Undergraduate Students' Summer Training on Design, Fabrication, and Testing of Antennas a Case Study for Effective Learning

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Abstract— **In India, it is observed that the subject Antennas and Propagation in undergraduate program of electronics and communication engineering is losing interest among students due to its complicated mathematical nature, inadequate laboratory facilities and lack of experience of young faculty members to correlate mathematics with the engineering phenomenon. In spite of core subject of the electronics and communication discipline both teacher and the students adopt casual approach about this subject and it remains effectively unattended. After graduation, few students select the profession as a microwave antenna engineer in the microwave antenna based industries. RF communication based industries are lacking qualified antenna designers and microwave engineers to cater their needs. Therefore, on an experiment basis summer training was conducted at the antenna and microwave laboratory of National Institute of Technical Teachers Training and Research, Chandigarh, India for a group of twenty students from Punjab Technical University, Jalandhar, India affiliated engineering institutions. In this activity the groups of students' could understand the theory and implemented the microstrip patch and wired antennas for different applications. This paper presents systematic strategies used for effective implementation of summer training to design, fabricate and test different antennas. This training module is found to be well-suited to understand the microwave theory, antennas and propagation by hands-on experience through different fabrication steps, testing and measurement of different antennas. The antennas have been designed, fabricated, tested and the various parameters have been measured by the students. The feedback provided by students and faculty experts indicated the success and fruitfulness of this approach to teach and learn the subjects like microwave engineering and antenna and propagation theory.**

Index Terms— **Antennas and propagation, electromagnetic simulators, implementation model, microwave theory, mixed mode learning approach, summer training**

I. INTRODUCTION

Punjab Technical University, Jalandhar, India (hereafter PTU) is located in the Northern region of India under which there are nearly 50 engineering colleges and institutions are affiliated to impart the technical education in the vicinity. The NITTTR, Chandigarh is a Ministry of Human Resource and Development (MHRD), Government of India institute which is a leading institute to conduct the training programs and refresher courses related to different engineering streams for faculty members and supporting staff serving in engineering colleges and polytechnics in India. It is an affiliated research centre of PTU for Doctoral programmes in Engineering and Technology. In the curriculum of PTU undergraduate course in electronics and telecommunication engineering the subjects namely Electromagnetic Field Theory, Microwave engineering, Radar Engineering and Antennas and Wave Propagation with theory and practical examinations have been introduced. In this curriculum a six weeks industrial/institutional training that is to be completed in the summer vacation has been incorporated after fourth semester to make the undergraduate students well acquainted with the different design, fabrication, testing, and installation of various electronic systems. In the evaluation scheme the marks allotted to the training are 100 out of which 60 marks and 40 marks are to be awarded by internal and external examiners respectively.

The teaching scheme of these subjects is divided into two parts (a) theory (b) practical sessions. Similarly, separate examination and marking scheme is defined for theory as well as for practical sessions. The theory part in these subjects is mathematics and assumption based with number of expressions, derivations and numerical to effectively understand the microwave, antenna and propagation theory. Another aspect in teaching-learning process of this subject is that the teacher and student have to-(a) assume number of parameters (b) imagine the electric and magnetic fields (c) imagine and analyze the propagation of signals (e) apply equivalent circuit theory, analyze current distribution and radiation patterns etc.

To conduct the experiments of these subjects, expensive and specialized laboratory equipments and set ups (as compared to other subjects) are required which comprises of different types of antennas, microwave bench and accessories, network analyzer, spectrum analyzer, power meter, anechoic chamber etc. This may not be affordable by many of the academic institutions. Some of the institutes have microwave and antenna laboratory but it is not properly maintained and attained due to unavailability of trained manpower in the microwave and antenna laboratory to handle these equipments.

In the rapidly changing scenario of 4G and 5G communication technologies, metamaterial based antennas, reconfigurable antennas, textile based wearable antennas, paper antennas are of growing interest [1]-[5]. These recent technologies are yet to be incorporated in the under graduate curriculum of microwave theory, antennas and propagation.

Looking into the existing implementation of these subjects following observations are listed.

1. Students try to just pass the examination or acquire minimum credits by memorization.
2. Limited number of faculty members are interested to teach these subjects.
3. Teachers' and students to large extend lack the understanding of mathematical treatment pertaining to these subjects.
4. As compared to other subjects like microprocessor/ microcontroller based system design, programming languages, embedded systems antenna and microwave based subjects involve more mathematics and theory.
5. Students face difficulty to develop equivalent circuit theory of various antennas and microwave circuits.
6. It is expensive to establish, develop as well as maintain the microwave and antenna laboratory.

Thus, the subject remains unattained effectively and a countable number of students select antenna and propagation based industries for their professional career. As a result of which the industries are striving for good antenna designers and microwave engineers to meet their requirements. Hence, to make this subject more interesting and simpler, to teach the authors conducted summer training for fifth semester undergraduate electronics and communication engineering students to design, fabricate and test various types of antennas.

In addition to summer training, curriculum involves industrial training after seventh semester in which the student has to indentify the industry for training. On both the industry and student point of view, some of the common drawbacks are observed in effective implementation of the industrial training. These are listed below.

1. It is difficult for the students of remotely located engineering colleges to search for an industry for training.

2. Even though the engineers/technicians in the industry are willing to guide the students but lack of time due to their own target oriented production.

3. Unwillingness of industry authorities to discuss the design aspects due to trade secrets and policies.

4. In some industries it is difficult for the students to have hands-on experience on the systems as the companies are reluctant to take risk.

5. Some times students forcibly join the industry other than their area of interest. Eventually student completes the industrial training for the sake of curriculum without fulfilling the required objectives of training.

The above-discussed aspects motivated the authors to organize summer training for students of electronics and communication engineering to train them in core area of electromagnetics, microwaves theory, antennas and wave propagation. The authors planned and implemented the summer training by allowing students to design, fabricate and test different types of microstrip patch and wired antennas at the microwave and antenna laboratory of NITTTR, Chandigarh, India. This paper is encompassed into following sections. The objectives of summer training are presented in section II. Section III discusses the implementation model for summer training. In this section, the contents and time plan of summer training are tabulated and explained. In summer training the undergraduate students have designed, fabricated and tested different antennas for various applications. The designing, fabrication and testing details of these antennas is discussed in Section IV. The photographs and measured results of the fabricated antennas are also presented. The student evaluation method is presented in section V. The tabulated question bank is presented In Section VI which is used to collect the student feedback after the summer training. Finally, the paper is concluded in Section VII.

II. Objectives of Industrial Training

The objectives to implement summer training for undergraduate students of electronics and communication engineering are;

1. Understand the antenna and microwave theory through experimentations.
2. Appreciate the necessity of microstrip patch antennas in personal communication scenario.
3. Teach electromagnetic (EM) simulator tools used in various types of antenna and microwave design
4. Fabricate the microstrip patch and wired antennas for various applications like Wi-Fi public safety band, ISM and Wi-Max.
5. Know the fabrication flow and methods.
6. Provide hands-on experience to test and measure various parameters of fabricated antennas.
7. Make the microwave, antenna and wave propagation theory interesting as well as more informative through practical executions.

These objectives can be fulfilled by blending lecture sessions and intensive hands-on experience through lab sessions.

III. Implementation of Industrial Training

A. *Prerequisite for Summer Training*

Fig. 1 shows the pre-requisite model applied to conduct the summer training. Initially, it has been verified whether the subjects depicted in the model are studied by the students or not before joining the training. Following prerequisite courses should be studied by the students to undergo the summer training. The prerequisite courses such as principles of communication, measurement and instrumentation systems, engineering drawing, mechanical and electronic workshops and transmission lines and networks are essential to learn about the microwave theory as well as to design, fabricate and test antennas. It is found that these subjects were already studied by the students in their previous semesters.

B. *Implementation Model for Summer Training*

Fig.2 depicts the model used to implement the summer training in antenna engineering. Before implementing the training, a model is developed to impart the subject knowledge as well to develop different skill sets amongst the students during the training period [6]-[10]. The training is systematically organized so that the students can acquire subject knowledge as well as different skill sets.

The training is divided into three sections (a) Subject knowledge (b) Technical hands on skills and (c) Management soft skills. The triangular dotted section of the model shows the different subjects for which the knowledge is to be acquired. In this section, following notations are used to indicate the subjects in the curriculum for which the training is organized. **A**: Microwave theory, **B**: Electromagnetics and **C**: Antenna and Wave Propagation. These subjects are internally co-related that deals with radio frequency (RF) communication systems. The A, B and C elements are externally linked which represents that while working on the project students can understand the principles and concepts of these three subjects. The element **D** represents the real life engineering applications of these three subjects to cater the needs of human life for day-to-day applications like satellite and radar communication, Wi-Fi, Wi-Max, WLAN, public safety band, body area networks etc. This helps the students to appreciate the importance and applications of these subjects in the real life. Apart from the subject knowledge, it is essential to inculcate the technical and soft management skills in the students during summer training.

Research attitude: In addition to the theoretical aspects research attitude of the students have has to be developed by through design procedures, simulations, mathematical calculations, design iterations, calibrations etc.

Product design: use of EM simulators, different fabrication process like PCB etching, drilling, soldering etc.

Prototyping: design and develop a miniaturized antenna for particular application with desired gain and bandwidth.

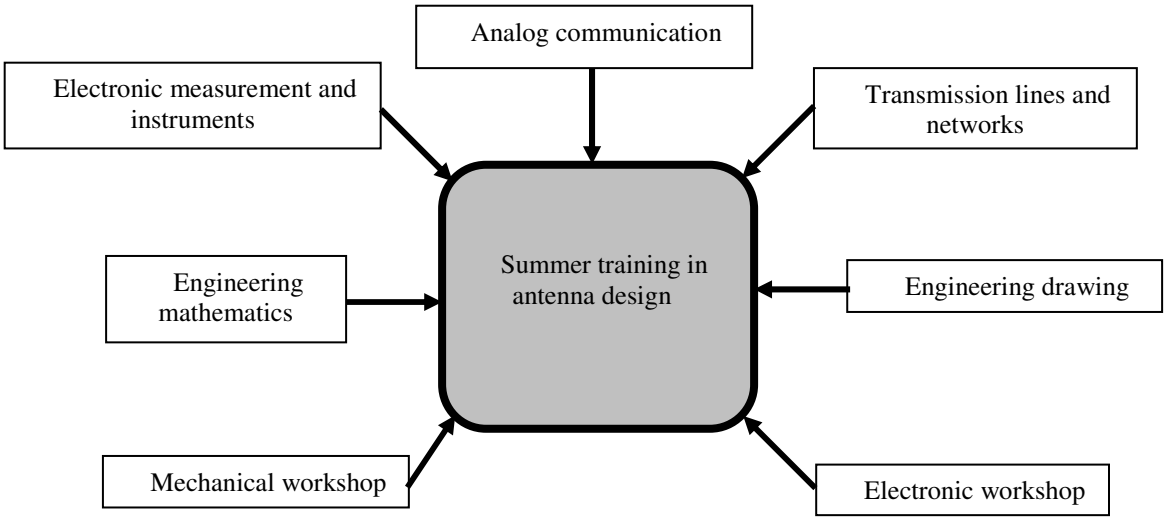

Fig.1 Pre-requisite subject model used to conduct the summer training on antenna engineering.

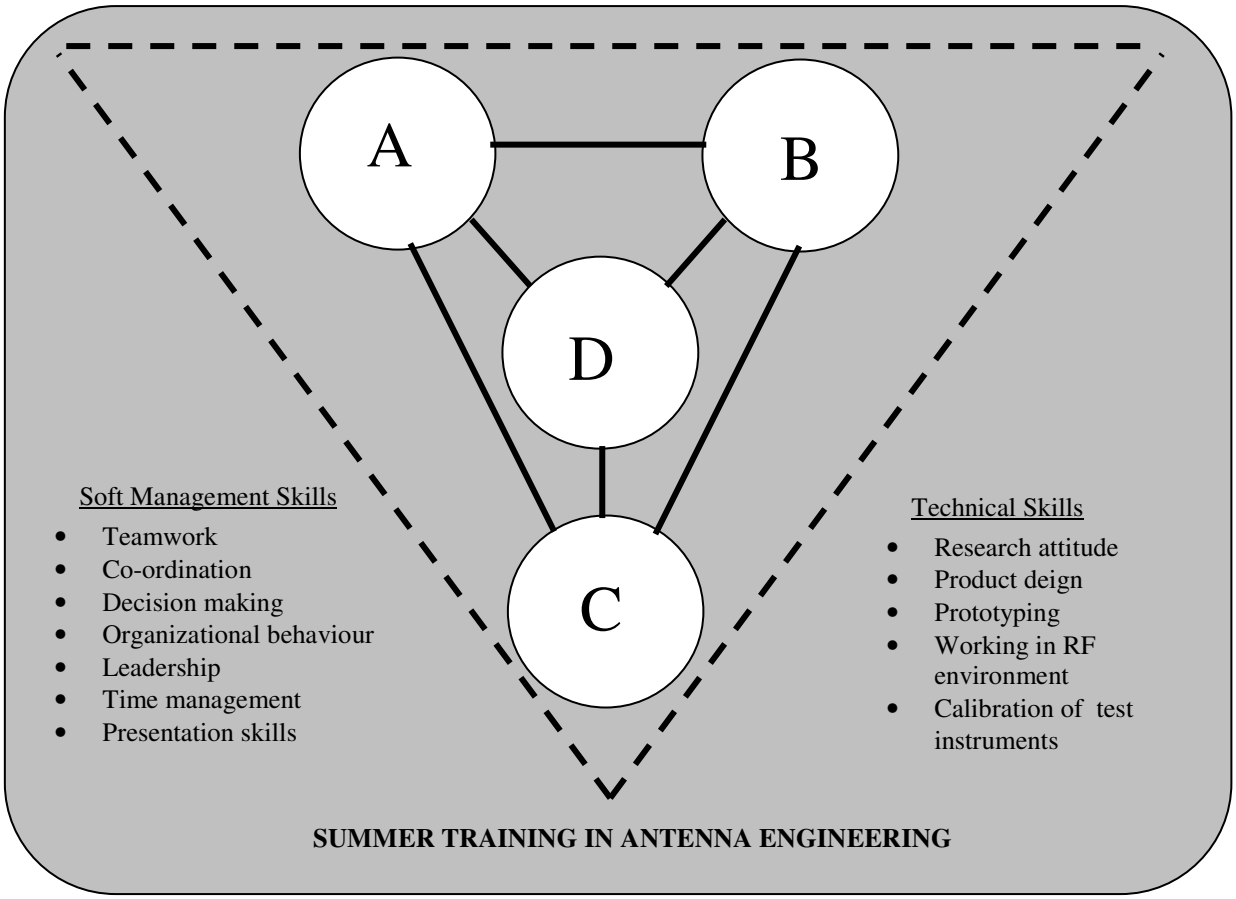

Fig.2 Model adopted to implement the summer training in antenna engineering.

Calibration of test instruments: To understand the importance of calibration and to perform the calibration process of test and measuring instruments such as site analyzer, spectrum analyzer etc. The students understand the required precautions and safety measures to be followed while working in the RF environment.

Another important aspect is the development of management skills through the training. The different soft managerial skills like team work, decision making, leadership, time management etc. are to be developed.

Lecture Sessions: In these sessions initially, the concepts and analysis of conventional antennas and more specifically microstrip patch antennas like rectangular, circular, and triangular with different size reduction, gain and bandwidth enhancement techniques are discussed. The recent topic on metamaterial is not incorporated in the graduate level curriculum hence, a special lecture sessions on applications of metamaterial in microwaves and antennas has been conducted. Special lecture sessions are organized to demonstrate the use of EM simulators like IE3D, Fidelity etc. and comparison of different EM simulators. All the topics are in-depth discussed by the Professors of the department and invited subject experts.

This training is organized into six weeks with the planned series of lecture sessions and lab work. The contents and time plan of the summer training is presented in Table I.

Lab Sessions:

After design process the geometrical dimensions are used to fabricate the proposed antenna. Fig.3 shows the steps followed to fabricate and test the assigned antennas in the laboratory.

Lab work 1: The working principle and operation of RF test and measuring equipments like Bird site analyzer, spectrum analyzer, power sensor, signal generator, is explained. The working and applications of microwave bench with the accessories is demonstrated.

Lab work 2: Initially, theoretical calculations and the dimensions of antenna structure were verified. According to the type of antenna the groups of students were permitted to simulate their antennas using either IE3D or Fidelity. Simulations were performed in number of iterations to attain the best matched (50 Ω) position of co-axial feed point on the radiating patch to get better bandwidth and gain at the designed resonant frequency. At the end of this session, it is found that the students were able to perform antenna simulation using IE3D and Fidelity simulators. Most importantly the students enriched with the experience in (a) analyzing the transmission and reflection coefficient at the

resonant frequency (b) measurement of bandwidth and gain (c) studying the radiation patterns in Cartesian and polar forms (d) current distribution (e) Concept of impedance, bandwidth and radiation patterns.

They realized the significance of feed point location for better impedance matching at the resonant frequency to obtain high gain and bandwidth respectively.

TABLE I
CONTENTS AND TIME PLAN FOR IMPLEMENTATION OF SUMMER TRAINING

Sr. No.	Activity	Topics	Contents	No. of days/ week*(s) allotted	Literature survey
1	Lecture Session in classroom	Review of microwave and antenna theory	Basics of EM theory, Types of antennas. Working principle, design equations, applications fields of different microstrip patch antennas. Antennas and their scope in future communication scenario	1	Literature survey is a continuous process. Students are directed to read, understand and discuss different journal and transaction papers like IEEE Transactions on Antennas and Propagation, Microwave Theory Techniques, IETE etc. IEEE Transaction on Education, IET.
2	Lecture Session in simulation laboratory	EM simulators	Introduction to IE3D and Fidelity simulation tools available in simulation laboratory. (Detailed discussion and demonstration).	1	
3	Lecture Session + Lab work 1 in microwave and antenna laboratory	RF Measurement and Instruments	Site analyzer, spectrum analyzer, power meter, microwave bench, different types of RF connectors. (Block diagram, working principle, specifications, precautions) Demonstration of these instruments.	3 Days	
4	Lab work 2 in simulation laboratory	Hands on experience on EM simulators	Design and simulation of assigned antenna using IE3D and Fidelity EM simulators. (For ISM, Wi-Fi and Wi-Max Bands)	1.2 week	
5	Lab work 3	Fabrication of antenna	To fabricate the antenna using different processes. Cutting, drilling, filing and fixing the required substrate of the antenna. Soldering of SMA connector to the patch, continuity testing etc.	1 week	
6	Lab work 4 in microwave and antenna laboratory	Testing of antenna	Return loss, Radiation patterns, measurement of the fabricated antenna. (Including corrective measures required if any). Theoretical and experimental validation of the results.	3 days	
7	Theoretical work	Analysis of designed antenna	Equivalent circuit analysis. Comparison of simulated, measured and theoretical results.	3 days	
* Number of working weeks :Six					

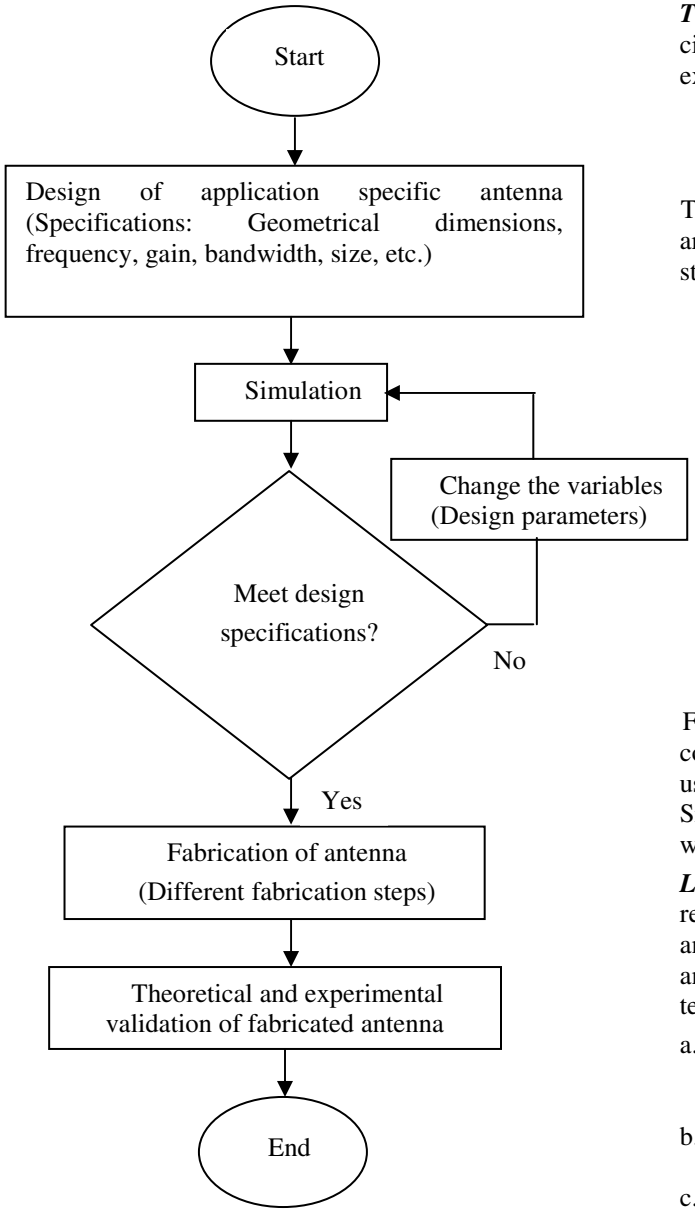

Fig. 3. Flow diagram to design, fabricate and test the assigned antenna.

Lab work 3: In the next step, the students were directed for etching of radiating patch and ground plane on detecting the exact feed point location on the radiating patch a 2-hole gold plated SMA connector is carefully soldered at that position. In this laboratory session, students learned to use different tools and equipments to fed the antenna

Lab work 4: After fabrication, the antenna is tested using measuring equipments as listed in Section IV. The return loss (S_{11}) characteristics, bandwidth, VSWR and radiation patterns of the antenna under test (AUT) are measured and recorded. The measurements are repeated on the same test bench with proper calibrations.

Theoretical Work: Students were asked to draw equivalent circuits, calculate the parameters and correlate the experimental findings with the theory.

IV. Designing, Fabrication & Testing of Different Antennas

Table II depicts the microstrip patch and wired antennas that are designed, fabricated and tested by the undergraduate students.

TABLE II
Different Fabricated & Tested Antennas

Sr. No.	Title of the antenna
1	Microstrip bow-tie
2	Collinear microstrip patch
3	Stacked rectangular microstrip patch
4	Microstrip blade patch
5	Log periodic microstrip patch
6	Wired square loop antenna

FR4 dielectric substrate of thickness 1.59 mm, dielectric constant (ε_r) = 4.4 and the loss tangent (tan δ) = 0.025 is used as a substrate to design the microstrip patch antennas. Similarly, hollow aluminium pipe is used to fabricate the wired antenna.

Laboratory Facilities The students were trained by the research scholar to understand, implement and analyze the antenna designs by the simulators. The microwave and antenna laboratory is fully equipped with isolated antenna test setup comprising of following equipments.

a. Bird site analyzer® (Model no. SA-6000EX, Frequency range 25 MHz to 6 GHz) interfaced with dedicated personal computer.
b. Spectrum analyzer (IfR Model No. 2394, 9 kHz to 13.2 GHz)
c. Power sensor (Boonton 52018 CW Power Sensor, 10nW-100 mW)
d. Signal generator
e. Shielded RF cable and connectors like BNC to N, N to SMA, etc.
f. Microwave benches with all necessary accessories

The institute has an Electronic Service Centre (ESC) with sufficient number of equipments and accessories for meeting the needs of fabrication and soldering.

Fig. 4 to Fig.10 shows the fabricated antenna and their measurements.

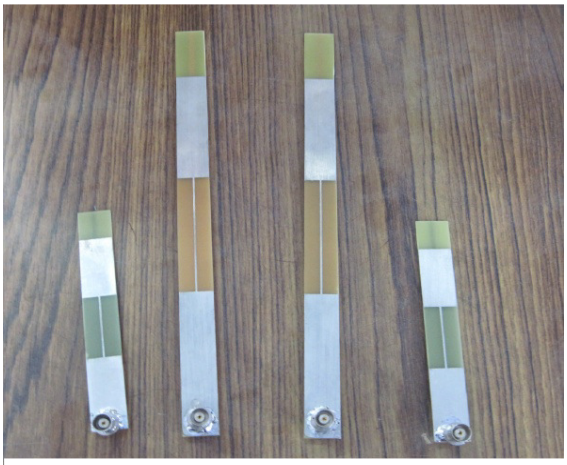

Fig. 4 Photograph of fabricated microstrip collinear antenna

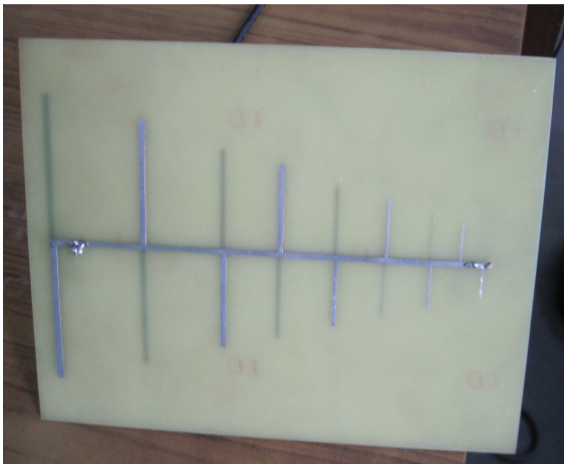

Fig. 5 Photograph of fabricated microstrip log periodic antenna.

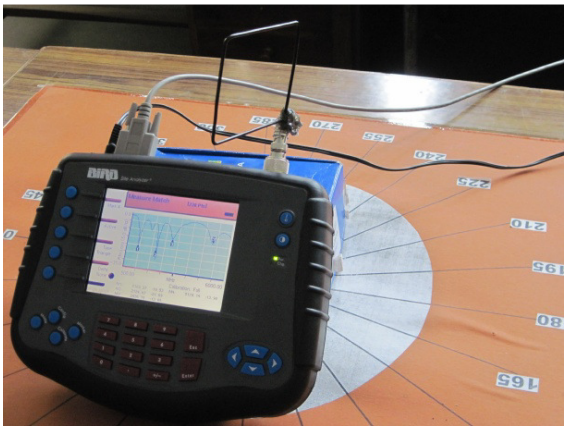

Fig. 6 Photograph of fabricated wired square loop antenna with site analyzer.

Fig.7 Photograph of test set up for microstrip bow-tie antenna.

Fig. 8 Photograph of Test set up of square loop antenna with spectrum analyzer.

Fig.9 Photograph of group of students with test and measurement set up for microstrip bow-tie antenna.

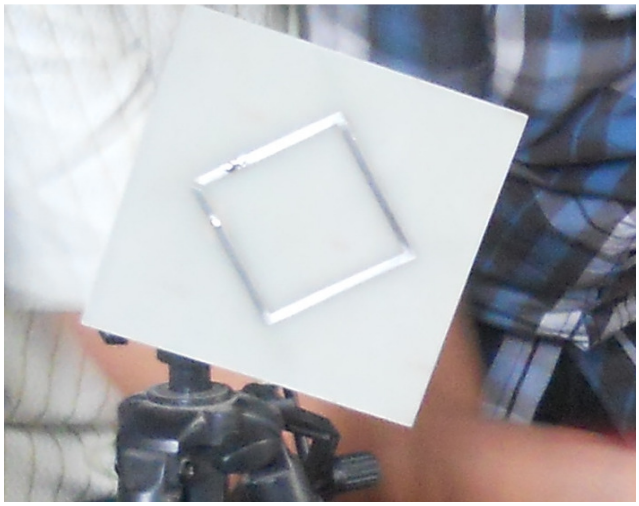

Fig.10 Photograph of microstrip patch blade antenna at test set up.

Experimental results and discussion

The return loss (S_{11}) plots of some of the measured antennas are presented in Fig. 11 to Fig.13. The students analyzed the results and compared the performance in terms of impedance bandwidth, resonances, multi-bands etc. The students also got exposure to smith chart plots of such antennas to understand the complex nature of input impedance and its dependency on frequency.

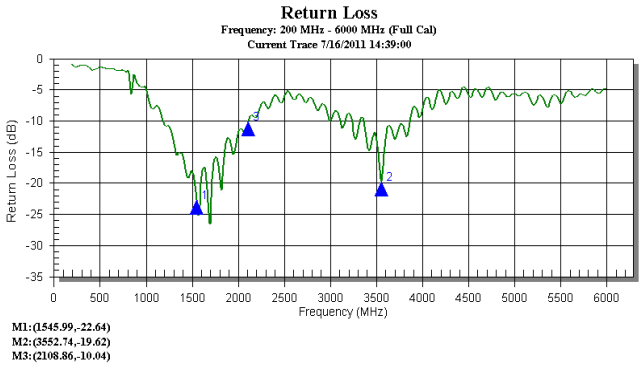

Fig. 11 Return loss (S_{11}) characteristics of Bat wing antenna.

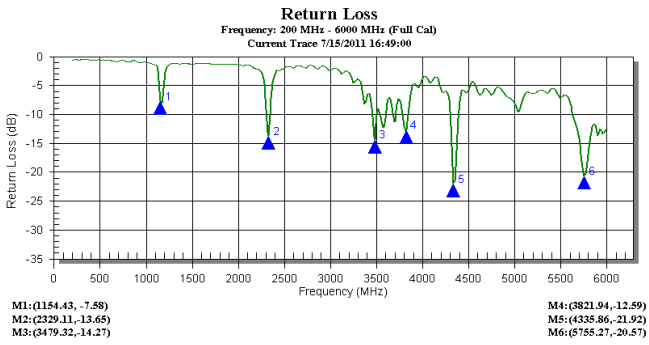

Fig.12 Return loss (S_{11}) characteristics of stacked rectangular microstrip patch antenna.

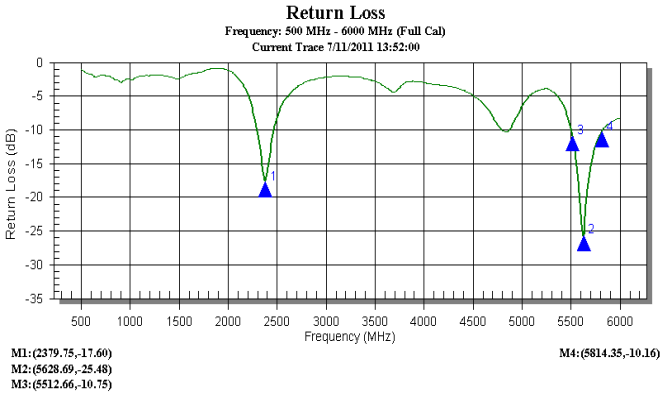

Fig.13 Return loss (S_{11}) characteristics of collinear microstrip patch

V. Student Evaluation

The performance of each student is evaluated on following basis- (a) Fabrication of assigned antenna (b) Comparison of simulated and measured results of the antenna (c) Theoretical analysis by drawing and analyzing equivalent circuit etc. (d) Report writing (e) Presentation and Viva-Voce. Table III depicts the format of contents summer training report.

TABLE III
Different Fabricated & Tested Antennas

Sr. No.	Chapter
1	Preface
2	Acknowledgement
3	Certificate
4	Objectives of Industrial Training
5	Introduction to Microwaves and Microstrip Patch Antennas
6	Theory of Antenna Design
7	Electromagnetic Simulator
8	Fabrication of Antenna
9	Testing and Measurement of Fabricated Antenna
10	Comparison of Simulation and Measured results
11	Theoretical analysis using equivalent circuit model or mathematical model
12	Learning Experiences during Training
13	Conclusion
14	References

VI. Student Feedback

The students' feedbacks has been collected based on questionnaires listed below.

National Institute of Technical Teachers Training and Research, Chandigarh, India
Educational Television Centre Questionnaire for Summer Training on "Antenna Engineering"

No.	Question
1.	Did you study microwave as a subject before joining the industrial training? (a) Yes (b) No
2.	Did you study Antenna Wave Propagation as a subject? (a) Yes (b) No if Yes what is your understanding of the subject 0~30 % 31~60 % 61~80 % 81~100 %
3.	Reason for joining the antenna training a) to learn better way b) to pursue career in antenna/relevant field c) no other option/industry was available d) friend joined
4.	Up to what extent this training helped you to understand the concepts of microwave and antennas? 0~30 % 30~60 % 60~80 % 80~100 %
5.	Do you have any prior experience of using electromagnetic simulator? (a) Yes (b) No
6.	Can you use IE3D/Fidelity antenna simulator confidently? (a) Yes (b) No
7.	Can you design and fabricate an antenna and test the antenna fabricated by you? (a) Yes (b) No
8.	How effective is learning the theory during the practical sessions? 0~30 % 31~60 % 61~80 % 81~100 %
9.	Do you think the working environment is supportive and enthusiastic while working in the laboratories? (a) Yes (b) No
10.	What is your experience while performing the experiments in the practical sessions as compared to the experiments listed in curriculum? (a) Poor (b) Good (c) Very good (d) Excellent
11.	Do you fill the antenna testing is a tedious and complex task as compared to other testing in electronics? (a) Yes (b) No if Yes, what is complexity 0~30 % 31~60 % 61~80 % 81~100 %
12.	Do you fill 6-8 weeks training period is sufficient to learn the basic antenna designing, fabricating and testing? (a) Yes (b) No
13.	Will you consider a career as an antenna designer/antenna engineer after attending this training? (a) Yes (b) No
14.	Upto what extend you can meet requirements of antenna design? 0~30 % 31~60 % 61~80 % 81~100 %
15.	Do you feel that subject like antenna and microwave should be taught like this? (a) Yes (b) No
16.	Do you recommend this training? (a) Yes (b) No
17.	Do you like to participate in software development for microwave and antenna design and simulation? (a) Yes (b) No

After analyzing the filled up feedback forms of students, the followings are summarized

1. The students should be taught in this type of mixed mode approach.
2. Realized the effect of metamaterial to miniaturize the antenna size.
3. Appreciated the experience of fabrication techniques.
4. Inspired to implement such type of antennas to meet the challenges of future 4G/5G communication systems.
5. Willing to opt the jobs in antenna and microwave industries.
6. Enhancement of theoretical and practical knowledge about the subjects.
7. Participate in software development of high frequency components and antennas.

VII. Conclusion & Future Scope

Through the organized summer training, the students are given an opportunity to learn subjects like antenna and microwave engineering through mixed mode approach. Learn theory while performing experiments generates lots of interests among the students to derive mathematics, draw equivalent circuits and analyze the results which they shy away in normal circumstances. The feedback of the summer training opens up a new method of teaching-learning of the subjects like antenna, electromagnetic theory, microwave control engineering, network and transmission lines etc. which involves tedious mathematics to derive while performing the theory class.

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