Substrate material selection and design optimization of patch antenna

Anil Kumar Dubey
Department of Electronics and Communication Engineering
Greater Noida Institute of Technology, Greater Noida, India
anilkumardubey10@gmail.com

Abstract- In this paper parametric analysis of different substrate materials used for microstrip patch antenna are analyzed based on its physical properties, also parametric calculation performed for selection of substrate working at operating frequency of 5.8 GHz. Proposed microstrip patch antenna was optimized by varying its design structure from rectangular patch to E-shaped structure. Method of moment based electromagnetic simulator IE3D was used for parametric calculation and optimization of proposed patch antenna design.

1. Introduction
Patch antenna consists of conducting patch on a ground plane separated by dielectric substrate and it radiates electromagnetic signals at high frequencies. This type of miniaturized design of patch antenna was first conceived in 1953 by G. A. Deschamp in USA [1]. Later on in 1955 H. Gutton and D. Baissinot patented an aerial antenna of similar design working in UHF band in France [2]. In 1975 J. Q. Howell elaborated design of rectangular shaped patch antenna and circular shaped patch antenna [3]. The patch antenna can be used as an transmitting and receiving device [4]. ISM Band frequency 5.8 GHz is chosen for designing of patch antenna as radio can support upto 1300 Mbps wireless speed and in 2.4 GHz it is between 450 Mbps to 600 Mbps[9]. Different substrate materials are considered for designing of patch antenna having dielectric constant lies between 2 to 12 i.e., $2 < \varepsilon_r < 12$ [6]. Patch antenna can be designed in the shape of rectangle, circle, triangle etc. Further its geometry can be modified using analyzing its radiation properties and its broadband applications [5]. Different parametric results like return loss, radiation pattern, gain, VSWR etc. are analyzed on simulating its design on electromagnetic simulator IE3D.

2. Design flow of Patch Antenna
As operating frequency selected for patch antenna design is 5.8 GHz. Rectangular shaped patch antenna dimensions are calculated using the antenna design equation [7]. Parameters for designing of rectangular patch antenna are-

Resonating frequency ($f_r$) = 5.8 GHz (ISM Band)
Width of Rectangular patch antenna ($W$) = 29 mm
Length of Rectangular patch antenna ($L$) = 18.35 mm
Height of dielectric Substrate ($h$) = 1.580 mm
Feed point position on rectangular patch is calculated and simulated. Final proposed design of patch with feeding point is shown in figure 1.

**Figure 1.** Structural view of rectangular patch antenna

On designing and analyzing the patch antenna using different substrate material, following three substrate materials have better performance on the basis of return loss, VSWR, gain and radiation pattern etc [8].

1. **Substrate 1: RT Duroid**
   Dielectric constant $\varepsilon_r$ of RT Duroid = 2.2, loss tangent $\delta = 0.001$, water absorption = 0.02%, tensile strength = 450 MPa.

2. **Substrate 2: RO4003**
   Dielectric constant $\varepsilon_r$ of RO4003 = 3.5, loss tangent $\delta = 0.002$, water absorption = 0.06%, tensile strength = 141 MPa.

3. **Substrate 3: FR4 Glass Epoxy**
   Dielectric constant $\varepsilon_r$ of FR4 = 4.4, loss tangent $\delta = 0.001$, water absorption < 0.25%, tensile strength < 310 MPa.

Parametric comparison of above chosen substrate materials after simulating different substrate material based antenna on electromagnetic simulator IE3D are compared and shown in Table 1 below. They are compared on the basis of return loss, VSWR and Gain.

**Table 1:** Comparison of various substrates

| Parameters / Substrate Materials | Return Loss (dB) | VSWR | Gain (dB) |
|----------------------------------|------------------|-------|-----------|
| RT Duroid                        | -24.04           | 1.26  | 3.42      |
| RO4003                           | -22.26           | 1.68  | 5.20      |
| FR4                              | -20.64           | 1.28  | 1.89      |
On the basis of above parametric comparison RT Duroid is selected for further design of rectangular patch antenna as its return loss is -24.04 dB that will be good radiating and can be used for designing of antenna.

3. Proposed patch antenna design

Parametric outputs of proposed designed rectangular patch antenna after simulating it on IE3D Electromagnetic Simulator.

3.1 Return Loss (RL) of proposed patch antenna:

Return loss of rectangular patch antenna is shown in figure 2.

![Figure 2. Return Loss of proposed patch antenna](image)

Return Loss = -24.0412 dB  
Highest Frequency ($F_{H}$) = 6.950 GHz  
Lowest Frequency ($F_{L}$) = 6.716 GHz  
Operating Bandwidth = $F_{H} - F_{L}$ = 234MHz

Bandwidth of 234 MHz achieved on designing rectangular patch antenna but the operating frequency band is from 6.7 GHz to 6.9 GHz and our requirement is around 5.8 GHz.

3.2 Current distribution of proposed patch antenna:

Current Distribution of proposed patch antenna is shown in figure 3. Obtained current distribution is not satisfying our requirement for designing practical patch.

![Figure 3. Current distribution of proposed patch antenna](image)
3.3 VSWR for proposed patch antenna:
Voltage standing wave ratio for proposed patch antenna is shown in figure 4. In operating range proposed antenna VSWR is close to one. i.e. $\text{VSWR} \approx 1$.

![VSWR of proposed patch antenna](image)

**Figure 4. VSWR of proposed patch antenna**

Parametric output results shows that center frequency of proposed antenna is 6.8 GHz but the required center frequency is 5.8 GHz. Further optimization in designing of patch antenna was possible. Optimization can be done by improving its design from rectangular shape to other shape like circular or triangular.

4. Optimized patch antenna design
Proposed patch antenna designed is further optimized by varying its geometry. Artificial neural network algorithm was used for calculations of dimensions variations and its effect was analyzed in wideband frequency application. Different geometry like circular, triangular etc. are simulated on electromagnetic simulator IE3D software. But our design requirement was satisfied by designing the patch that resemble to the geometry shape of English alphabet “E” [10] [11]. The pattern structure of proposed patch antenna is shown in figure 5.

![Pattern structure of E shaped patch antenna](image)

**Figure 5. Pattern structure of E shaped patch antenna**
Parametric outputs of designed E-shaped patch antenna after simulating it on IE3D electromagnetic simulator.

### 4.1 Return Loss of E-shaped Patch Antenna:
Return loss of E-shaped patch antenna is shown in figure 6. Center resonating frequency of 5.8 GHz achieved, also its operating bandwidth is 150 MHz.

![Figure 6. Return Loss of E shaped patch antenna](image)

- Return Loss = -23.3053 dB
- Highest Frequency ($F_{H}$) = 5.875 GHz
- Lowest Frequency ($F_{L}$) = 5.725 GHz
- Operating Bandwidth = $F_{H} - F_{L}$ = 150 MHz

### 4.2 Current distribution of E shaped patch antenna:
Current distribution of E shaped patch antenna is shown in figure 7. Uniform current distribution is achieved.

![Figure 7. Current distribution of E shaped patch antenna](image)
4.3 VSWR of E shaped patch Antenna:
Voltage standing wave ratio for designed patch antenna is shown in figure 8. In Operating range designed antenna VSWR is close to one. i.e. VSWR ≈ 1.

Figure 8. VSWR of E shaped patch antenna

5. Result and Conclusion
Final design of patch antenna of E shape having substrate RT Duroid of dielectric constant 2.2 on simulating on electromagnetic simulator IE3D shows the bandwidth of 150 MHz at operating frequency of 5.8 GHz which satisfy the requirement of patch antenna design as its return loss is -23 dB at operating frequency, and voltage standing wave ratio is approximately equal to one. Current distribution and near far field electric and magnetic distribution are also fulfilling the requirement. The proposed patch antenna of E-shape can be commercially used for the applications like-fixed satellite, radiolocation, amateur satellite services and mobiles.

6. References
[1] G A Deschamps 1953 Microstrip microwave antenna (3rd USAF symposium on antenna)
[2] G Baissinot and H. Gutton 1955 High frequency antenna (French patent no 703113)
[3] J Q Howell 1975 Microstrip Antennas (IEEE Transaction antennas propagation) vol. AP-23, pages: 90-93
[4] M Kanda 1990 A microstrip patch antenna as s standard transmitting and receiving antenna (IEEE Transactions on Electromagnetic Compatibility) vol. 32, Issue: 1
[5] J H Lu, C L Tang and K L Wong 2000 Novel dual frequency and broadband designs of loaded equilateral triangular microstrip antenna (IEEE Transaction antenna propagation) vol. 48, pages: 1048-1055
[6] K L Wong 2002 Compact and Broadband Microstrip Antenna John Wiley and sons
[7] C A Balanis 2005 Antenna theory analysis and design John Wiley and sons
[8] A A Roy, J M Mom, D T Kureve 2013 Effect of dielectric constant on the design of rectangular microstrip antenna (IEEE International conference on emerging & sustainable technologies for power & ICT in a developing society NIGERCON)
[9] N P Ojaroudi 2014 Design of microstrip patch antenna for 2.4/5.8 GHz RFID applications (German microwave conference GeMic)
[10] S Shivani, D Tarishi, K Manoj, S Avinash 2018 Microstrip E-shaped patch antenna for ISM Band at 5.3 GHz frequency application (IEEE International conference on microelectronics and telecommunication engineering ICMETE)
[11] A K Rastogi, G Pravin, S Sharma 2019 Comparative study of rectangular and E-shaped microstrip patch antenna array for X-band applications (Chapter in advances in intelligent systems and computing)