Design and Simulation of 2.4GHzMicrostrip Patch Antenna for IoT Applications

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Abstract:

Antennas plays a vital role in wireless communications. The Internet of things (IoT) refers to the Internet connectivity among computers, mobile devices and sensors. These devices can able to communicate and interact with each others over the Internet, and they can also be remotely monitored and controlled.[1]

Most of the IoT applications function in the unlicensed ISM (The Industrial, Scientific, and Medical radio) bands of 2.4GHz, Wireless connectivity for IoT devices can be done using Bluetooth, Zigbee, Wi-Fi which can utilize the frequency zone of ISMband . the Institute of Electrical and Electronics Engineers agreed that 2.4 GHz, with its wide channel selection and range/penetration/cost potential, was a safer bet. Today, some Wireless N routers can operate on both 2.4 GHz and 5 GHz bands concurrently.[6] The 2.4 GHz ISM band is a commonly accepted band for worldwide operations. MW ovens, cord-less phones, medical machines, military RADARS and industrial heaters are uses this ISM band which is also be called unlicensed bands.[2]

In this paper, a 2.4 GHz microstrip patch antenna with both coaxial feed and microstrip line feed on Rogers RT/duroid 5880(tm) substrate whose relative permittivity is 2.2 aredesigned, the antenna can be operated at 2.3625GHz frequency with a return loss of -35.9002dB.For coaxial feed and at 2.2875 GHz frequency with return loss of -10.0902dB.respectively

Keywords: Antennas, Internet of Things, Blue Tooth, Wi-Fi, AnsysHFSS13.

1. INTRODUCTION

Many of IoT networks uses star, mesh, or point-to-point topologies to smartly guide the uplinks and downlinks between gateways and end-devices. This means the job of establishing a link is accomplished through the use of omni-directional antenna structures such as chip, PCB, whip, rubber duck, patch, and wire antennas. Many IoT-based development kits and radio modules such as Qualcomm's Internet-of-Everything (IoE) development platform or the Arduino GSM come with GPS, Bluetooth, and WiFi antennas.

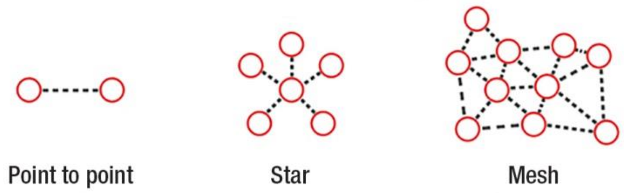

Fig:1IoT devices rely on specific topologies

2. Antennas Parameters:

There are generally two defining parameters for antennas: gain and directivity.

Gain of an antenna is defined as "the ratio of maximum radiation intensity in given direction to the maximum radiation intensity from a reference antenna produced in the same direction with same power input".

Gain(G)=(Max. Radiation Intensity from test antenna) /(Max. Radiation from reference antenna with same input power)

Where reference antenna is taken as isotropic antenna then gain of subject antenna is denoted by $G_0$and is also known as Gain with respect to isotropic antenna.

Gain(Go)=(Max. Radiation Intensity from test antenna)/(Radiation Intensity from isotropic antenna with same input power)

Directivity or directive gain (G_d) in given direction is defined as "the ratio of the radiation intensity in that direction to the average radiated power".The directive gain is a function of angles (θ and φ)

Let Φ (θ, φ) = Radiation Intensity in particular direction and
Φav= average radiation intensity in that direction = Wr/4π

Directivegain=(Radiation intensity in a particular direction)/(Average radiated power)

Directive gain in decibels is given as Gain dB= 10log10{(4πΦ (θ,φ))/(∫ΦdΩ)}

Directive gain G_d=(Power density radiated in a particular direction by subject antenna)/(Power radiated in that particular direction by an isotropic antenna)

IoT networks that utilize the unlicensed ISM bands must be within the Equivalent (or Effective) Isotropic Radiated Power (EIRP) required, The EIRP is the total power an ideal isotropic antenna would have to put out to provide the same signal strength as the Antenna Under Test (AUT) in the direction of the AUT's strongest beam. This parameter takes into account the gain, transmitter output power, as well as the loss due to the antenna feed and therefore provides a more holistic perspective of the transceiver module.

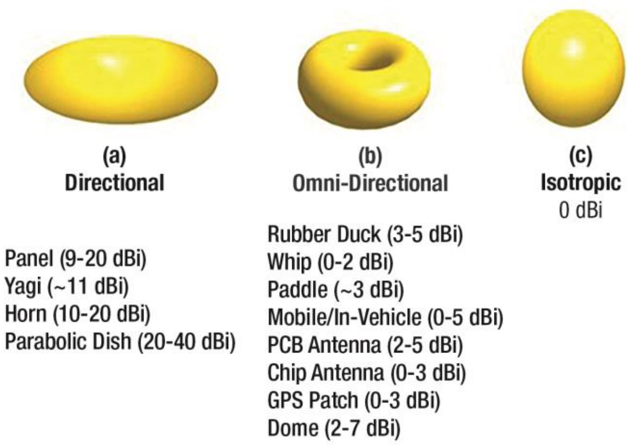

Figure 2: Antennas can present either directional or omni-directional radiation patterns.

3. Various types of Antennas Used in IoT Devices:

The typical antennasare wire, whip, rubber duck, paddle, chip, and PCB. As stated earlier, the frequency of the given IoT application must fall into the antenna's bandwidth. Table 1 depicts some common IoT applications and their respective wireless networking technologies, along with the frequency bands in which they function.

Applications	IoT Technology	Frequency
General (smart home, smart building, etc)	Zigbee	915 MHz, 2.4 GHz
	Z-wave	2.4 GHz
	Bluetooth	2.4 GHz
	WiFi	2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, and 5.9 GHz
	GPS	1575.42 MHz, 1227.6 MHz, 1176.45 MHz
IIoT	WirelessHART	2.4 GHz
	ISA 100.11a	2.4 GHz
LPWAN (smart city, smart farming, etc)	LoRa	915 MHz for the U.S., 868 MHz for Europe, and 433 MHz for Asia
	Sigfox	868 MHz, 902 MHz
Medical	MBAN (IEEE802.15.6)	2360 to 2400 MHz
	WBAN (IEEE 802.15.6)	2.4GHz, 800MHz,900MHz,400MHz
Avionics	WAIC	4200 MHz to 4400 MHz

Table 1: Operational frequencies of various IoT technologies

3.1**Whip Antennas and Ground Plane Considerations:**

Whip, rubber duck, and paddle antennas like monopole or quarter wave λ/4 antennas have the benefit of modularity, as they are not integrated onto the PCB of the IoT device, a dipole has two radiating elements that meet at the feed-point, while a monopole antenna replaces the second one with the ground plane.

Compared to the lesser used dipole antenna, the monopole has a lower angle of radiation allowing for a longer propagation range particularly at low UHF frequencies.

3.2Patch Antenna Considerations

Patch antennas can be designed for dual polarization and are often used in IoT devices with GPS capabilities as signals transmitted by satellites are often either right-handed circular polarization, or left-handed circular polarization .

3.3Chip and PCB Antenna Considerations:

PCB antennasincluding inverted-F, L, and folded monopole often exhibit higher gains than their chip-based counterparts and IoT devices with embedded antennas like chip and PCB have the benefit of fitting into small spaces, shrinking a sensor node's dimensions.

Omni-directional chip antennas have a cardioid-shaped radiation pattern with lowest gains. When tested in real environments, these antennas can show a higher directionality in a particular direction, Wearable IoT applications like WBANs will most likely require the use of chip antennas due to its benefits of size.

3.4Directional Antennas for IoT:

High-gain Directional antennas like Yagi-uda andPanel (sector) antennas can are often used in Supervisory Control and Data Acquisition (SCADA) systems for IIoT and in SigFox, LoRa, and WLAN base stations respectively.

4.PROPOSED ANTENNA DESIGN

Microstrip Patch antenna is designed for 2.4 GHz operation on a Rogers RT/ Duroid5880(tm) substrate with 2.2 permittivity and 1.57 mm thickness. The length (L) was chosen to be the same as W to obtain a symmetric radiation pattern.

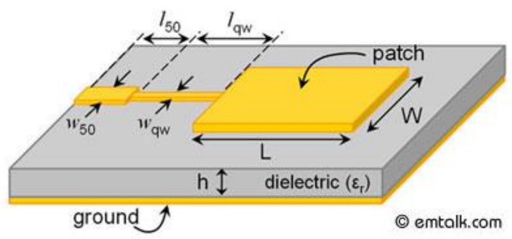

Fig:3Microstrip patch antenna model

HFSS Process Flow topics: High frequency simulator structure software is a high performance full wave electromagnetic field simulator for arbitrary 3D volumetric passive device modeling. Ansoft HFSS employs the finite element method (FEM), adaptive meshing and effective graphs for all 3D EM problems.
Ansoft HFSS can be used to calculate parameters such as S-parameters, resonant frequency and fields. It is used to design an Electromagnetic wave processing devices such as antennas, waveguides, resonators, MW filters ect.

Fig:*4*HFSS Process Flow

The Ansoft HFSS Desktop provides an intuitive, easy-to-use interface for Developing passive RF device models. Creating designs, involves the following:

- Parametric Model Generation – creating the geometry, boundaries and Excitations.
- Analysis Setup – defining solution setup and frequency sweeps.
- Results – creating 2D reports and field plots.
- Solve Loop - the solution process is fully automated.

Model Setup:

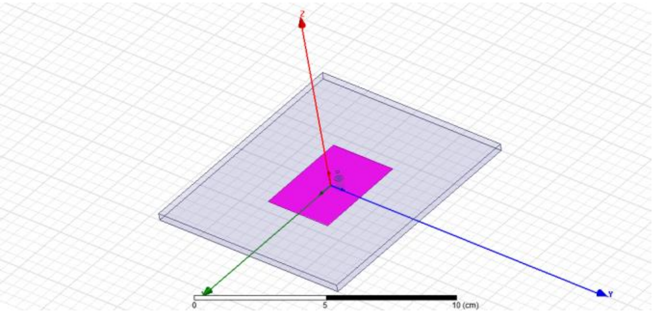

Fig:5Microstrippatch antenna with probe feed layout

It consists of rectangular substrate and the metal trace layer as shown in Fig.4The dimensions of antenna can be found as

- W: 41.08 mm
- L: 41.08 mm
- l_{qw}: 24.05 mm
- w_{qw}: 0.72 mm
- l_{50}: 15.00 mm
- w_{50}: 4.84 mm

we can create our own material in HFSS by mentioning the relative permittivity, relative permeability, dielectric loss tangents values.

S.NO	Material	Dielectric Loss Tangent	Relative Permittivity	Impedance Band Width
1	Air	0	1.0006	42%
2	Rogers RT/Duroid 5880	0.0009	2.2	35%
3	Epoxy	0	3.6	24%
4	FR4 epoxy	0.02	4.4	10%

Table:2. Different Bandwidths Obtained For Different substrate Materials

To open a new project:
- select the menu item File > New.
- Select the menu Project > Insert HFSS Design.

The solution type window is
- Select the menu item HFSS > Solution Type

Choose the following:
- Driven Terminal

Excitations:
- Wave Ports (External)
- Lumped Ports (Internal)

Surface Approximations:
- Symmetry Planes
- Perfect Electric surface or perfect Magnetic Surfaces
- Radiation Surfaces
- Background surface or Outer Surface

Material Properties:
- Boundary between two dielectric materials
- Finite Conductivity of a conductor

Add Solution Setup
- Adapt Frequency
- Convergence Criteria
- Initial Mesh Options
- Adaptive Options
- Low-Order Basis Functions

Setup
- Properties

- Add Sweep
- Sweep – Properties and Types of Sweeps

There are three Frequency Setup Options:

- Linear Step -- specify a linear range of values with a constant step size.
- Linear Count -- specify a linear range of values and the number, or count, of points within the variable range.
- Single Points -- specify a single value for the sweep definition.
- It is possible to save the Field data for every point in the Fast Sweep andthe Discrete Sweep. To save the Field information make sure that the Save Fields (All Frequencies) box is checked.
- For the Interpolation Sweep, only the Field data for the last solved frequency will be available for post-processing.

HFSS uses the following equation: ‘’ Max. Freq. = (0.5/T_r) * Time Steps Per Rise Time ’’ where T_r=Signal Rise Time
To Create a Plot:
1. Select HFSS > Results > Create Report
2. Click OK and the Report Editor will be displayed – we will go over the options in the dialog.

The antenna with airbox&waveport setup is shown in Fig. 6

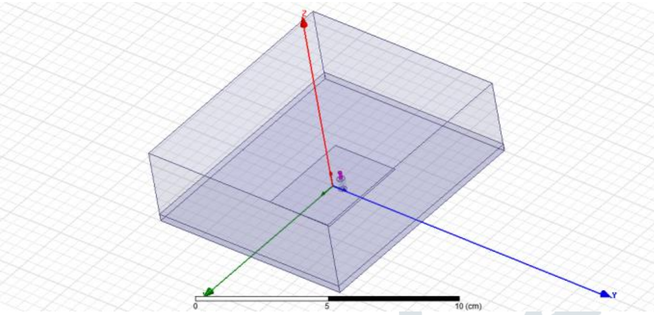

Fig:6. Probe feed patch antenna layout showing air-box and wave-port.
Analysis/Sweep Setup
A Solution Setup is added to the analysis with the following:
Solution Frequency: 2.4 GHz
Maximum # of Passes: 15
Maximum Delta S: 0.02

Plotting Results:
The return loss of the 2.4GHz antenna is shown in Fig. 7.

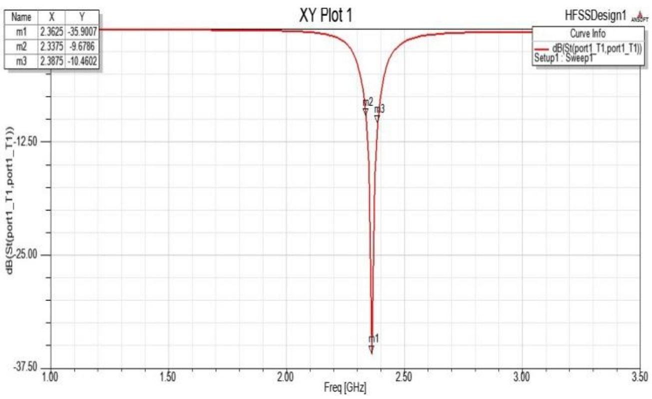

Fig:7. Antenna Return loss from 1 GHz to 3.5 GHz.

From Fig. 7, the resonance frequency of the antenna occurs at 2.36 GHz with a return loss of -35.9002dB.

The field plot is shown in Fig. 8

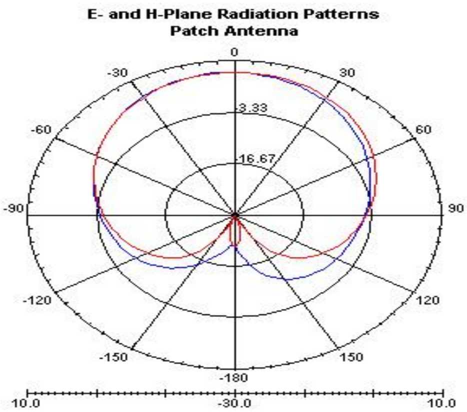

Fig:8. E-field distribution on antenna at 2.36 GHz.

To plot the far-field patterns of the antenna, a far-field setup has to be created.

To create each far-field setup go to *HFSS>Radiation>Insert Far-Field Setup>Infinite Sphere*.

For the 2D pattern, the default values have to be changed such that Phi should start at 0 degree and stop at 90 degrees with a step size of 90 degrees.

Fig. 9 shows the 2D patterns and Fig. 10 shows the 3D patterns.

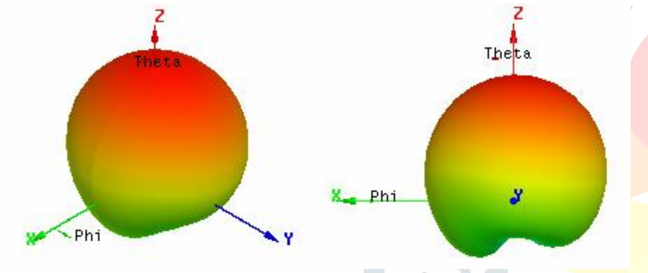

Fig:9. 3D far-field patterns.

To obtain the antenna radiation efficiency and antenna peak gain, etc. go to *HFSS>Radiation>Compute Antenna/Max Param* and choose 2.36 GHz as the frequency of interest.

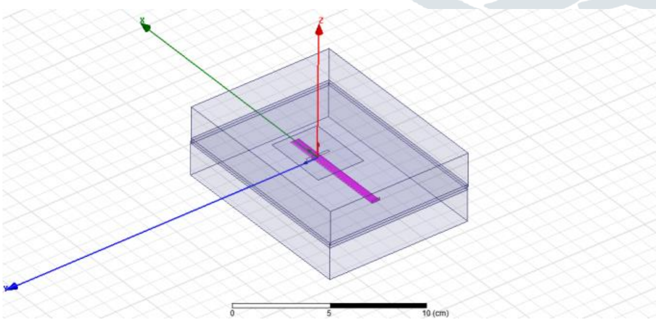

Fig:10Microstrip slot antenna with microstrip feed

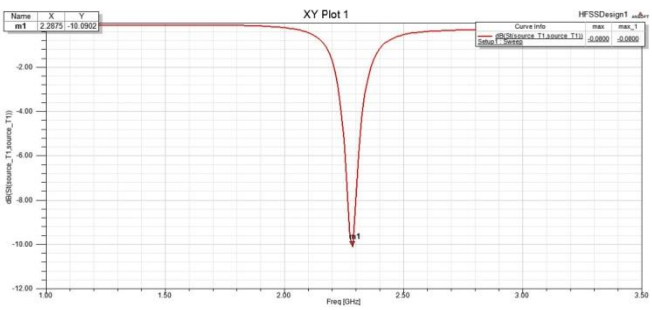

Fig:11Return loss of slot antenna with microstrip feed

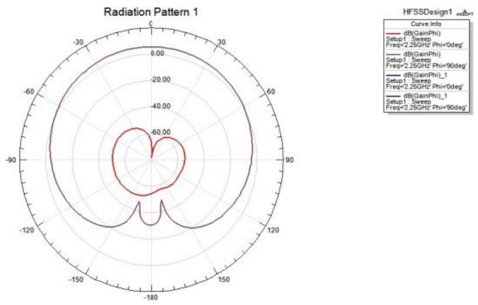

Fig:12 gain plot of slot antenna with microstrip feed

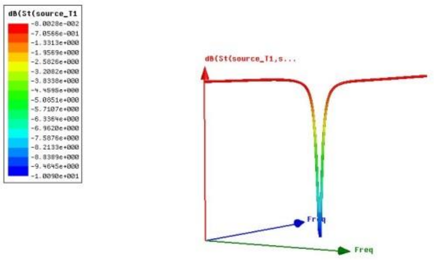

Fig:13 3D plot of Return loss of slot antenna with microstrip feed

4. CONCLUSION

A rectangularmicrostrip patch antenna with coaxial feed and microstrip feed has been designedon Rogers RT/duroid 5880(tm) substrate whose relative permittivity is 2.2 and simulated, optimized and analysed using HFSS (High Frequency Structure Simulator) software version 13. the antenna can be operated at 2.3625GHz frequencywith a return loss of -35.9002dB.For coaxial feed and at 2.2875 GHz frequency with return loss of -10.0902dB.respectively.

5. REFERENCES

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