An Ultra-Wideband CPW Fed Slot Antenna for IoT Applications

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Abstract. An Ultra-wideband (UWB) radio is a fast-emerging technology. It is offering several unique attractive features that promotes major advances in wireless communications, networking, imaging, radar and positioning systems. Here, an Ultra-Wideband Coplanar Waveguide fed Monopole antenna for IoT Applications is proposed. The bandwidth of the antenna is enhanced due to the partial rectangular patch and the round corner of the rectangular slot. To validate the simulation results, prototypes of the proposed antenna are fabricated and tested. Based on the results, good agreement has been achieved between the measurement and simulation. The antenna prototype with a total size of 138 mm × 40 mm achieves good impedance matching, constant gain and stable radiation patterns. The impedance bandwidth of the antenna reaches up from 600 MHz to 6.0 GHz for S11 with good omnidirectional radiation performance has also been achieved.

1. Introduction

Antennas are an important integral part of wireless communication. With the advances in wireless communication and a wider range of applications utilizing wireless technology, the antenna selection and design are significant. Ultra-Wideband (UWB) is now gaining a lot of attention in the academia and industry field. The benefits of UWB technology come from its unique features on how it provides more efficient solutions to wireless broadband compare with other technologies. The UWB antenna is important for providing wideband wireless communications. This is based on the use of very narrow pulses on the order of nanoseconds, covering an ultra-wide bandwidth in the frequency domain, and over short distance at very low spectral power densities. Furthermore, the antennas required to have a non-dispersive characteristic in time and frequency hence it is providing a narrow pulse duration to enhance a high data throughput.
The Internet of Things, or known as IoT refers to the billions of physical devices around the world that are now connected to the internet, all collecting and sharing data. Table 1 depicts some common IoT applications and their respective wireless networking technologies, along with the frequency bands in which they function. These days, Fifth Generation (5G) wireless communication is a new conventional technology, which is an evolution of 4G LTE network that are very important to our future. 5G communication has allow data to be transferred from one place to another with a very high-speed transfer rate. With the high-speed transfer of 5G, now it is possible to perform machinery from long distance. The use of communication technology such as mobile phone and computer is very popular in this Industry 4.0 era where the number of users increases every day. Furthermore, with 5G, huge number of devices can be connected to into a network with ease. To achieve 5G, the antenna use needs high gain and broad bandwidth.

There are numerous methods to enhance the bandwidth of an antenna. One of them by using four dipole antenna elements and four pairs of parasitic strips. [1]. The antenna is compact and produce high bandwidth. However, the antenna produced low gain which is not suitable for 5G application. On the contrary, the dipole antenna with defected ground structure produce high gain [2-4] but, the structures are complex and bulky in size. More recently, there is another technique that able to improve the bandwidth by combining two antenna structures [5-8]. With this technique, a high bandwidth and gain can be produced but it will be more complex geometrical in structure and design.

In this paper, a new design of a Co-Planar Waveguide (CPW) fed monopole antenna for IoT communication application is presented. A technique for enhancing the impedance bandwidth is also studied. Details of the proposed design performance are presented and discussed. Finally, the simulated results are validated with measurement results.

### Table 1. Operational frequencies of various IoT technologies

| Application                  | IoT Technology | Frequency (MHz)       |
|------------------------------|----------------|-----------------------|
| Smart home, smart building, etc | Zigbee Technology | 915, 2400             |
|                              | Z-wave Technology | 2400                 |
|                              | Bluetooth Technology | 2400                |
|                              | WiFi Technology | 2400, 3600, 4900, 5000 and 5900 |
| IIoT                         | GPS Technology | 1575.42, 1227.6, 1176.45 |
| LPWAN (smart city, smart, etc) | WirelessHART | 2400                 |
|                              | ISA 100.11 a | 2400                  |
| Medical Application           | LoRa Technology | 915, 433              |
|                              | Sigfox Technology | 868, 902             |
| Avionics                     | MBAN Technology | 2360 to 2400          |
|                              | WBAN Technology | 2400, 800, 900, 400   |
|                              | WAIC Technology | 4200 to 6000          |

2. Antenna development and configuration

Selecting antenna topology for UWB design, numerous factors shall be considered including compatibility, physical profile, radiation pattern, gain, directivity, impedance bandwidth and radiation efficiency. Specially for microwave wireless communications, there are special design development considerations for UWB Antenna systems. In this section, the proposed UWB antenna is presented in detail. The novelty slotted CPW fed monopole antenna are attained by assessing various slots configurations. Former the actual prototype is built, the effect of adding the slot to the antenna impedance bandwidth are examined by using CST Microwave Studio 3D EM simulation tool software.
2.1 Antenna design development

Patch antenna is very convenient because the antenna is printed straight on the circuit board. Patch antenna easy to fabricate and cost effective [9]. Their low-profile design allows the antennas to be mounted on the flat surfaces without a problem. There are several shapes of patch antenna. The most common one is rectangular shape that consist of the Length, L and Width, W which will determine the size of the rectangular. It also has a dielectric substrate constant, εr and thickness of the substrate, h. The initial design of the proposed antenna is shown in the Figure 1. However, the optimization is required in order to obtain a wide bandwidth result. Hence the alteration of the antenna is done as shown in Figure 2. Table 2 shows the antenna parameter.

Numerous geometries of planar monopole antennas have been used as guidelines in the proposed CPW fed monopole antenna design. Several planar monopole geometries such as elliptical, circular, pentagonal, rectangular, hexagonal, and square, have been proposed in numerous papers, providing ultra-bandwidth [10-16]. In this paper, the rectangular geometry is chosen as initial geometry to form numerous originalities polygonal. Furthermore, rectangular shape is flexible to be modified.

In order to design a UWB antenna, two or more resonant frequency with each one operating at its own resonance is required. The overlapping of these multiple resonances will create a broadband or multiband performance. Hence, this design is selected to produce two or more resonant bands for achieving ultrawide bandwidth. Moreover, disparate the conventional UWB monopole antenna that use a solid ground plane on the other side, the two grounds were etched on the same plane of the monopole were used in this design as shown in Figure 1. The mentioned design skills are introduced to obtained UWB with a good impedance matching over the entire operating band. Figure 2 shows the modifications of the antenna.

![Figure 1. Modelling of initial design of the antenna, (a) Front view, (b) Tapered Feed, (c) Antenna Ground Plane](image-url)
To analyze the performance of the proposed antenna, the antenna is designed and simulated using the CST Microwave Studio 3D EM simulation tool. The effects of adjusting the antenna parameters are investigated to provide insight on the effect of the parameter on the impedance matching of the antenna. Parametric analysis for different parameter values has been carried out by varying one parameter and keeping all the other parameters as constant. Next, the bottom edge of the rectangular patch antenna has been blended to form a semicircular shape and slot has been created in the middle. The measurement of the substrate is FR4 substrate ($\varepsilon_r = 4.3$) with the size of (138 x 40) mm has been used for the design. Initially, the design has a monopole radiating with a rectangular shape of a width ($w$) 36 mm and a length ($l$) of 90 mm. The main objective in this antenna design is to create a wide bandwidth omnidirectional antenna. Thus, the dimension of this rectangular radiator is kept constant to maintain the gain. For the left and right ground, the size has been reduced where $G1 = 2$ mm, $G2 = 42$ mm, $G3 = 15$ mm, $G4 = 15$ mm, and $G5 = 29.97$ mm. The radiator is varied and have a smooth bottom or a bevel for better impedance matching as shown in Figure 2. The results from the simulation have shown that the bevel at the bottom or at upper edge of radiator and a slot give a very broadband bandwidth after optimization. Figure 2 shows several beveling techniques applied to the rectangular monopole antennas. Beveling at the left side, right side and both sides have shown a different simulation result. The optimized size of a bevel that found to increase the impedance bandwidth is shown in Figure 2(c). Following are the modifications performed to enhance the bandwidth of the antenna.

- Change the shape of the rectangular patch.
- Reduce the size of the ground
- Alter the size of feed.

| Parameters | Value (mm) | Parameters | Value (mm) |
|------------|------------|------------|------------|
| $W_S$      | 40         | $L_f$      | 44.80      |
| $L_s$      | 138        | $G_1$      | 6          |
| $W_p$      | 36         | $G_2$      | 42         |
| $L_p$      | 90         | $G_3$      | 15         |
| $W_f1$     | 0.35       | $G_4$      | 25         |
| $W_f2$     | 1.80       | $G_5$      | 19.24      |

Figure 2. Transition design of polygonal monopole antennas
2.2 Prototype and Fabrication

The antenna was fabricated as a real prototype once the required performance of antenna has been achieved. The proposed antenna was design using FR-4 substrate and copper with thickness of 1.6mm and 0.035mm respectively with permittivity of 4.8 and tangent loss = 0.001. The fabricated antenna is shown in Figure 3.

3. Result and Discussion

![Fabricated antenna in measurement process. (a) CPW fed monopole antenna during S11 measurement, (b) CPW fed monopole antenna inside the anechoic chamber for radiation pattern measurement.](image)

An Agilent network analyzer was used to measure the electrical performance of the proposed antenna such as S11 bandwidth and impedance matching. The wide bandwidth of the antenna with a dimension of $138 \times 40 \times 1.6$ mm$^3$ is achieved with a feed line size is $0.35 \times 1.80 \times 44.80$ mm$^3$. Figure 4 shows the return loss of the designed antenna at S11, -10dB. A good agreement between the measured and simulated results is observed. The small difference between the measured and simulated results is because of SMA connector soldering and fabrication tolerance. The measurement result shows that the antenna achieves the frequency range of 600 MHz to 6000 MHz which is in the range of sub-6GHz. Based on the result in the figure 4, the antenna produced a very wide bandwidth which is 163% of bandwidth hence it is suitable for current application. With this kind of result and performance this antenna can be considered as good wideband antenna.

Figure 5 shows the simulated and measured radiation pattern at three planes cut namely Azimuth, Elevation Phi 0 deg and Elevation 90 degree at sampling frequencies of 698 MHz, 960 MHz, 2400 MHz, 3800 MHz, and 5900 MHz, respectively. Figure 5 shows the linear polarization of electric field at resonance frequency. This elevation plane pattern lies on yz- plane shows better agreement results between simulation and measurement result. It is found that the antenna has nearly good omnidirectional radiation patterns at all frequencies in the Elevation plane (yz-plane) and Azimuth plane (xy-plane).
Hence, this antenna is suitable for many types of application. It is also observed that simulated results show a good agreement with measured results.

Figure 6 depicted the measured gain of the proposed antenna. The gain and radiation pattern antenna are measured using SG 24 anechoic chamber. It can be observed that the gain is significantly low at the low band edge.

![Figure 4. Measurement vs simulation result of S11 for CPW fed monopole antenna.](image)

![Simulation Radiation Pattern at 698 MHz](image)
Figure 5. Various result of Measured and Simulated result of Radiation Pattern. (a) 689 MHz, (b) 960 MHz, (c) 2400 MHz, (d) 3800 MHz, and (e) 5900 MHz
4. Conclusion
The CPW fed slot antenna was designed for wireless applications and IoT application. In this paper, the proposed CPW fed slot antenna has shown a good sync for the IoT communication frequency standard. The antenna has operating range of 750MHz to 6.5GHz with bandwidth of 163% which is very wide. The antenna also produces high gain between 1dBi to 4dBi. The radiation pattern is omnidirectional at the low frequency band while directional in the broadside at the higher frequency band. In the low band, the antenna is designed to have linear polarization and omnidirectional radiation for realizing a reliable wireless connection with base stations and terminals around. It exhibits lower return loss, broader bandwidth, high gain and better impedance matching compared to conventional antennas.

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