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ORIGINAL RESEARCH ARTICLE

Sustainable spectrum sharing 5G network antenna design for smart city

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ABSTRACT

The objective of this research paper is to propose the design of an integrated circuit (IC) combined with an antenna to reduce the footprint on the Printed Circuit Board (PCB). The aim is to enhance its power, space efficiency, and sustainability in order to improve its usefulness, especially in smart city communication. This paper introduces a smart antenna design that enables message transmission and reception through multiple channels while also facilitating wireless spectrum sharing over a 5G network. The effectiveness of a sustainably designed 2 × 2 Planner array antenna is evaluated by measuring the return values (in dB) and Voltage Standing Wave Ratio (VSWR) values with respect to frequency changes. The operational frequencies of the antenna are 44.3 GHz and 35.2 GHz, achieving a maximum gain of 15.4 dB at 29 GHz. The radiation efficiency is determined to be 85% at the resonance frequencies. In future, it would be beneficial to focus on developing an antenna with similar characteristics while utilising a smaller number of elements.

Keywords: 5G communication; planar antenna array; on-PCB footprint

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1. Introduction

Wireless communication media has undergone tremendous improvements and transformations in the era of a few decades. Nowadays, the information consumed by an average customer through their smart devices is increasing rapidly which necessitated the deployment of 5G Communication networks all over the world to provide better QoS to customers through wireless communication networks. The goal of 5G communication over 4G communication can be summarised using the following key points[1–6]:

1) Increase in capacity by 1000 times;
2) Support for 100+ billion connections;
3) Speeds Up to 10 Gbit/s;
4) Latency below 1 ms.

This can be achieved by utilizing the techniques namely[7–9]:

1) Enhancing the wireless spectrum availability;
2) Use of MIMO (Multiple Input Multiple Output) Antennas;
3) Increasing the deployment density of the Base-station.

The antenna acts as a critical component as it is responsible for the transmission and reception of the signal over the wireless transmission medium and the first two techniques mentioned above are linked with or based upon the design of the antennas[10–18].

In the first technique, the antenna should design should support transmission over the newly introduced spectrums, and in order to achieve this goal, we must explore the conceptual advantage of the MIMO (Multiple Input Multiple Output) antennae[19–26]. The following are the problems arising out by installing multiple antennas in a device:

1) Mutual coupling between antennas placed in close proximity;
2) Space utilization within the device.

Most of the communication systems use a single carrier/ channel for transmitting and receiving signals. With the evolution of higher versions of 4G and the introduction of the 5G communication systems (as shown in **Figure 1**), the use of multiple carriers/channels has come into practice. This practice is often called “aggregation of carriers”. By using carrier aggregation, telecommunication equipment becomes able to send and receive data over multiple channels simultaneously which allows simultaneous transmission as well as the reception of data at enhanced data rates. These channels can be placed in the same frequency bands (intra-band Aggregation) or can be in separate frequency bands (inter-band Aggregation).

The efficiency level and the operational bandwidth of the designed antenna largely depend upon the size and electrical characteristics of the antenna. In case, we intend to use the antenna in a handheld device especially a mobile device, the antenna dimensions have to be very small as well as must be having quality operation simultaneously and effectively over multiple frequency bands. Through tuning of the frequencies, the above-mentioned issue can be addressed and the same can be achieved by selecting of the particular frequency over which the designed antenna has to operate, enabling the device to transmit and receive over that particular frequency only, further keeping silent over other frequencies. A few methods used to tune the antenna are:

1) By using the tuning components[14–17].
2) Diodes like PIN diode[19–21].
3) FET switches[23,24] etc.

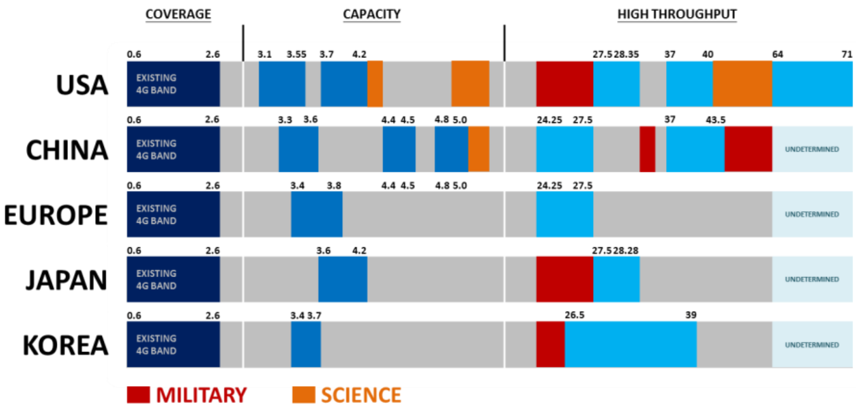

Figure 1. Diagrammatic representation of the 5-G spectrum.

2. Background

2.1. Specification of the designed antenna

In this work, our target was to create an antenna smart enough and more sustainable for the transmission and reception of data for modern wireless communications networks using 5-G communications standards. The smartness of the antenna design lies in the concept that it can transmit and receive data on several different bands of frequencies at the same time in order to support 5-G standards of Wireless communications shown in **Figure 2**. The antenna design is sustainable enough to support different bands of frequencies used in 5G communication, so for this investigation, we have assumed that the antennas have to transmit and receive data over bands of wireless frequencies between 5.356 to 6.327 GHz and 3.31 to 4.56 GHz.

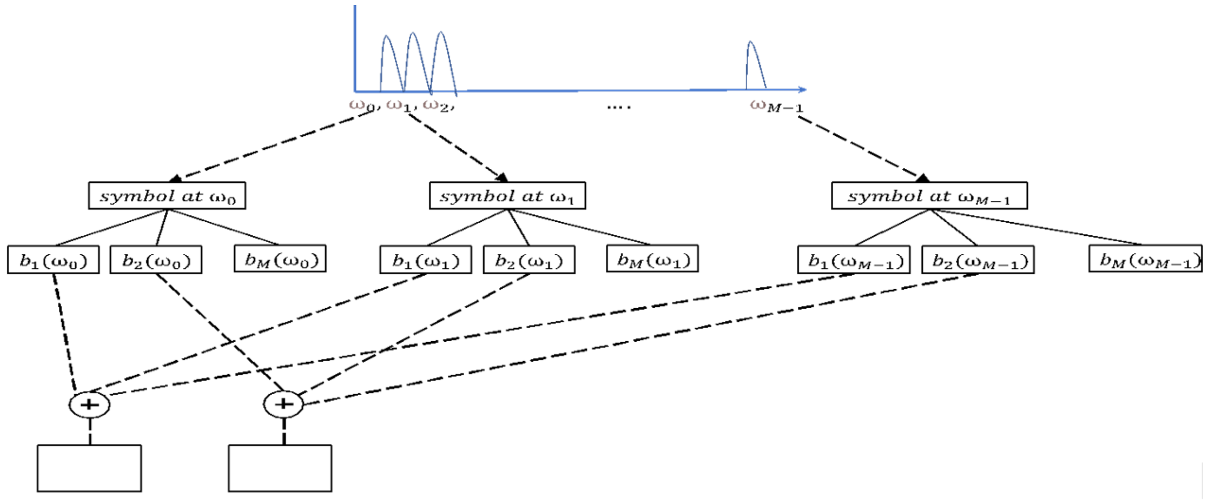

Figure 2. The weight of every carrier is done one by one in order to get the system operating over multiple bands, adding these values and *transferring* them to the *input ports* of the antennas.

2.2. Operating principles

The depiction of an antenna consisting of ports of N numbers and the parameters of scattering for such a device is mentioned in Equation 1. In Equation 1, the vector named a represents the vector wave that has been reflected and the vector b represents the vector wave that is being incident and the scattering parameters are denoted by the matrix S and S_{ij} denotes the parameters of scattering. In case the antenna is used inside a small mobile device, the different ports of the antenna and the different antennas are placed in such close proximity that they may couple the ports of each other. Apart from this the dependency of the antenna is on frequencies and variation of the matrix of scattering occurs with the alterations of frequencies.

$$a = [a_1 \dots a_M] = [S_{11} \dots S_{1M} .. \quad .. \; . \; .. \quad .. S_{M1} \dots S_{MM}][b_1 \dots b_M] = Sb \tag{1}$$

$$R_i = \frac{a_i}{b_i} = \frac{1}{b_i}(S_{i1}b_1 + S_{i2}b_2 + \cdots + S_{iM}b_M) \tag{2}$$

The coefficient of reflection is obtainable by virtue of the Equation (2). The coefficient of reflection is denoted by the variable R_i. In this equation i denotes the index of the port.

Through the measurement of power that is being accepted, the performance of the antenna can be evaluated. But for the type of antenna system under consideration the entire structure should be taken into account instead of considering the individual ports in a separate manner. In order to achieve that, Coefficient of Total Active Reflection value is evaluated by the help of Equation 3. The value of CTAR represents the power that is reflected to the power that is incident ratio raise to the power of 0.5 (as depicted in the study of Hakanoglu and Turkmen[27]).

$$CTAR = \sqrt{\frac{aa^H}{bb^H}} = \sqrt{\frac{a(SS^H)a^H}{bb^H}} \tag{3}$$

The matrix of scattering is denoted by S and the symbol S^H denotes the transpose operator acted upon the conjugate of the matrix representation of S. Through the evaluation of the parameter called the efficiency of matching the working of the antenna can be characterized instead of using the parameter if CTAR.

$$\mu_{matched} = 1 - CTAR^2 \tag{4}$$

In Equation 5, I represent the identity matrix.

$$\mu_{matched} = \frac{b(I - SS^H)b^H}{bb^H} \tag{5}$$

The quotient of Raleigh makes up the structure of the Equation 5. It is expressed explicitly in Equation 6.

$$\frac{y^H M y}{y^H y} \tag{6}$$

M is assumed to be a Hermitian matrix and the biggest magnitude of M equals the biggest magnitude of the expression presented in Equation (6).

2.3. Operation over multiple bands

As per the specification the designed antenna is smart in a way that has been designed in a way so as to be sustainable in its working over 3 bands of frequencies at the same time and separate tuning of every one of the frequencies must be achieved. At this part of the document the description is provided on how every band of frequencies will go through tuning process one by one. For the operations of systems of cellular communications, the bands of frequencies under reservation are diverse and rough. During the time of communications, the smart devices use a single frequency one by one over a narrow band. This property has enabled tenable antennas capable of covering one narrow frequency range at a time. In some of the novel patterns of usage, more than one bands are used at the same time to aggregate the carriers and boosts the throughput of the system. The frequencies that are used at the same time for the "aggregation of carriers" may be in the same band of frequencies of may be in separate bands of frequencies. The procedures to tune frequencies of antenna are not utilized as they allow only single frequencies in an instance. As per out expectations the method under proposition in this paper do not have this hindrance of having to tune to only a single frequency in a single instance.

3. Description of specimen of the proposed antenna

3.1. Design of the antenna

The antenna has been created on a substrate which is 1.535 millimetres thick. The permittivity of dielectric of the substrate is $\epsilon_r = 2.43$ and a tangent of loss of 0.0015. At the plate of the ground of the antenna a clearance of 13 millimetres have been kept. In the **Figure 3**. The dimension of the full structure has been displayed. The entire frequencies that have been designed the parameters of scattering is maximized. As a result, the designing of the antenna is based on experiments at the current stage of the research.

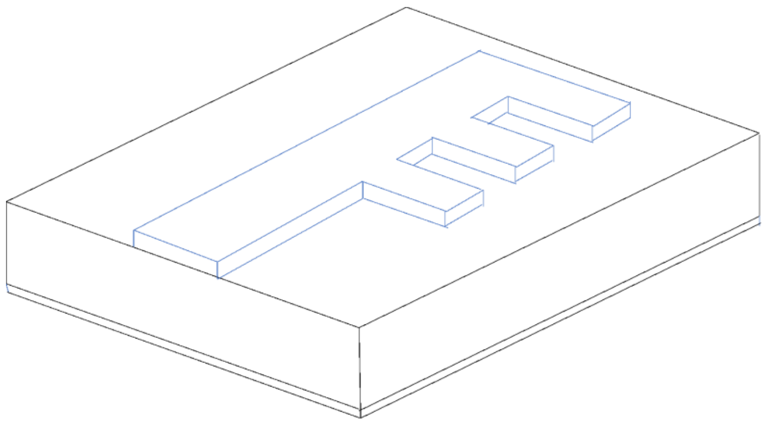

Figure 3. Demonstrates the design that has been simulated.

3.2. Prototype created

From the picture in **Figure 4** we can conclude that all port numbers will not emit the largest possible output energy. The above-mentioned aspect should be kept in mind at the time of designing of amplifiers because the little amplifier which drive the little antennas may assist in reduction of efficiency when the small amplifiers operate at low power output. As a practical instance, in the current proposition, the other antenna acts as an element of support since it is not inputted the biggest signals for any one of the frequencies. After knowing the difficulties of the transmitter and receiver limitations and requirements are established for the design of the antenna in **Figure 5**.

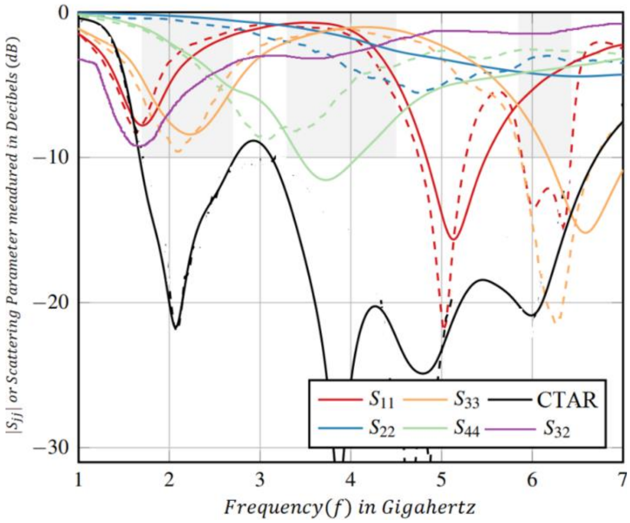

Figure 4. Values of parameters of scattering and their CTAR values.

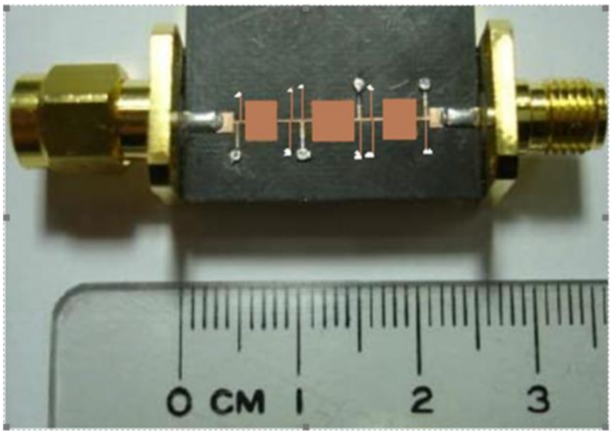

Figure 5. Prototype of the antenna as per the design that have been under proposition.

4. Experiment performed

4.1. Measurement of efficiency and parameters of scattering for the antenna

The measurement of the parameter of the created prototypes are performed by the use of measurement of parameters of scattering like parameters of scattering of 4 ports and determining values of efficiency in the ports, one by one shown in **Figure 6**. Utilizing Equation (3), for the entire antenna structure, the value of CTAR is calculated. The outputs of these experiments are demonstrated in **Figure 6**. For those parts of the antenna that are the shortest, the resonant frequencies are pushed to the low levels. Anyhow, the values of TCAR obtained are closely similar.

4.2. Simulation results

The outputs obtained after analysing the results of the antenna are evaluated in term of mathematics. To prove that the designed antenna performs in the manner as have proposed in this research, we have to put signals inside each of these antenna ports all at the same time. From **Table 1** we obtain the best coefficient for 2 frequencies that are under operation, namely 2.1 Gigahertz and 4.5 Gigahertz. The coefficients of reflection at each of the ports is got by the application of equation 2, the results have been presented in **Figures 7** and **8**.

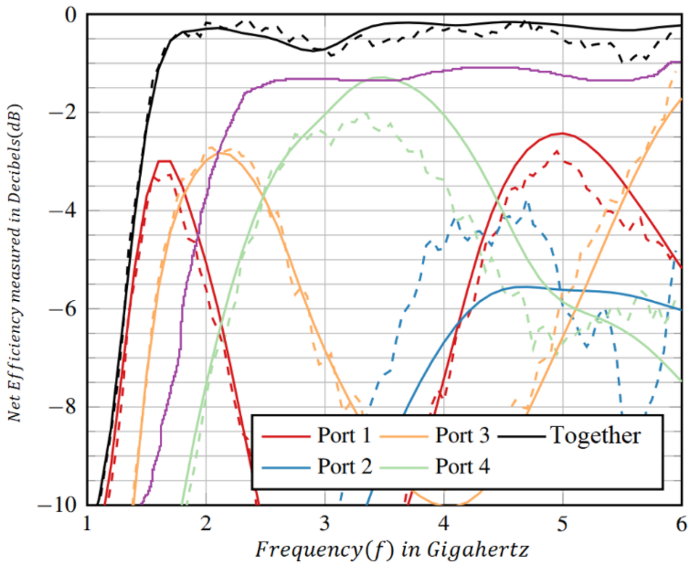

Figure 6. Values of efficiency calculated over the 4 ports of the antenna, The solid lines represent the experimentally derived values and the dashed lines represents the simulated values.

Table 1. Excitations coefficient optimizing.

S. No.	at 2.1 Gigahertz at 3 ports	at 4.5 Gigahertz at 3 ports
1	−5.56 decibels 153.4 degrees	−7.23 decibels −109.5 degrees
2	−23.34 decibels −89 degrees	−6.98 decibels −68.56 degrees
3	−4.57 decibels 91.4 degrees	−13.45 decibels 82.4 degrees
4	−8.91 decibels 0.23 degrees	−3.5 decibels 1.4 degrees

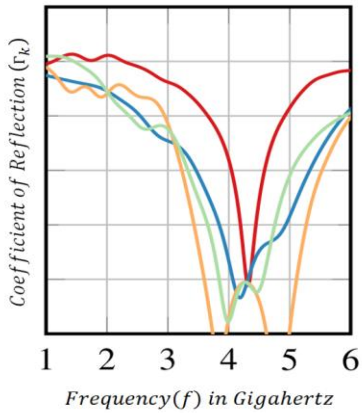

Figure 7. Coefficients of reflections for 2 excitations.

For the designed antenna we have evaluated the directivity in Far-field at varied angles of Azimuth. This has been depicted aptly in the **Figure 8**. In **Figure 8a** we see the representation of the antenna when acting for an input frequency of 2.1 GHz at $\Phi = 180\ degrees$. In **Figure 8b** we see the representation of the antenna when acting for an input frequency of 4.5 GHz at $\Phi = 270\ degrees$. From **Figure 8a** it can be observed that the main lobe position is at 50 degrees and from **Figure 8b** we can observe that the main lobe of the designed antenna has the principal lobe of the designed antenna directed in the azimuthal angle of 68 degrees. The graphs have been formulated using the data obtained from the use of Rhode-Schwartz Digital Spectrum Analyzer FPC-1500 and the obtained data has been plotted on the graph using RF Toolbox of MATLAB 2019b on a server using Core i5 (10th Generation) processor of 4.5 GHz speed and a RAM of 8GBs.

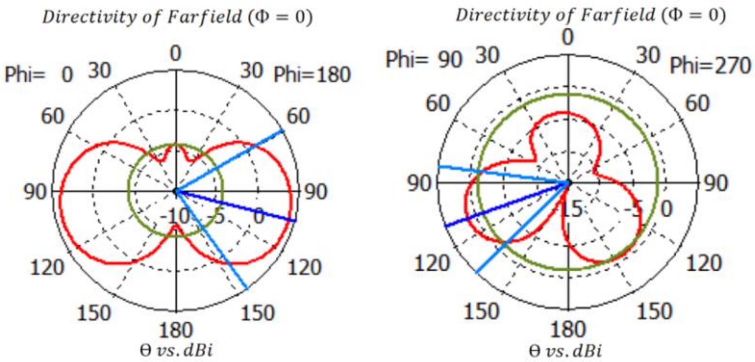

Figure 8. (a) Pattern of Radiation at 2.1 Gigahertz for phi = 180 degrees; **(b)** Pattern of Radiation at 2.1 Gigahertz for phi = 270 degrees.

5. Conclusions

This work mentions many significant findings that have come out of this research. A demonstration of the form factor for mobile has been done and measurements of the designed antenna have been presented. From the power fed into the port of input of the antenna and the far-field have been measured and then the antenna efficiency has been found. As a result, which were obtained theoretically have been backed up by practical measurements done in order to properly characterize the operations of the antenna.

The proposed antenna in this work is an underlying plan where there is a lot of scope for upgrades and advancement through optimization of the parameters of the antenna. As additional antennas will be added to the device, the transmitter and receiver complexity will be upgraded. In future enhancement on getting comparable results while utilizing lesser number of elements of the antenna should be possible for additional exploration.

Author contributions

Conceptualization: VW, MRM and VM; methodology: VW, MRM; software (design and simulation): VW and MRM; analysis: VW and MRM; Fabrication and measurement: VM and VW; original draft preparation: VW and MRM; reviewing and editing: VW, MRM and VM; visualization: RM and VM; supervision: VW. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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