A Review of the Design of a Single Antenna and Antenna Arrays at 60 GHz for 5G Applications System

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Abstract: Modern mobile technology is rapidly improving due to its considerable influence on social life. Therefore, it is necessary to study antenna devices' developments, as they are considered essential for wireless technology. This document contains a review of previous research results of different antennas and antenna arrays at 60GHz for fifth-generation (5G) application systems. We present a comparative study of the different types of designs. For fifth generation technology applications, it is essential to design antennas with essential features such as large bandwidth, substantial gain and directivity, minimization of size and flat profile, and ease of integration in-package or on-chip with other elements.

1 INTRODUCTION

Today's wireless technology is considered one of the most sensitive areas of communication systems. 5G technology uses high frequencies and wide bandwidth to increase transmission rates, enabling better coverage with low battery consumption at a low cost, which is the main objective of 5G technology (Abdelhafid, 2020; Mohammed, 2020; Salah-Eddine, 2021). As part of the frequency allocation, the 2015 World Radiocommunication Conference (WRC-15) allocated identification frequencies in the range between 24GHz and 86GHz for upcoming cellular and mm-wave wireless systems (Iskandar, 2017; Abdelhafid, 2021).

The band around 60 GHz is the frequency band chosen for the new WLAN network standard, WiGig (Wireless Gigabit). Its main advantage for very high-speed applications, such as streaming multimedia content without compression, is the wide available bandwidth. We standardized the band around 60GHz for wireless data transfer, the Gigabit Ethernet in WPANs (Wireless Personal Area Networks). WiGig provides technical specifications for 60 GHz communications for high-speed and short-range applications such as modulation type, coding rate, and power (Kohei, 2014; Muhammad, 2018; Marwa, 2019). In the past, these frequencies were not feasible for BANs. The 60 GHz band is attractive for body area network (BAN) applications because of its high atmospheric reduction, low interference with other networks, compactness of the components, sizeable available bandwidth, and low skin absorption by the human body(Daghouj, 2020; Solofo, 2014). Nevertheless, thanks to the evolution of circuit integration solutions, technological and cost barriers have fallen.

The millimetre band has been identified as potentially promising for wireless communications on the human body, particularly the frequency band around 60 GHz (Mohammed , 2019; Raad, 2013). First of all, this is also true for the entire millimetre spectrum, the wavelengths in the vacuum $\lambda 0$ are small (only 5 mm at 60 GHz). This characteristic makes it possible to develop antennas whose dimensions are centimetres or even millimetres, thus facilitating their integration into the body. The second advantage is the atmospheric absorption peak at 60 GHz, of 16 dB/km, which reduces the risk of interference with neighbouring arrays (Arriola, 2011). This isolation can be an essential criterion for specific applications, such as in the military domain. The third advantage is that the 60GHz band is royalty-free and extends over several GHz (57-64 GHz in North America, 57-66GHz in Europe, 59-66 GHz in Japan). This latter advantage offers data rates of up to several Gbit/s (Masood, 2017), which has met the growing need for faster data transfers.

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The exciting properties related to the technology of wireless communication systems operating in the 60 GHz frequency band are all criteria taken into account in designing this type of system. In wireless systems, one of the significant elements is the antenna, as it has significant effects on the receiver's overall sensitivity, and therefore on the bidirectional design, the selection of digital modulation schemes, and the link budget. As a result, research in the area of 60 GHz antenna technology development has been attracting much interest, and, significantly, both the conception and analysis of these antennas are described in detail in various research works(Saravanya, 2017; Younger, 2018).

The technology of the waveguides incorporated in the support (SIW), particularly adapted, makes an essential step in the research sector concerning the millimetre waves. The new developments and applications concern antennas as well as filter circuits and coupling devices for RF input (Fan fan , 2012), the orientation of the beams, and MIMO systems (Sam, 2016). Until now, most designs of the SIW antenna that have been suggested within the 60 GHz band documentation have had to choose between providing adequate bandwidth. It has been shown that SIW slot antenna arrays produce excellent bandwidths(Thomas, 2017; Cyril, 2018). In (Carlos, 2016), Design of V-Band SIW Fed Cavity Backed Aperture Coupled Microstrip Patch Array (ACMPA) Element for Applications in Body Area Networks. Is proposed, which can realize a bandwidth of 14.25%, between 56.16GHz and 64.8GHz and whose gain reaches 5.6dBi. In (Rubén, 2017), The results of the circularly polarized microstrip patch array element for bodyworn applications provide a wide bandwidth of 8.64 GHz as well as a maximum gain of 7.2 dBc. Another antenna proposed in (Samuel, 2018) offers a very high gain of 10.55dB and a bandwidth of 7.23GHz. It has an omnidirectional radiation pattern.

In the available literature, we note that millimetre-wave antennas represent a significant development in recent years. This paper reports on the research work concerning millimetre-wave antennas' design, hoping that this paper contains sufficient essential data for future studies on this topic for integration into future 5G wireless communication systems.

This article is organized as shown below: the second chapter explains an analysis of the status and costs associated with 60 GHz links. The third chapter illustrates the design aspects of millimetre-wave antennas. The fourth chapter examines 60GHz antenna technology with comparative analysis. Finally, the Fifth and last part of this article is devoted to the conclusion.

2 ANALYSIS OF THE STATUS AND COSTS ASSOCIATED WITH 60 GHZ LINKS

The frequencies from 30 to 300 GHz are called "millimetre waves" or "high-frequency waves." These frequencies have great appeal because of multi-gigabit communication services, such as high-quality digital multimedia and video systems, high-speed Internet, gigabit wireless data transmission, and short-range automotive radar sensors. Nevertheless, there are concerns regarding the implementation of millimetre-wave frequency bands due to the higher interference effects of penetration, rain, and foliage. These additional propagation losses vary depending on the construction materials, the rainwater's strength, or the trees' height (Maroua , 2019; Sulyman, 2014).

Because of the higher propagation losses and oxygen absorption, on the order of 10-15dB per km, in the vicinity of the 60 GHz band, the size of 60-GHz links is small, allowing for more frequent frequency reuse to build higher throughput. It is an exciting property for the conception and development of systems dedicated to the 5G wireless communication system, but high gain antennas are also required. Therefore, the system design must use antenna arrays with good gain and high-efficiency properties to lower overall cost and improve system performance. With the low transmitting power and the high path attenuation in the 60GHz band (68dB at 1m), it is necessary to use directive antennas to obtain very high throughput rates. Table 1 shows the performance that can be found in some countries.

Table 1: Frequency range with maximum transmit power and maximum gain for a 60 GHz system.

Countries	FR(GHz)	Power(mW)	Gain(dB)
USA	57-64	500	-
Japan	59-66	10/250	47
Europe	57-66	20	37
China	59-64	10	34
Canada	57-64	500	-

3 DESIGN ASPECTS OF MILLIMETRE-WAVE ANTENNAS

5G has requirements to design and implement high transmission speeds and colossal data throughputs with a high footprint for various applications, including sensor networks and intelligent buildings.

Other preferred characteristics for antenna Construction are Highly efficient radiation patterns and stability throughout the required band and small dimensions, and low profiles with easy integration. Improvements in the antennas' gain and efficiency must be considered when designing the system, as propagation losses are higher at higher frequencies, which means a better-received signal. The following essential and vital element to consider during the design phase is the supply lines' choice. Conventional feeds such as microstrip lines and waveguides are subject to undesirable influences when transmitting and radiating at millimetre-wave frequencies, decreasing the total radiation performance and significantly reducing the gains generated by the various antennas and antenna arrays.

4 60GHZ ANTENNA TECHNOLOGY WITH COMPARATIVE ANALYSIS

Reflector, lens, or horn type antennas for millimetre-wave communication systems are not suitable for 60 GHz radio systems because of their high price, difficulty integrating into a component, and large size, but they have a high gain. Because of this, the researchers decided to focus on designing printed antennas for millimetre-wave systems. These printed antennas have several different and pleasing features: low profile, small size, low cost, and easy integration on components or the human body. Due to their simplicity of design, several slot antenna structures are employed to increase the antenna's performance. In this part, we present the several types of antennas for the 60GHz band, which offer considerable flexibility and low cost. Low profile design capabilities are presented in table 2, which gives the possibility to compare the performance of these antennas.

Table 2: performance comparisons of the different existing antennas.

Ref	DS	Sizes mm^3	Types	NA	ET
(Jyoti, 2017)	RT	8×8×1.6	AP	-	IS
(Aishah, 2017)	RT	3.6×4.3×0.127	AP	-	IS
(Hang, 2013)	RT	9.5×7.5×0.508	AP	-	IS
(Alam, 2013)	RT	1.48×1.5×1.575	AP	-	IS PF
(Nacer, 2012)	RHF	10×100×100	Yagi-Uda	-	-
(Ahmed, 2019)	UL	33.5×20×0.05	AP	-	IS
(Saravanya, 2017)	FR4	-	AP	-	IS PF
(Seongkyu, 2018)	FR4	5×5×0.127	Yagi-Uda	8	PF
(Nacer, 2013)	Tex	-	AA	4	-
(Da Silva Júnior, 2019)	Si	-	AA	2	IS
(Younger, 2018)	TLY	-	AA	8	PF

Ref	BW GHz	Gain (dB)	S11 (dB)	PT
(Jyoti, 2017)	4.028	5.6	-40.99	-
(Aishah, 2017)	-	7.55	-29.23	-
(Hang, 2013)	7	7,73	-	-
(Alam, 2013)	11.3	9.52	-41	C-P
(Nacer, 2012)	7	11.9	-	P-P
(Ahmed, 2019)	-	2.19 4.43	-13.99 -19.26	-
(Saravanya, 2017)	11.9 /12	-	-13.55 -13.76	-
(Seongkyu, 2018)	0.4085	2.86	-23	-
(Nacer, 2013)	-	8.6	-	C-P
(Da Silva Júnior, 2019)	5.88	8.83	-30.4	-
(Younger, 2018)	-	14,8	-27.5	-

where **DS** is the term for the support used for the design, **RT** refers to Rogers RT5880 substrate with a relative permittivity of ε_r=2.2, **RHF** refers to Rohacell 51 HF substrate with a relative permittivity of εr=1.05, **UL** refers to ULTRALAM® 3850HT substrate with a relative permittivity of ε_r=3.14, **Tex** refers to a textile substrate, **SI** refers to a silicon substrate, **TLY** refers to TaconicTLY substrate, **AP** means it's a patch antenna, the term **AA** indicates that it is an antenna array, The symbols are as follows: **ET**: technical enhancements, **PF**: probe feed, **IS**: Inserting the slot, **PT**: polarization type, **C-P**: cross polarization, **P-P**: parallel polarization, and **NA**: number of antenna array elements.

Table 2 above details the previous results obtained with the different antennas, as well as the type of antenna, the number of elements in the antenna array, the type of antenna polarization and the methods of improving the antenna performance. Table 2 shows that the antenna array mentioned in (Da Silva Júnior, 2019) has a better bandwidth, and a larger reflection coefficient S_{11} than those mentioned in (Younger, 2018; Nacer, 2013; Seongkyu, 2018), as well as the number of antenna elements being smaller than the arrays mentioned in (Younger, 2018; Nacer, 2013; Seongkyu, 2018), But the array in (Younger, 2018) achieves a high gain among other antenna arrays. The performance of the antenna (Alam, 2013), including bandwidth, gain, and S_{11} is better than that of the other antennas mentioned in (Jyoti, 2017; Aishah,2017; Hang, 2013; Nacer, 2012; Ahmed, 2019; Saravanya, 2017; Younger, 2018), as well as its smaller size than the latter.

The work done on the propagation mode in the 60 GHz frequency band shows that the technique of slot insertions at the antennas allows obtaining very efficient results, as shown in Table 2.

5 CONCLUSIONS

In recent decades the discipline of broadcasting has undergone a period of considerable growth. Some new antennas' technical progress, such as the millimetre-wave antenna, broadband, dual/multiband or reproducible structures, as well as dimensional decrease, compactness, reduced profile, impedance bandwidth, increased gain, or linear and circular polarization applications, etc., have all contributed to this growth. Even if a sufficient level of maturity has been reached, several issues remain to be resolved. The microstrip patch antenna can be designed to integrate with a large part of the architecture to develop the 5G application system features. This report presents single antennas and antenna arrays in the 60GHz bane for 5G communication; the purpose of each antenna is to improve the performance of other antennas.

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