A review of planar antennas for millimeter wave 5G network

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Abstract: In order that wide implement of 5G network is realizable in the future, special features in the propagation of millimeter wave is required, which are much different from that of current operating 4G network and still have great potential to explore. As a result, the antennas used in future 5G network will be much more sophisticated in design and will need a lot of frontier technologies. The key factors in 5G millimeter wave antenna design are reconfigurable antennas, beamforming, antenna array, orbital angular momentum antennas, meta-surface antennas and massive MIMO. The purpose of this work is to illustrate some designing idea of planar antennas used in 5G millimeter wave network by presenting some of the contemporary theoretical and practical design idea investigated by this paper. Since currently there is great amount of research ongoing in this field, this paper can serve as a brief guide and introduction for those who are interested in 5G planar antennas to get a picture of the latest theories and technologies used in those designs.

Keywords: Millimeter wave 5G band, Antenna design, Planar antenna.

1. Introduction

The world is witnessing massive and rapid changes in wireless communication generation. It has been a few decades since the first generation of voice-only systems. And now, the communication networks are going to step into the 5G era, where the wireless connection network will be operating on millimeter wave bands, including sub- 6GHz bands and possibly millimeter-wave band, also called high bands. There is a strong expectation for countries to fully establish a 5G communication network domestically and develop its technology as competition. In all these areas, key enabling physical factor consists of massive MIMO, Orbital Angular Momentum, antenna beam forming, and SDMA, which can only be realized depending on advanced antenna system design for 5G millimeter band [1,2].

Millimeter wave antenna will be quite different from previous communication generations since it is quite a hard situation for signals of the millimeter wave frequency to propagate in space. Firstly, there will be much more free space propagation losses in the outdoor environment. Thus, the communication quality will not meet the basic standard after propagation that covers long distance [3,4].

Moreover, signal attenuation through obstacles is also challenging for 5G communication networks because it will strongly restrict non-linear communication.

The table below shows the main parameters between 5G communication network and previous 4G communication network. We can learn from the statistics that many unprecedented challenges will be brought to the 5G millimeter wave antenna design stages. Based on contemporary research results, latest 5G possible antenna technologies include

(1) Reconfigurable antennas which provide different diversities such as frequency,
radiation pattern, polarization and spatial.
(2) OAM (Orbital Angular Momentum) antennas
(3) Meta-surface antennas
(4) Massive MIMO
(5) Antenna Array
(6) Beam forming

This paper aims to focus on the planar antennas for 5G millimeter communication network. The discussion will consist of the basic structures and the principles for millimeter-wave antenna design

and some contemporary work done in the design of 5G millimeter wave antenna design. 3 design idea will be included in this paper.

2. Theoretical Analysis of planar antenna

2.1 Comparison of air interface in 4G and 5G

Table1. Comparison of the main differences for antenna working at 4G and 5G bands

property	4G	5G
Frequency	645MHz-3GHz	10 -50GHz
directional type	half directional	directional
Scale	Big	Tiny
Forming Array	Selective	Necessary
Beam Forming	Selective	Necessary
Fractional Bandwidth	about 3%	about 10%

2.2 Geometries of basic microstrip patch planar antenna

This type of antenna was not developed until 30 years ago, meaning that they are quite brand new compared to other classes of antennas. Basically, a patch antenna contains the substrate tab made with dielectric medium, the patch made with high frequency board and some transmission lines. The structure is shown below [5].

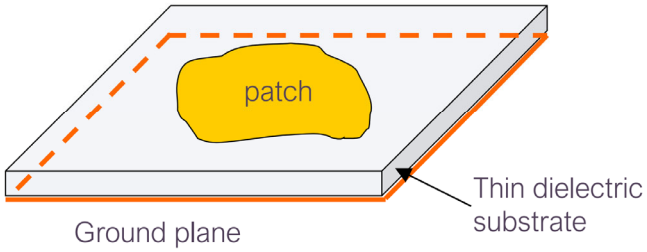


Figure1.the general geometry of a planar patch antenna

2.3 Material considerations of microstrip patch antenna

Commonly speaking, the metal-based patch consist of thin copper lamina. The main function of this material is mostly to provide the radiating patch elements with mechanical support and keep the prescriptive space in between the ground plane and the patch.

The thickness of the substrate plate ranges from 1% to 5% of the free-space wavelength. Note that the thickness of commercially available substrate is not continuous or random.

Dielectric constant varies from 1 to 10 and is normally classified into three types:

(1) Those varies from 1 to 2 are often pure air, PS foam or dielectric nest.

(2) Those from 2 to 4 are materials containing Teflon made with fiber-glass reinforcement.

(3) Those between 4 and 10 are materials that are made of Alumina, Quartz, or Ceramic [1,3].

2.4 Microstrip feedline and impedance matching

A microstrip patch can be connected directly to a microstrip transmission line. But the impedance of both elements must match before signal is transported. Commonly, the chosen impedance is 50 ohm in the middle of the patch. However the impedance is usually much higher than 50 ohm at the edge of a patch. In order to prevent signal loss due to impedance mismatch, quarter wavelength converter sections are used to change the higher input impedance to 50 ohm.

Also, a way to match the impedance is to make the microstrip line go deep into the patch, as shown in the figure. The further transmission line goes into the patch, the less impedance it will reach, so it is important to make sure the distance is appropriate for impedance matching[1,3,5].

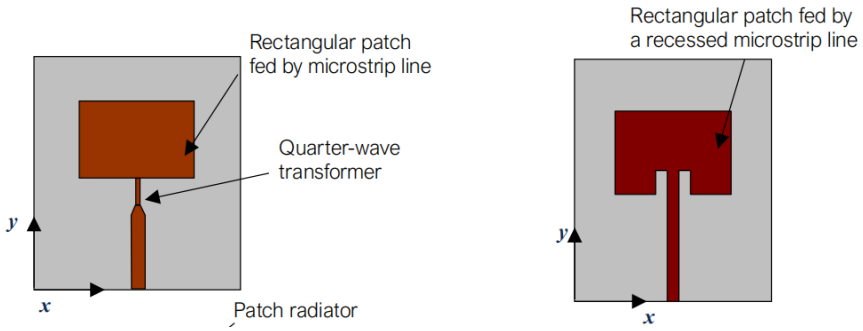


Figure 2.Two types of microstrip antenna feedline design

2. 5 Basic parameters of a microstrip antenna

2.5.1 Fractional bandwidth

The fractional bandwidth is operating frequency divided by the full length of the antenna's available band. The bigger it is, the more capable the antenna is. The empirical formula can estimate the fractional bandwidth of a rectangular patch antenna which is commonly used in basic design of planar antennas [4-6].

$$BW = \rho \cdot \frac{h}{\lambda_0} \cdot \sqrt{\frac{W}{L}}$$

3. Recent progress in millimeter wave 5G antenna design

3.1 Reconfigurable Antennas

Configuration is organizing parts of an antenna such as determining the shape of the antenna, substrate scales, position and sort of the feed line. To make the antenna keep working at the needed frequency, the shape of the antenna should be able to change as soon as the wanted frequency changes. There are several ways for reconfigurable antennas to change such as altering the current, starting controllable parts, activating phase converters, tunable and active materials. It is important to notice that reconfigurable antenna can either be in a singlar form or a whole array of antennas [3,7].

There are many fields designer should focus on aside from its performance, including speed of reconfiguration, power efficiency, reconfiguring requirements, fabrication availability, device using lifetime, weight, size, cost, dynamic range, sensitivity. Though electronic counterparts have faster reconfiguration movements, the complexity of their movements is normally worse than the mechanical reconfiguration movements achieved by physical structures [10-12].

However, there are certain kinds of mechanical reconfiguration that are more powerful and less complex, but those components are often fragile and cannot bear much pressure to realize the operating features.

It is easily noticed that no matter which reconfiguration methods are used, the weight, cost and complexity will rise a lot compared to those fixed antennas. However, the balance lies behind the extra functions that reconfiguration enables the antenna [5,9].

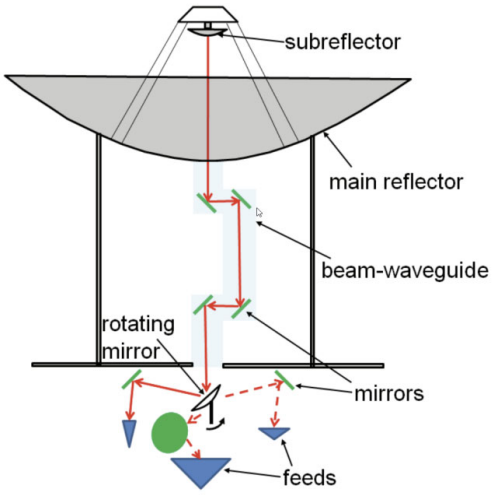


Figure 3.A diagram of the structure of a beam-waveguide reconfigurable antenna

3.2 OAM antennas

As it is in nowadays wireless communication networks, multiplex techniques using variable frequency, amplitude and polarization are normally used to improve the system's transmission efficiency. Yet, efficiency of spectrum resources cannot be infinitely increased through multiplex techniques since several factors are limited including spectrum resource and capacity [13].

Lately, as millimeter wave technologies are developing rapidly, there has been a growing demand of solving the limited wireless spectrum resources and growing demand of larger bandwidth to get better communication experience. Thus, it is essential to seek a proper way to solve this dilemma. It was not until great scientific work was accomplished before. One possible way is to apply orbital angular momentum(OAM in short). It is of great importance that this method provide antenna designers with brand-new extent of freedom. What's more, it has more possibility to provide limitless channels for future communication network at useful frequency .

Using OAM in wireless communications is a relatively new concept in the how an EM wave propagates when compared to linearly and circularly polarized waves.

OAM antennas allows transmission of multiple signals simultaneously at the same frequency which theoretically infinitely increase the spectral efficiency in a communication link. Ideally, an OAM antenna could generate diverse fields at the same time, each one related to a different figure of the 'orbital momentum'.

Orbital momentum is the angular variation of the phase $e^{jm\varphi}$ around the predetermined direction [8,13]. (m is 0, ±1, ±2 …… and φ is the azimuth in the area of observation)

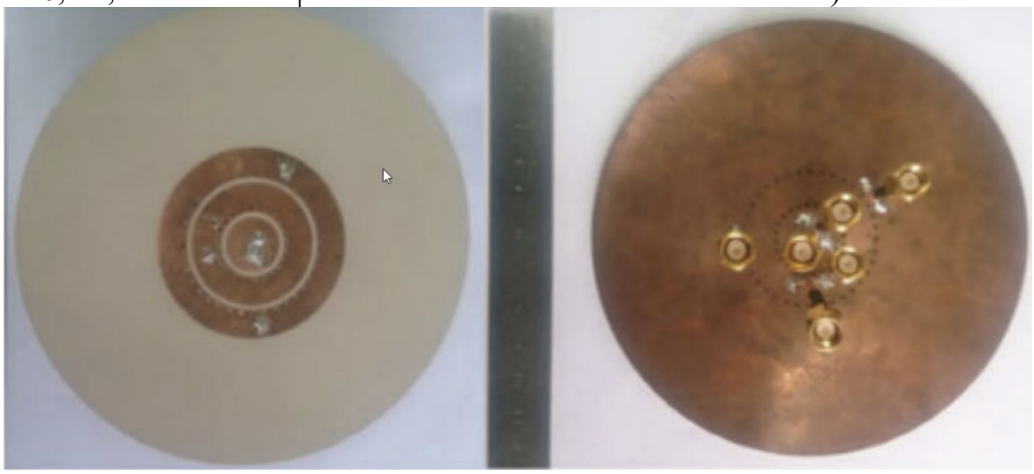


Figure 4. Microstrip patch antenna with oval-shaped patch connected with a feeder to realize multiple OAM modes

3.3 Meta-surface antennas

Meta-surfaces are thin man-made layers made of periodic material of tiny elements placed on a dielectric medium on the ground. They can be constituted by a densed- distributed metal pins on the ground plane at sub-millimeter wavelength.

They have so many functions such as achieving unusual reflection/transmission properties of space waves, modifying the dispersion properties of surface or guided waves.

it will reproduce a wanted aperture field radiation according to the leaky wave effect when the surface wave interacts with modulated, periodic boundary conditions imposed by a MTS at that part of the antenna.

The reflection coefficient and transmission coefficient of the meta cells are able to be electronically programmed to control the amplitude or phase of reflected or transmitted electromagnetic waves on the surface in real time, therefore the modulation of radiation patterns of the meta-surface antenna can be effectively realized, it has appeal in the 5G mobile communications [1,8] .

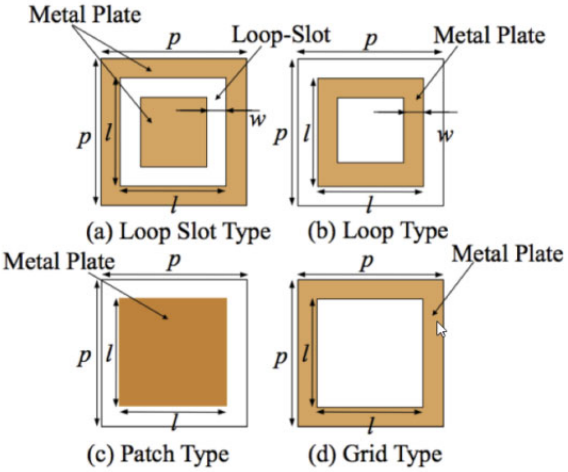


Figure 5. Meta-surface used in planar antennas

3. 4 Massive MIMO

As the cost of online communication is greatly decreased thanks to rapid progress in mobile devices. Therefore, wireless communication network is much more popularized in almost all places where people step in [8]. Take the high population density into consideration, more and more frequent mobile communication network builders have been faced with the growing requirement for higher data rate, higher energy consumption efficiency, larger communication capacity and higher flexibility. One solution to this is to realize a tremendous network with great amount of input and output devices which work at the same time to meet the communication need of the users in a large area [8].

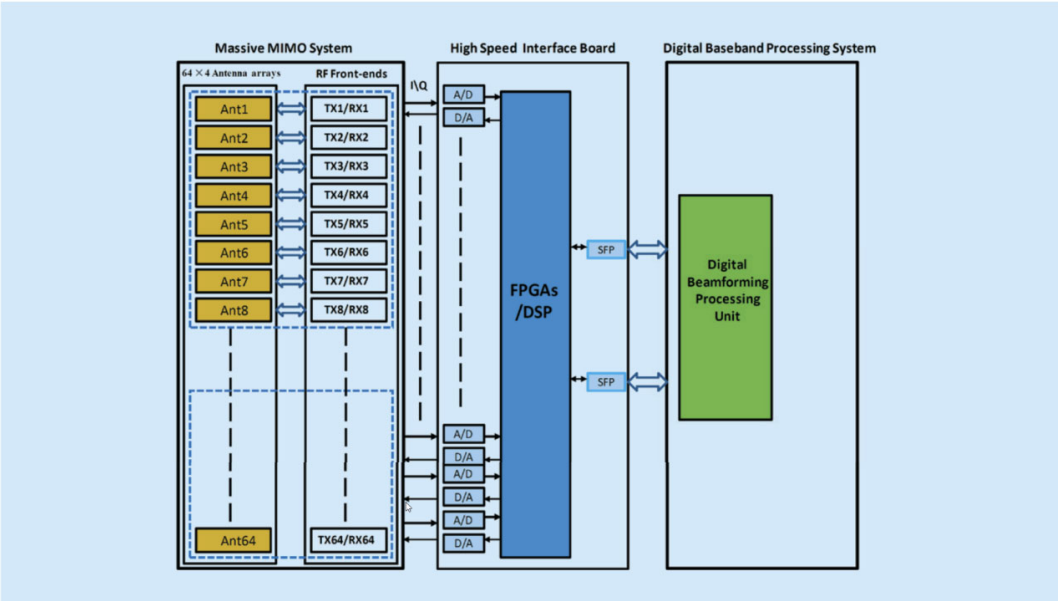


Figure 6. The theoretical structure of a Massive MIMO system

The difference between conventional MIMO and Massive MIMO can be measured in various dimensions. Here is a table about the main differences. We can learn that Massive MIMO is much harder in both design and complementation.

Table2.Comparison of conventional MIMO and Massive MIMO

Antennas A, users U	Conventional MIMO	Massive MIMO
Number	$A \approx U$	$A \gg U$
Signal processing mode	Non-linear	Optimal linear
Duplexing mode	TDD and FDD	TDD with reciprocity
Instantaneous channel	Acknowledged at base stations and users	Acknowledged at base stations
Communication quality	Fading rapidly and frequency-selective	Stable
Variation of user load	Scheduling needed if $K > M$	Scheduling seldom needed
Resources distribution	Rapid	Slow

3.5 Antenna Array and Beam forming

An antenna array can consist of multiple single elements. The directivity of a single antenna element is limited. Antenna arrays can change the directivity, most of the time gain as well to provide the flexibility for different communication ranges and requirements. To change the directivity, the aperture of the antenna has to be changed. It can be realized by utilizing more than one antenna element to form an antenna array. In the simplest form of antenna array, the elements, spacing, amplitude and phase of the signals are identical, but it is not universal.

Beam forming is one of the most significant technologies used in antenna design, it guarantees the antenna system to be capable of containing plenty of individual antennas' signals whose phase and amplitude can be changed to have the array form new beams according to communication requirement [5,8,9].

In addition to the parameters of the single antenna element, there are five common array parameters to use when shaping the radiation pattern of an array.

(1) geometrical layout of the overall array such as linear or spherical
(2) distance between each element
(3) amplitude of a single element
(4) signal phase variation of a single element
(5) relative pattern of radiation of each element

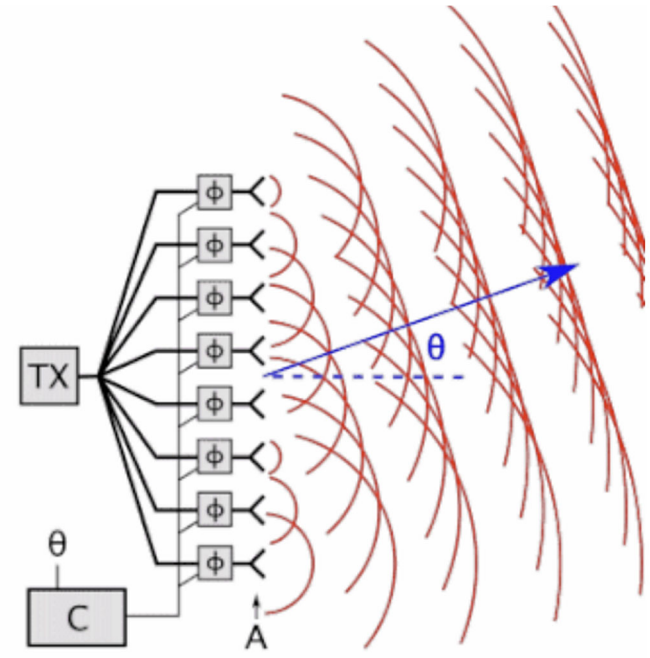


Figure 7.A possible structure of a 1*8 antenna array and its radiation pattern

4. Recent work in millimeter wave 5G antenna design on beam forming

Based on the idea of spatial beamforming, in order to meet the need of multi-beam massive MIMO systems, Jiang and his fellows came up with a design of thin planar lens antenna. The antenna is mainly constructed with a very thin metamaterial-based surface with two separate layers so that the regular intersection and reflection can be reduced to a great extent. The shape of the whole element is also unique, a Jerusalem cross is used shown in the picture below. It has a long history of using for frequency selective surface applications because it has a lot of advantages including small size, changeable frequency choices, wide bandwidth and steady operating frequency features when it comes to a situation where wide angle is needed. In the picture, **s** is the size of a single Jerusalem cross which should be no more than half of free space wavelength of its working frequency, the length of the cross arm **a** defines the resonant frequency while the end cap length **c** is responsible for obtaining various phase shifting and the width of metal line is described as **w**[11].

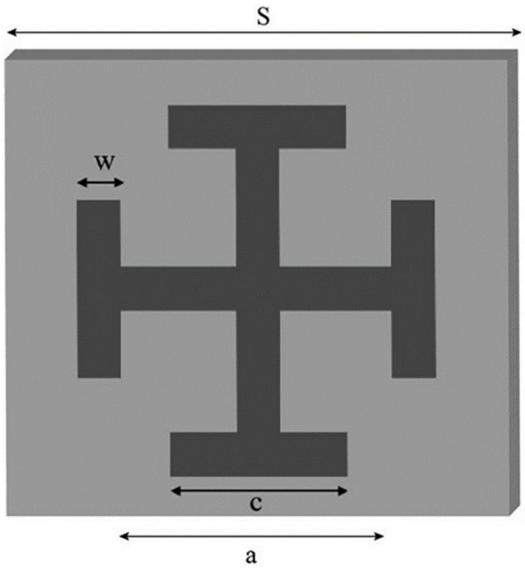


Figure 8. Jerusalem cross widely used in building frequency selective surfaces

Jang introduced a 1x4 array using dipole antennas as single element. The special part about this array design is that they use microstrip lines to apply a Butler matrix for beamforming. In order to have better gain and bandwidth, the proposed work use this beam forming antenna as to feed a horn antenna. The horn antenna has a self-isolating property, leading to the characteristic of possessing higher gain while beamforming is done by dipole antenna with the Butler matrix. As a result, it achieved better parameters when doing measurement including 13.4 dBi and 105°range of switching which are realized by combining the two antennas[12].

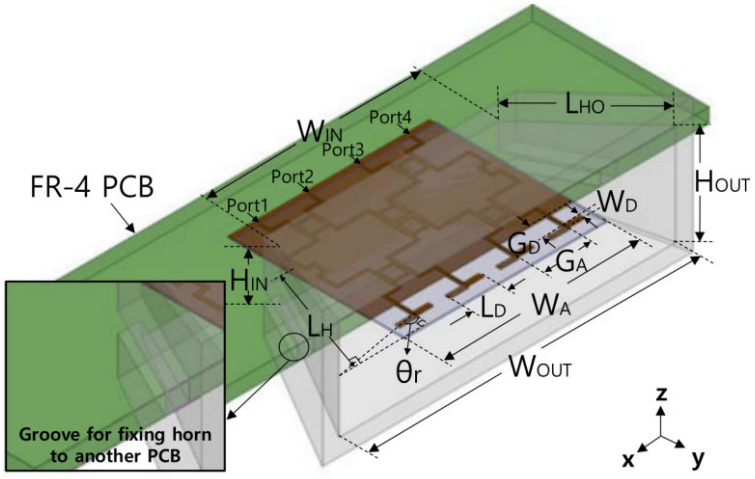


Figure 9. The geometry of the hybrid antenna

5.Conclusions

This paper has shown some of the latest antenna design ideas and key factors that are significant to learn before exploring the design of millimeter 5 G antenna. It is strongly emphasized that beam-forming is vital for 5G antenna design, and both two types of technique to realize beam forming have been thoroughly discussed in this work. In conclusion, the most important idea to beam forming is get the proper geometry and better gain while reduce the size. Since currently there is great amount of research ongoing in this field, this paper can serve as a brief guide and introduction for those who are interested in 5G millimeter wave planar antennas to get a picture of the newest theories and

technologies used in those designs. It is compact that in the future, antenna designs mentioned in this paper will be widely used in implementation of 5G millimeter wave network.

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