Compact wide band antenna for millimetric communications

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Abstract. A single-layer ultra-wideband microstrip patch antenna loaded with an asymmetrical U-shaped slot for millimetre wave application is presented in this paper. The antenna is coaxial fed, and it is implemented on a Roger 5880 substrate with a relative dielectric constant of 2.2, thickness 3.15 mm, and loss tangent 0.0009. It operates over the frequency in the Ka-band from 31 to 37 GHz in the microwave spectrum. The results of the simulated reflection coefficient, radiation pattern, and maximum gain of the antenna are in fair agreement with the measured ones. Moreover, the measured reflection coefficient is carried out in the labs. The gain of the peak value of 7.4 dB is obtained at 34 GHz.

1. Introduction

Along with the significant increase in the mobile data requirements, the fifth-generation mobile network (5G) is expected to use a large quota of the millimeter-wave spectrum bands [1], which is expected to increase the current communication capacity significantly. Moreover, people’s needs and ways of living change and the demands to improve communication system facilities increase. Most of the devices were developed and reached much higher standards to have a low profile, lightweight, and low cost, which are often highly demanded. Due to the compact structure, low profile, and simple integration, the microstrip patch antenna has been widely used to achieve these requirements [2,3]. However, conventional microstrip antennas suffer from a very narrow frequency band, which is usually just a portion of a percent or at the fewest percent [4].

On the other hand, core differences currently exist between the ongoing communication systems, particularly in directivity, propagation losses, and antenna technology. To achieve the 5G and millimetric wave applications using microstrip antenna technology, the researcher has presented several ways to get a wider bandwidth of microstrip patch antennas [5,6]. As a common example, they used some slots in the patch radiators [7], which provides more controllable characters for better bandwidth. In addition, researchers in [8,9,10,11,12,13] inserted shorting vias into the antenna dielectric substrate.
Our work aims to grow a low-profile wideband antenna with acceptable radiation performance covering the entire 31 to 37 GHz frequency band. The asymmetrical U-shaped slots were sized to increase the resonance than that of the original patch. Our antenna is fabricated and measured to verify the adopted design concept in millimeter and microwave bands.

Moreover, our design could be considered a broadband antenna since it achieves the wideband antenna condition. This antenna can be used for different airborne applications, point-to-point communication systems, satellite internet [14], and cellular systems.

This paper is prepared as follows. The design of the antenna is explained in section II. In section III, simulation results are presented. Finally, conclusions are drawn in Section IV.

1.1. *Microwave Band Antenna*

The antenna dimension is inversely proportional to the operating frequency[15]; moreover that the ratio between the aperture size and the wavelength determines the directive gain [16]. It is not difficult to build a wide aperture antenna to get high gain with narrow beamwidths for shorter wavelengths or higher frequency. This is why microwave frequencies are used for Space communication and radars. As the directivity of the antenna gets higher, the resolution gets greater. The most critical activity to achieve the necessary radiation patterns is the antennas design in microwave communication systems. Slotted waveguide antennas are one of the most crucial antenna classes among the different microwave antennas.

The expression microwave shows the signals within the frequency range between 300 MHz and 300 GHz. Microwave antennas can be grouped into four types: (1) Wire antennas, (2) Array antennas, (3) Lens antennas, (4) Reflector antennas, and (5) Aperture antennas [15].

One of the most simple practical antennas is the dipole antenna. The half-wavelength dipole is created by extending the conductors of the two-wire transmission line out along a straight line. It has named “Hertz” most of the time. The current is zero at both ends and the peak at the center. This antenna impedance is solely resistive at 730, which is a little easier to align with many transmission lines. It has a beam diameter of around 78 ° and an overall gain of 2.1 dB.

Aperture antennas are this type of antenna that occupies an aperture or equivalent area where it obtains energy by-passing radio waves into free space [16]. They can also be recognized as horn antennas. Horn antennas are basically composed of a waveguide that its end walls are flared outwards to build a megaphone like structure. Pyramid horn, conical horn, sector horn, and rectangular waveguide are also types of aperture antennas. These antennas are super useful for a wide variety of uses, such as aircraft or spacecraft applications, as they can be conveniently mounted on the skin of any aircraft or spacecraft. Other than this, they can be coated with a dielectric material to be protected from any dangerous environmental conditions that can be exposed. In the microwave region, horn antennas can be widely used, as waveguides are the traditional feeding technique. Horns offer higher gain, lower VSWR, relatively wider bandwidth, lower weight, and construction flexibility. The horn aperture may be rectangular, circular, or even elliptical [15].

The antenna’s shape and scale differ according to the reason it is used and its frequency. Also, the necessary antenna used for any of the following uses, such as radio communications, television broadcasting and broadcasting, radar, satellite communications, etc., varies according to the operating wavelength band, the radiated or received power volume, also the transmitting range. Massive horizontal bimetallic grids are utilized for long-wave (LW) transmission. Mediumwave (MW) antennas are commonly mast or tower antennas. As wire dipoles arrays, single and double rhomboid antennas banned from towers are mostly used for short-waves (SW) transmission [17]. For the receiving, different antennas such as traveling wave antennas and loop antennas are commonly utilized. The following antennas, such as microwave, dipole antennas, slot antennas, parabolic antennas, horn antennas, helical antennas, spiral antennas, and dielectric antennas, are used loaded metal antennas. These antennas were also created for the region of the millimeter-wave too.
Both dielectric and dielectric metal loaded antennas are types of antennas that use dielectric elements to distribute electromagnetic energy or receive electromagnetic energy[17]. They can come in different structures, such as cylinders, cones, spheres, and rectangular rods, circular and rectangular horns, or any shape, as for these antennas. Dielectric antennas are distinguished by the following: lightweight, excellent sealing and corrosion properties, as well as attracting much interest in terms of comfort that can be generated with current techniques available for dielectrics.

1.2. Millimetric Band Antenna

The millimeter-wave frequency band is the band of frequency from around 30 to 300 GHz [15]. The International Telecommunications Union (ITU) declared it as, 1st Extremely High Frequency (EHF) 2nd very High Frequency (VHF). It falls between the categories of both the Super High-Frequency band and the Far Infrared band, its lower part is known as the Terahertz Gap. Millimeter-wave is a newly developed spectrum band that might be used in numerous service on any Wireless Networks, and Mobile as well. It possesses the capability of permitting data rates up to groups of Gbps.

Millimeter-length electromagnetic waves were explored in the 1890s for the first time by Indian scientist Jagadish Chandra Bose and back to the 1890s when the initial experiments on millimeter-wave frequency band were traced [18]. In the earlier, considerable researches have been dedicated to the study of millimeter-wave communication for the fifth-generation (5G) Mobile Networks to fulfill the various obligations of developing traffic; further, than millimeter-wave communication, terahertz radiation is a more robust wireless technology with a larger bandwidth. Terahertz waves are also recognized as submillimeter radiation. Respectively, the terahertz waves, extremely high frequency (THF), T-rays, T-waves, T-light, T-lux, or THz contain electromagnetic waves surrounded by the ITU-designated band of frequencies ranges from 0.1 to 30 THz.

At THz frequencies, wider channel bandwidth, such as 50 GHz, is available. Hypothetically, this means that to reach incredibly high data speeds (100 + Gbps), even basic low-order modulation schemes such as quadrature phase-shift keying (QPSK) are in theory required. To accomplish these goals, however, countless conflicts would also have to be resolved to implement modern architectural principles and revolutionary technology.

Despite the available spectrum at the high-frequency bands previously listed being much broader than that distributed to today’s wireless networks, until recently, research on millimetre wave connectivity for cellular networks remains a relatively unknown frontier. Therefore, new architecture principles and emerging technology for cellular connectivity on high-frequency bands must be thoroughly explored. High-speed mobile communications above sub-6 GHz have proved to be high potential technology with the latest advances in low-cost and high-performance coherent chips at millimeter waves. The following spectrum will be available for 5 G connectivity, like the ITU’s 3.4-3.6, 5.0-6.0, 24.25-28.35, 37-43.5, and 61-74 GHz bands, under the rise of cell data traffic.

In recent years, numerous protocols have been developed for wireless networking on millimeter-wave frequency bands, such as the 1st Wireless HD (2010), 2nd IEEE 802.15.3c Wireless Personal Area Network (WPAN) (IEEE 2009), 3rd European Computer Manufacturers Association (ECMA 2010), 4th IEEE 802.11ad Wireless Local Area Network (WLAN) (IEEE 2012), 5th IEEE 802.11a China and 6th IEEE 802.11ay WLAN (IEEE 2019).

The purpose behind these standards is to sustain a high data rate (up to 20Gbps) and accommodate short-distance high rate transmission traffic requirements.

The WirelessHD is designed to provide a high-definition multimedia interface operating on a 60 GHz frequency band. The WirelessHD products are incredibly pricey since they facilitate high-definition devices to be connected without wires. As a result, despite the WirelessHD has been established a long time ago, it has not been widely implemented and practiced. The first-generation application achieves data rates of 4 Gbps, but hypothetically technology supports data rates as high as 25 Gbps.
This is a touch more than the 10.2 Gbps data rate for High-Resolution Multimedia Interface (HDMI) 1.3 and 21.6 Gbps for DisplayPort 1.2. This helps WirelessHD to propose a better resolution, color depth, and range. WirelessHD version 1.1 improving the overall data rate efficiency to 28 Gbps, supporting standard of 3D format, 4 K Resolution, WPAN data, low-power portable system mode, and high-bandwidth wireless content protection (HDCP) 2.0.

2. Antenna Design

Based on the equations of length and width of printed patch antenna [15,19,20,21,22], the preliminary values of the parameters PL and PW can be obtained from these equations. The patch is implanted on a Roger 5880 RT substrate with relative dielectric constant equals to 2.2, and loss tangent equals 0.0009. All missing dimensions of the figure (1) are depicted in table (1).

The first mode relies on transmitting and cavity mode strategies and is analyzed and simulated through five equations measured using computer technology:

\[ \varepsilon = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2} \left[ 12 \frac{h}{W} \right]^{1/12} \quad \text{for} \ W/h > 1 \quad (1) \]

\[ L_{\text{eff}} = \frac{C}{2f_0(\varepsilon_{\text{reff}})} \quad (2) \]

\[ \frac{\Delta L}{h} = 0.412 \left( \frac{\varepsilon_{\text{reff}}+0.3}{\varepsilon_{\text{reff}}-0.258} \right) \left( \frac{W}{W+0.264} \right) \quad (3) \]

\[ L_{\text{eff}} = L + 2\Delta L \quad (4) \]

\[ L_g = 6h + L \quad (5) \]

\[ W_g = 6h + W \quad (6) \]

\[ W = \frac{V_0}{2f_r \sqrt{2(\varepsilon_r+1)}} \quad (7) \]

Initial values:
\[ L_{\text{eff}} = 18 \, \text{mm} \quad \Delta L = 0.438 \quad W = 12 \, \text{mm} \quad \varepsilon = 0.15 \]
Figure 1. Top and side view of our proposed antenna
(a) Top view
(b) Side view (1) Conductive GND plane (2) Radiating patch (3) Coaxial cable connector

Figure 2. Elevated view of the planned antenna for dimensions illustration

The patch is implanted on Roger 5880 RT substrate with a relative dielectric constant is 2.2 and loss tangent 0.0009. The radiating patch is loaded with a U-slot and fed using a coaxial probe, as shown in figure 1. The overall dimensions of the antenna are 10 mm x 8 mm x 3.165 mm.
Table 1. Proposed antenna dimension

| Label                        | Dimension (in mm) |
|------------------------------|-------------------|
| Ground length (L)            | 10                |
| Ground width (W)             | 8                 |
| Ground height (t)            | 0.015             |
| Substrate height (hs)        | 3.15              |
| Patch length (PL)            | 4                 |
| Patch width (PW)             | 3                 |
| Slot dimension (L1)          | 1.8               |
| Slot dimension (L2) and (L3) | 1                 |
| Feeder Location (Px)         | 0                 |
| Feeder Location (Py)         | 0                 |

2.1. Simulated Results
The reflection coefficient of the antenna is illustrated in figure (2). It operates over a frequency band of 6.6 GHz. Notice that the band from 31 to 37 GHz touches the -10 dB line.

Figure 3. designed antenna Reflection coefficients

According to the manufacturing and practical facilities, the antenna structure’s dimensions are depicted in the table (2) associated with the dimension of our millimeter band antenna illustrated in table (1).
Table 2. Proposed antenna dimensions for ease of fabrication

| Label                  | Dimension (in mm) |
|------------------------|-------------------|
| Ground length          | 30                |
| Ground width           | 24                |
| Ground height          | 0.015             |
| Substrate height       | 3.15              |
| Patch length           | 12                |
| Patch width            | 9                 |
| Slot dimension (L1)    | 5.4               |
| Slot dimension (L2) and (L3) | 3               |

The simulation of the maximum gain of the proposed, designed antenna is presented in figure 12. It is bounded between 6 and 9 dB. The two-dimensional radiation pattern at three different frequencies 32 GHz, 34 GHz, and 36 GHz in the plane $\Phi = 90$ are shown in figure (3), figure (4), and figure (5).

Figure 4. 3D and 2D simulation of the planned antenna Radiation pattern at 32 GHz frequency
Finally, the millimeter band antenna is compared with some similar literature [16,22]. The frequency band, fractional bandwidth, gain, applications, and computational methods are depicted in table 3 for the adopted antennas and others in the literature. (see table 3)

Table 3. Comparison of the planned antenna with further works and papers.

| Ref     | Frequency (GHz) | Min. S11 (dB) | Bandwidth (GHz) | Gain (dBi) |
|---------|-----------------|---------------|-----------------|------------|
| [231]   | 28              | -18           | 0.3             | N.A        |
|         |                 | -35           |                 |            |
| [24]    | 28              | -2.4          | 0.278           | 8.03       |
| [25]    | 26              | -30           | av 0.4          | 3.7        |
|         | 36              | -50           |                 | 4.7        |
| [26]    | 28              | -12.5         | 1.0             | N.A        |
|         | 38              |               |                 |            |
| [proposed] | 32         | -11.5         | 6.6             | 7.2        |
|         | 34              |               |                 | 7.56       |
|         | 36              |               |                 | 6.66       |
It is clear that the adopted antenna achieves higher fractional bandwidth and can be used in different applications with acceptable gain.

2.2. Antenna Optimization

The reflection coefficient of the antenna is illustrated. It operates over the frequency band 31 to 37.6 GHz. It is noticed that the band from 32.5 to 34.5 GHz is very close to the -10 dB line. (see figure 2). Therefore, we attempted to optimize the antenna by changing the feed position in the x-direction and y-direction along the U-shaped antenna to get a better frequency band besides the appropriate reflection coefficient. For simplicity, we set a reference value of 0.3. We had five different options for Px and Py {(0.3,0.3),(0.3,-0.3),(-0.3,-0.3),(-0.3,0.3),(0,0)}. The parametric study showed that the optimum $S_{11}$ was achieved when the feeder’s coordinates were (0.3,0). The green curve in figure 7 highlights this.

![Figure 7. Reflection coefficient S11 results for different feeder positions along X-axis and Y-axis
{(0.3,0.3),(0.3,-0.3),(-0.3,-0.3),(-0.3,0.3),(0,0)}](image)

3. Conclusion

This paper presents a single-layer ultra-wideband microstrip patch antenna loaded with an asymmetrical U-shaped slot for both millimeter and microwave applications. The antenna is fed using coaxial cable. It is implemented on a Roger RT5880 Substrate with relative dielectric constant equals to 2.2, thickness equals to 3.15 mm, and the loss tangent equals to 0.0009. It operates over the frequency band from 31 to 37GHz in the millimeter band.

3.1. Future Work

We shall consider adding an array of patches to the ground; we can get a noticeable enhancement in the radiation efficiency, the transmission coefficient of the transmission line, and the reflection coefficient of the antenna.
References

[1] M. Shafi, A. F. Molisch, P. J. Smith, T. Haustein, P. Zhu, P. De Silva, F. Tufvesson, A. Benjebbour, and G. Wunder, “5G: A tutorial overview of standards, trials, challenges, deployment, and practice,” IEEE journal on selected areas in communications, vol. 35, no. 6, pp. 1201–1221, 2017.

[2] A. Jaiswal, M. P. Abegaonkar, and S. K. Kou, “Highly efficient, wideband microstrip patch antenna with recessed ground at 60 ghz,” IEEE Transactions on Antennas and Propagation, vol. 67, no. 4, pp. 2280–2288, 2019.

[3] A. Abdelaziz and E. K. Hamad, Design of a compact high gain microstrip patch antenna for triband 5G

[4] Da Xu, H. Xu, Y. Liu, J. Li, and Q. H. Liu, “Microstrip patch antennas with multiple parasitic patches and shorting vias for bandwidth enhancement,” IEEE Access, vol. 6, pp. 11 624–11 633, 2018

[5] E. K. Hamad and N. Gehad, “Bandwidth extension of ultra-wideband microstrip antenna using metamaterial double-side planar periodic geometry,” Radioengineering, vol. 28, no. 1, p. 25, 2019.

[6] J.-Y. Sze and K.-L. Wong, “Slotted rectangular microstrip antenna for bandwidth enhancement,” IEEE transactions on antennas and propagation, vol. 48, no. 8, pp. 1149–1152, 2000

[7] M. F. A. Sree, W. Swelam, M. Hassan, and H. El-Hennawy, “An inverted f with dual frequency for radar & 5g applications above 85 ghz,” 2019 PhotonIcs & Electromagnetics Research Symposium, vol. Spring (PIERS SPRING), Rome, Italy, no. 11, pp. 4152–4160, 17-20 June 2019.

[8] W. Yang and J. Zhou, “Wideband low-profile substrate integrated waveguide cavity-backed e-shaped patch antenna,” IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 143–146, 2013.

[9] S.-H. Wi, Y.-S. Lee, and J.-G. Yook, “Wideband microstrip patch antenna with u-shaped parasitic elements,” IEEE transactions on antennas and propagation, vol. 55, no. 4, pp. 1196–1199, 2007.

[10] Z. Chen, Y. P. Zhang, A. Bisognin, D. Titz, F. Ferrero, and C. Luxey, “A 94-ghz dual-polarized microstrip mesh array antenna in ltcc technology,” IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 634–637, 2015.

[11] S. Liao and Q. Xue, “Dual polarized planar aperture antenna on ltcc for 60-ghz antenna-in-package applications,” IEEE Transactions on Antennas and Propagation, vol. 65, no. 1, pp. 63–70, 2016.

[12] Y. Li and K.-M. Luk, “60-ghz dual-polarized two-dimensional switchbeam wideband antenna array of magneto-electric dipoles,” in 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting. IEEE, 2015, pp. 1542–1543.

[13] P. Lee, “Computation of the bit error rate of coherent m-ary psk with gray code bit mapping,” IEEE Transactions on Communications, vol. 34, no. 5, pp. 488–491, 1986.

[14] X. Qu, S. Zhong, Y. Zhang, and W. Wang, “Design of an s/x dualband dual-polarised microstrip antenna array for sar applications,” IET Microwaves, Antennas & Propagation, vol. 1, no. 2, pp. 513–517, 2007.

[15] C. A. Balanis, Antenna theory: analysis and design. John wiley & sons, 2016

[16] Harrington, R. F. (1960). Effect of antenna size on gain, bandwidth, and efficiency. J. Res. Nat. Bur. Stand, 64(1), 1-12.

[17] P M, Hadalgi. (2005) Study of microwave materials for antenna applications. Karnataka University. Shodhganga

[18] He, S. and Huang, Y. (2019). An Introduction on Millimeter Wave Communications. In Wiley 5G Ref(eds R. Tafazolli, C.-L. Wang and P. Chatzimisios). doi:10.1002/9781119471509.w5GRef080

[19] M. F. A. Sree, W. Swelam, M. Hassan, and H. El-Hennawy, “An inverted f with dual frequency for radar & 5g applications above 85 ghz,” 2019 PhotonIcs & Electromagnetics Research Symposium, vol. Spring (PIERS SPRING), Rome, Italy, no. 11, pp. 4152–4160, 17-20 June 2019.

[20] M. F. A. Sree and A. Allam, “Design and fabrication of ultra-wideband leaky wave metamaterial antennas,” Journal of Instrumentation, vol. 14, no. 11, pp. P11 006–P11 006, Nov 2019.

[21] S. Abdelfattah, E. Hamad, and W. Swelam, “60 ghz rectangular patch antenna with cavity resonator for 5g applications,” 2019 PhotonIcs & Electromagnetics Research Symposium, vol. Spring (PIERS - SPRING), Rome, Italy, no. 18, pp. 4377–4384, 17-20 June 2019.

[22] M. F. A. Sree, M. A. Ibrahim, W. Swelam, M. H. A. El-Azeem, and H. El Hennawy, “Ultra-wide
band microstrip antenna for 4G applications,” IOP Conference Series: Materials Science and Engineering, vol. 610, p. 012025, Oct 2019.

[23] Novel Metamaterial Structures with Low Loss at Millimeter Wave Frequency Range Yassine JANDI, Fatima Gharanati and Ahmed Oulad Said

[24] “Design of a compact Dual bands patch antenna for 5G Applications” International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS) 2017

[25] Broadband Printed Slot Antenna for the Fifth Generation (5G) Mobile and Wireless Communications On the Design of Millimeterwave Antennas for 5G

[26] Ehab K. I. Hamad1, Mohamed Z. M. Hamdalla2” Design of a Compact Dual-Band Microstrip Antenna Enabled by Complementary Split Ring Resonators for X-Band Applications” journal Advanced Electromagnetics, vol. 7, no. 3, August 2018, PP. 82-86