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Dual-Band Patch Antenna with Six-Port Receiver Module on Silicon substrate

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***Abstract*— This article details the design of Dual-band patch antenna integrated with monopulse/microwave comparator for dual-band (1.575GHz and 2.680GHz) applications. Proposed planar architecture consists of dual-band linearly polarized patch antenna, single-stage (1:2) Wilkinson Power Divider and three numbers of quarter-wave 3-dB branch-line couplers working simultaneously at dual band of frequencies. Present article describes the designing of dual-band reconfigurable patch antenna finally integrated with six-port receiver module. Main challenge of this design is to design the dual-band reconfigurable patch antenna by introducing the capacitive type MEMS switch and optimize various RF parameters simultaneously at two arbitrarily chosen frequencies for higher permittivity substrate like Silicon. And this kind of antenna with 6-port mono-pulse receiver module, used for RADAR application.**

Index Terms*— Dual-band Branch-line coupler, Dual-band WPD, Multi-frequency antenna, power divider, stepped-impedance stub..

I. INTRODUCTION

Patch antennas have been popular for their low-profile, compatibility with monolithic microwave integrated circuits (MMICs) and light weight but one of the main limitations of this antennas have been their narrow bandwidth, which is due to the resonant nature of the patch structure. These features are major design for considerations for practical applications of microstrip antennas such as those for satellite links (GPS, Vehicular, etc.), wireless local networks (WLAN) and thanks to their lightness are most suitable for system to be mounted on airborne platform, like synthetic-aperture radar (SAR)[1].In previous research, a circularly polarized small-size microstrip antenna is designed using a proximity coupled feed method [2] which is used for mobile satellite communication. On the contrary, wideband circularly polarized aperature-coupled microstrip antenna [3] is described. A dual-band, dual-polarisation antenna is capable for terrestrial cellular communication as well as for satellite mobile communication [4].The dual-band antenna [5] is suitable for use in communication, defense applications, surveillance and countermeasures etc. In recent years, MIC based techniques have been initiated to develop various planar RF circuits on high resistive silicon ($\rho > 8$ kΩ-cm, $\tan\delta = 0.01$). RF performances on this are comparable to conventional microwave substrates, like-Alumina, GaAs, RT Duroid, FR4.

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A microstrip patch includes a conducting patch of any planar or non-planar geometry on one side of a dielectric substrate with a ground plane on the other side shown in fig1.

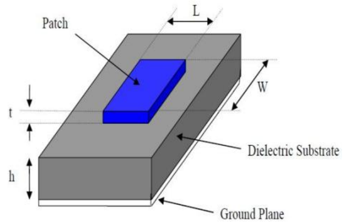

Figure 1. Structure of a Microstrip Patch Antenna

The patch is usually made of conducting material like gold, copper and can take any conceivable shape.

A. *MMIC*

Multiband circuits are getting utmost importance in present communication circuits. Simple configuration, compact size and easier fabrication processes are driving the new methodology to be adopted.

Six port architecture as suggested [6] deals with single frequency operation. Due to present scenario of multiband communication with compact size, it is necessary to develop system on higher permittivity substrates and adopting techniques for dual-frequency operation. Basic building block of the 6-port front-end receiver is power splitter to deliver desired power ratio with required amount of phase shift. Out of six-ports of the receiver block, two ports are used for input and from the rest of the ports output signals are taken out, which bears the information regarding the phase comparison of input signals. The six-port topology is being used extensively in radar system for distance or velocity analysis or for Direction of Arrival (DOA) detection [6]. Dual-band patch antenna which is integrated with 6-port mono-pulse receiver module is used for RADAR application.

B. *Targeted Specification*

Table 1 shows the standardized specifications kept in mind for each parameter.

Center frequency(f_o)	Dual-band(L & S-band) / Ku-band / Ka-band
I/O Impedance	50Ω
Return Loss	>12 dB(min.)
Fractional BW	< 5%
Polarization	Linear/Circular
Implementation	QWT
Substrate	High Resistive Substrate Silicon (h= 675μm, Si(ρ>8kΩ-cm , $\tan\delta$= 0.005)
Application	Space and missile applications.

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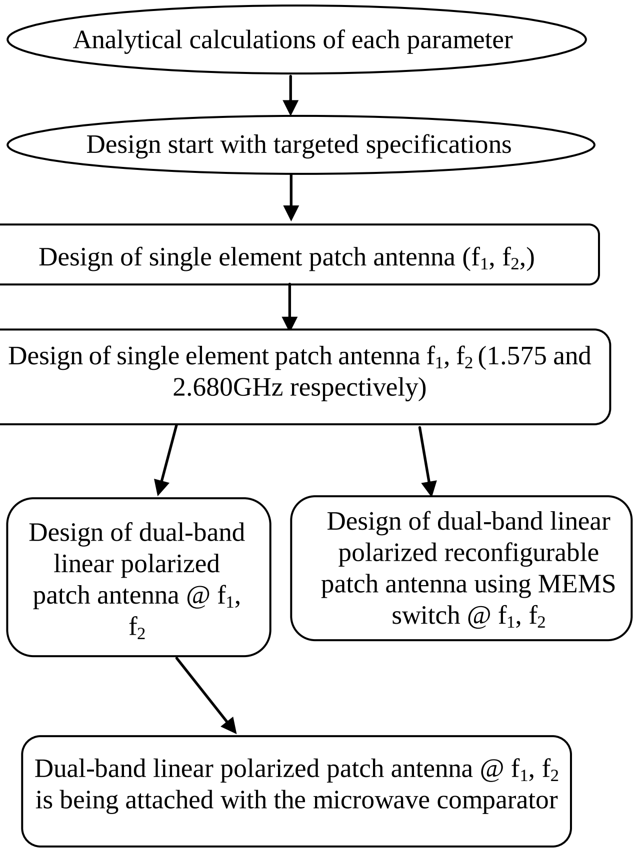
II. ALGORITHM USED

Step 1: Firstly, we had to do analytical calculations of all the desired parameters of the patch antenna.
Step 2: Start designing the single element patch antenna in software for various bands.
Step 3: Further, we design the dual-band linear polarized patch antenna at f_1, f_2.
Step 4: In this step, we introducing the MEMS switch into the slot of the patch. This will acts as a reconfigurable patch antenna.
Step 5: Last step is to place the designed antenna i.e. in step 3 for f_1, f_2 with the monopulse/microwave comparator [7] to have a complete subsystem for INS application.



III. DESIGN DETAILS

To design a rectangular microstrip patch antenna following parameters such as dielectric constant (ε_r), resonant frequency (f_o), and height (h) are considered for calculating the length and the width of the patch. The following equations are referred from[8].

Height of substrate (h) = 675 microns;
Resonant frequency of patch (f_o) = 1.575GHz , 2.680GHz
Dielectric constant of silicon substrate = 11.8

Wavelength(λ_o)= $\frac{c}{f_o}$ (1)

Guided wavelength(λ_g)= $\frac{\lambda_o}{\sqrt{\varepsilon_r}}$ (2)

$$f_r = \frac{v_0}{2L\sqrt{\varepsilon_r}} \quad (3)$$

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (4)$$

Effective dielectric constant of antenna (ε_{reff}):

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{\frac{-1}{2}} \quad (5)$$

Effective electrical length of antenna:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \quad (6)$$

The extended length of antenna (ΔL):

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)}\,\frac{\left(\frac{W}{h}+0.264\right)}{\left(\frac{W}{h}+0.8\right)} \quad (7)$$

The length of the patch is:

$$L= L_{eff} - 2\Delta L \quad (8)$$

$$\text{Conductance(G)}=\frac{W}{120\,\lambda_o} \times \left[1-\frac{1}{24}\right] \times [k \times h]^2 \quad (9)$$

$$\text{Effective Impedance } (Z_{in})=\frac{1}{2G} \quad (10)$$

$$Z_o=Z_{in}\cos^2\left(\frac{\pi\, y_0}{L}\right) \quad (11)$$

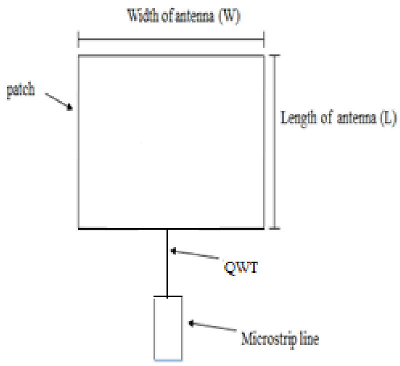


Figure 2.Basic structure of patch antenna.

IV. SIMULATION RESULTS AND DISCUSSION

a. Design of dual-band Linearly Polarized Patch antenna in L and S-band in FEM solver:

Length of the patch = 27.43mm
Width of the patch = 23.73mm
QWT length = 12.39mm
QWT width = 0.023mm
Slot length (l) and Slot width (w) = 16.41mm, 0.15mm respectively.

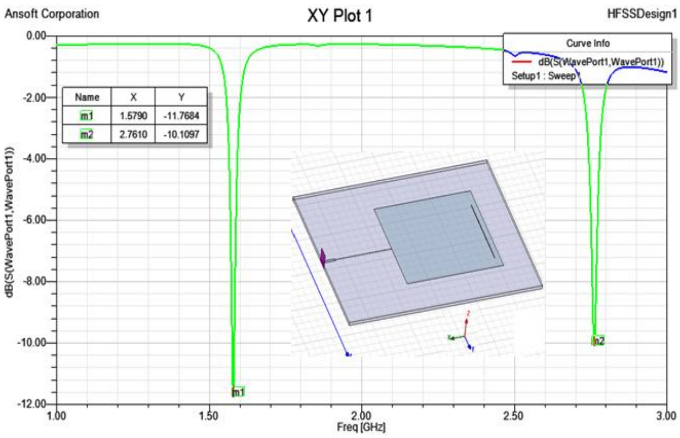
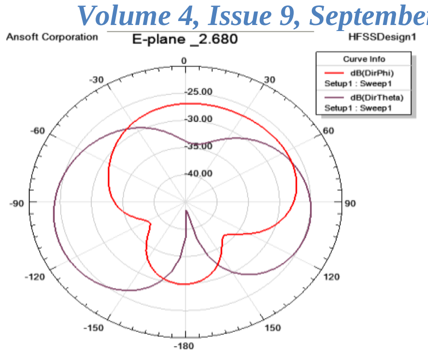
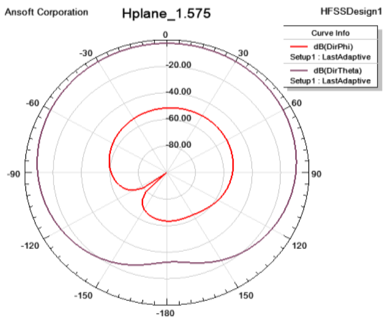


Figure 3. Dual-band linear polarized patch antenna in L and S-bandin FEM solver

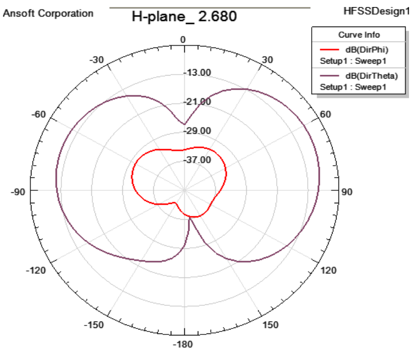


b) E-plane @2.680GHz

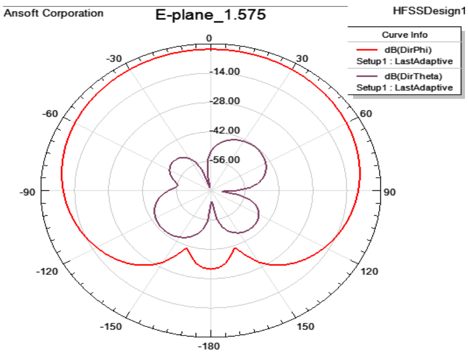
Figure 4. Far-field Radiation Pattern



a) H-plane @1.575GHz



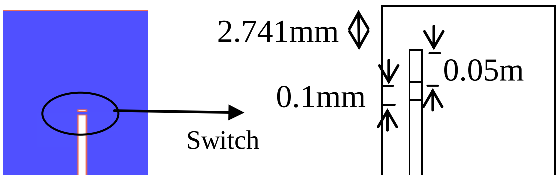
b) H-plane @2.680GHz



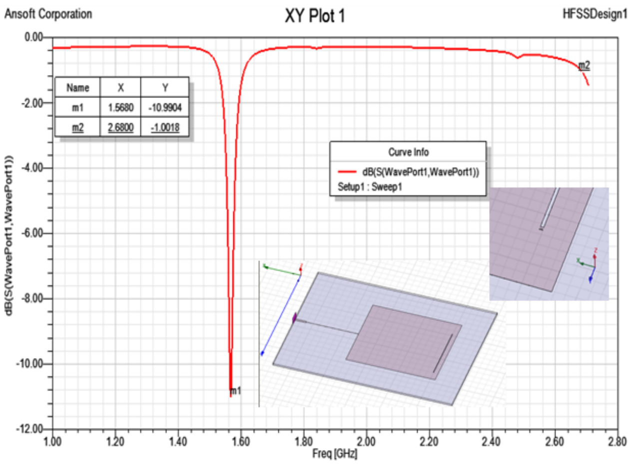
a) E-plane @1.575GHz

b. Design of dual-band linearly polarized reconfigurable patch antenna in FEM solver.

Length of the patch = 27.43mm
Width of the patch = 23.73mm
QWT length = 12.39mm
QWT width = 0.023mm
Slot length (l) = 16.41mm
Slot width (w) = 0.15mmth
Switch's dimensions – length= 0.1mm, width = 0.15mm



a)



b)

Figure 5.(a) Dimensions of switch, (b) Dual-band linear polarized Reconfigurable patch antenna in L and S-band in FEM solver.

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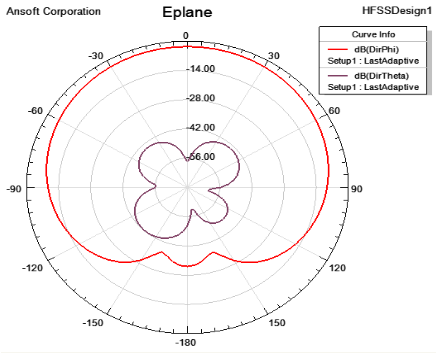
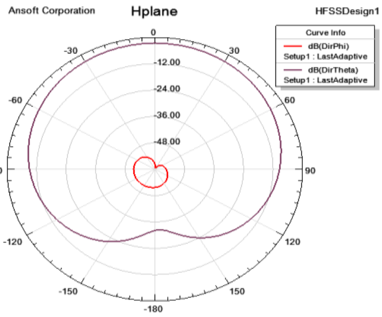


a) E-plane



b) H-plane

Figure 6. Far-field Radiation Pattern

Design of the six-port direct conversion front-end module consists of individual block design of quadrature branch line coupler and Wilkinson's power splitter working in dual frequencies. Following three sub-sections describe the design in detail.

B. Branch-line coupler

Coupler Branch-line coupler is the back-bone of the phase-shifting network of the receiver architecture. Traditional 3-dB branch-line couplers consist of (λ/4) branches with 50 Ω and (50/√2 Ω) impedances. These branches have an electrical length of 90° at a single frequency [9,10].Figure 7 is same as fig 1 of [7].

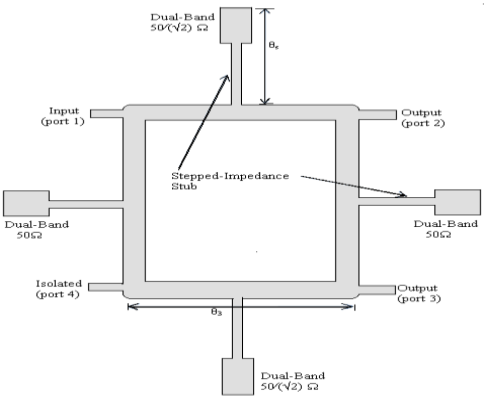


Figure 7.Schematic diagram of the dual-band branch-line coupler with stepped-impedance stub

Proposed layout is shown in Fig.8 is same as fig 2 of [7], which occupies an area of 24.25 × 18.5 mm^2, which is 80 % reduction in size as compared to conventional topologies & 64% reduction compared to earlier structure [11].

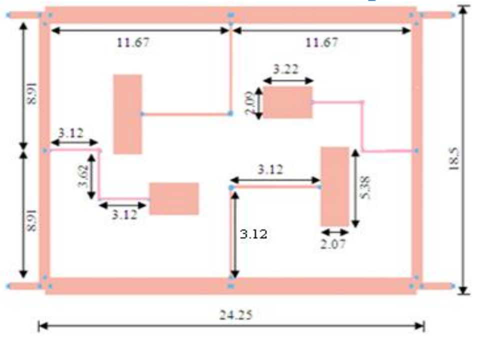


Figure 8.Layout of the proposed coupler.

C. Power Divider

Signals received by the front-end antenna of the receiver module is splitted equally in amplitude and phase with the aid of Wilkinson's power divider network, which provides excellent isolation between the two output ports as compared to other reported topologies [12]. Current receiver module demands power splitter which operates at two desired frequencies (L and S-band). In context with this, a simplified compact MIC based circuit was reported on 675µm High-Resistive Silicon substrate, whose layout structure is shown in Fig 9 which is same as fig 2of [12]. The divider occupies an area of 28×14 mm^2.

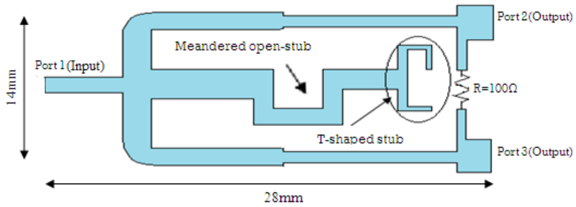


Figure 9.Layout of the dual-band power divider.

D. Receiver Module

The complete receiver module is made by integrating power divider and quadrature hybrids for dual-band operation. Fig-10is same as fig 4(a) of [7]shows the schematic diagram of the six-port architecture.

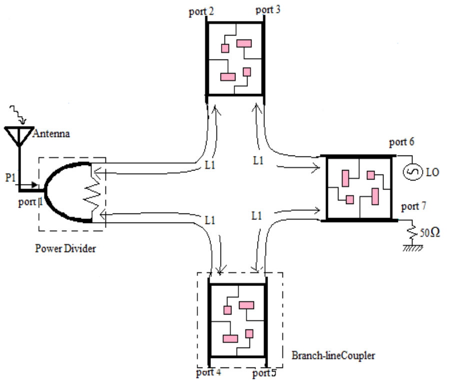


Figure 10.Schematic diagram of the six-port architecture.

E. Fabrication and Measured results

Fabrication of the structure is done by using standard CMOS process on 6" high resistive (ρ > 8 kΩ-cm) wafer of 675 µm thicknesses. PECVD oxide of 5 µm thickness is deposited as a buffer layer. Metallization is completed using sputtering and standard wet chemistry is engaged for etching purpose. The

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dimension of the structure is around 150 μm. Micro-strip ground plane is created by evaporating 1 μm chrome-gold layer at the backside of wafer. Standard dicing tool is used for dicing purpose with diamond cutter and after this it is integrated on jig using conductive epoxy. Fig. 11 and 12 show the fabricated pictures with RF connectors at the I/O ports.

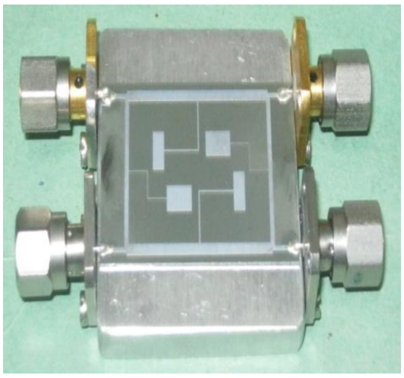

Figure 11. Photograph of the fabricated branch-line .

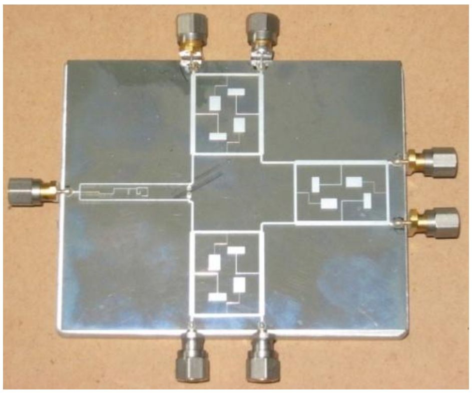

Figure 12. Photograph of the fabricated coupler 6-port receiver.

The performance parameters are measured in R&S ZVA-40 Vector Network Analyzer. These are in close agreement with simulated results as can be seen in Fig 13-18. The slight deviations are attributed to finite resistivity and its deviation from the assumed value. The performance parameters like insertion loss, return loss and isolation indicates that silicon is a viable RF substrate and can be implemented as MIC substrate.

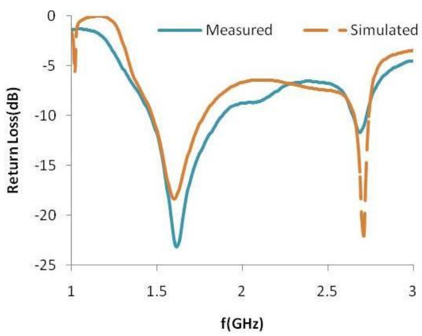

Figure 13.I/O Return loss performance of the coupler.

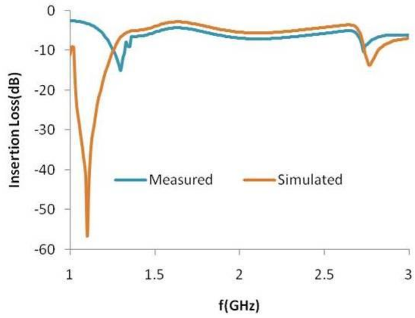

Figure 14.Insertion loss performance of the coupler.

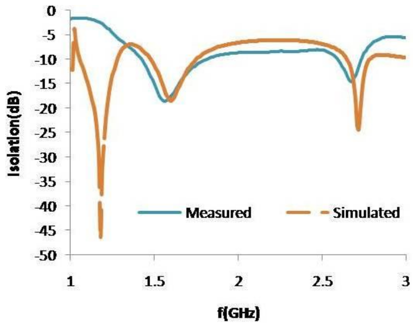

Figure 15. Output port isolation of the coupler

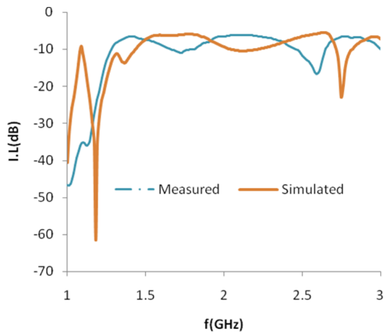

Figure 16. Insertion loss of the complete receiver

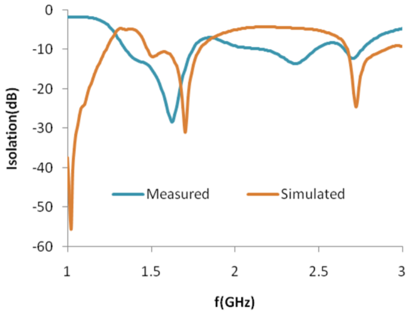

Figure 17.Output port isolation of the receiver module.

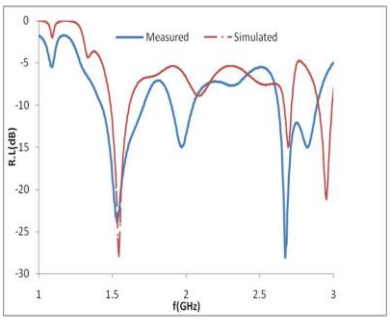

Figure 18.I/O Return loss performance of the receiver module.

F. Discussion

The design of proposed dual-band patch antenna with six-port receiver module which is shows in fig 19 is targeted for Indian Navigation System (INS). This designed antenna is then integrated with mono-pulse microwave comparator (Direct conversion type) [7]. The final designed is meant for applications like direct of arrival (DOA) and for GPS.

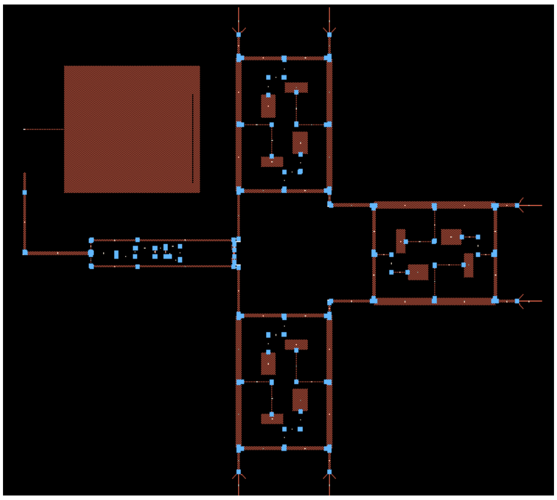

Figure 19. Final Proposed Design

V. CONCLUSION

In this work, the design and development of dual-band patch antenna is emphasized. Various configurations have been tried to obtain linear and circular polarization in the same design. Finally, reconfigurable concept is employed utilizing capacitive type MEMS switch. By changing the capacitance ratio, the resonant frequency of the antenna is altered. Dual-polarization (linear and circular) can be adopted in the single patch antenna with dual-band operation.

In future the present work can be extended further by integrating this kind of antenna in the 6-port mono-pulse receiver module, used for RADAR application. And, moreover dual-polarization antenna can be useful for SAR applications. And, finally an array of big size can be tried to maximize the gain of the overall antenna structure

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