Avrupa Bilim ve Teknoloji Dergisi
Özel Sayı, S. 405-411, Nisan 2020

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
Special Issue, pp. 405-411, April 2020

Research Article

Comparative Analysis of the Effects of the Substrate Material and Deltoid Shaped Slots on Patch Antennas for 5G Networks at 37 GHz and 39 GHz*

Barış Gürcan Hakanoğlu[1**], Burak Koç[2], Şekip Esat Hayber[3], Hüsnü Yalduz[4], Mustafa Türkmen[5]

[1] Kirsehir Ahi Evran University, Vocational School of Kaman, Electronics and Automation Dept., Kirsehir, Turkey (ORCID: 0000-0002-5157-8414)
[2] Ankara University, Institute of Accelerator Technologies, Ankara, Turkey (ORCID: 0000-0001-9774-4126)
[3] Kirsehir Ahi Evran University, Engineering-Architecture Faculty, Electrical-Electronics Eng. Dept., Kirsehir, Turkey (ORCID: 0000-0003-0062-3817)
[4] Hitit Univeristy, Vocational School of Technical Sciences, Electronics and Automation Dept., Corum, Turkey (ORCID: 0000-0001-9776-3896)
[5] Erciyes University, Engineering Faculty, Electrical-Electronics Eng. Dept., Kayseri, Turkey (ORCID: 0000-0002-5257-8256)

(Conference Date: 5-7 March 2020)

(**DOI:** 10.31590/ejosat.araconf53)

ATIF/REFERENCE: Hakanoğlu, B. G., Koç, B., Hayber, Ş. E., Yalduz, H. & Türkmen, M. (2020). Comparative Analysis of the Effects of the Substrate Material and Deltoid Shaped Slots on Patch Antennas for 5G Networks at 37 GHz and 39 GHz. *Avrupa Bilim ve Teknoloji Dergisi*, (Özel Sayı), 405-411.

Abstract

In this study two rectangular patch antennas with deltoid shaped slots are proposed. It is aimed to show the effects of the slots for different frequencies and different dielectrics. The antennas are designed for 37 GHz and 39 GHz which are among the projected 5G frequencies in millimeter wave bands. For the designs RT5880 and RO3003 dielectric substrates are selected for each antenna to obtain the effects of the materials. At different operating frequencies and different substrate materials, the deltoid shaped slots result in different amounts of improvements in return loss levels. The antenna with the slots designed with RT5880 has a return loss reduction of 18.81 dB for 37 GHz and 16.37 dB for 39 GHz which means a progress in S_{11} levels of 44.47% for 37 GHz and 36.14% for 39 GHz. The antenna with the slots designed with RO3003 has a return loss reduction of 25.17 dB for 37 GHz and 27.54 dB for 39 GHz which means a progress in S_{11} levels of 58.44% for 37 GHz and 78.80% for 39 GHz. The results can give a good insight for antenna designers how the antennas react to same modifications at different frequencies for different substrate materials in millimeter wave bands.

Keywords: 5G, millimeter wave, low return loss, slot effects, patch antenna.

5G Ağları için Alttaş Malzemesi ve Deltoid Şekilli Yuvaların Yama Antenler Üzerindeki Etkilerinin 37 GHz ve 39 GHz'de Karşılaştırmalı Analizi

Öz

Bu çalışmada deltoid şekilli yarıklara sahip iki dikdörtgen yama anten önerilmiştir. Farklı frekanslar ve farklı alttaşlar için yarıkların etkilerinin gösterilmesi amaçlanmaktadır. Antenler, milimetre dalga bantlarında öngörülen 5G frekansları arasında yer alan 37 GHz ve

[*] This paper was presented at the ***International Conference on Access to Recent Advances in Engineering and Digitalization (ARACONF 2020)***.

[**] Corresponding Author: Kirsehir Ahi Evran University, Vocational School of Kaman, Electronics and Automation Dept., Kirsehir, Turkey, ORCID: 0000-0002-5157-8414, bghakanoglu@ahievran.edu.tr

39 GHz için tasarlanmıştır. Tasarımlar için RT5880 ve RO3003 dielektrik alttaşlar, malzemelerin etkilerini elde etmek üzere her anten için ayrı ayrı değerlendirilmiştir. Farklı çalışma frekanslarında ve farklı alttaş malzemelerinde, deltoid şekilli yarıklar, geri dönüş kayıplarında farklı seviyelerde iyileşmeler sağlar. RT5880 ile tasarlanan yarıklara sahip antenin geri dönüş kayıplarında, 37 GHz için 18,81 dB ve 39 GHz için 16,37 dB iyileşme elde edilmiştir. Bu değerler yüzde olarak 37 GHz için %44,47 ve 39 GHz için %36,14'lük bir iyileşmeye karşılık gelir. RO3003 ile tasarlanan yarıklara sahip antenin geri dönüş kayıplarında, 37 GHz için 25,17 dB ve 39 GHz için 27,54 dB iyileşme elde edilmiştir. Bu değerler benzer şekilde yüzde olarak 37 GHz için %58,44 ve 39 GHz için %78,80'lik bir iyileşme anlamına gelir. Sonuçlar, anten tasarımcıları için, antenlerin milimetre dalga bantlarındaki farklı alttaş malzemeleri için farklı frekanslarda aynı modifikasyonlara nasıl tepki verdiğini göstermesi açısından önem taşımaktadır.

Anahtar Kelimeler: 5G, milimetre dalga, düşük geri dönüş kaybı, yarık etkileri, yama anten.

1. Introduction

The increasing demand for faster mobile communication has resulted in searching for new technologies and standards. The latest improvements bring with them the higher demand for bandwidth and faster data transmission where todays' latest technology, fourth generation long term evolution, 4G LTE, won't be able to accommodate. So, the wireless communication will use the bands which have never been utilized before and a new name which is fifth generation or 5G (Agiwal et al., 2016). 5G wireless communications are expected to significantly increase speed and data rates, and support the connection of billions of devices, including autonomous vehicles and smart appliances, through Internet of Things (IoT) (Rozenfeld, 2017). Federal Communication Commission (FCC) approved the allocation of large bandwidths at 28, 37 and 39 GHz in July 2016 (Federal Communication Commission Website, 2016). 5G communication will therefore create the need to investigate newer and more efficient designs for antennas. Due to their number of merits like low cost, easy fabrication and compatible dimensions with a variety of surfaces, microstrip patch antennas are popular choices for 5G communication systems. A major disadvantage of such antennas, however, is their limited bandwidth. This drawback can be overcome with different methods such as etching slots on the radiating patch or on the ground plane. For example, it has been found that introducing T and U-shaped slots on a microstrip patch antenna designed for S band produced enhanced return loss levels (Mishra et al., 2016). In recent studies, a circular slot is etched on a circular microstrip patch antenna to achieve low return loss levels at 5.8 GHz for wide-band applications (Ayyappan et al., 2016). Furthermore, defected ground method is used for gain and bandwidth enhancement of a coplanar waveguide fed patch antenna for wide-band applications (Saxena et al., 2016). Moreover, it is attained dual-band operations for Wireless Fidelity (Wi-Fi) and Worldwide Interoperability for Microwave Access (WiMax) applications using C-slot on a rectangular microstrip patch antenna (Yassin et al., 2014).

There are myriad studies and applications in wideband frequencies to improve characteristics of the antennas in terms of bandwidth and return loss. However, there are few proposals for millimeter wave (mm- wave) bands. In recent studies, a rectangular microstrip patch antenna is proposed with rectangular slot on the radiating part resonating at 10.15 GHz (Verma et al., 2016). A T-shaped patch antenna with defected ground plane is studied for 5G wireless networks which operates in multiple frequencies between 25.1 GHz and 37.5 GHz (Jilani & Alomainy, 2016). Additionally, the design issues for 5G broadband is investigated for a rectangular patch at 28 GHz and 60 GHz (Outerelo et al., 2015). It is clear that more advanced designs are required for mm- wave band to meet the demands of high bandwidth and efficient transmission.

In this study, we search for the effects of deltoid shaped slots on rectangular patch antennas at mm-wave frequencies. In addition, the effects are tested for two different dielectric materials. First, we design reference antennas operating at 37 GHz using the substrates RT5880 and RO3003 and reference antennas at 39 GHz using the substrates RT5880 and RO3003. These types of substrates are chosen for mm-wave designs because of their operating capability at wide frequency ranges. RT5880 substrates are glass microfiber reinforced polytetrafluoroethylene (PTFE) composites and RO3003 substrates are ceramic-filled PTFE composites (RT5870/5880 & RO3003 Data sheet). For improved radiation characteristics, we propose deltoid-shaped slots on the radiating parts of the antennas. Consequently, at both frequencies for both substrate materials it is obtained significant return loss decreases.

2. Materials and Method

The antenna prototype is shown in Figure 1. Reference antennas are designed separately on two different dielectric substrates which are Rogers RT5880 and RO3003 having relative permittivity of 2.2 and 3, respectively. For all models the dimensions of the substrates are optimized as $W_{subs} \times L_{subs}$=10 mm×8 mm, denoting the width with Wsubs and the length with L_{subs}. For each substrate, we design two antennas for two different resonant frequencies. In order to perform a good comparison between the results physical heights of these substrates are chosen commercially available and almost equal to each other which are 0.254 mm for RT5880 and 0.25 mm for RO3003. After determining the operating frequency and the type of the substrate, the width and the length of the patch can be calculated using Equations 1-4 (Balanis, 2005).

$$W_p = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W_p}\right)^{-\frac{1}{2}} \tag{2}$$

$$\frac{\Delta L_p}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{W_p}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W_p}{h}+0.8\right)} \quad (3)$$

$$L_p = \frac{v_0}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L_p \quad (4)$$

In the equations W is the width of the patch and L is the length of the patch. In addition, ε_{eff} shows effective dielectric constant and ΔL shows the length extension due to the fringing effects. All optimized dimensions for different substrates and frequencies are shown in Tables 1-3.

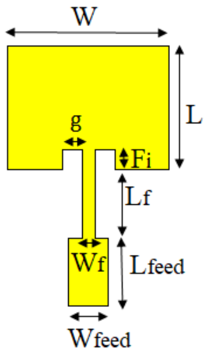

Figure 1. Reference antenna model for 37 GHz and 39 GHz operating patch antennas

Table 1. Optimized dimensions for the antennas with RT5880 dielectric substrate (ε_r=2.2)

f_r (GHz)	L (mm)	W (mm)	L_{feed} (mm)	L_f (mm)	W_f (mm)
37	3.32	4.28	1.80	1.81	0.17
39	2.48	3.28	1.36	1.37	0.26

Table 2. Optimized dimensions for the antennas with RO3003 dielectric substrate (ε_r=3)

f_r (GHz)	L (mm)	W (mm)	L_{feed} (mm)	L_f (mm)	W_f (mm)
37	2.87	3.79	1.54	1.55	0.14
39	2.14	2.87	1.16	1.17	0.16

Table 3. Optimized dimensions which are the same for all antenna prototypes

f_r (GHz)	F_i (mm)	g (mm)	W_{feed} (mm) ε_r=2.2	ε_r=3
37	0.40	0.40	0.78	0.63
39	0.40	0.40	0.78	0.63

For improved return loss levels, we propose deltoid shaped slots on the radiating part. Deltoid is composed of two isosceles triangles which gives us the possibility to control the operating frequency and return loss level by changing the dimensions of the diagonals. In the beginning the deltoid shaped slots are designed symmetrically having one corner on the face center point of the patch. Figure 2 shows the antenna with deltoid shaped slots.

Here diagonal_y denotes the shorter diagonal in y-direction and diagonal_x denotes the longer diagonal of the deltoid in x-direction. In addition, parameter distance_x denotes the spacing between the slots and parameter distance_y denotes the distance to the reference point in y-coordinate. All these parameters affect the performance of the antenna. So, a detailed parametric analysis is performed to attain the best results beginning from distance_x=0 mm, distance_y=0 mm diagonal_y=0.001 mm and diagonal_x=0.1 mm. To see the effects of the slots for different 5G frequencies the analysis is conducted for four antennas separately which are designed for 37 GHz and 39 GHz with two different dielectrics RT5880 and RO3003.

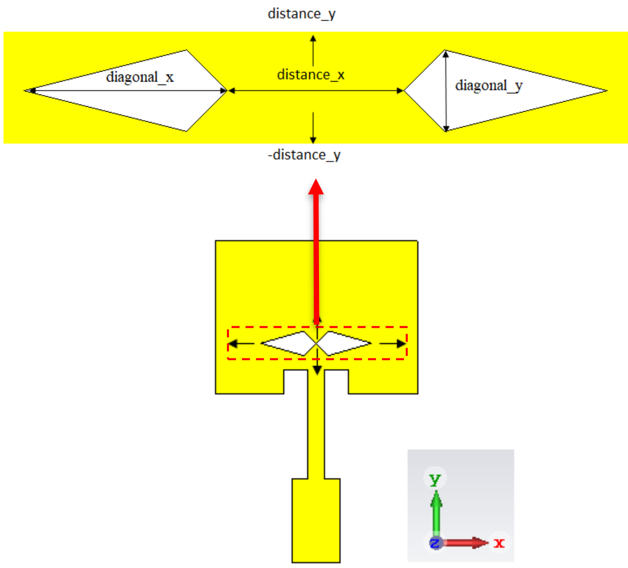

Figure 2. Proposed model with deltoid shaped slots for 37 GHz and 39 GHz operating patch antennas

3. Results and Discussions

The antennas are designed and optimized using the software CST Microwave Studio (Computer Simulation Technology, 2016). Figure 3 and Figure 4 show the reflection coefficient results of the conventional rectangular patch antennas and the reflection coefficient results of the proposed antennas with the dielectric substrate RT5880 and RO3003, respectively. For the substrate RT5880 the reference antennas resonate exactly at 37 GHz and 39 GHz with return loss levels of -42.30 dB and -45.29 dB, respectively. In addition, 10 dB bandwidths are 1.17 GHz for 37 GHz and 1.29 GHz for 39 GHz antenna. After the slots are etched and performed a detailed optimization return loss levels have decreased to -61.11 dB for 37 GHz and -61.66 dB for 39 GHz. The bandwidths for both frequencies have remained the same. For the antennas with the slots there occurred small frequency shifts, 37 GHz antenna resonates at 36.87 GHz and 39 GHz antenna resonates at 38.86 GHz.

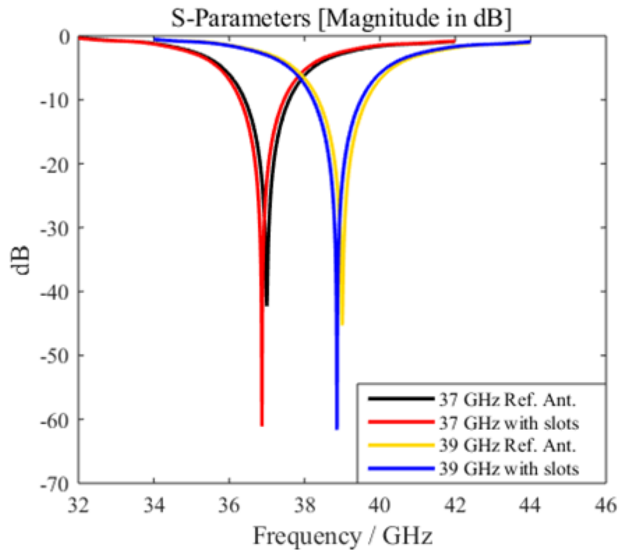

Figure 3. S_{11} results of the antennas with the substrate of RT5880 (ε_r=2.2, h=0.254 mm).

The reference antennas designed with the dielectric substrate RO3003 without the slots have return loss levels of -43.07 dB for 37 GHz and 34.95 dB for 39 GHz. When the same procedure is applied with the slots the return loss levels has decreased to -68.24 dB for 37 GHz and -62.49 dB for 39 GHz. For both designs with RO3003 with and without the slots the bandwidths are 0.98 GHz for 37 GHz antennas and 1.07 GHz for 39 GHz antennas. S_{11} results are shown in Figure 4 both for the reference antennas and the proposed antennas. There occurred small frequency shifts also here, 37 GHz antenna resonates at 37.15 GHz and 39 GHz antenna resonates at 38.94 GHz.

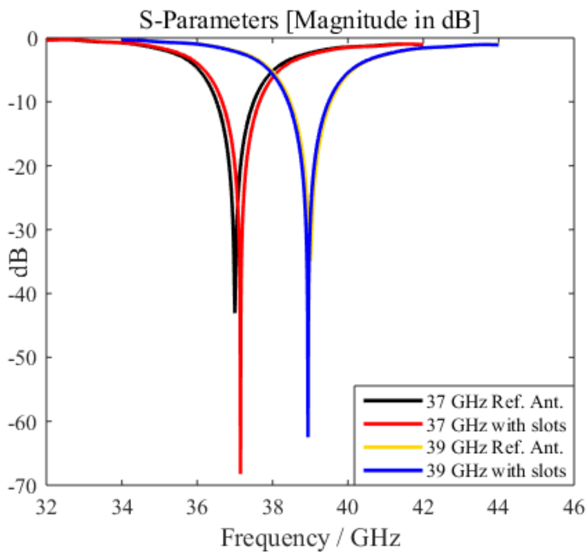

Figure 4. S_{11} results of the antennas with the substrate of RO3003 (ε_r=3, h=0.25 mm)

From the figures, it can clearly be concluded that the return loss reductions with higher dielectric substrate has been more than the reductions with RT5880 for both frequencies. Figure 5-8 show the far field patterns for the proposed antennas. While main lobe magnitude for 37 GHz antenna with RO3003 substrate increases by 0.08 dBi compared to the antenna with RT5880 substrate, 39 GHz antenna with RO3003 has 0.04 dBi lower main lobe magnitude level compared to the antenna with RT5880 substrate. In addition, both 37 GHz antenna and 39 GHz antenna with RT5880 substrate have higher value of 3 dB angular width than the antennas with RO3003.

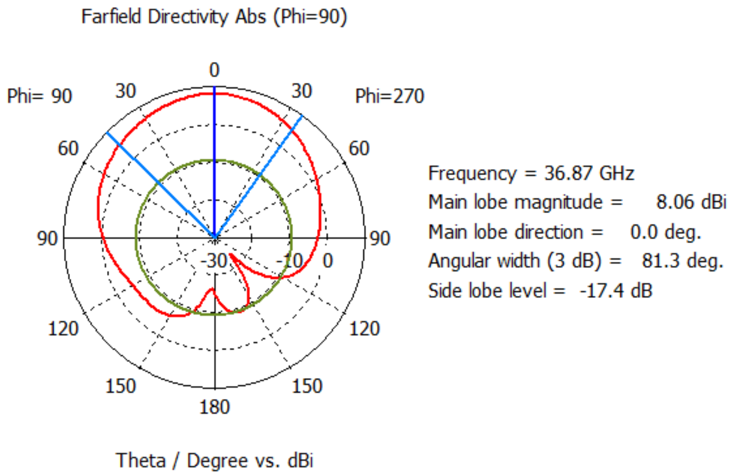

Figure 5. Far field patterns of 37 GHz antenna with deltoid shaped slots (RT5880)

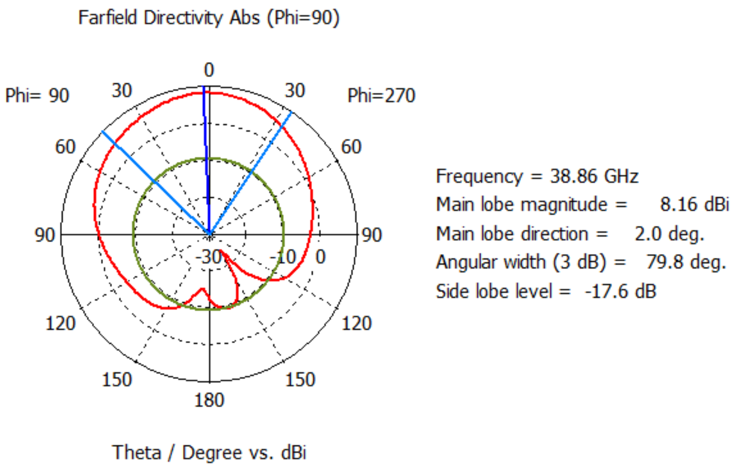

Figure 6. Far field patterns of 39 GHz antenna with deltoid shaped slots (RT5880)

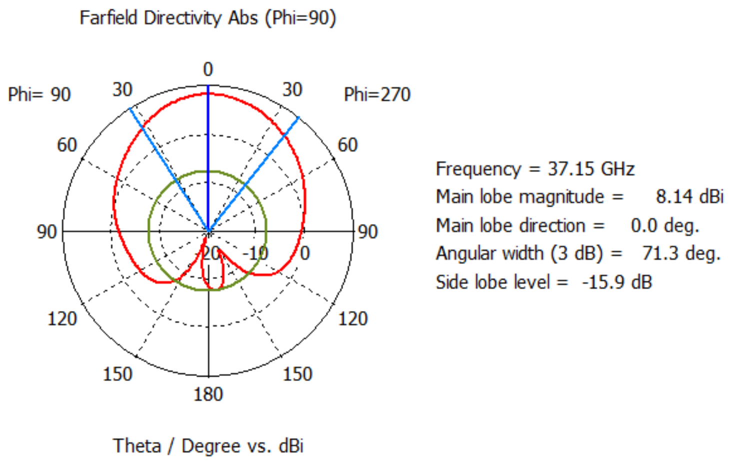

Figure 7. Far field patterns of 37 GHz antenna with deltoid shaped slots (RO3003)

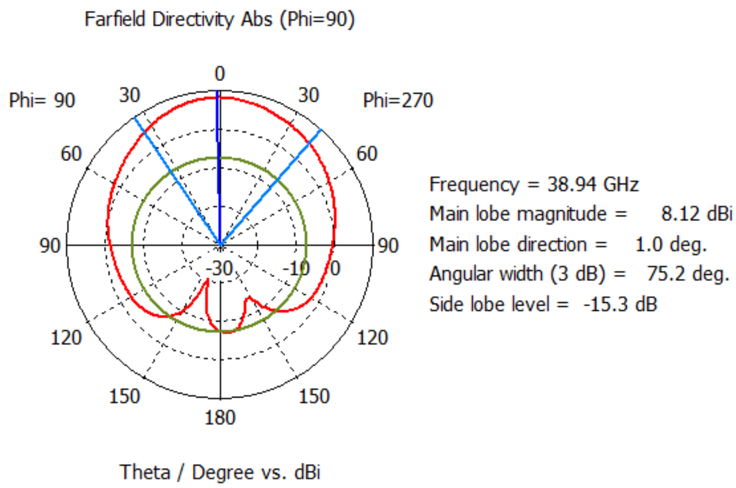

Figure 8. Far field patterns of 39 GHz antenna with deltoid shaped slots (RO3003)

4. Conclusions

The effects of the deltoid shaped slots on rectangular patch antennas are investigated for two different operating frequencies and for two different dielectric substrates. The selected frequencies are 37 GHz and 39 GHz which are among the projected 5G spectrum and the selected dielectrics are RT5880 with permittivity of 2.2 and RO3003 with permittivity of 3. For both design frequencies, it is obtained return loss level reductions with different amounts. At both design frequencies, the structures with RO3003 resulted in more S_{11} level reductions than the structures with RT5880. This study proposes both a new design of patch antennas and compare them between different frequencies and materials. The improved results are given in detail and from different points of view. The aim of this study is not only creating a novel structure but also to show that the designed structure can be used with other dielectrics and at other operating frequencies as well.

References

Agiwal, M., Roy, A., & Saxena, N. (2016). Next generation 5G wireless networks: A comprehensive survey. IEEE Communications Surveys & Tutorials, 18(3), 1617-1655.

Ayyappan, M., Manoj, B., & Rodrigues, S. (2016, March). Low return loss circular microstrip patch antenna at 5.8 GHz for wide-band applications. In 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT) (pp. 3023-3026). IEEE.

Balanis, C. A. (2005) Antenna Theory Analysis and Design, New Jersey: J. Wiley & Sons.

Computer Simulation Technology (CST) Microwave Studio, Ver. 2016, Framingham, MA, USA, 2016.

Federal Communication Commission Website. (2016). Available: https://www.fcc.gov

Jilani, S. F. & Alomainy, A. (2016) Milimeter-wave t-shaped antenna with defected ground structures for 5g wireless networks. Loughborough Antennas & Propagation Conference (LAPC), Loughborough, UK.

Mishra, S., Wankhade, P., & Sahu, A. (2016, March). Design and analysis of T and U shaped slots with truncated corner rectangular microstrip patch antenna for return loss enhancement. In 2016 Symposium on Colossal Data Analysis and Networking (CDAN) (pp. 1-7). IEEE.

Outerelo, D. A. Alejos, A. V. Sanchez, M. G. & Isasa, M. V. (2015) Microstrip antenna for 5g broadband communications: overview of design issues," International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver, BC, Canada.

Rozenfeld, M. (2017). Getting to Know 5G. IEEE The Institute, 41(1).

RT5870/5880, RO3003 High Frequency Laminates Data Sheet. Rogers Corporation, AZ, USA.

Saxena, A., Joshi, S., Gupta, A., Saxena, S., & Kumar, D. (2016, May). Gain and bandwidth enhancement of CPW-fed patch antenna for Wideband applications. In 2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT) (pp. 1622-1625). IEEE.

Verma, S., Mahajan, L., Kumar, R., Saini, H. S., & Kumar, N. (2016, September). A small microstrip patch antenna for future 5G applications. In 2016 5th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions)(ICRITO) (pp. 460-463). IEEE.

Yassin, A. A. Saeed, R. A. & Mokhtar, R. A. (2014) Dual-band microstrip patch antenna design using c-slot for wi-fi and wi-max applications. International Conference on Computer and Communication Engineering (ICCCE), Kuala Lumpur, Malaysia.