A Design of Dual-Band Coplanar Waveguide (CPW) Printed Antenna for 1.9-3.6GHz Applications

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Abstract

A dual-band coplanar waveguide (CPW) printed antenna for IoT application is proposed, mounted on a low-profile RT/Duroid 5880 substrate with dielectric constant of 2.2, loss tangent of 0.0009 and a standard height of 0.787mm. This design aims to cover the major frequency bands from LTE to Bluetooth/Wi-Fi band/WiMax/Zigbee, Extended IMT and 5G whereby the bandwidth range between 1.7 GHz to 3.6 GHz. The antenna is miniaturized through the CPW technique and has a rectangular size of 60 × 30 × 1.187 mm^3. The design and simulation of the result records a return loss of -25.12dB, peak gain of 4.23dBi, voltage standing wave ratio (VSWR) close to 1, omnidirectional radiation, and current distribution. Radiation efficiency reaches approximately 94%, with a total efficiency of 89.4% between 1.9GHz-3.6GHz.

Keywords: Dual-band CPW, Internet of Things, impedance bandwidth, reflection coefficient, radiation pattern, current distribution

1. Introduction

With increasing world population and the incorporation of Internet of Things (IoT) in multiple computer networks, microelectronics and modern communication, there are higher demands for better, flexible, and advance antenna module to support the embedded systems [1]. Antennas play a primary role in supporting such systems because they enable long-distance communication and efficient use of frequency spectrum that allows maximization of data transmitted over a given frequency band. An example is the dual-band antenna which is designed to support two frequencies that can cover multiband applications and provide sufficient bandwidth for the operating frequencies as well as reduced interference by neighbor devices.

In recent years, coplanar waveguide (CPW) has garnered immense attention across the globe especially in modern wireless communication systems due to their simple integration with microwave integrated circuits, low radiation loss and reduced dispersion as compared to microstrip antenna [2]. This type of waveguide has an additional third conductor centered in the slot region and specifically useful in developing active circuitry. The presence of the additional strip can support even or odd quasi-TEM mode at low frequencies as well as TE mode at high frequencies [3]. The modification of the dimensions of the signal strip or ground plane such as thickness, length and width play a vital role in determining the characteristics of a CPW-fed antenna [2].

There are a few main challenges in designing a dual-band CPW antenna which include miniaturization, large gain, high bandwidth coverage, low return loss, impedance matching, power, and radiation efficiency. Some of the techniques introduced to satisfy the abovementioned criteria includes the usage of metamaterials and complementary split ring resonator (CSRR) to increase gain or implementation of a magneto electric (ME) to achieve wider impedance bandwidth, higher gain, and compatible radiation patterns on both electric and magnetic plane [3].

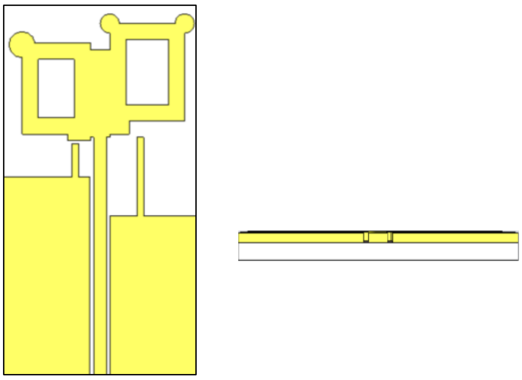
Hence, in this paper, the design of this waveguide is done by utilizing the CST software which involves careful selection of substrate properties, structure of CPW, and feed network. The simulation result allows optimization and evaluation of antenna performance over a desired frequency range. The proposed antenna presents a dual-band coplanar waveguide using copper conductor and RT/Duroid 5880 as substrate material. The width of the microstrip and gap between the sides of the ground is adjusted to obtained impedance matching of 50 Ohm. The main consideration of the paper is to develop a design that operates on all major frequency bands from LTE (1900MHz) to Extended LTE (2100MHz), Bluetooth/Wi-Fi band/WiMAX/Zigbee (2.4GHz) and 5G (3.4-3.6GHz). Table 1 shows the summary of comparison between existing CPW-fed antennas and proposed work.

Table 1. Summary Of Comparison Between Existing CPW-Fed Antennas and Proposed Work.

References	Feeding Technique	Operating Frequency (GHz)	Gain (dBi)	Dimension (mm^3)	Substrate Type
[2]	CPW	2.54-2.69/ 5.68-6.05	5.30 3.44	18.2 × 20 × 1.6	FR-4
[3]	CPW	2.9-21.0	-	23.0 ×10 ×0.8	FR-4
[4]	CPW	1.10-2.70/ 3.15-3.65	8.90	35.0 × 25 × 1.6	FR4
[5]	CPW	3.24-8.29/ 9.12-11.25	4.33 4.90	24.90 × 20 × 1.6	FR-4
[6]	CPW	1.28-4.50	3.5	73 × 65 × 1.52	Rogers RO4232
[7]	CPW	5.15-7.29	2.25	20 × 8.7 × 0.4	FR-4
[8]	CPW	2.45/ 4.0-6.0	0.38 0.765	30 × 30 × 2	Glass
[9]	CPW	2.19-2.51	> 4.2	46.5 × 29.0 × 0.76	Rogers RT6002
[10]	CPW	3.04-10.70/ 15.18-18.0	3.94	47 × 25 × 0.135	PET
Proposed work	CPW	1.90-3.60	4.23	60 × 30 × 1.187	RT/Duroid 5880

2. Related Works

The configuration of the proposed antenna shown in Fig. 1 is inspired by the basic design from S. Das, H. Islam, T. and Bose, N. Gupta [7]. The fundamental structure of the antenna consists of two layers which are antenna layer on top and dielectric substrate at the bottom. Our design assumes no ground plate is placed underneath the dielectric which means it is of free space or air.



a. Front View b. Bottom View

Fig 1. Structure of proposed antenna design.

The material chosen for the antenna patch is copper (annealed) because this form of copper is much softer and malleable which makes it easier to shape during the fabrication stage. On the other hand, the dielectric substance used is the RT/duroid 5880 with dielectric constant of 2.2 and tangent loss of 0.0009. Some key features according to the datasheet of this substrate material include low moisture absorption, resistance towards chemicals, isotropic and uniform chemical properties over frequency. It is mostly found in microstrip and stripline circuits, as well as point-to-point digital radio antennas. The thickness of the dual-band CPW is 1.187mm with copper (annealed) 0.4mm and substrate as 0.787mm respectively.

The detailed geometry of the proposed antenna is shown in Fig. 2. Some of the parameters such as length and width of the main rectangular patch were taken from the values by S. Das, H. Islam, T. and Bose, N. Gupta [7] and is progressively modified to fit the requirements of our antenna. The characteristic impedance of the feed line can be calculated with a certain formula, however, in this paper, we considered utilizing the coplanar waveguide calculator found online which requires value including substrate thickness, width of antenna strip, ground plane spacing, and dieletric substrate [11]. We ran a couple of trials and errors to achieve matching impedance of 50 Ohm and the result was to adjust antenna width to 2mm while spacing between the edge of feed element and ground plane is 0.1933mm. The calculator equations are based on the 'Coplanar Waveguide Circuits, Components, and Systems' textbook written by R. N. Simons [12].

The equations applied in the online calculator are just an approximation of the CPW impedance as it does not consider the thickness of antenna strips, hence may not display the most accurate results. When creating critical design, the usage of 3D electro-magnetic analysis of CPW needs to be considered. The gap between the ground plates and antenna feed line is calculated to be 0.193mm which is less than half of the substrate thickness to control leakage of electromagnetic energy in free space. The antenna design is gradually modified to fulfil the required frequency range and the evolution of the proposed antenna design is shown in Fig. 3. The detailed antenna parameters of the final design are depicted in Table 2.

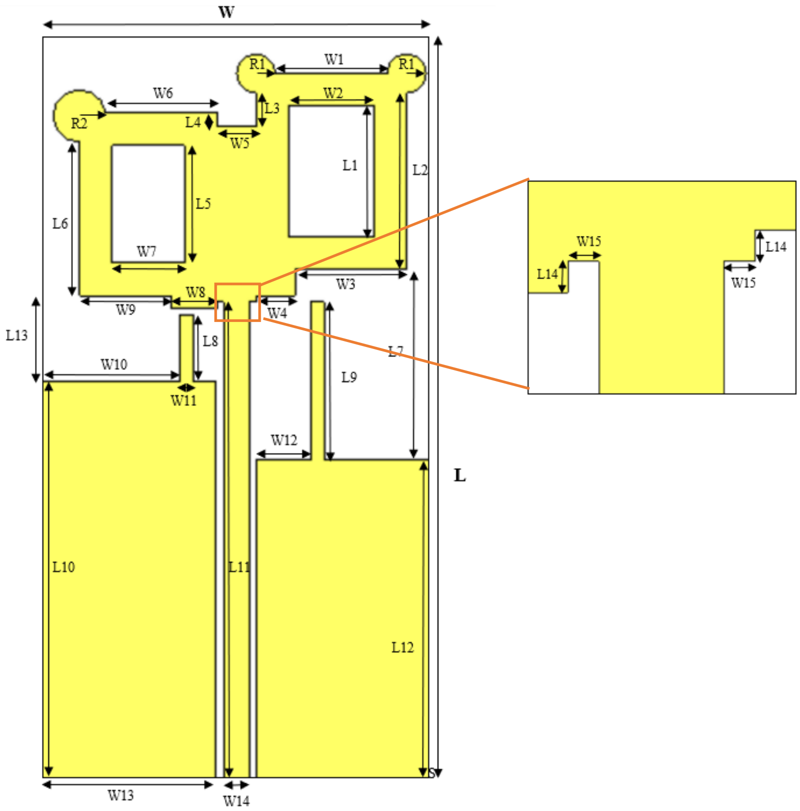
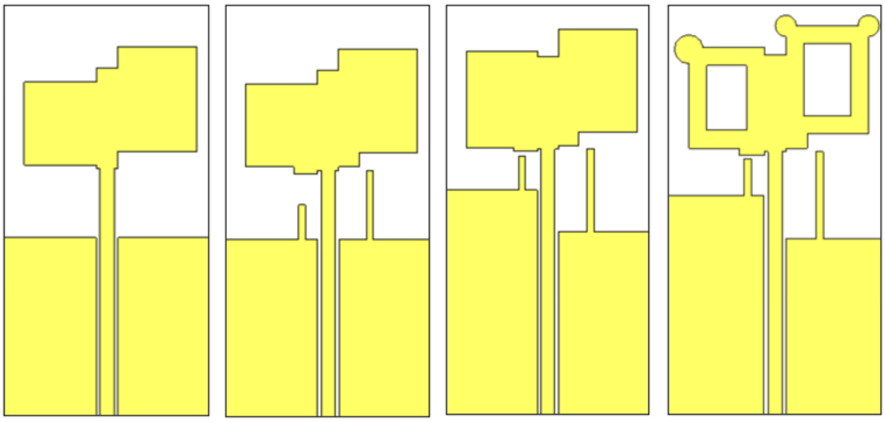


Fig 2. Geometry of proposed antenna.

Table 2. Proposed CPW Antenna Design Parameters Value.

Parameters	L	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
Value(mm)	60	10	13.5	2.5	1.0	9.0	11.75	13.5	5.0	12	33.0
Parameters	L11	L12	L13	L14	R1	R2	W	W1	W2	W3	W4
Value(mm)	39.0	27.0	0.5	6.5	2.0	1.5	40	8.5	6.5	8.5	3.0
Parameters	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Value(mm)	3.0	8.52	5.5	3.5	7.0	10.7	1.0	4.11	13.41	2.0	0.5



a. Antenna 1 b. Antenna 2 c. Antenna 3 d. Antenna 4

Fig 3. Evolution process of antenna.

3. Result and Discussion

The different layout of CPW antennas were designed and simulated to determine the antenna performance in different aspects including S11-parameter (return loss), reflection coefficients, gain, radiation pattern, current distribution, , and voltage standing wave ratio (VSWR).

The S11 parameter graph shows the return loss of the antenna design which is a measure of the reflection coefficient. The simulated result for return loss from the first to the final proposed antenna is displayed in Fig. 4. The first antenna result (red line) shows a narrow impedance bandwidth less than 30% (2.0-2.6GHz) for S11 < -10dB threshold. Besides, the return loss value is fairly small, which is -13.88dB and this may cause more power reflected back to the system which is not desirable.

This leads to our second antenna (green line) which is designed to increase the return loss as can be seen in Fig. 4. By adding two rectangular patches with 1mm width on each side of the ground plate as shown in Fig. 3 (b), the return loss improved to -21.47dB.

Moving on, the goal of antenna 3 (blue line) is to increase the impedance bandwidth to fulfill the criteria for IoT applications which covers all major frequency bands between 1.7GHz to 3.6GHz. By changing the length between the newly added rectangular strips with the ground plate, the bandwidth coverage improved from the initial antenna design which is 2.0GHz-2.6GHz to 1.97GHz-3.58GHz with more than 80% of the desired spectrum. This design also produces two resonant frequencies at 2.215GHz and 3.28GHz.

Lastly, the addition of circular slots on the corner of the rectangular patches further decreases the return loss to -25.12dB (orange line) and improved the impedance bandwidth to 1.88GHz-3.62GHz. However, one of the major frequency spectrums failed to be covered by this design, which is the LTE with frequency of 1.7GHz. More detailed parametric studies need to be done such as modifying the major length and width of antenna and dieletric substrate, positions of rectangular strips, separation distance between feed line and ground plates to achieve wider frequency spectrum. Additional tuning and optimization are also needed to attain the appropriate frequency response.

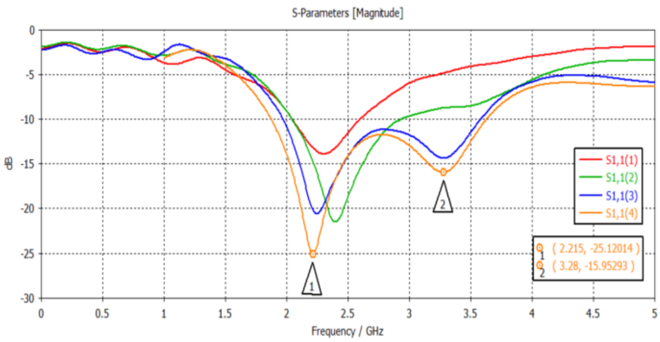


Fig 4. Simulation result of S11 parameter (return loss) for all four antennas.

The gain for final proposed antenna is shown in Fig 5 with the peak gain captured at 4.23dBi when the operating frequency is around 3.6GHz. At resonant frequencies of 2.215GHz and 3.28GHz, the gain observed is 2.59dBi and 3.92dBi respectively.

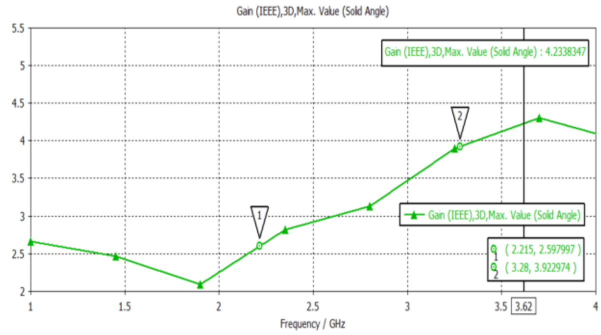
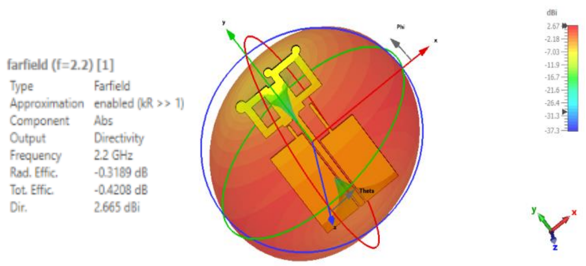
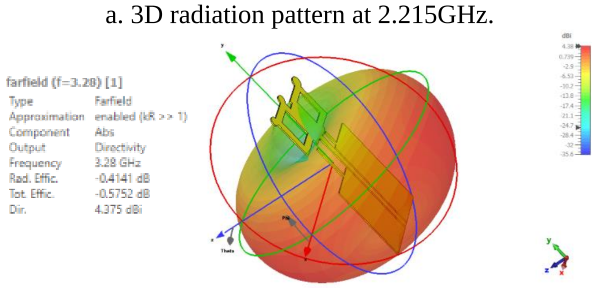


Fig 5. Simulation result of gain for final proposed antenna.

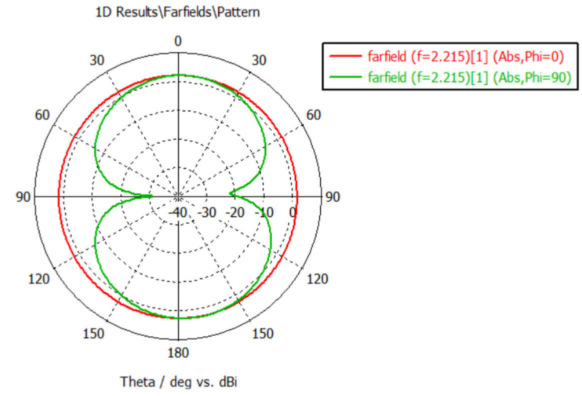
The radiation pattern of the final proposed antenna at 2.215GHz and 3.28GHz frequencies viewed in 3D is shown in Fig. 6 (a) and (b). Based on the results, the antenna design is omnidirectional, or commonly referred to as 'omni' whereby its shape is similar to a bagel. This type of antenna radiates and receives signal in all directions equally. Along its axis, this antenna evenly emits electromagnetic radiation in all directions. An omnidirectional antenna has the benefit of being able to send and receive signals from any direction without the requirement for exact targeting. The directivity recorded at 2.2GHz and 3.28GHz is 2.665dBi and 3.28dBi respectively. The radiation pattern in E-field and H-field can also be viewed in 2D for operating frequency at 2.215GHz and 3.28GHz as shown in Fig. 6 (c) and (d).



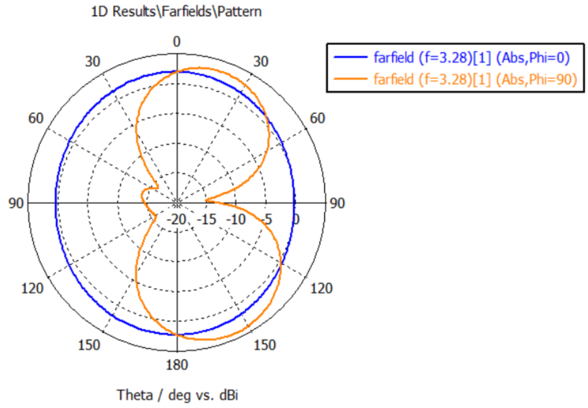
a. 3D radiation pattern at 2.215GHz.



b. 3D radiation pattern at 3.28GHz.



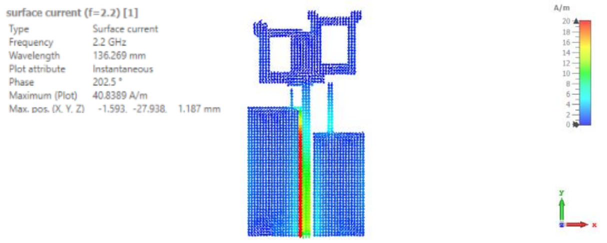
c. Far field radiation pattern at 2.215GHz.



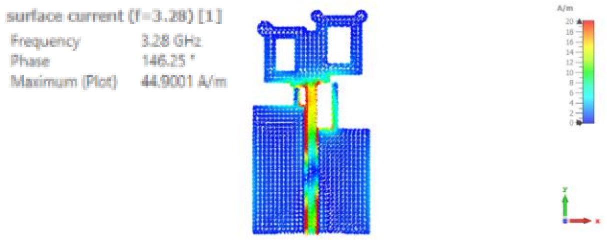
d. Far field radiation pattern at 3.28GHz.

Fig 6. Radiation pattern of final proposed antenna.

The surface current distribution is measured at both resonant frequencies of 2.215GHz and 3.28GHz as shown in Fig 7 (a) and (b). In both figures, the current density is most evident at the antenna strip denoted by red and orange color map which has higher potential for losses and prone to heating easily due to high dissipation of electromagnetic fields and energy. Some methods to reduce these losses include having proper grounding and optimizing the feed network as well as geometry design. The rest of the areas that are mostly drawn in blue or green area experience low current density whereby it indicates that the performance of the antenna still has room for improvement.



a. Current distribution at 2.215GHz.



b. Current distribution at 3.28GHz.

Fig 7. Current distribution on final proposed antenna.

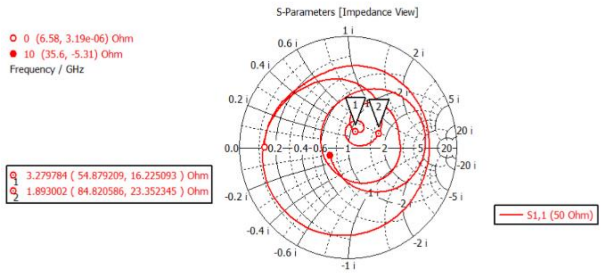


Fig 8. Smith chart of the final proposed antenna.

Smith chart is shown in Fig. 8. The VSWR value plotted at 2.215GHz is 1.11 and at 3.28GHz is 1.38 as shown in Fig. 9 whereby both values can be considered close to 1. This value of VSWR indicates a well-matched antenna with the transmission line and also reduces power loss due to impedance mismatch.

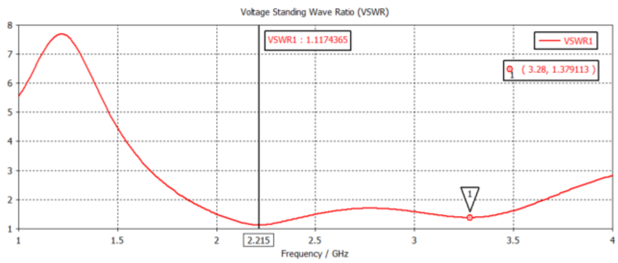


Fig 9. VSWR graph of the final proposed antenna.

Based on Fig. 10, efficiencies are recorded in terms of magnitude (dB). The highest radiation efficiency and total efficiency converted into percentage are 98% and 92.4% respectively at 2.35GHz. The radiation and total efficiency for resonant frequencies of 2.2GHz and 3.28GHz are mostly above 90% and values are tabulated in Table 3.

Table 3. Radiation efficiency and total efficiency of different resonant frequencies.

Resonant Frequency (GHz)	Radiation efficiency (%)	Total efficiency (%)
2.2	92.2%	86.6%
3.28	94.6%	90%

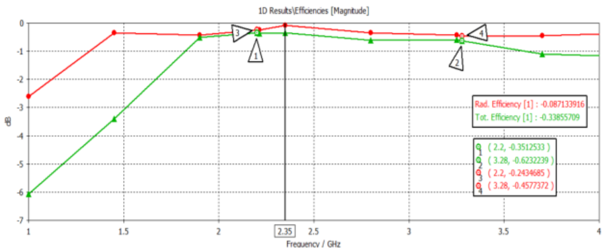


Fig 10. Radiation efficiency and total efficiency of dual-band CPW.

4. Conclusion

In this proposed paper, the rectangular dual-band CPW antenna structure with RT/duroid 5880 as substrate that has standard height of 0.787mm and dieletric constant of 2.2 is designed and simulated using CST software. The design can be classified for the usage on the applications of Internet of Things as it can satisfy most of the major frequency bands from LTE to Bluetooth/Wi-Fi band/WiMax/Zigbee, Extended IMT and 5G. However, it is also worth mentioning that the proposed design fails to cover a lower bandwidth spectrum of LTE which is 1.7GHz and this can be due to various factors such as dimensions, size, and layout of the antenna design as well as substrate material. The final antenna design has a wide impedance bandwidth of 1.9GHz-3.6GHz, improve in overall antenna gain with highest peak value at 4.23dBi in the two working bands and VSWR approximately close to 1. The final antenna design demonstrates monopole radiation patterns (omnidirectional) characteristics and high radiation efficiency up to 98% between the stated impedance bandwidths. The proposed antenna also exhibits moderate return loss of -29.54dB with an acceptable size of 1800m^2 and total efficiency of approximately 92.4% which makes it a comparable candidate for portable handheld communication devices.

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