# Realistic Antenna Array Modeling for 5G Communications

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***Abstract*— The 5th generation mobile networks promise a revolution in the way we connect, with faster data transfer and the capacity to support a higher density of users. 5G is expected to improve along this line of services to offer high speed internet, high definition video streaming, efficiency and real time connectivity to IoT enabled devices, thus promising ubiquitous connectivity at three times the speed of 4G. In the presented work, a street intersection environment, signal communication between the street light pole and moving car is studied. A printed patch antenna array with capacitive coupled microstrip fed is designed and simulated at 28GHz. Antenna array feeding network is illustrated to be installed on a car roof for 5G communication with street light poles and communication towers.**

***Index Terms*—5G mobile network, Internet of Things (IoT) Technology, signal communication, antenna array, solar loading.**

## I. Introduction

Since early 1980s, basic voice communication was made available. From that point on, text messaging was added as well as internet access culminating with 4G today which also offers streaming. With the excessive increase in wireless data traffic 5G is expected to improve along this line of services to offer high speed internet, high definition video streaming, efficiency and real time connectivity to IoT enabled devices. Hence mm-wave communication has become one of the most attractive techniques for 5G systems implementation since it has the potential to achieve these requirements and enable multi-Gbps throughputs, although propagation losses and sensitivity to blockage make it a challenge [1]. With that in mind, beam-steerable high gain phased array antenna design is the key component for 5G cellular systems [2-3].

Although mm-wave systems were mainly used for indoor scenarios, it has been recently implemented for outdoor environments and studies showed that possible limitations may occur in such cases for mobile communication systems operating in mm-wave bands. Therefore, several antenna array configurations were investigated for 5G applications such as patch antennas, printed microstrip antennas as well as cylindrical conformal microstrip antennas [4-7].

Antenna array beamforming is a key element in 5G implementations since that will directly influence the capacity of cellular networks by enhancing the signal to interference ratio (SIR) using narrow transmit beams that will offer sufficient signal power at the receiver terminal at larger distance in urban environments. Recently, its been studied that 5G systems can use adaptive beamforming antenna arrays by enabling technology multi-user massive MIMO which can achieve more efficient usage of radiated power [8].

In this paper, a realistic mm-wave planar antenna array will be illustrated for 5G communication. The goal is to install the modeled array on a car and allow V2X communication with installed street light pole. Finally, Link budget analysis of the antennas in their installed environments using appropriate RF propagation models and standards-based radio libraries is illustrated to assess the quality of service for the system in the presence of other potentially interfering wireless systems. Section II will describe the modeling workflow of mm-wave antenna array starting with single antenna element design. Series of optimization and design tuning were done using ANSYS HFSS [9] to obtain the targeted antenna far field pattern. With the use of infinite array approximation, one can predict the performance of the array quickly then use finite array analysis to accurately capture all effects such as edge effects and mutual coupling in Section III. The proposed scene for more realistic implementation of the proposed array will be discussed in Section IV where light pole and handheld devices as well as vehicle structures are implemented, and the goal is to investigate the communication between the light pole and the proposed antenna array with high power transfer and solar loading in mind. Finally, Section V will summarize the current work and put some light on future work.

## II. Antenna Modeling for 5G Outdoor Applications

The proposed rectangular patch antenna geometry is shown in Fig. 1 where a simple capacitive coupled microstrip fed rectangular patch antenna is designed to operate at 28GHz. The antenna was printed on a 0.381mm thickness Rogers RT/Duroid 5580 with dielectric constant of 2.2. The implemented feeding technique will help increasing the antenna bandwidth to be around 1GHz. Parametric studies were performed to optimize the antenna performance with different capacitive gap values as shown in Fig. 2(a) using ANSYS HFSS [9]. Antenna far field gain plot is illustrated in Fig. 2(b).

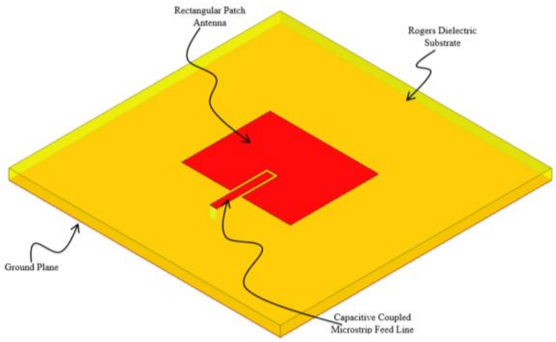
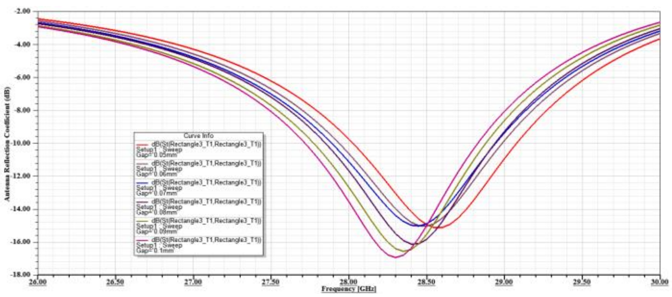
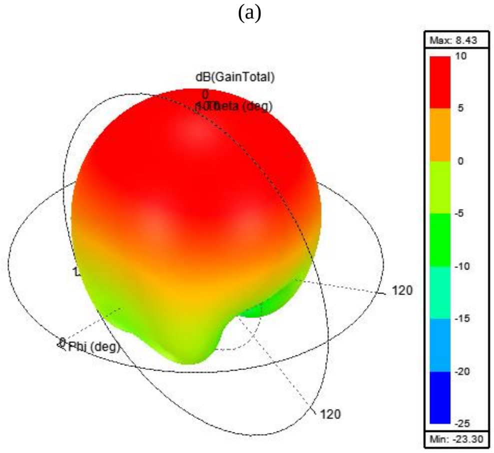



Fig. 1. Complete model of single emelemnt capacitive gap coupled microstrip feed patch antenna.




(a)

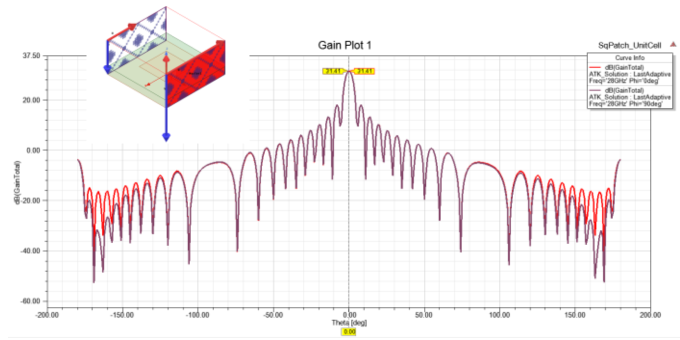



(b)

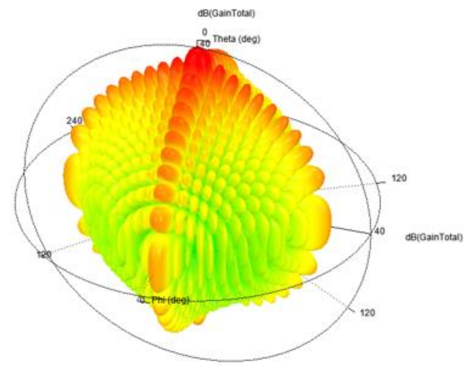
Fig. 2. (a) Parameteric study for capacitive gap tuning, (b) Optimized antenna far field gain 3D polar plot.

## III. Antenna Array Modeling Techniques

The use of the theoretical infinite array allows the designer to model the full array from a single cell thus saving on computational time and resources, and at the same time, allows the designer to calculate antenna parameters such as element pattern and impedance for boresight as well as oblique angles. Using ANSYS HFSS [9], one can use the unit cell approximation method with assigning linked boundary conditions to obtain the far field antenna radiation performance approximation. Fig 3. Illustrates the total gain patterns for an infinite regular conventional rectangular patch antenna array that will be installed on the streets' light poles for later analysis. This step will help concluding the number of array elements that will end up using for the physical array implementation.




(a)



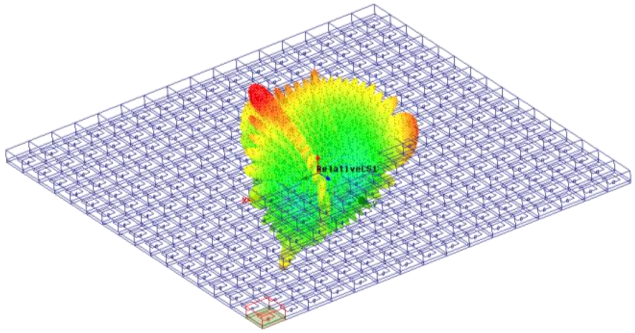

(b)

Fig. 3. (a) Total simulated gain for infinte conventional edge fed rectangular patch antenna, (b) 3D polar plot of the resulted array pattern.

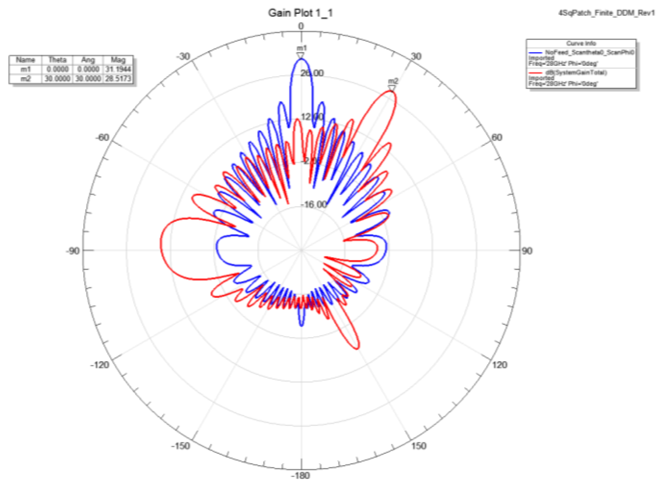
## IV. Finite Array Implementation with ANSYS Domain Decomposition Methodology

The periodic domain decomposition method available in ANSYS HFSS [9] uses a distributed-memory parallel technique for finite periodic geometries, such as antenna arrays. This method distributes unit cell mesh subdomains to a network of processors and RAM, while an industry-standard MPI maintains communications between domains. Simulation capacity and speed are substantially increased by re-using the adaptive mesh from a single unit cell for a large finite periodic structure and processing the duplicated unit cells across many processors. Using this method, a finite array is created to account for edge effect and coupling as shown in Fig. 4. ANSYS HFSS offers beam steering toolkit as well where designers can see the performance of the array when the beam is steered to different angles to provide coverage to different end user devices at the street level.

On the other hand, complete feeding network is created for the antenna array with back to back substrate where the antenna array is printed on the top face while the feeding network is implemented on a second substrate layer on the bottom face of the overall design as shown in Fig. 5. Probe feeding was used to couple the microstrip feeding network to the modeled antenna array.



(a)




(b)

Fig. 4. (a) Conventional Finite Rectangular Patch Antenna Array operating at 28GHz design using ANSYS HFSS Domain Decomposition Methodology, (b) Antenna Array Beam steering using ANSYS HFSS tool kit.

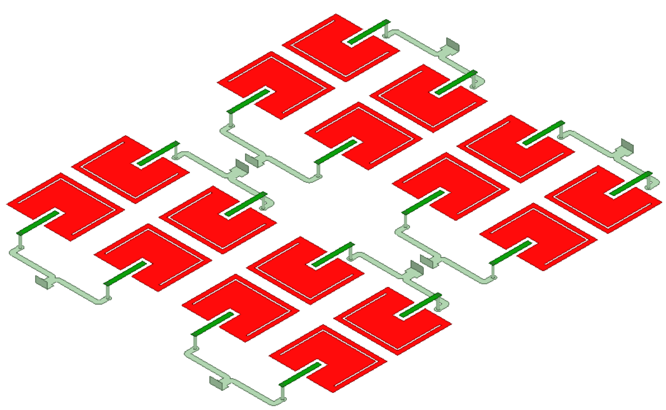


Fig. 5. Early design stage of a section of NxN capacitive coupled microstrip fed patch antenna where microstrip feeding network is printed on the bottom face of two-layer back to back substrates.

The next step is to install the finite antenna array on a large platform such as the light pole or the car for more realistic implementation and to uncover the actual array performance that can be different than when its designed in free space. Furthermore, shooting and bouncing rays technique provided by ANSYS HFSS SBR+ [9] can give insight on the coverage zones in the city block with each bounce of the signal. This helps the designer identify the coverage area footprint and work on reducing dead zones as shown in Fig. 6.

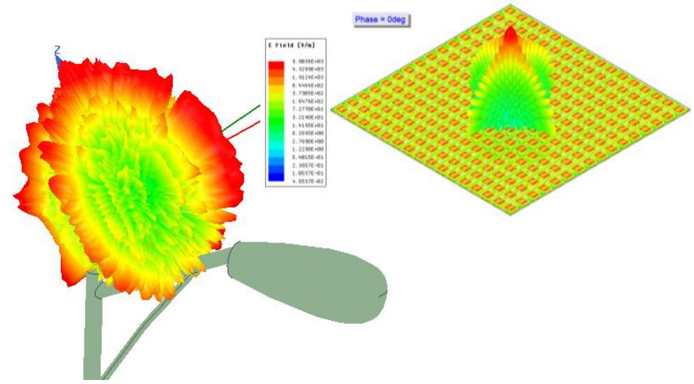


Fig. 6. Conventional patch antenna array in free space (right) and on electrically large platform like light pole (left).

The final scene where the implemented arrays will be installed is shown in Fig 7 where authors are investigating the bigger picture of intelligent road transportation with 5G communication systems with vehicle to infrastructure communication. With that, all vehicles and street infrastructure systems will start interacting with each other and passing along messages regarding road conditions and traffic flow.

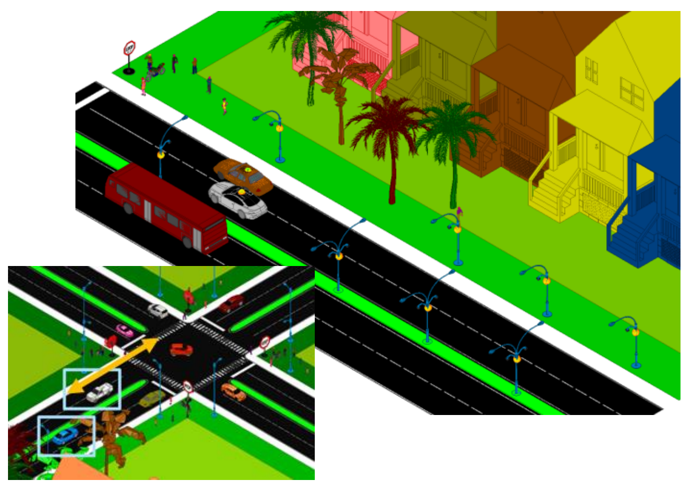


Fig. 7. Modeled street intersection for V2X communications with 5G array implementations.

The modeled case was tested first at a lower frequency range of 5.9GHz. The “Link Margin” indicates the strength of the wireless signals relative to the minimum necessary for successful communications. Link margins above 0-dB are acceptable while below 0-dB indicates that the link cannot be achieved. The plot shown in Fig. 8 is the link margin as a function of distance between the vehicle in an urban environment and accounts for the presence of buildings that causes “shadowing” of the radio signal. The maximum range of the V2V communication in this scenario is about 65 meters. This means the vehicles will become aware of each other, be able to communicate and exchange situational data at this distance.

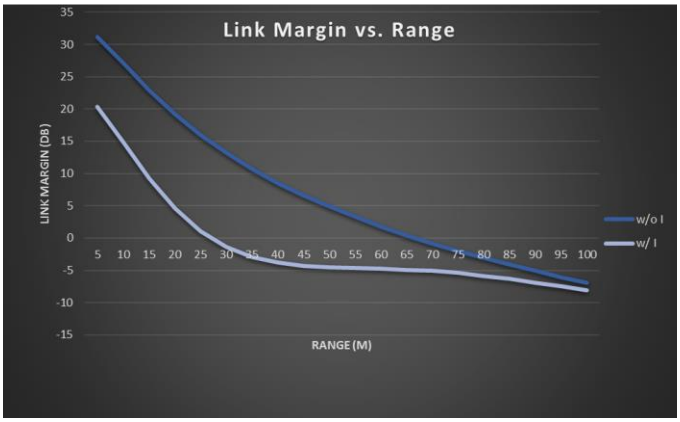


Fig. 8. Vehicle to street Infrastructure link budget analysis results using ANSYS EMIT [] at 5.9GHz.

To get a more realistic assessment of the performance in a realistic environment, we need to account for the presence of other wireless systems and noise sources that have the potential to interfere with and degrade the performance of the V2V system. ANSYS EMIT [9] allows the impact of complex interference environments to be included in the link analysis. For example, here we simulate a wideband noise source located at the roadside. When we include the interference in the link analysis for the V2V system, the achievable range is degraded significantly going from 70 meters to 30 meters as shown in Fig. 8.

## V. CONCLUSION

The proposed work demonstrated the efficient antenna array design procedure for 5G communication applications starting with a single element design then using the infinite array approximation to obtain the array size and finally with the use of ANSYS domain decomposition concept for periodic structures. Analyzing the performance of the installed arrays on realistic scene is an important aspect when it comes to mm-wave system design where ANSYS can help performing a number of analysis for this design stage. Future work will include applying the link budget analysis to 5G frequency range as well as enhancing the modeled antenna array radiation performance.

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