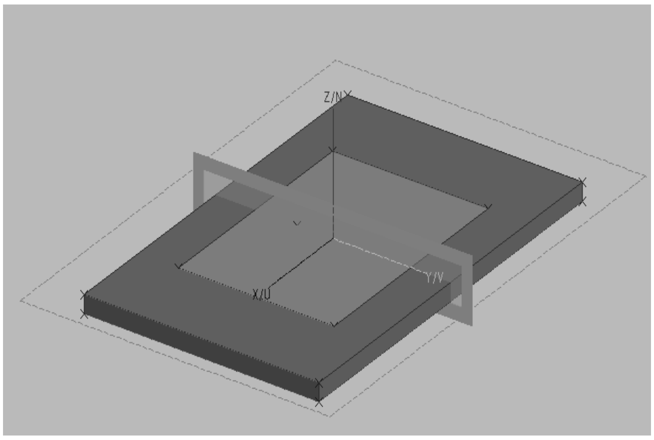

Fig 3 Simple Patch

B. Slotted Patch

Slot dimensions: 8mm x 0.5mm

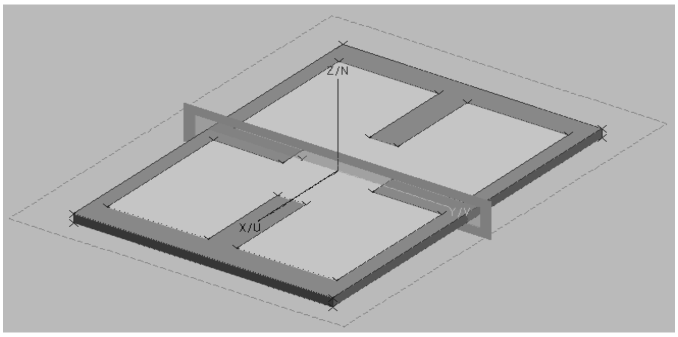

Fig 4 Slotted Patch

IV. MATHEMATICAL RELATIONS

A. Calculations for Metamaterial:

Permittivity ε and the Permeability μ measurements:

The constitutive parameters are the permittivity ε and the permeability μ, which are related to the refractive index n by

$$n = \pm\sqrt{\varepsilon_r \mu_r} \qquad (1)$$

Where, *ε_r and μ_r are the relative permittivity and permeability related to the* free space permittivity and permeability by

$$\varepsilon_0 = \varepsilon / \varepsilon_r = 8.854 \text{ x } 10^{-12} \qquad (2)$$

$$\mu_0 = \mu / \mu_r = 4\pi \text{ x } 10^{-7} \qquad (3)$$

Maxwell's equations:

$$\nabla \times \mathbf{H} = + \partial \mathbf{D} / \partial t \qquad (4)$$

$$\nabla \times \mathbf{E} = - \partial \mathbf{B} / \partial t \qquad (5)$$

From the point of view of Maxwell's Equations, the material is some collection of objects (whether atoms, molecules, composites or anything else) that can be described by a Permittivity **ε** and a Permeability **μ**.

The reflection coefficient (Γ) at the interface is found from the measured reflection (S_{11}) and transmission (S_{21}) coefficients.

$$\Gamma = X \pm \sqrt{(X^2 - 1)} \qquad (6)$$

Where,

$$X = \frac{S_{11}{}^2 - S_{21}{}^2 + 1}{2S_{11}} \qquad (7)$$

The propagation factor P is found from S_{11}, S_{21} & Γ

$$P = \frac{S_{11} + S_{21} - \Gamma}{1 - (S_{11} + S_{21})\Gamma} \qquad (8)$$

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

The complex dielectric constant and permeability can be determined from P and Γ:

$$\frac{1}{\Lambda^2}=\left(\frac{\varepsilon_r\mu_r}{\lambda_0^{\ 2}}-\frac{1}{\lambda_c^{\ 2}}\right) \quad (9)$$

$$\frac{1}{\Lambda^2}=-\left[\frac{1}{2\pi l}\ln\left(\frac{1}{p}\right)\right]^2 \quad (10)$$

$$\mu_r=\frac{1+\Gamma}{\Lambda(1-\Gamma)\sqrt{\left(\frac{1}{\lambda_0^{\ 2}}-\frac{1}{\lambda_c^{\ 2}}\right)}} \quad (11)$$

Where,

λ_0 free space wavelength

λ_c cutoff wavelength of the transmission line section

B. Calculations for Patch:

- General Patch dimensions:

$$A = a_p + 6H \quad (12)$$
$$B = b_p + 6H \quad (13)$$

Where,

Variables: A is substrate length= 52.4 mm; B is substrate width B = 36.2 mm; H is substrate height= 1.56 mm;

Hence, from calculation patch dimensions are obtained:
a_p is patch length= 43.04 mm; b_p is patch width= 26.84 mm.

In general, the resonance frequency of the MSA excited at any TM_{mn} mode is obtained using the following expression [12]:

$$f_0=\frac{c}{2\sqrt{\varepsilon}}\left[\left(\frac{m}{L}\right)^2+\left(\frac{n}{W}\right)^2\right]^{1/2} \quad (14)$$

where *m* and *n* are the modes along the $L \approx a_p$, *length* and *W* b_p, *width of patch*, respectively.
For an RMSA to be an efficient radiator, *W* should be taken equal to a half wavelength corresponding to the average of the two dielectric mediums (i.e., substrate and air) [13].

$$W=\frac{c}{2f_0\sqrt{\left(\frac{\varepsilon_r+1}{2}\right)}} \quad (15)$$

The expressions for approximately calculating the percentage BW of the RMSA in terms of patch dimensions and substrate parameters is given by

$$\%BW=\frac{Ah}{\lambda_0\sqrt{\varepsilon_r}}\sqrt{\frac{W}{L}} \quad (16)$$

Where,

$$A=180\ for\ \frac{h}{\lambda_0\sqrt{\varepsilon_r}}<0.045$$

$$A=200\ for\ 0.045<\frac{h}{\lambda_0\sqrt{\varepsilon_r}}<0.075$$

$$A=220\ for\ \frac{h}{\lambda_0\sqrt{\varepsilon_r}}\geq 0.075$$

The width *W* of the patch can be taken smaller or larger than the value obtained using (7). If *W* is smaller, then the BW and gain will decrease. If *W* is larger, then the BW increases due to the increase in the radiated fields. The directivity also increases due to the increase in the aperture area.

V. PARAMETRIC STUDY OF MSAS

A. *Effect Of* b_p

The width b_p of the RMSA has significant effect on the input impedance, BW, and gain of the antenna. With an increase in b_p the following effects are observed: The resonance frequency decreases from 3.14GHz to 2.46 GHz. The BW of the antenna increases by 8.7%. The aperture area of the antenna increases resulting in an increase in the directivity, efficiency, and gain.

B. *Effect Of* ε_r

With an increase in ε_r the following effects are observed: BW increases due to a decrease in ε_r and an increase in h/ λ_0, because the resonance frequency has increased. A better comparison of effect of ε_r is obtained when the antenna is designed to operate in the same frequency range for different values of ε_r.

C. *Effect Of Finite Ground Plane*

The finite ground plane effect can be taken into account by numerical techniques. However, it should be noted that the simulation time is least when the ground plane is infinite because then only the patch is analyzed with its perfect image. For the finite ground plane, on the other hand, both the patch and the ground plane are divided into number of segments and hence the simulation time increases. Also, as the size of the ground plane increases, the simulation time increases [7].

VI. DESIGN AND METHODOLOGY

Objective: To obtain the response of slotted patch within desired frequency band. To compare the response of metamaterial include patch, which is used as artificial substrate with the patch cover.

VII. COMPARATIVE ANALYSIS

A. *Slotted Patch with metamaterial.*

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

For different dimensions of patch: After simulating various models, best results are displayed below.
d_y x w_x = 7mm x 0.5mm,
d_x x w_y = 8mm x 0.5mm

a_p= 45.9 mm, b_p= 30 mm;

TABLE II. SHOWS OPTIMUM DESIRED BAND 1.4-2.4GHZ

a_p (mm)	No. of Bands	Band-1		Band-2		Band-3	
		Max Freq (GHz)	S11(dB)	Max Freq (GHz)	S11 (dB)	Max Freq (GHz)	S11 (dB)
45.9	3	1.4450	-17.9261	2.1000	-16.3489	2.4100	-35.1532

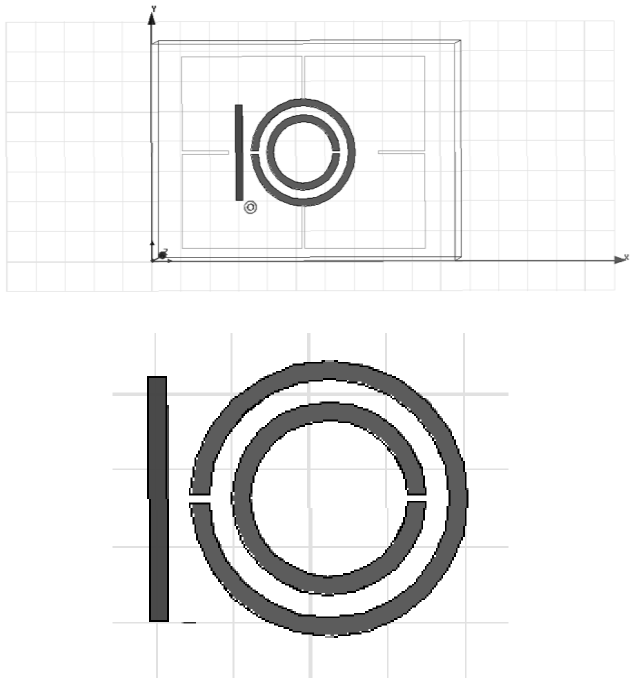

Fig 5 Slotted Patch with metamaterial

Simulated Result:

Return loss/ S-parameter:

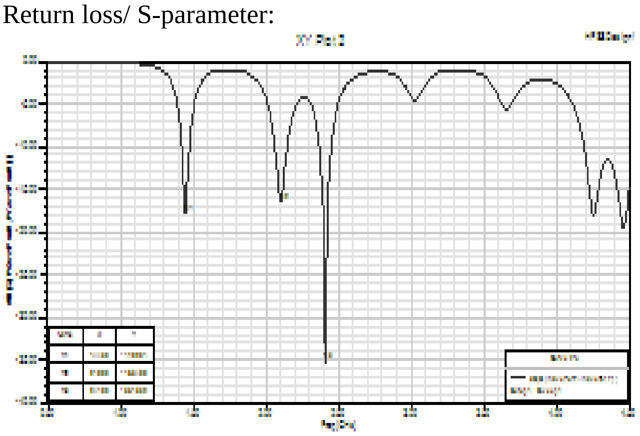

Fig 6 Results for slotted patch with metamaterial dimension 45.9mm x 30mm

RESULT ANALYSIS: Slotted Patch with metamaterial responds between *1.4450 - 2.4100 Ghz* for patch dimensions 30mm x 45.9mm. Tribands are further shifted towards left of the frequency axis with good results of return loss.

B. Metamaterial Cover over Patch

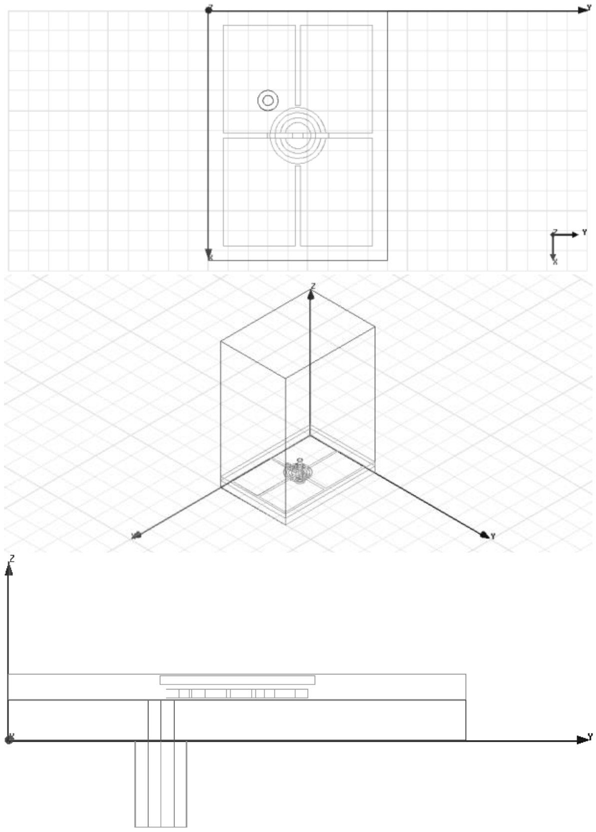

Fig 7 Metamaterial Cover over Patch

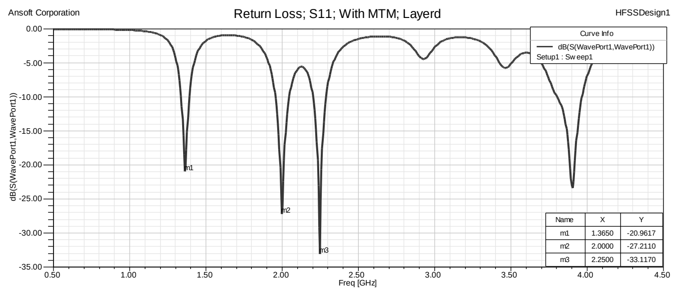

Fig 8 Results for slotted patch with metamaterial cover dimension 45.9mm x 30mm

TABLE V. SHOWS OPTIMUM DESIRED BAND 1.3-2.2GHZ

a_p (mm)	No. of Bands	Band-1		Band-2		Band-3	
		Max Freq (GHz)	S11(dB)	Max Freq (GHz)	S11 (dB)	Max Freq (GHz)	S11 (dB)
45.9	3	1.3650	-20.9617	2.0000	-27.2110	2.2500	-33.1170

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

VIII. FUTURE SCOPE

Task to be performed includes the implementation of multilayer patch, using one or two layers of metamaterial over patch cover. To introduce the concept of Fractal Antenna and Array of metamaterial inclusions in patch substrate.

IX. CONCLUSION

Triband Operation of slotted patch antenna for 1 to 4 GHz of frequency band is obtained with optimized results in terms of return loss. It can be concluded that after appropriate slotting the patch the triband is shifted more towards left of the frequency axis i.e. upto 1.4910 GHz. Moreover all the three bands are obtained between 1.4450-2.4100GHz.

This paper has demonstrated two ways to simulate a patch antenna. The return loss is obtained for metamaterial include slotted patch and compared with the patch cover response. Applying metamaterial to patch antenna is an important development of new high-directivity patch antenna.

The results showed that the metamaterial cover, which works like a lens, could effectively improve the patch antenna's directivity. The physical reasons for the improvement are also given.

The important factors that are considered are the difference in solution time and the deviation in the results. With increase in width of the patch from 25mm to 30 mm 8.71% increase in bandwidth is observed.

Miniaturization of the patch antenna is to the core of our effort and the enhancement of bandwidth is obtained by slotting of the patch. After inclusions of the metamatrial the bandwidth increment is 11.13% as compared to the substrate with teflon as the dielectic. Future scope of metamaterials hold great promise for new applications in the megahertz to terahertz bands, as well as optical frequencies which includes super-resolution imaging, cloaking, hyperlensing, and optical transformation.

ACKNOWLEDGMENT

Surabhi Dwivedi along with the team of authors would like to thank Rajeev Jyoti, SAC division of ISRO (Indian Space Research Organisation) and Soham Patel for providing support to carry our project. We are also thankful to Dr. Ved Vyas Dwivedi for providing academic support.

REFERENCES

1. Deschamps, G. A., ''Microstrip Microwave Antennas,'' Proc. 3rd USAF Symposium on Antennas, 1953.
2. Munson, R. E., ''Single Slot Cavity Antennas Assembly,'' U.S. Patent No. 3713162, January 23, 1973.
3. Munson, R. E., ''Conformal Microstrip Antennas and Microstrip Phased Arrays,'' IEEE Trans. Antennas Propagation, Vol. AP-22, 1974, pp.
4. Howell, J. Q., ''Microstrip Antennas,'' IEEE Trans. Antennas Propagation,Vol. AP-23, January 1975, pp.90–93.
5. Bahl, I. J., and P. Bhartia, Microstrip Antennas, Dedham, MA: Artech House, 1980.
6. Carver, K. R., and J. W. Mink, ''Microstrip Antenna Technology,'' IEEE Trans. Antennas Propagation, Vol. AP-29, January 1981, pp. 2–24.
7. Girish Kumar, K. P. Ray, "Broadband Microstrip Antenna", Boston London, Artech House , 2003, pp. 26-46.
8. Enoch, S., Tayeb, G., Sabouroux, P., Guerin, N., Vincent, P.,2002. A metamaterial for directive emission. Phys. Rev.Lett., 89(21):213902(1-4).
9. J B Pendry, A J Holden, D J Roddins, W J Stewart, Magnetism from Conductors, and Enhanced non- Linear Phenomena London: Imperial College, 1999
10. HU Jun ,YAN Chun-sheng, LIN Qing-chun, "A new patch antenna with metamaterial cover" *Zhejiang University,China*,2005; revision accepted Nov. 28, 2005
11. Ashwin K.IYER and Gearge V. Eleftheriades,"Negative refractive-Index Transmission-Line Metamatrials",University of Toronto,Canada.
12. Okoshi, T., and T. Miyushi, ''The Planar Circuit—An Approach to Microwave Integrated Circuitry,'' *IEEE Trans. Microwave Theory Tech.*, Vol. 20, April 1972, pp. 245–252.
13. James, J. R., and P. S. Hall, *Handbook of Microstrip Antennas*, Vol. 1, London: Peter Peregrinus, Ltd., 1989.
14. HU Jun, YAN Chun-sheng, LIN Qing-chun "A new patch antenna with metamaterial cover", China, Nov. 28, 2005.

AUTHORS PROFILE

Surabhi Dwivedi, full-time research scholar of SVNIT Surat, has completed her dissertation and research work in the area of microwave engineering under ISRO respond scheme under the guidance of Dr. Yogesh Kosta. She has pursued her M.Tech in Communication System engineering from Charusat University, Changa and B.E. in Electronics and Communication from Babaria Institute of Technology, Gujarat University, Baroda. She is a member of IETE. She has published 3 conference papers and 1 journal paper in various International and National Journals including IETE and IEEE proceedings.

Dr. V. Mishra was born in UP, India, on January 10, 1973. He pursued Bachelor and Master of science (Electronics) from Purvanchal University U. P. India, and completed Doctor of Philosophy from Indian Institute of Technology (I.I.T.) B. H. U. India in 2001. He worked as Lecturer in Multimedia University and then Assistant Professor in UTAR, Malaysia for nine years and now working as Associate professor in SVNIT, Surat, Gujarat, India. Dr. Mishra was member and chairperson for many center of excellence research center in MMU, and UTAR Malaysia. He is a senior Member of IEEE, Fellow of IETE and published more than 70 papers in various International and National Journals. He has completed two external projects Funded by E-Science, Malaysian Government, and working on three projects from DST and DRDO India.

Yogesh p. Kosta served as a Scientist/Engineer with the Indian Space Research Organization (ISRO), Department of Space, Government of India for eight years (1992 –2000). During his tenure, he functioned as a project engineer for the Indian National Satellite Project (INSAT) – a prestigious National project of the Government of India, and successfully pioneered the design and development of Ku-Band Communication Payload (for the first time) for the INSAT-2C, INSAT-2D and INSAT-3B Satellite. After resigning from ISRO, he joined Teledyne Wireless (MNC) at Mountain View, California (Silicon Valley) as a senior MMIC design engineer, here, he worked towards the design and development and characterization of Power MMIC amplifiers at 5.0 GHz for wireless and military applications. After sufficient technology exposure (2 years), he was successfully heading an institute (Charotar Institute of Technology-Changa) involved in imparting quality technical education since last eight years. He is at presently director of Marwadi Education Foundation's Group Of Institutions, Rajkot,India. My professional work experience encompass Space Science & Technology, Engineering & Technology Education, Research, Consultancy and Management consolidating to 18 years (as on 2010) of which, 8 years with the Department of Space, Govt. of India, Ahmedabad, Gujarat, 2 years with MNC's in the Silicon Valley, California, USA and 8 years in professional technical education with a private trust in Anand, Gujarat, India.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)