Modeling and Designed of a Monopole Antenna that Operate at 3.3 [GHz] for Future 5G sub 6 [GHz]

Gholam D Aghashirin, MagedKafafy, Hoda S. Abdel-Aty-Zohdy, Mohamed A. Zohdy, Adam Timmons

Abstract: *Antenna unit is an importantpart of ADAS L2, L2+ and Automated Driving L3 systems. It needs to function as needed in dGPS, HD Map Correction Services, OEM Radios and Navigation Systems. The presented monopoleantenna model for 5G below 6 [GHz] operating at 3.3 [GHz] is developed. This work demonstrates the modeling, design, and determining of monopoleantenna with intended targeted applications within the automotive system emerging autonomous vehicles space and as well as 5G Wireless Cellular Technology domain. FEKO simulation is undertaken rather than mathematical modeling to create the structure and conduct the analysis of the proposed monopole antenna.In order to support the fifth generation (5G) of wireless communication networks, SOS messages, vehicle tracking, remote vehicle start, Advanced Driver Assistance Systems (ADAS) L2, L2+/ Autonomous Driving (AD) L3 systems self-driving vehicles powered by 5G with rapidly growing sets of ADAS and AD features and functions within the autonomous space, USA cellular carriers mobile phone communication standard 4G MISO and 5G MIMO, LTE1, LTE2, connected functions, features/services, IoT, DSRC, V2X, and C-V2X applications and 5G enable vehicles destined for the NAFTA (USA, Canada and Mexico) market, a new single monopole antenna that operate at 3.3 [GHz] for future 5G (MIMO) below 6 [GHz] modeling, design and simulation with intended automotive applicability and applications is proposed.*

The presented novel new 5G below 6 [GHz] monopoleantenna:

1. *Is not being investigated on the literatures review and published papers studied.*
2. *No paper exists on these frequency bands.*
3. *The desired monopole antenna is a new antenna with fewer components, reduction in size, low profile, competitive cost, better response to received RF signals for frequencies for future 5G below 6 [GHz] with each of the following:*
   - *a. Range of operating frequencies, 0.6 [GHz] to 5.9256 [GHz].*
   - *b. Centerfrequency = 3.2628 [GHz] ~ 3.3 [GHz] for the above band.*
   - *c. Lambda (λ) = (3.0 x10^8 [m/sec^2])/(3.3x10^9 [Hz])=0.090 [m] = 90 [mm], lambda (λ) /4 = (0.090 [m])/4=0.0225 [m]=22.5 mm ~ 23 [mm], the overall monopole antenna height.*

To be more direct, simulation studies are carried out and are done utilizing FEKO software package from Altair to model the proposed monopole antenna for 5G below 6 [GHz] frequency band. The focus is on the frequency band for 5G sub 6 [GHz] cellular system.

The paper will introduce the following key points:

1. *Modelled and anayzed single element 5G sub 6 [GHz] monopole antenna.*
2. *Student version of CAD FEKO program was used to design our desired monopole antenna with a wire feed excitation coupled with step-by-step instructions is undertaken to highlight the model geometry creation of our monopole antenna. POST FEKO program is used to plot and view our simulation results.*
3. *We report the development of 5G below 6 [GHz] for fifth generation (5G) system that meets automotive and vehicle homologation specification requirement of antenna height < 70 [mm]. So that the proposed monopole antenna can easly be integrated into multi tuned cellular antenna system.*
4. *The FEKO simulation is conducted in 2D and 3D element model, in terms of Far-Field Vertical Gain as a function of an Elevation Angle plots.*
5. *Future research work and study for the next steps will be recommended.*

Keywords: Differential Global Positioning System (dGPS), Advanced Driver Assistance Systems (ADAS), Automated Driving (AD), Long Term Evolution1 (LTE1), Long Term Evolution2 (LTE2), Multiple Input Single Output (MISO), Multiple Input Multiple Output (MIMO), Internet of Things (IoT), Dedicated Short Range Communications (DSRC), Vehicle to Everything (V2X), Cellular Vehicle to Everything (C-V2X), High-Frequency Structure Simulator (HFSS), Ultrawideband (UWB) and Wireless Local Area Network (WLAN)

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I. INTRODUCTION

An antenna in general could be defined as a wireless communication transducer, such as a single piece of wire (Monopole) for radiating and/or capturing traveling and/or impinging electromagnetic wave. To be specific, antenna is reciprocal module, which can be utilized as a launching and/or as receiving device. Electromagnetic field emitted by an antenna satisfies James Maxwell's set of differential and integral form equations, which are used to describe the relations of the field vectors, charge densities, and current densities at any time and at any point in space per Balanis [3].

Curl $\vec{E} = -j\omega\mu\vec{H}$
Curl $\vec{H} = \vec{J} + j\omega\mathcal{E}\vec{E}$

Where:

$\vec{E}$ = Vector Electric Field Intensity (volts/meter)
$\vec{H}$ = Vector Magnetic Field Intensity (amperes/meter)
$\vec{J}$ = Electric Current Density (amperes/square meter)
$\mathcal{E}$ = Time-Varying Permittivity of the Medium (farads/meter)
μ = Time-Varying Permeability of the Medium (henries/meter)
ω = Angular Frequency

According Balanis [1], wire or linear antennas are some of the simplest, cheapest and in many cases are the most versatile for many applications.

It is deemed necessary to use an antenna that provides an optimum coverage coupled with a constant gain over its service area and simultaneously suppresses undesired electromagnetic wave fronts and/or interference impinging signals on its input terminal. The proposed 5G below 6 [GHz] monopole antenna would successfully meet and satisfy the above requirements. The electromagnetic wave signal fronts arriving at monopole antenna is a planar Transverse Electromagnetic (TEM) wave, which indicates the Electric Field vector ($\vec{E}$) and Magnetic Field vector ($\vec{H}$) are everywhere perpendicular to each other and orthogonal to the direction of electromagnetic wave propagation. More preciously, the angle between our two vector field quantities, $\vec{E}$, $\vec{H}$ and direction of wave traveling is a 90 [degrees].

Our proposed monopole antenna system consists of:

1. A vertically polarized radiating elementmonopolewire antenna with its corresponding length of 23 [mm].
2. The conducting rectangular ground plane with the dimensions $40\ x\ 40$ $[\text{mm}]^2$ supports as a base for our monopole antenna.
3. A feeding pin with a length of 0.5 [mm].

And it is designed to have a gain pattern that is a function of elevation angle.

A Student Edition of FEKO software package is an electromagnetic wavesimulatoralong with numberical technique, such as the Method of Momments was used to design the 3D geometric model of our 5G below 6 [GHz] monopole antenna along the z-axis.Fig. 1, below shows our model. This model being excited by a voltage source of excitation with each of the following set of scalar parameters:

1. Magnitude = 1 [V]
2. Phage Shift = 0 [Degrees]
3. Impedance = 50 [Ohm]

At the conclusion of the above process of our monopole antenna model creation in the CADFEKO environment, a 3D Radiation Pattern, and 2D Far-Field/Gain were ploted generated by using the POSTFEKO program.

To be more specific, monopole antenna,have a lot ofapplications across multiple areas of scientific and engineeringdiscipline and it plays a significant role in wirelesscommunication systems, inautomotive space involving Radios, Navigation Systems,ADAS/Automated Driving L2 and L3 Systems, precise positioning andmobile phones. Because of its low profile and effective cost, itconsidered as a better antenna solution choice in wide varietyof applications. We investigated and presented our monopoleantenna geometry model creation within the "CADEFEKO programandthan "POSTFEKO was used to obtain our antenna solution in terms of Far field/passive gain results.

Deng [4], covered a coplanar waveguide-fed monopole antenna that is made up of a rectangular monopole patch notched at the bottom with a T shaped coplanar waveguide as its ground plane. Their study was carried out via simulation with HFSS and experimential method, in order to achieve "a fractional impedance bandwidth of 164% for S11 $\leq$ -10 [dB], which is about 2.3 times of the conventional one. Furthermore, Deng [4] highlighted monopole antenna has been largely utilized in wireless communication system because of their less costs, simple structure, omnidirectional radiation pattern and it is also suitable for portable mobile ultrawideband (UWB) applications.Wen [7], proposed a monopole antenna that made up of a capacity loaded matching patch two resonators, two meandering monopoleantenna.Wen's, paper presents a compact monopole antenna with filtering response for WLAN related applications.Wen's work focuses mainly on the simulation versus an experimental measurement results that points out their proposed monopole "antenna has a wide impedance bandwidth of 16% for S11<-10 [dB]" plus an omnidirectional radiation pattern was achieved and realized by their study. Hong [5], has shown a trapezoid patch monopole radiator that isplaced on a "quasi-fractal" solid ground plane, where the antenna system operates in a dual band that covers the frequency range of WLAN, "1.74-2.38 and 4.46-5.56 [GHz]". Chen [5], reports a triband planar monopole antenna with dual inverted L-slot are etched, to obtain three radiating elelments that functions in three resonant modes of operation with WLAN/WiMAX applications as its intended focus. Different monopole antenna structure with various radiating element shapes coupled with variety of ground plane designed with applications related to WLAN, and WLAN/WiMAX (Chen [6]) published papers studied, however observed that there is a problem related to cellular 5G below 6 [GHz] monopole antenna coupled with an antenna solution that would satisfy the automotive and vehicle homologatioin specification of an antenna height < 70 [mm], which has not been investigated. In this work, a compact, robust, low profile monopole antenna solution is proposed and designed via FEKO simulation tool to cover cellular 5G sub 6 [GHz] frequency band with an overall antenna height of appromimately 23 [mm].

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II. 5G SUB 6 [GHZ] MONOPOLE ANTENNA DESIGN, MODELING AND SIMULATION

A. Monopole Antenna Structure Configuration and Analysis

Fig. 1, illustrates the monopoleantenna general structure model, where we have a metallic line radiating element, that ispositionover aconducting base rectangular sheet that acts as our antenna ground plane.

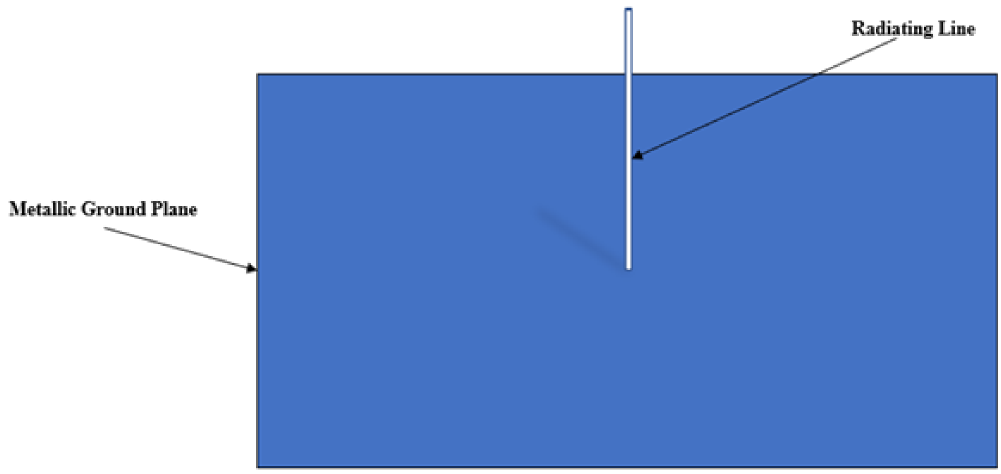

Fig. 1. Monopole Antenna Geometry

B. FEKO Model Generation of our 5G sub 6 [GHz] Monopole Antenna

The presented new 5G sub 6 [GHz] monopoleantenna is designed, modeled, simulated by using FEKOStudent Edition software package. The FEKO is an electromagneticfield simulator, and it can be used to design, model, analyzea simple to a large and complex antenna structure. FEKO is acommercial software tools chain. The entire monopoleantennamodel was constructed within the “CADFEKO” environment[3].

The steps below were used for our proposed 5G below 6 [GHz], FEKO model creation within the “CADFEKO” [3] and our antenna simulation results wereobtained from the “POSTFEKO” [3] environment:

1. Started the “CADFEKO” program and window as in Fig. 2, is observed.

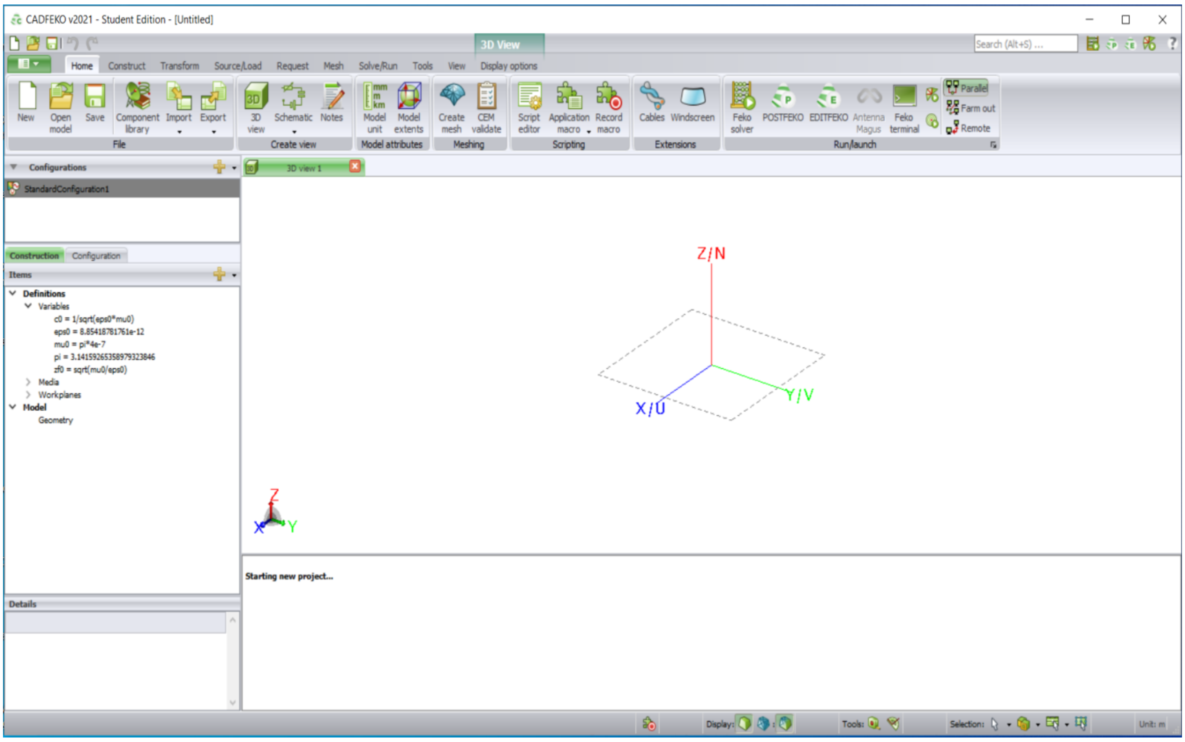

Fig. 2. “CADFEKO” Modeling Window

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2. We selected and set the antenna model unit to millimeters [mm] in CADFEKO space as shown in Fig.3.

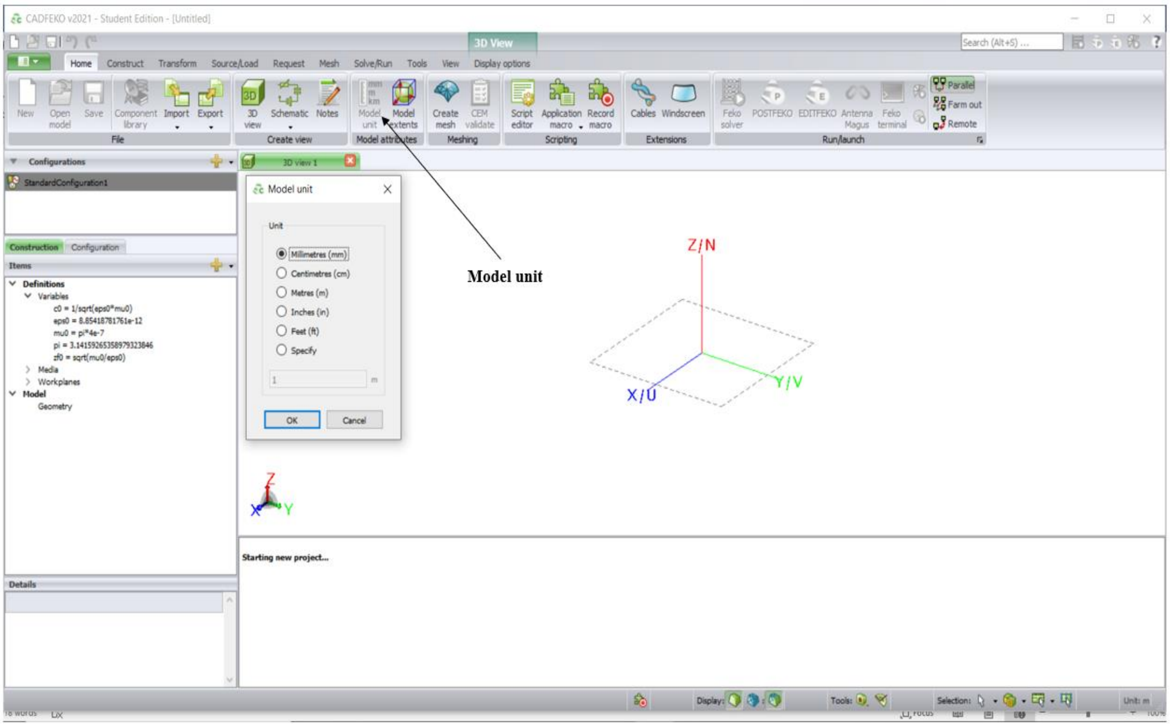

Fig. 3. "CADFEKO" Modeling Window ("Model unit")

3. Next, declaredadded variables, such as the operating frequency, ground plane length, ground plane width, monopole antenna length, feeding pin lengththat defined the antenna geometry as indicated in Fig. 4.

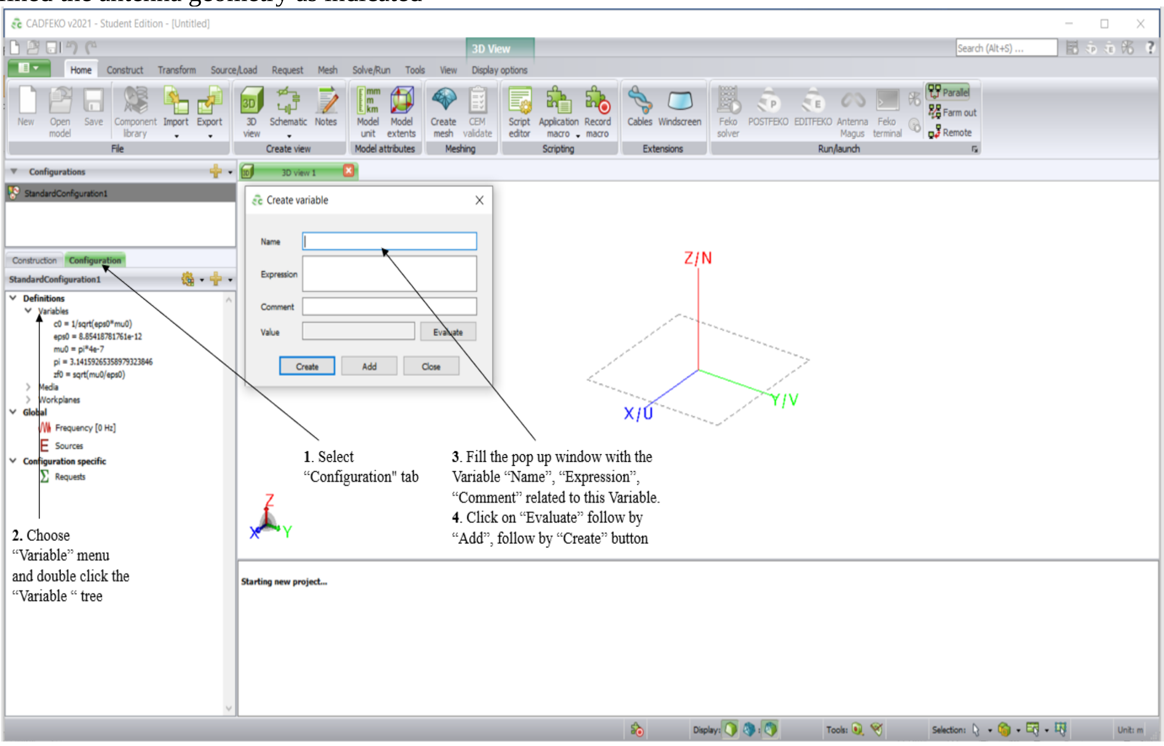

Fig. 4. "CADFEKO" Modeling Window ("Create variable")

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4. A "Rectangular" [3] ground plane surface geometry with its corresponding media type was selected to be a Metallic was created by clicing on the "Rectangle" icon function located under the "Construct" tab as displayed in Fig. 5.

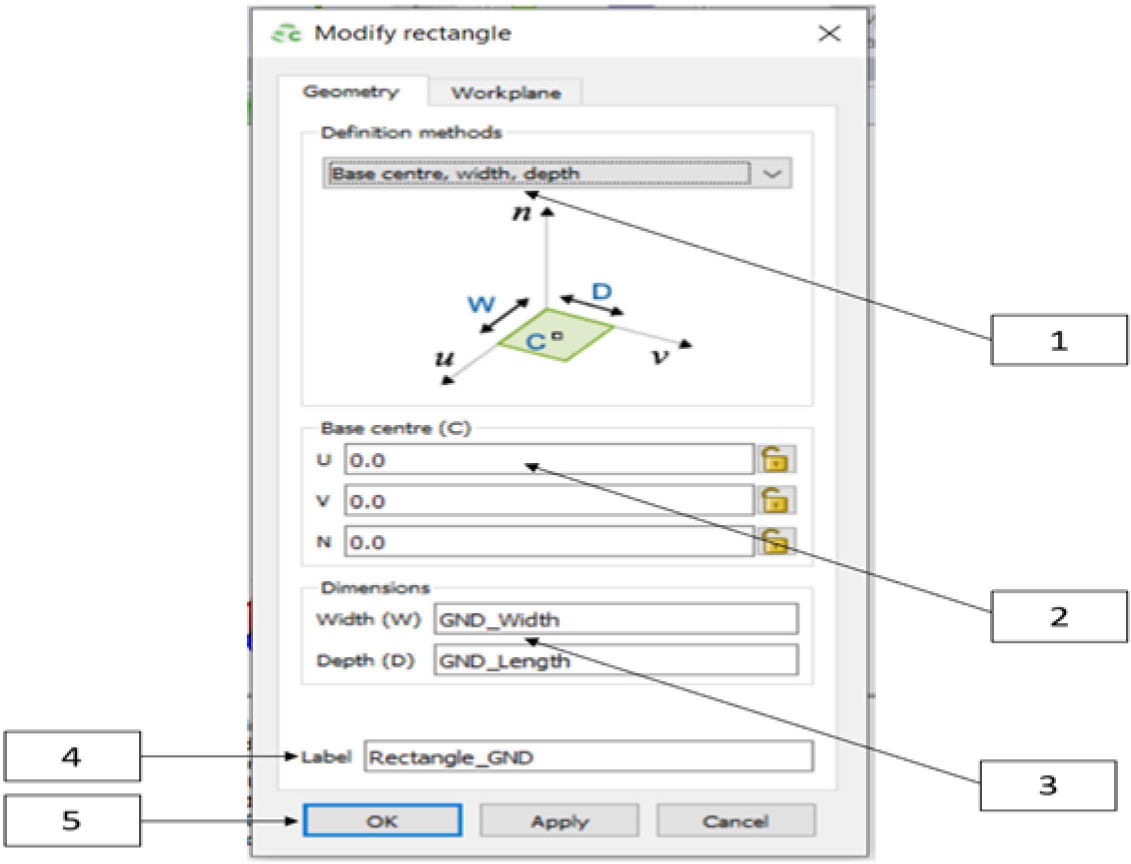

Fig. 5. "CADFEKO" Modeling Window ("Create variable")

From the above popup window, under the "Definition methods", "Base", "centre", "width", "depth" option was picked from the drop-down menu first. "Base centre (C)" coordinates for U=0, V=0, & N=0 was filled second. The "Dimensions" of our ground plane in terms of the defined variables were inputed into the "Width (W)" and "Depth (D)" field third. A label was filled in the "Label" field area next. Lastly, we clicked on the "OK".

5. Added our radiating elelment by selecting the "Line" [3] function.
6. Created the feed pin by using the "Line" [3] curve function to excite or energize our antenna.
7. Added a wire port at the start of the Line location followed that by a source of excitation, such as a voltage source was placed at this port.
8. Requested the "Far fields" [3] solution from under the "Configuration" [3] tab.
9. Used the "Union" [3] function to group each component or elements of the overall GNSS patch antenna geometry together.
10. Set the operation and/or simulation frequency.
11. Run the "Create mesh" [3] function followed by the "CEM validate" [3] feature, in order perform the "Meshing" [3] and "Computational electromagnetic validation" [3].
12. Conducted and executed the "Feko solver" [4] function and after the simulation is finished, next run and launch the "POSTFEKO" [4] post-processing program.
13. "POSTFEKO" [3] environment was used to plot the 2D Average Gain and/or Far fields and view the Passive Gainresults.

Due to FEKO LITE (Student Version of FEKO) limitedcapabilities, one may need to use the Full version, the nonacademicvariant of the FEKO software package in theirsimulation studies, in order to reduce uncertainty, errors barand ultimately enhance the mathematical calculationcapabilities of the desired model meshing.

C. 5G sub 6 [GHz] Monopole Antenna Design Parameters Electrical, Mechanical and Enironmental Detail Requirements

Table-I, indicates the design, modeling, and simulation ofthe monopole antenna geometry creation numeric parametervalues and Table-II, shows the model meshing valueswhitnin the CADEFEKO space.

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Table-I:Model Creation Parameters of MonopoleAntenna Structure

Electrical Requirements	
Range of Operating Frequency	0.6 [GHz] to 5.9256 [GHz]
Center Frequency	3.3 [GHz]
Full Lambda (λ)	90 [mm]
Impedance	50 [Ω]
Excitation Source (Voltage)	Magnitude = 1 [V] Phase Shift = 0 [Degrees]
Mechanical Requirements	
Monopole Antenna Length, Lambda (λ)/4	23 [mm]
Feeding Pin Length	0.5 [mm]
Ground Plane Length	40 [mm]
Ground Plane Width	40 [mm]
Environmental Requirements	
Operating Temperature	-40 [degrees] to +85 [degrees]

Table-II:Feko Meshing Parameter Value

5G sub 6 [GHz] MonopoleAntenna Meshing Parameter (Wire Segment Radius)	0.01 [mm]

D. 5G sub 6 [GHz] Monopole Antenna 3D Model in CADFEKO andPOSTFEKO Environment

Fig. 1, plot illustratesour monopoleantenna structure with a rectangular orangecolor ground plane and a line radiating element modeled.

Fig. 1, and Fig. 2, indicates the Top View and Cross SectionView within the “CADFEKO” [3] space. Fig. 3, captures theCross Section View of themonopoleantenna within the“POSTFEKO” [3] environment.Fig. 4, depicts our monopoleantenna 3D omni-directional radiation pattern in the“POSTFEKO” [3] space.

Fig. 1 and Fig. 2, depicts our monopole antenna model in the“CADFEKO” [3] page.

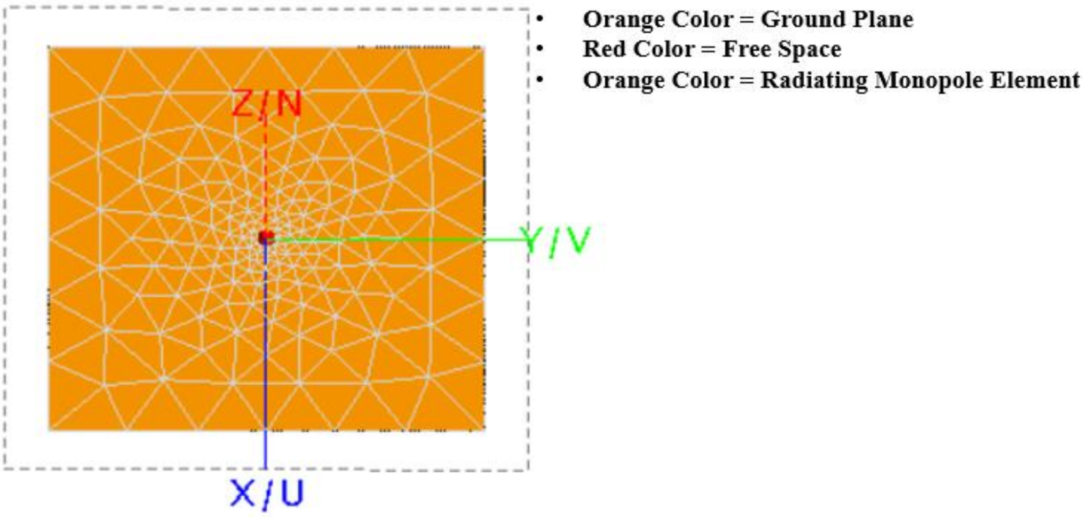

Fig. 1. 5G below 6 [GHz] monopole antenna operating at 3.3 [GHz] (Top View).

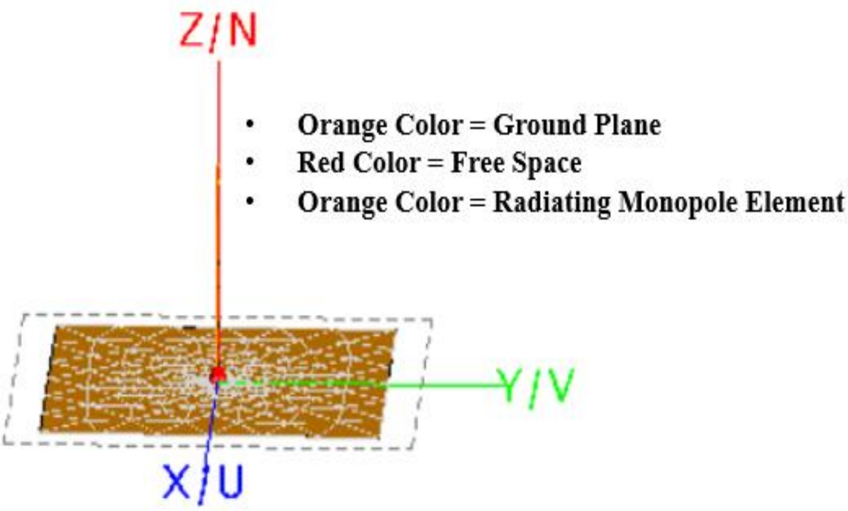

Fig. 2. 5G below 6 [GHz] monopoleantenna operating at 3.3 [GHz] (Cross Section View).

Fig. 3 and Fig. 4, indicates our 5G below 6 [GHz] monopoleantenna model coupled with the 3D pattern in the“POSTFEKO” [3] page.

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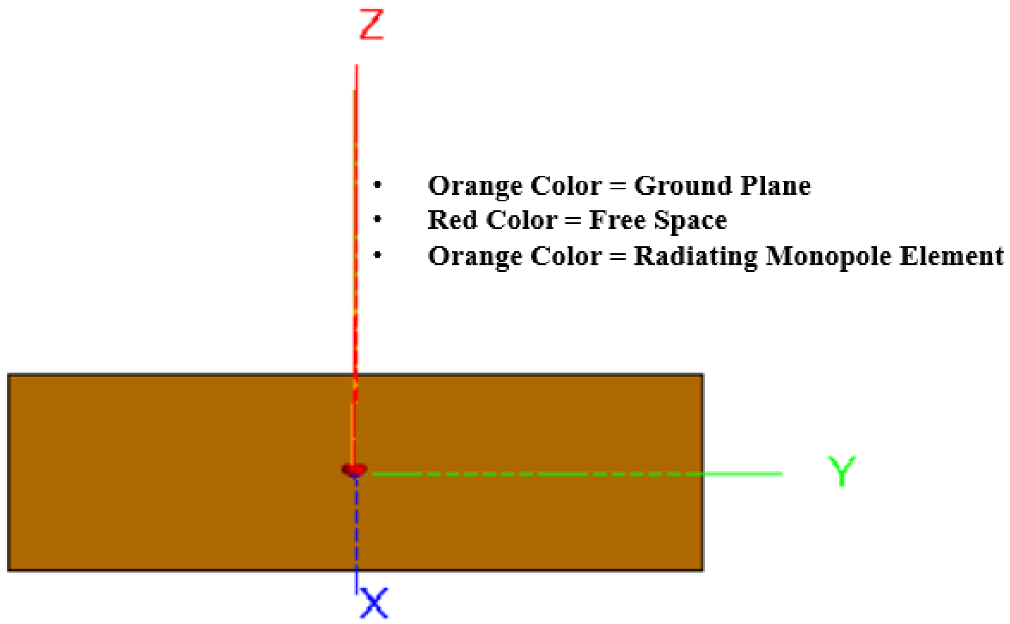

Fig. 3.5G below 6 [GHz] monopoleantenna operating at 3.3 [GHz] (Cross Section View).

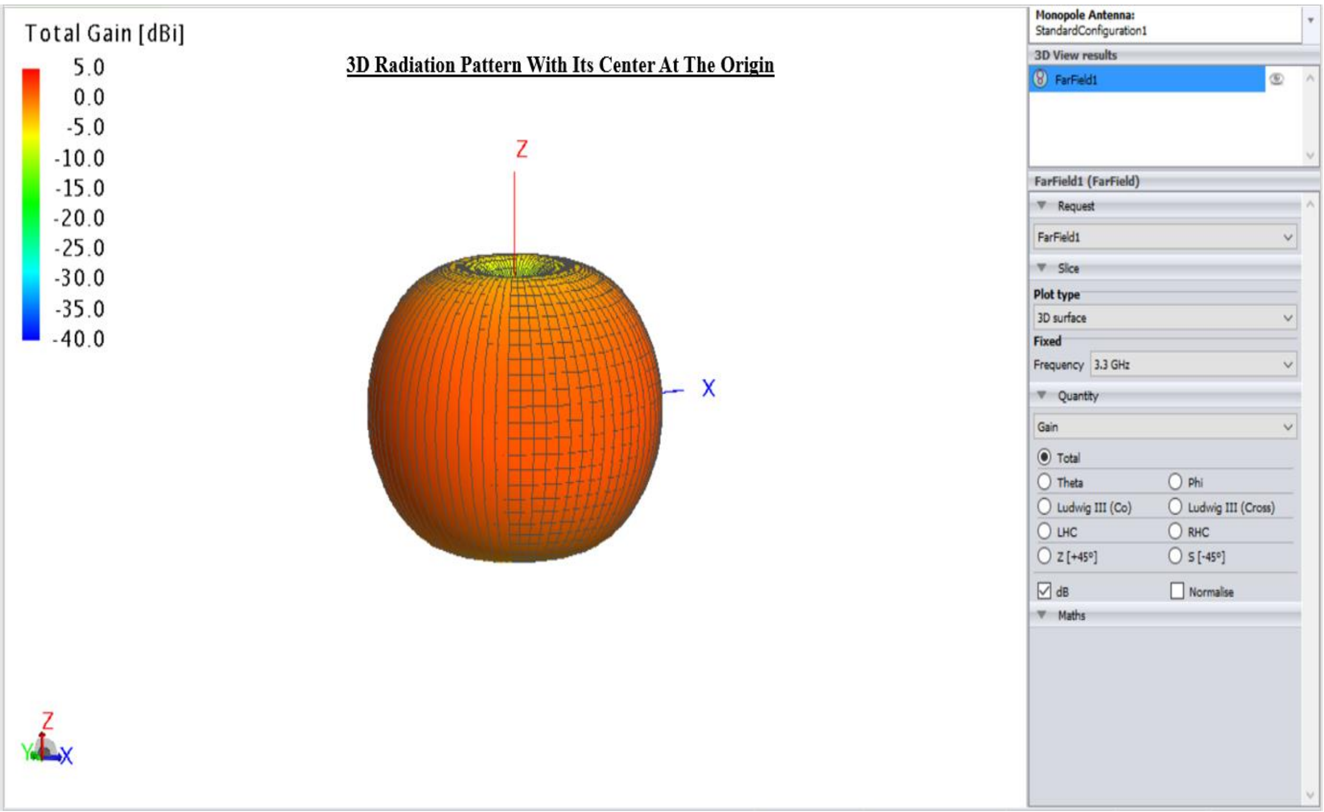

Fig. 4. 5G below 6 [GHz] monopole antenna operating at 3.3 [GHz] (3D Radiation Pattern).

E. FEKO Simulated Far Field Rectangular and Polar 2D Graphic of 5G below 6 [GHz] Monopole Antenna

Fig. 5, displays our simulatedpassive gain of the proposed monopole antennawith dielectric constant or the time vary permittivity of the free space (Ɛo) = $\frac{10^{-9}}{36\pi}$ $[^{farads}/_{meter}]$ [2], tomodel, design, and simulate the presented 5G sub 6 [GHz] monopoleantenna with center frequency = 3.3 [GHz]. In the 2D modelplot from Fig. 5, we can see about 1.84 [dBi] passive gain was obtained, bytaking the difference in gain between 30 and 90 [degrees].

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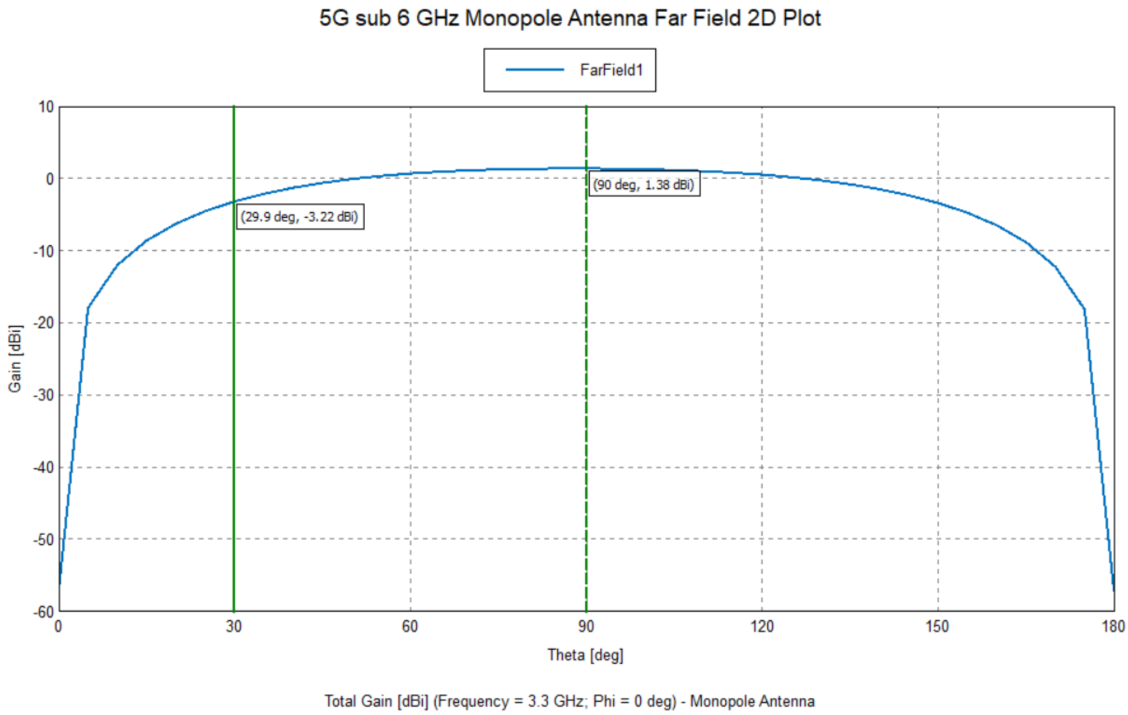

Fig. 5. 5G below 6 [GHz] monopole antenna operating at 3.3 [GHz] (Rectangular 2D plot).

III. CONCLUSION AND FUTURE WORK

In this paper we have presented, investigated, and has been discussedthe NEW cellular 5G sub 6 [GHz] with center frequencyat 3.3 [GHz] monopole antenna design, modeling and simulationby using FEKO software package. We have successfully demonstrated the creation of our proposed monopole antenna geometry, configuration model in the CADFEKO space and obtained results in terms 2D Far-Field, Gain plots coupled with 3D Radiation Pattern in the POSTFEKO domain.

The proposed monopole antenna finds applications in cellular wireless communication networks, modern automotive components, systems,autonomous vehicle space and it also finds application in wideareas of other scientific and engineering disciplines. Ourmonopleantenna model was created, simulated and then it iscorresponding antenna characteristic, such as Far-field/vertical gain wasfound to be 1.84 [dBi] for monopole antenna delta between30 and 90 [degrees] within the POSTFEKO [3] environment. The emphasis of this paper was to examine and investigate the design of a new cellular monopole antenna that operate in the frequency band of 0.6 [GHz] to 5.9256 [GHz], met the automotive vehicle homologation requirement with our proposed monopole antenna λ /4 overall height of 23 [mm] and the this was successfully achieved.

For future work, the simulation studies can be extended tofocus on a single monopoleantenna that will supportmulti-band frequencies and its operating frequency upper limit can be extended up to 7.125 [GHz] [8] band of frequencies. A physical prototype for the proposed 5G below 6 [GHz] monopole antenna can be created, installed, and mounted on an optimal location on a vehicle body structure and/or vehicle roof location areafor the purpose of core vehicle level Verification and Validation testing. The presented monopole antenna solution can also be a Device Under Test (DUT) as a receiving test antenna at an Anechoic Chamber and/or Indoor Antenna Range in support of the measuring the basic antenna characteristics such as Gain, Radiation Pattern, Radiation Efficiency, Directivity, Impedance, Bandwidth, Polarization and Current draw and/or Antenna Surface Current.

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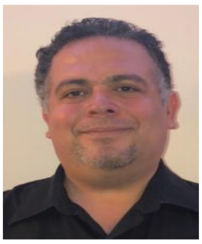

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