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## APPENDIX-I

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### 1. Electronics Design Automation (EDA) Tools

The advancement in full wave electromagnetic numerical techniques like Finite Element Method (FEM), Method of Moment (MOM), Finite Difference Time Domain (FDTD), Finite Integration Techniques (FIT) etc. leads to design and analysis of more complex antenna structure which was not possible with transmission line modelling and cavity method of microstrip antenna analysis. With complex structures, these numerical techniques requires lots of computational power and memory requirement but with the progress in modern computer technology these constraints can be compensated. Ansoft's High Frequency Structure Simulator (HFSS) and/or Computer Simulation Technology's Microwave Studio (CST MWS) have been used in thesis to design and analysis of microstrip antenna before fabrication. The details about these softwares are given below:

#### A. High Frequency Structure Simulator (HFSS)

HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modelling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modelling, and automation in an easy-to-learn environment where solutions to 3D EM problems are quickly and accurately obtained. Ansoft's HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give unparalleled performance and insight to all of 3D EM problems. Ansoft HFSS can be used to calculate parameters like  $S$ -parameters, resonant frequency, fields etc.

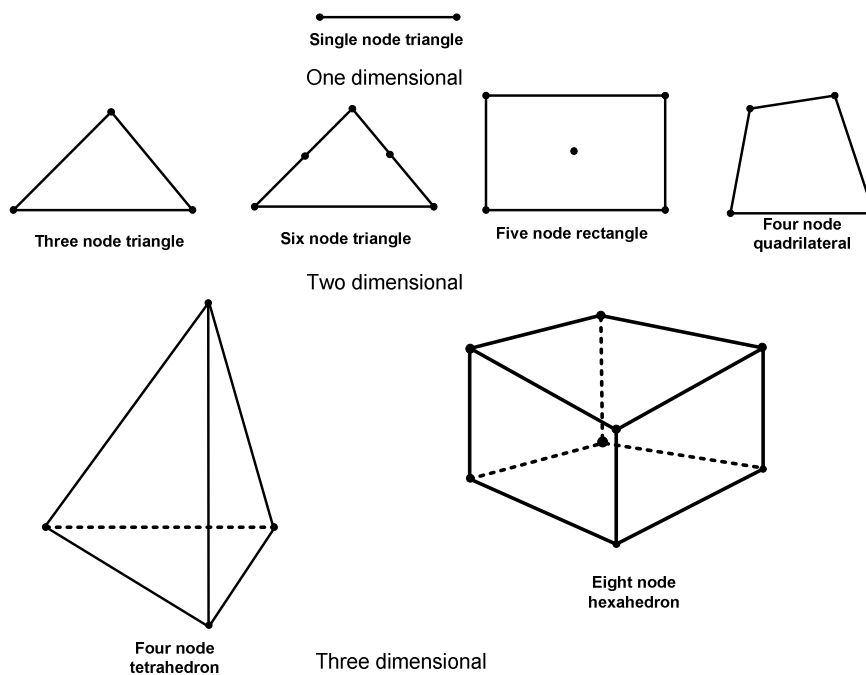
HFSS is an interactive simulation software whose basic mesh element is a tetrahedron. This allows to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time it would take using other techniques.

However, FEM is more powerful and versatile numerical technique for handling problem involving complex geometries and inhomogeneous media. The FEM involve following steps for any problem analysis:

- Discretizing the solution region into a finite number of *subregions* or *elements*,
- Deriving governing equations for a typical element,
- Assembling of all elements in the solution region, and

- Solving the system of equations obtained.

Discretization of a problem involves dividing up the solution region into bu-domains, called finite element. Some typical finite elements for one-, two-, and three-dimensional problems are shown below.



Figure

## B. Computer Simulation Technology Microwave Studio (CST MWS)

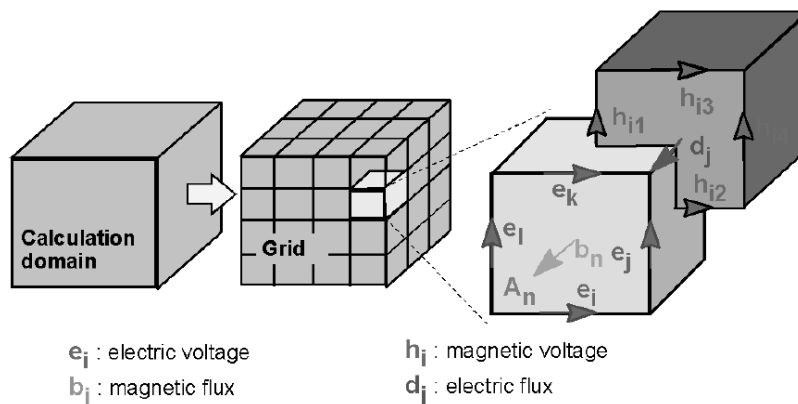
CST MWS is a specialist tool for the 3D EM simulation of high frequency components. It enables the fast and accurate analysis of high frequency devices such as antennas, filters, couplers, planar, and multi-layer structures. It is a general-purpose electromagnetic simulator based on the Finite Integration Technique (FIT). This numerical method provides a universal spatial discretization scheme, applicable to various electromagnetic problems, ranging from static field calculations to high frequency applications in time or frequency domain.

Unlike most numerical methods, FIT discretizes the following *integral* form of Maxwell's equations, rather than the differential one:

$$\oint_{\partial A} \vec{E} \cdot d\vec{s} = - \int_A \frac{\partial \vec{B}}{\partial t} \cdot d\vec{A}, \quad \oint_{\partial A} \vec{H} \cdot d\vec{s} = - \int_A \left( \frac{\partial \vec{D}}{\partial t} + \vec{J} \right) \cdot d\vec{A},$$

$$\oint_{\partial V} \vec{D} \cdot d\vec{A} = \int_V \rho \cdot dV, \quad \oint_{\partial V} \vec{B} \cdot d\vec{A} = 0.$$

In order to solve Maxwell equations numerically a finite calculation domain is defined, enclosing the considered application problem. By creating a suitable mesh system, this domain is split up into several small cuboids, so called grid cells. The griding of the calculation domain are shown below:



After completion of griding of a calculation domain, Maxwell's equations are formulated for each cell facets separately and done the calculation accordingly.

In this thesis, Ansoft's HFSS is used to design and optimized the MIMO/Diversity antenna further CST MSW is used to verify the simulated results of HFSS before antenna fabrication. Further, CST MWS is used for radiation performances and diversity performances study. Because it is user friendly and has more options to analysis the MIMO/Diversity parameters than HFSS.

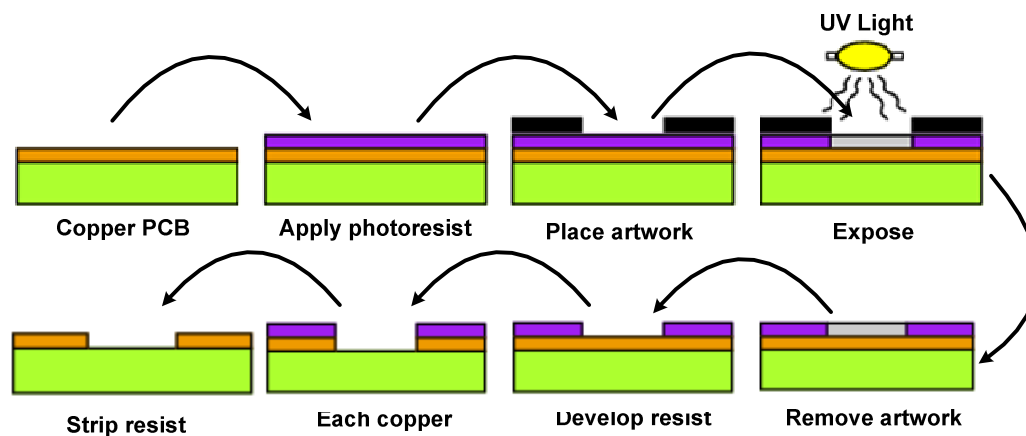
## 2. Antenna Fabrications

The printed antenna can be fabricated by using either photolithography process or PCB prototyping machine. In presented thesis, printed antenna is fabricated by using both process. The details of process used for antenna fabrication in both the techniques are elaborated below one by one.

### A. Photolithography Process:

The mostly used method to fabricate the printed microstrip antenna is the Photolithography technique. The major procedure included in this technique is explained in brief. The steps involve to print the microstrip antenna is given below;

- First step to make artwork of the proposed geometry by using Auto CAD tool. Then, a negative of this geometry printed on transparent sheet serves as the mask. Further, a copper clad sheet of antenna size is taken and cleaned using acetone and dried it because dust particles or impurities present on the copper clad surface may introduce discontinuity in the etched pattern that alters the resonant frequency.
- Second step involve negative photo-resist film lamination to the cleaned and dried copper clad substrate.
- Further, the negative mask prepared in the first step is firmly placed on the photo-resist laminated copper clad substrate.
- In the fourth step, the masked and photo-resist laminated copper clad substrate is exposed to ultra violet (UV) light.
- Further, remove the artwork from the exposed copper clad substrate.
- The sixth step is to develop the UV exposed photo-resist laminated copper clad substrate. The photo-resist exposed to UV light becomes hard and dark blue in colour while unexposed photo-resist remains light blue and dissolves in the developer solution.
- Finally, the developed copper clad substrate is chemically etched by Ferric Chloride ( $\text{FeCl}_3$ ) solution. The copper parts except underneath the hardened photo resist dissolve in  $\text{FeCl}_3$ . The etched substrate is rinsed in running water to remove any etchant and then dried.



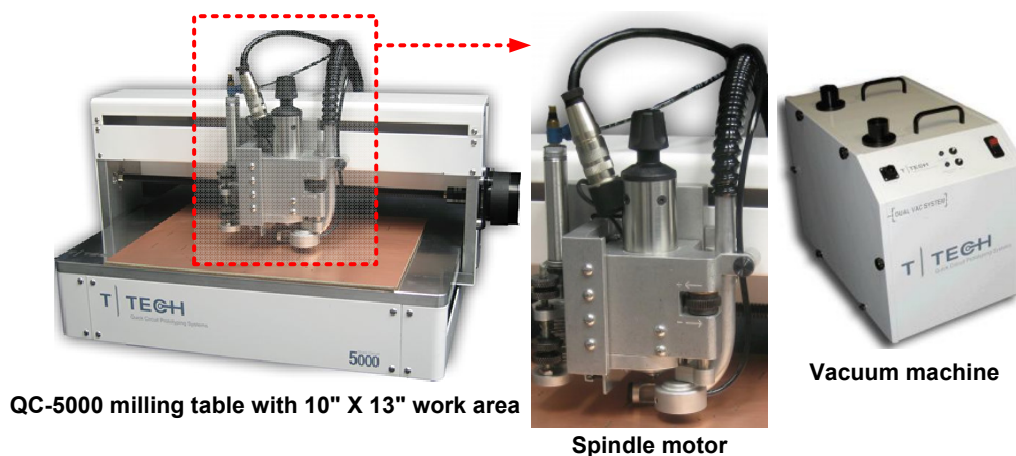
## B. PCB Prototyping Machine

The printed antenna can also be fabricated by using PCB prototyping machine. One of the antenna in this thesis is fabricated by using T-Tech Quick Circuit-5000 (QC-5000) prototyping system which is available in the Microwave Laboratory of the Department of Electronics Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi. The details of the prototyping machine are given below;

The Quick Circuit model is equipped with a 10" x 13" work area. This system provides circuit board prototypes within hours. The QC 5000 can easily produce high quality analog, digital, or RF/Microwave prototypes.

T-Tech's Quick Circuit QC 5000 provides everything we need to produce RF or Microwave circuit board prototypes within hours. The software controlled high speed spindle provides variable motor speeds between 5,000 and 60,000 RPM. The higher speeds produce the smooth and precise cuts required to create RF and Microwave prototypes. Additional high speed spindle benefits include; extended tool life and faster milling speeds. This system is equipped standard with IsoPro software, which enables automatic data conversion from almost any CAD package.

The QC-5000 machine consists of number of parts as shown in below figure;



There are following steps are involve to produce the RF and Microwave circuits:

- Initially, designed circuits are exported into DXF formate (.dxf) and convert it into the Gerber file (.gbr).

- Further, Gerber files imported into IsoPro software (which used to interface the QC-5000 system from computer).
- If antenna structures are multi layers, then different layers are formed in IsoPro software and run accordingly.
- After the complete etching of the copper (finally antenna structure has been printed) from substrate, PCB board is removed.