Chapter Three

METHODOLOGY

The experimental and simulation methodology utilized for the analysis of the proposed filters are described in this chapter. Photolithographic process is used to fabricate different filter geometries, while the filter characterization is done with the help of Vector Network Analyzer. The FEM based Ansoft HFSS is used to perform the parametric analysis of the filter geometry.
3.1 Techniques for Design and Optimization of Filters

A short description of the softwares used for the simulation and optimization of the filter structures is presented. The fabrication methods and the measurement techniques utilized are also described. The simulation of different filter structures presented in this thesis is performed using the commercial software Ansoft High Frequency Structure Simulator (HFSS) and IE3D.

3.1.1 Ansoft HFSS

Ansoft HFSS is one of the globally accepted electromagnetic solver which utilizes a 3D full-wave Finite Element Method (FEM) to compute the electrical behavior of high-frequency and high-speed components. With HFSS, engineers can extract parasitic parameters (S, Y and Z), visualize 3D electromagnetic fields (near- and far-field), and generate Full-Wave SPICE™ models to effectively evaluate signal quality, including transmission path losses, reflection losses due to impedance mismatches, parasitic coupling, and radiation. It is one of the most popular and powerful applications used for microwave structure design. The optimization tool available with HFSS is very useful for antenna engineers to optimize the antenna parameters very accurately. There are many kinds of boundary schemes available in HFSS. Radiation and PEC boundaries are widely used in this work. The vector as well as scalar representation of E, H and J values of the device simulation gives a good insight in to the problem under simulation.

The first step in simulating a structure in HFSS requires the definition of the geometry of the structure by giving the material properties and boundaries for 3D or 2D elements available in HFSS window. The next step is to draw the intended architecture using the drawing tools available in the software (Fig. 3.1). The designed structure is excited using the suitable port excitation schemes. The next step involves the assigning of the boundary scheme. A radiation boundary filled with air is commonly used for
radiating structures. The size of air column is taken to be equal to a quarter of the free space wavelength of the lowest frequency of operation.

![Modelled structure in the HFSS window](image)

**Fig. 3.1** Modelled structure in the HFSS window

Now the simulation engine can be invoked by giving the proper frequency of operation and the number of frequency points. Finally the simulation results such as scattering parameters (Fig. 3.2), port surface characteristic impedance, 3D static and animated field (electric or magnetic) plots (Fig. 3.3) on any surface, radiation pattern, current distributions and vector and magnitude are displayed and visualised in various forms like 2D/3D Cartesian/Polar plots, Smith charts and Data tables. The vector as well as the scalar representation of E, H and J values of the device under simulation gives good insight into the structure under analysis [1].
Fig. 3.2 Simulation results showing the Scattering parameters

Fig. 3.3 Field distribution plot of the simulated structure

Advanced version, HFSS v11, features new higher-order, hierarchical basis functions combined with an iterative solver that provides accurate fields, smaller
 meshes, and more efficient solutions for large, multi-wavelength structures. A new fault
tolerant, high-quality finite element meshing algorithm further enhances HFSS's ability
to simulate very complex geometric models, including models imported from 3D CAD
environments.

3.1.2 Zealand IE3D

IE3D is a full-wave, method-of-moments based electromagnetic simulator
solving the current distribution on 3D and multilayer structures of general shape. It has
been widely used in the design of MMICs, RFICs, LTCC circuits,
microwave/millimeter-wave circuits, IC interconnects and packages, HTS circuits,
patch antennas, wire antennas, and other RF/wireless antennas. The designed structure
is drawn and the material characteristics for each object are defined, and identified the
ports and special surface characteristics (Fig. 3.4).

Fig. 3.4 Modelled structure in IE3D window

The system then generates the necessary field solutions and associated port
characteristics and S-parameters.
Methodology

Fig. 3.5 S-parameter plots of the simulated structure

IE3D comes with the MODUA post-processor for display of S (Fig.3.5), Y, and Z-parameters in data list, rectangular graphs and Smith Chart. MODUA is also a circuit simulator (Fig 3.6a). A user can graphically connect different S-parameter modules and lumped elements together and perform a nodal simulation.

(a)  (b)

Fig. 3.6 (a) Circuit simulator MODUA (b) Field distribution of the simulated structure

Current distribution (Fig. 3.6b), both 2D and 3D radiation pattern and field distribution images are also provided [2].
3.2 Filter Fabrication

Different resonators designed for constructing bandpass and bandstop filters are based on OLR, folded U-shaped loop and SRR. The optimized filters are fabricated using photolithographic technique. This is a chemical etching process by which the unwanted metal regions of the metal layers are removed so that the intended design is obtained. Depending upon the design of filter, uniplanar or biplanar, double or single sided substrate is used. Filters were fabricated on two types of substrates, FR4 and RT Duroid. The substrate used to fabricate the SRR and folded U-shaped filter under study is the FR4 epoxy and that of OLR filter is RT Duroid. The FR4 substrate has a dielectric constant of 4.4, and a thickness of 1.6mm and corresponding values for RT Duroid are 3.2 and 1.6mm. RT Duroid which is costlier than FR4 has a low loss tangent of 0.0009 compared to 0.02 for FR4. The geometry of the resonators in the filters under study are given below which are designed to operate in conjunction with 50Ω microstrip transmission line fabricated on the corresponding substrate material.

**OLR based bandstop filter**

Geometry of the square OLR of size WxL is shown in Fig.3.7:

- *s* is the slit width
- *t* is the metal width and
- \(p_{oa}\) is the average perimeter of the open loop

Typical dimensions on RT Duroid substrate (\(\varepsilon_r = 3.2\)):

\[
W = L = 14mm ,
\]

\[
s = 1mm \text{ and } t = 0.5mm
\]

Fig.3.7 Layout of OLR
Folded U-shaped bandpass filter

Geometry of the folded U-shaped resonator is shown in Fig. 3.8:

- $W$ is the coupling length
- $L$ is the length of the side arm
- $t$ is the metal thickness of the metal
- $d$ is the gap between the folds and
- $s$ is the gap between the two open ends

Typical dimensions on the FR4 substrate ($\varepsilon_r = 4.4$):

- $L = 20\text{mm}$
- $w = 6\text{mm}$
- $t = 0.3\text{mm}$
- $d = 0.2\text{mm}$ and
- $s = 0.5\text{mm}$

![Fig.3.8 Layout of Folded U resonator](image)

SRR based filter

Geometry of the SRR is shown in Fig. 3.9:

- $r_1$ is the inner
- $r_2$ is the outer
- $c$ is the metal width between the rings
- $s$ is the slit width of the rings
- $d$ is the gap between two rings

Typical dimensions on the FR4 substrate:
3.2.1 Photolithographic technique

Photolithography is a process of transferring geometrical shapes from a photolithographic mask to the surface of a substrate which results in optical accuracy. After the proper selection of the substrate, a computer aided design of the structure was made and a negative mask of geometry is generated. The precise fabrication of a prototype falling within the microwave frequency is very essential. With the help of a high resolution laser printer, the computer designed filter geometry was printed on a transparent sheet for the use as the mask.

The copper clad substrate of suitable dimension was cleaned with solvents like acetone to remove any chemical impurities and dried. Thereafter, a thin layer of negative photo resist material was coated over the substrate using a high speed spinner. This substrate was then exposed to U.V. light through the carefully aligned mask. Extreme care was taken to ensure that the region between the copper clad and mask remains dust-free. The U. V. exposure results in the hardening of the photo resist layer. Subsequently, the substrate was immersed in a developer solution and followed by ferric chloride treatment to remove the unwanted copper.
Then the substrate was cleaned to remove the hardened photoresist using acetone solution. Photolithography process is illustrated in Fig. 3.10.

### 3.3 Filter Characteristics Measurement

A short description of equipments and facilities used for the measurements of filter characteristics is presented in this section.

#### 3.3.1 HP 8510C Vector Network Analyzer

The HP 8510C microwave vector network analyzers provide a complete solution for characterizing the linear behaviour of either active or passive networks over the 45 MHz to 50 GHz frequency range. The network analyzer system consists of a microwave source, S-parameter test set, signal processor and display unit as shown in Fig. 3.11.
The network analyzer measures the magnitude, phase, and group delay of two-port networks to characterize their linear behaviour. The analyzer is also capable of displaying a network’s time domain response to an impulse or a step waveform by computing the inverse Fourier transform of the frequency domain response. The synthesized sweep generator HP 83651B uses an open loop YIG tuned element to generate the RF stimulus.

Frequencies from 10 MHz to 50 GHz can be synthesized either in step mode or ramp mode depending on the required measurement accuracy. The frequency down converter unit separates the forward and reflected power at the measurement point and down converted it to 20MHz. It is again down converted to lower frequency and processed in the HP8510C processing unit with Motorola 68000 processor. All the above systems are interconnected with HPIB bus and RF cables.
Methodology

The device under test (DUT) is connected between the two ports of the S-parameter test set HP8514B. The filter characteristics such as insertion loss, return loss in magnitude and phase are measured using the Network Analyzer. The indigenously developed CREMASOFT, which is Matlab based data acquisition software in IBM PC, is used for the automatic measurement of the characteristics using the network analyser. It coordinates the measurements and records the data in csv format [3].

3.3.2 E8362B Precision Network Analyzer (PNA)

Some of the measurements were carried out using PNA E8362B. Precision Network Analyzer (PNA) is the recent series from Agilent Vector Network Analyzer family which provides the combination of speed and precision for the demanding needs of today’s high frequency, high-performance component test requirements. The modern measurement system meets these testing challenges by providing the right combination of fast sweep speeds, wide dynamic range, low trace noise and flexible connectivity. The Analyzer is capable for performing measurements from 10 MHz to 20 GHz and it has 16,001 points per channel with < 26 μsec/point measurement speed. The photograph of the PNA E8362B used for the antenna measurements is shown in Fig. 3.12 below.

Fig. 3.12 PNA E8362B Network Analyzer
3.3.3 Measurement procedure

The experimental procedure followed in determining the filter characteristics is discussed below. Power is fed to the filter from the S parameter test set of the analyzer through the cables and connectors. The connectors and cables tend to be lossy at higher microwave frequencies. Hence the instrument should be calibrated with known standards to get accurate scattering parameters.

3.3.4 S Parameters, Resonant Frequency and Bandwidth

The network analyser is calibrated for full two ports by connecting the standard short, open and thru loads suitably. Proper phase delay is introduced while calibrating to ensure that the reference plane for all measurements in the desired band is actually at zero degree thus taking care of probable cable length variations. The two ports of the filter is then connected to the ports of the S parameter test unit as shown in Fig. 3.11. The magnitude and phase of $S_{11}$, $S_{22}$ and $S_{21}$ are measured and stored in ASCII format using the CREMASOFT. $S_{11}$ and $S_{22}$ indicate the return loss at the two ports of the filter and $S_{21}$ indicate the insertion loss (transmission characteristics) of the filter from which the resonant frequency and the bandwidth are calculated.

References