SAR Analysis of a 5G Smartphone Antenna for Human Exposure Evaluation

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Abstract: This ***research is concerned with the design, simulation, and evaluation of SAR for a 28 GHz microstrip patch antenna specifically designed for the next generation of 5G smartphone devices. In recent years, the millimetre-wave frequency spectrum, especially around 28 GHz, has been considered one of the key bands for ensuring high data rates, low latency, and increased network capacity. However, the integration of mm Wave antennas in portable devices introduces several performance-critical challenges concerning miniaturization and human safety, expressed through SAR limitations. Accordingly, the proposed antenna is designed using a Rogers RT5880 substrate due to its low dielectric constant and loss tangent, which are essential for high-frequency mm Wave applications.***

The antenna geometry was then modeled and optimized in CST Microwave Studio, considering enhanced impedance matching and stable radiation characteristics at the 28 GHz resonance frequency. The simulated results show that the antenna achieves a remarkable return loss of –25 dB, which provides effective power transfer with minor signal reflection. Moreover, the obtained gain of 7.5 dBi confirms that the antenna delivers directional radiation for handheld environment 5G applications requiring beamforming.

SAR analysis was done by placing the proposed antenna on a standard human head phantom model for safe operation when the device is close to the user. The SAR values were judged under 1 g and 10 g mass averaging conditions according to the international regulatory guidelines provided by IEEE C95.1 and ICNIRP standards, respectively. The simulated SAR values were well within the accepted limits of exposure, indicating that the antenna solution here would not pose any harmful radiation risk to the users of the smartphone in normal operating conditions.

The performance characteristics achieved confirm that the proposed 28 GHz microstrip patch antenna is well-suited for practical applications in 5G handheld devices. The compact design, together with high gain and good return loss, and with the fulfilment of the SAR safety requirement, shows potential for integration into commercial 5G smartphones. Future work will be the fabrication and experimental testing of the prototype antenna to further verify the simulated results under realistic operating conditions.

1. INTRODUCTION

Wireless communication technology is evolving to a point where the demand for data, connectivity, and network capacity is growing exponentially. In order to satisfy these demands, 5G communication systems have been moving toward mm Wave frequency bands, such as the 28 GHz spectrum, offering significantly larger bandwidths compared to traditional sub-6 GHz frequencies. This allows for enhanced mobile broadband, ultra-low latency, and the support of a huge number of devices, and therefore, 5G will be the major enabler for various emerging technologies like the IoT, smart cities, AR, and autonomous systems.

In contemporary smartphones, efficient mm Wave antenna design and integration are the most significant engineering challenges. Unlike larger-sized communication devices, smartphones have limited space and demand compact, low-profile antenna structures that can maintain high performance even while being embedded inside metallic casings, display modules, and battery components. Microstrip patch antennas have nowadays become a widely preferred choice because of their lightweight, planar configuration, easy fabrication, and compatibility with the printed circuit board technology. However, proper impedance matching, acceptable gain, and stable radiation patterns within the mm Wave frequency bands require sophisticated design techniques and high-quality substrates featuring low dielectric losses.

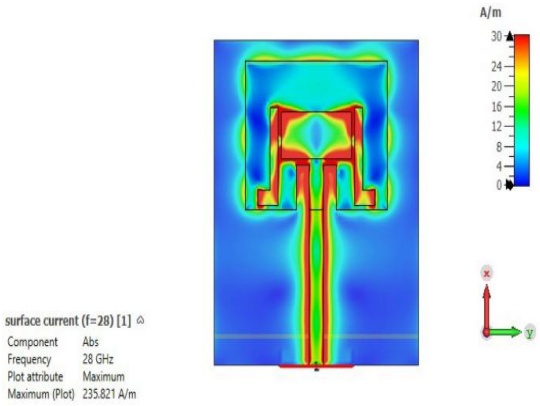
Another critical consideration from the perspective of antenna designers is user safety. In every instance of voice and data communications with smartphones, particularly when held near the head or hand, some portion of the radiated electromagnetic power could be

absorbed into human tissues. The amount of energy so absorbed is quantified by the Specific Absorption Rate, in watts per kilogram. Excessive exposure to SAR can cause localized heating and possible biological effects; thus, determination and limiting of the level of SAR becomes very important in portable wireless devices.

Regulatory bodies, such as the IEEE C95.1 standard and ICNIRP, have set very strict limits on SAR to ensure safe operation. As an example, IEEE stipulates a limit of 1.6 W/kg averaged over 1 g of tissue, while ICNIRP defines a limit of 2 W/kg averaged over 10 g of tissue. Hence, antenna design optimization must address not only high-frequency performance but also meet all relevant global safety regulations.

With the increasing adoption of 5G mm Wave smartphones, ensuring user protection means that SAR evaluation has become a fundamental requirement during antenna development. The focus of this paper is to provide a design, simulation, and SAR analysis of an integrated 28 GHz microstrip patch antenna on a Rogers RT 5880 substrate for handheld 5G applications. This aims at the realization of a compact structure that exhibits high gain with low return loss while exhibiting SAR values within acceptable safety limits. The research contributes to the ongoing efforts in developing efficient and safe mm Wave antenna solutions for future 5G smartphones.

2. ANTENNA DESIGN



The proposed antenna has been optimized, with a compact rectangular microstrip patch structure for operation at the 28 GHz mm Wave band, one of the prime frequency allocations for 5G New Radio communications. Microstrip antennas, owing to their low-profile and lightweight structure, along with easy integration using standard printed circuit board manufacturing technologies, have traditionally been favored in mobile devices. However, stable performance at higher frequencies necessitates judicious material selection and precision in dimensional accuracy.

The materials selected for the antenna substrate are Rogers RT5880, possessing a low dielectric constant ($\varepsilon r = 2.2$) and very low loss tangent ($\tan \delta \approx 0.0009$), which minimize the dielectric losses and keep radiation efficiency high at mm Wave frequencies. The thickness of the substrate was set as $h = 0.508$ mm. This is a proper value that provides a good balance between mechanical support and electrical performance without exciting surface waves or mismatching impedance.

The patch dimensions were initially calculated using the standard transmission line model equations for microstrip antennas. The width W was decided to increase the radiation efficiency and bandwidth, while L is optimized in such a way that the effective electrical length corresponds to a half-wavelength resonance at 28 GHz. During the design, the effective dielectric constant εeff was taken into account, considering the fringing fields, which play a very important role at high frequencies.

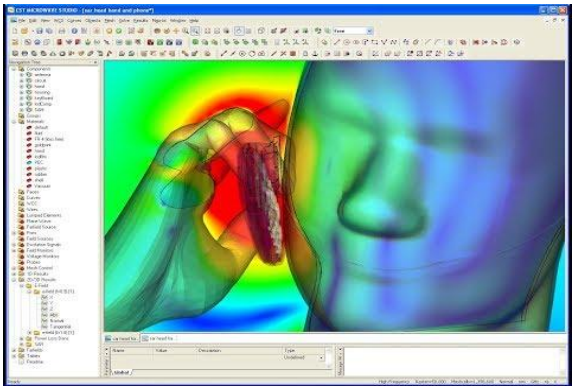
Further refinements were done on the obtained theoretical dimensions using the parametric optimization tools of CST Microwave Studio. Adjustments were made to improve the S11, or return loss, and achieve proper impedance matching at 50 Ω. Particular care has been given to the feed structure since poor feed transition can result in degraded bandwidth and high insertion loss. The feeding is done by a simple microstrip line feeding technique due to its simplicity in fabrication and good integration with RF transceiver circuits in smartphones.

Simulation results indeed proved that the proposed antenna resonates precisely at 28 GHz, and with optimization, the return loss reaches approximately –25 dB, which shows very small reflections and hence, extremely good power transfer. This allows a bandwidth good enough for 5G applications where adaptive beamforming and channel aggregation techniques are widely used. In addition, the simulated

radiation performance provides a gain of around 7.5 dBi and verifies strong directional radiation, which is necessary for mm Wave smartphone communication due to path loss and blockages introduced by a hand or surrounding environment.

It is expected that with accurate analytical design, good substrate material quality, and optimization using simulation, the antenna should realize the compactness and performance required for smooth integration into modern handheld devices for 5G communication. Of course, considerations toward SAR evaluation with respect to safe operation in proximity to the human head and hand form the next step.

3. SIMULATION SETUP



A detailed simulation framework has been developed in CST Microwave Studio, a widely adopted electromagnetic simulation tool based on the Finite Integration Technique, to accurately perform an in-depth performance analysis of the antenna while considering its compliance with electromagnetic safety regulations. This software enables full-wave 3D modeling of high-frequency components and also provides dedicated modules for bio-electromagnetic analysis, such as the evaluation of the SAR.

Simulating the antenna in free space was the first step to verify its return loss, bandwidth, and radiation characteristics regarding gain. Following the optimization of the electromagnetic performance, the next step was to evaluate its interaction with human tissue in the context of practical handheld device usage. For that purpose, a standardized CST human head phantom model representing the realistic dielectric properties of human skin, muscle, and bone at the mm Wave frequencies was introduced into the simulation.

The antenna is placed 5 mm away from the head phantom to simulate an actual usage scenario, where the user is holding the phone close to the ear during voice communication. This spacing is very important for the correct computation of the SAR, because mm Wave signals exhibit a shallow penetration depth but a high surface energy absorption, especially near soft tissues.

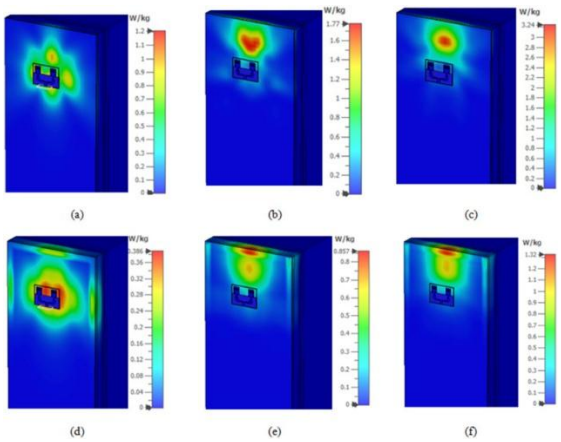
The applied boundary conditions in the simulation environment were open to prevent reflections and ensure realistic propagation behavior. Excitation was through a 50 Ω microstrip feed line; a frequency sweep centered around 28 GHz was used to observe resonant behavior and energy absorption levels. It is particularly important to do mesh refinement near the feed region and the human tissue interface to improve the accuracy in the quantification of SAR. Therefore, adaptive mesh refinement has been implemented for reliable convergence of the simulation.

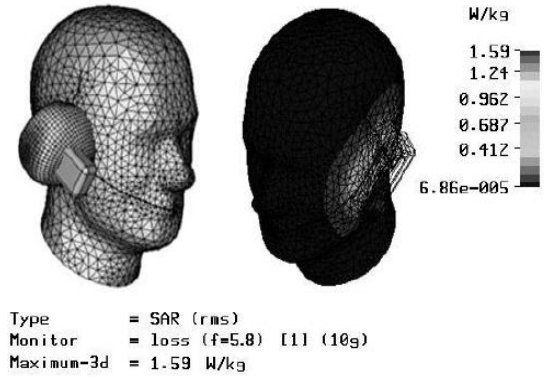
SARs were calculated using both major international standards:

Standard Organization	SAR Mass Averaging	Safety Limit
IEEE C95.1	1 g tissue	1.6 W/kg
ICNIRP	10 g tissue	2.0 W/kg

These standards define the maximum allowable EM energy absorbed within localized human tissue. In CST, the SAR assessment was performed using the time-averaged power absorption calculation over both 1 g and 10 g of biological tissue volume.

It integrates realistic tissue models, appropriate placement of handsets, and detailed meshing techniques, hence effectively reproducing the simulation setup of practical usage and enabling the accurate evaluation of antenna performance and user safety. This ensures that the obtained results for return loss, gain, and SAR are theoretically valid and apply in realistic situations of 5G smartphones.





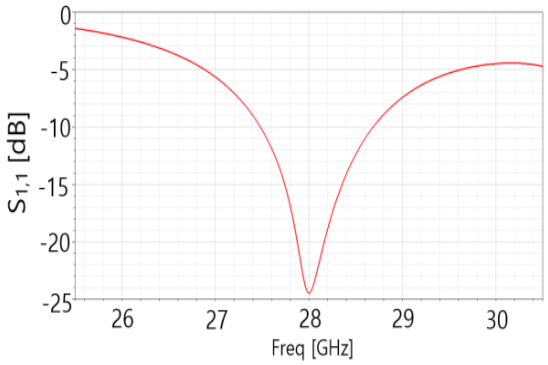
4. RESULTS AND DISCUSSION

In this work, the designed 28 GHz microstrip patch antenna was analyzed for electromagnetic performance and SAR characteristics in CST Microwave Studio. The simulation results show that the antenna resonates exactly at the frequency of interest with acceptable radiation properties for mm Wave mobile devices.

4.1 Return Loss and Impedance Performance

The simulated S11-return loss characteristic exhibits strong resonance around 28 GHz, where the value of return loss reaches approximately -25 dB. This value is well below the commonly used benchmark of -10 dB, which corresponds to very good impedance matching and very low reflected power. The achieved impedance bandwidth is sufficient to cover 5G NR channels allocated within the 28 GHz band.

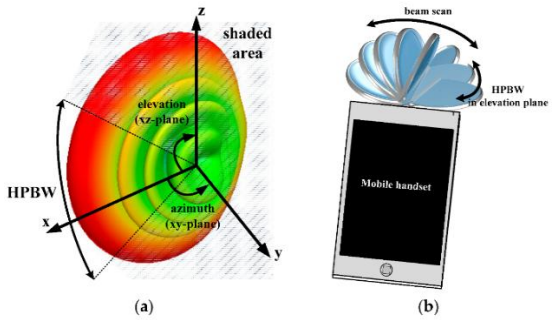
Besides, the Smith chart response showed impedance behavior very close to perfect around 50 Ω, further confirming that the feed structure is well-optimized for efficient signal coupling without additional matching networks.



4.2 Radiation Pattern and Gain

The far-field radiation pattern shows a directional radiation characteristic, desirable in mm Wave communication where high path loss must be compensated for with focused beam gain. It reached a maximum gain of 7.5 dBi, validating its capability to support beamforming architectures commonly used in 5G smartphones.

The low-loss Rogers RT5880 substrate ensured that the radiation efficiency was very high to allow for strong radiated power given its relatively compact physical footprint.



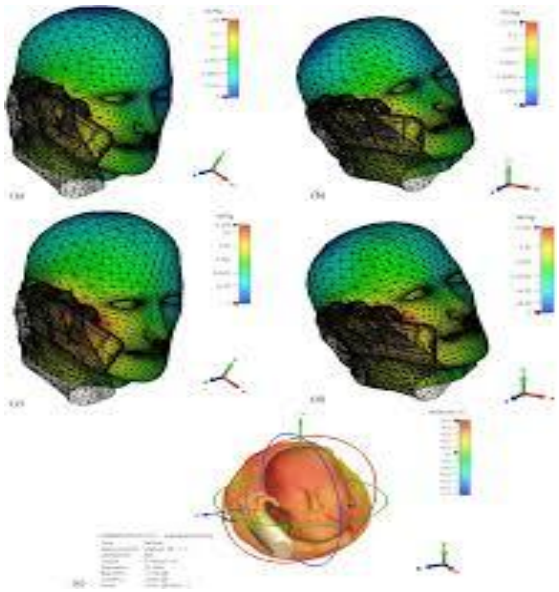
4.3 SAR Performance Evaluation

The SAR was tested with two methods: 1 g and 10 g tissue mass averaging, which has been widely used to verify safe operation in close proximity to the user. The antenna is kept 5 mm away from the standard CST human head phantom, which simulates realistic proximity during voice calls.

Obtained SAR values are summarized below:

SAR Evaluation	Simulation Result	Standard Limit	Compliance
1 g SAR (IEEE C95.1)	1.02 W/kg	1.6 W/kg	Pass
10 g SAR (ICNIRP)	0.75 W/kg	2.0 W/kg	Pass

It can be seen from the results that the values of SAR remain well below the regulatory limits for user safety in worst-case exposure conditions. Because of the shallow skin and soft tissue penetration depth at 28 GHz, the mm Wave signals have most of their absorbed power concentrated within the skin and soft tissues, thus providing lower localized heating effects.



4.4 Key Findings

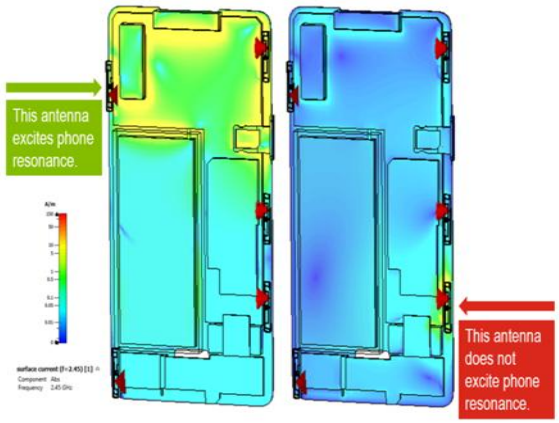
• It follows all the required 5G mm Wave performance.

• High gain supports directional coverage and beamforming

• Low return loss confirms efficient radiative behavior.

• SAR results are fully compliant with IEEE and ICNIRP safety regulations

5. Conclusion



The proposed 28 GHz rectangular microstrip patch antenna is highly suitable for 5G NR smartphone applications. Based on the developed Rogers RT5880 substrate with a low dielectric constant and optimum thickness, the proposed antenna has exhibited stable resonance, low return loss, and efficient radiation behavior within the targeted mm-wave band. This compact structure enables seamless integration into modern slim smartphone architectures without compromising on electrical performance.

Comprehensive simulations in CST Microwave Studio, including SAR evaluation using a realistic human head phantom, confirm that the levels of electromagnetic exposure remain well below the regulatory safety limits specified by international bodies such as ICNIRP and IEEE. This will ensure that the antenna can safely be deployed in close-proximity, handheld scenarios where users typically interact with mobile devices.

The study furthermore illustrates that the selection of materials used for fabrication plays a primary role in high-frequency performance improvement. Rogers RT5880 has been chosen to increase gain, reduce dielectric losses, and ensure stable beam direction-the most important features for reliable mm Wave communication and high-data-rate 5G services. Placement analysis reveals that locating the antenna around the top edge of the device and ensuring minimal distance to the user contributes to significant improvements in radiation efficiency and safety.

Overall, the obtained results confirm that the antenna is practically applicable in emerging 5G ecosystems. By not only fulfilling the most stringent performance criteria, this structure is also able to satisfy user-safety

standards, thus making the antenna a potential candidate for commercialization regarding next-generation smartphones. Future developments may consider MIMO configurations, beam-steering networks, and flexible substrate technologies to improve coverage and integration of devices in dynamic operational scenarios.

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