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DESIGN OF SRR-LOADED PATCH ANTENNA FOR 5G COMMUNICATIONS AND ESTIMATION OF ANTENNA SUBSTRATE MATERIALS

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Abstract

A microstrip patch antenna loaded with Split Ring Resonator is proposed for 5G Communication systems. The overall dimension of the antenna is 50 mm x 40 mm x 1.6 mm. The designed antenna operates in n77, n78, and n79 bands of the fifth generation (5G) Communication system. The parameters of Return Loss, VSWR, Radiation Pattern and radiation efficiency are investigated in the sub 6 GHz range. The proposed antenna is fabricated and analyzed experimentally to verify the simulation results. Additionally, linear regression analysis is used to determine the relative permittivity of the substrate. Different substrate materials with the thickness of 1.6 mm are selected and the antenna is analyzed with these substrate materials. The dataset consists of the real and imaginary parts of the electric and magnetic field components with respect to the spatial coordinates. Coordinates are $-40.625 \leq x \leq 40.625$, $-45.5 \leq y \leq 45.5$, and $-20.325 \leq z \leq 21.925$. A total of 52780 instances are obtained by changing the substrate material. As a result of the linear regression analysis, the mean absolute error (MAE) is found to be 0.0748 and correlation coefficient to be 0.9758. Thus, the dielectric constant of the substrate material could be estimated by the proposed approach without using numerical or analytical models. In summary, multiple linear regression is a useful tool for designing SRR-loaded patch antennas for 5G communications and estimating antenna substrate materials. It allows for predictive modeling, variable selection, interpretability, and flexibility, which can help to optimize the antenna performance and substrate material selection for various 5G communication applications.

Keywords: antenna design, fifth generation communication systems (5G), multiple-linear regression, metamaterial, microstrip patch antenna, split ring resonator, sub-6GHz

1. Introduction

Fifth generation (5G) technology is of great interest to the scientists and researchers due to the advantages of the next generation systems such as less latency, improved data rates, enhanced coverage and zero dropped calls [1-4]. Hence, 5G communication systems pioneer to new technology experiences [5-11]. Various groups of researchers and communities have focused on developing the technical features of 5G communication systems [12-18]. The 3rd Generation Partnership Project (3GPP) Communities are the essential organizations to standardize the 5G communication systems. According to Releases carried out for 5G standards in 3GPP, two types of frequency bands are allocated for 5G systems; FR1 (sub-6 GHz) and FR2 (above 6 GHz) [2, 19, 20]. FR1 covers the range from 450 MHz to 6 GHz and FR2 covers the range from 24.25 GHz to 52.6 GHz. Additionally, the operating frequency bands are specified as n77 for 3.3 GHz - 4.2 GHz, n78 for 3.3 GHz - 3.8 GHz, and n79 for 4.4 GHz - 5 GHz [2]. On the other hand, former communication systems such as Wi-Fi, 2G, 3G, and LTE still need to work with

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5G technologies [2, 21]. In this sense, antenna design is an important issue for integrating the systems or devices with 5G communication system features.

Metamaterial antennas have become very popular for the researchers due to their compactness, compatibility, and robustness properties. Therefore, these antennas can be used in many applications such as RFID systems, wearable structures, wireless communications and sensor design [22-25].

Split-ring resonators (SRR) are key part of negative index metamaterials (NIM) or double negative metamaterials (DNG). They are also crucial components of single negative metamaterials (SNG), which have either negative permittivity or negative permeability. The early studies on Split Ring resonators are performed by Pendry et al [26]. In their study, Pendry et al. design microstructures with non-magnetic conducting sheets, namely Split Ring Resonators (SRR) [26]. These structures consist of two concentric metallic Split Rings printed on dielectric substrate. Since then, various structures have been developed by using SRRs for many applications [27-38]. Alternatively, complementary split ring resonator (CSRR) is another structure which is examined and integrated into the antennas by the researchers [39]. There are also various studies on the design and examination of metamaterial-based antennas for 5G communication systems in the literature [40-51].

The choice of machine learning or artificial intelligence technique depends on the specific problem being addressed, the data available, and the desired outcome.

It is important to note that other machine learning and artificial intelligence techniques such as neural networks, decision trees, and support vector machines may also be appropriate for predicting the relative permittivity of substrate materials for 5G antenna applications. These techniques may offer higher accuracy or better performance under certain conditions, but may also require more data, expertise, and computational resources. Therefore, the choice of technique should be based on the specific requirements and constraints of the problem being addressed. There are several advantages of using multiple linear regression analysis over other machine learning techniques such as neural networks, decision trees, and support vector machines (SVM) for the estimation of SRR-Loaded Patch Antenna Substrate Materials for 5G Communications:

- Simplicity and interpretability: Multiple linear regression is a simple and easy-to-understand technique that produces a model that is easy to interpret. This can help to gain insights into the physical mechanisms that govern the antenna behavior and substrate material properties, making it a practical choice for applications where interpretability and simplicity are important.

- Validity and accuracy: Multiple linear regression can provide accurate predictions for the relative permittivity of different substrate materials, especially when the data is well-prepared and appropriate variables are selected. It allows for the selection of relevant independent variables that have a significant impact on the dependent variable, which can improve the accuracy of the predictions.

- Efficient use of data: Multiple linear regression requires a relatively small amount of data to produce accurate predictions compared to other machine learning techniques such as neural networks or decision trees, making it a practical choice for applications where data availability is limited.

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• Flexibility: Multiple linear regression can be extended to include higher-order effects and interactions between variables, allowing it to capture more complex relationships between the variables. This flexibility makes it a versatile technique that can be adapted to different design scenarios and requirements.

Overall, multiple linear regression is a practical and effective technique for the estimation of SRR-Loaded Patch Antenna Substrate Materials for 5G Communications, providing a balance between simplicity, accuracy, and interpretability. In this study, SRR-loaded microstrip patch antenna with partial ground plane is investigated in the n77, n78, and n79 bands for 5G communication systems. The SRR structure is modeled on the partial ground plane side. The proposed antenna is examined in terms of Return Loss, radiation efficiency, and radiation pattern parameters in the frequency range from 1 GHz to 6 GHz. The designed antenna is fabricated and examined experimentally to verify the simulation results. Then, linear regression analysis is applied to the proposed antenna structure with different substrate materials to determine the relative permittivity of the substrate. Spatial coordinates x (mm), y (mm), z (mm), and the real and imaginary parts of the Electric Field **E** (V/m) and Magnetic Field **H** (A/m) components are assigned as inputs; and the relative permittivity of the substrate material (ε_r) is estimated as the output. The total data set has 10556x5 instances and 16 attributes including the type of substrate material.

2. Design of the SRR Loaded Antenna

The circular microstrip patch antenna with partial ground plane is designed by using a 50 mm × 40 mm FR-4 substrate with relative permittivity of 4.3 and tangent loss of 0.0025. Ground plane is made of copper and its dimensions are 20 mm × 40 mm. The SRR metamaterial is loaded at the bottom side of the antenna. The geometries of the antenna and SRR structure are shown in Figures 1 and 2, respectively. Antenna dimensions are given in Table 1 and the dimensions of SRR are listed in Table 2.

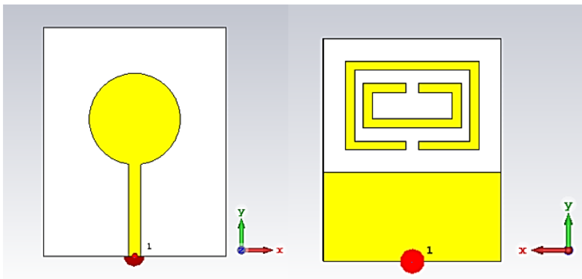

Figure 1. Top layer (Left) and Bottom layer (Right) of the patch antenna with SRR loaded partial ground plane

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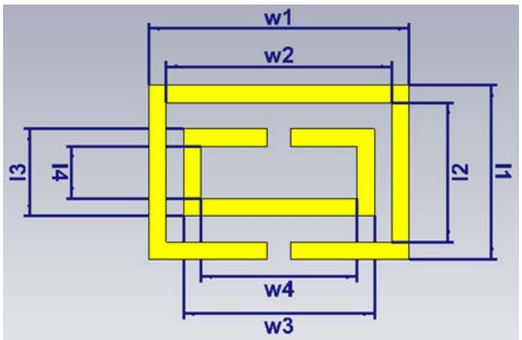

Figure 2. Geometry of the Split-Ring Resonator (SRR)

Table 1. Dimensions of Designed Antenna

Parameters	Unit (mm)
Feed Line Length	20
Feed Line Width	2.7
Substrate Width	40
Metal Thickness	0.035
Patch Radius	10
Substrate Height	1.6

Table 2. Dimensions of the SRR Structure

Parameters	Unit (mm)
l1	20
l2	16
l3	10
l4	6
w1	30
w2	26
w3	22
w4	18
Gap	2.7

Return Loss characteristics of the designed antenna is shown in Figure 3. According to the figure, antenna bandwidth is 2.58 GHz from 2.55 GHz to 5.13 GHz. Three resonances occur at 2.8 GHz, 3.9 GHz, and 4.9 GHz with S11 values of -22.97 dB, -29.9 dB, and -21.61 dB, respectively. The 3D and polar radiation patterns for $\theta=0^0$ and $\theta=90^0$ planes at the resonance frequencies are illustrated in Figures 4a-c. It is clear from these figures that the antenna has omni-directional pattern.

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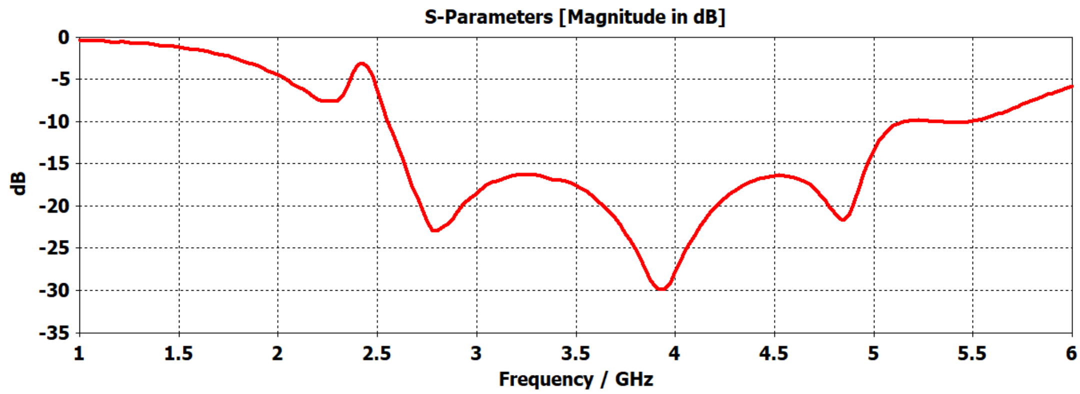
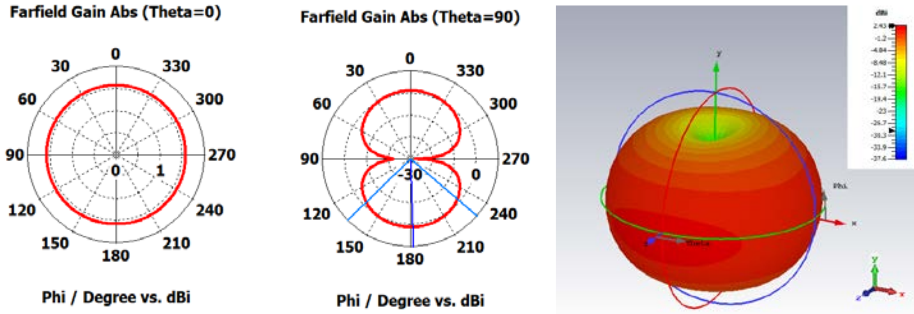
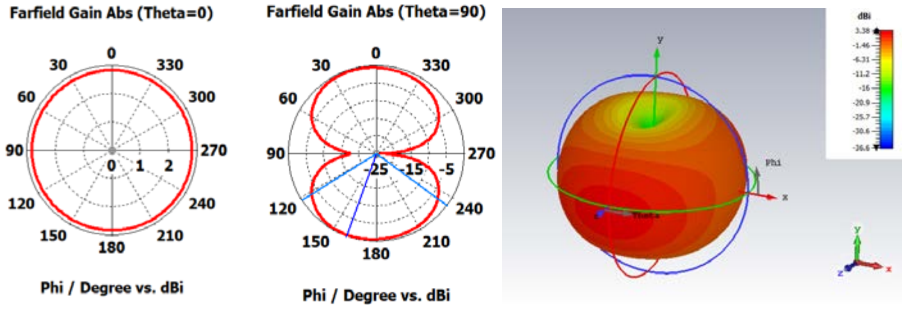


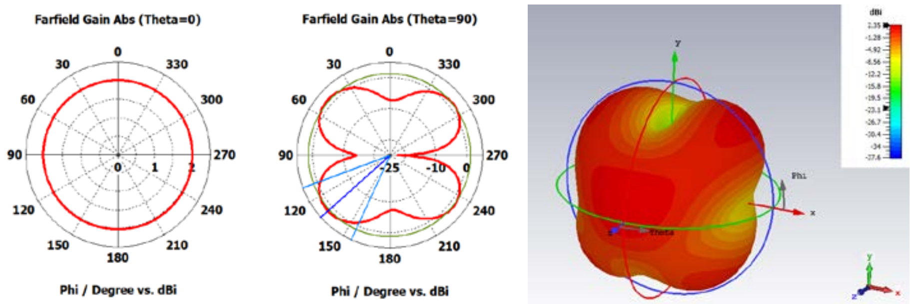
Figure 3. Return Loss of the SRR loaded patch antenna



a)



b)



c)

Figure 4. Radiation pattern of the SRR loaded patch antenna a) 2.8 GHz, b) 3.9 GHz, c) 4.9 GHz

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Figure 5 shows the radiation efficiency of the designed antenna. As seen in the figure, the radiation efficiency is almost stable and it is approximately equal to or larger than 90% in the range from 2.8 GHz to 4.1 GHz. The radiation efficiency is slightly reduced after 4.1 GHz until it reaches its minimum value of 74% at 5 GHz. Then it starts to increase slightly again. Thus, the radiation efficiency does not change significantly over the whole range.

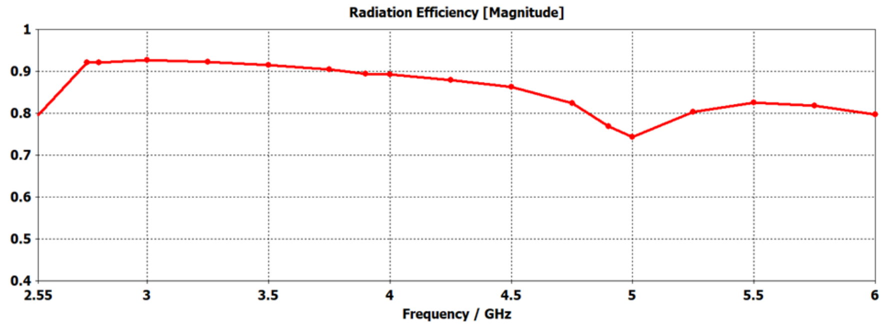

Figure 5. Radiation Efficiency of the antenna

3. Measurement Results

To verify the simulation results, the proposed antenna is fabricated by using FR-4 substrate as shown in Figure 6. PCB prototyping machine is used for the fabrication process. Figures 7 and 8 show the Return Loss and VSWR characteristics of the proposed antenna, respectively. These parameters are measured via network analyzer. There are slight differences between the simulation and measurement results due to the soldering process and the SMA connector. Additionally, minimum Return Loss values of the fabricated and simulated antennas have minor discrepancies due to the reflection between the fabricated antenna and the probe. Addition to this, there are no equipment to measure the radiation pattern, and gain parameters due to the poor laboratory. Hence, the measured results of the radiation pattern and gain are not presented in this section. As abovementioned, this proposed antenna has the permissible feature when the measurement results are compared with the simulation results along with S_{11} and VSWR.

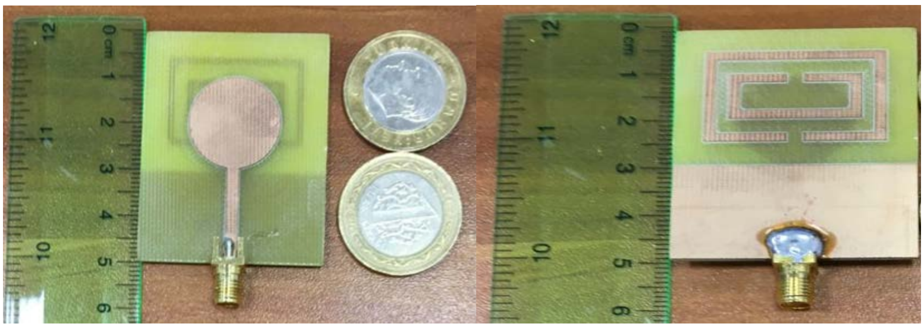

Figure 6. Front (Left) and Back (Right) views of the fabricated antenna

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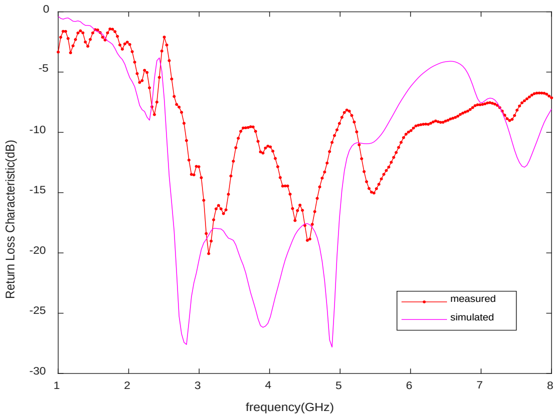

Figure 7. Simulated and measured Return Loss characteristics of the SRR loaded patch antenna

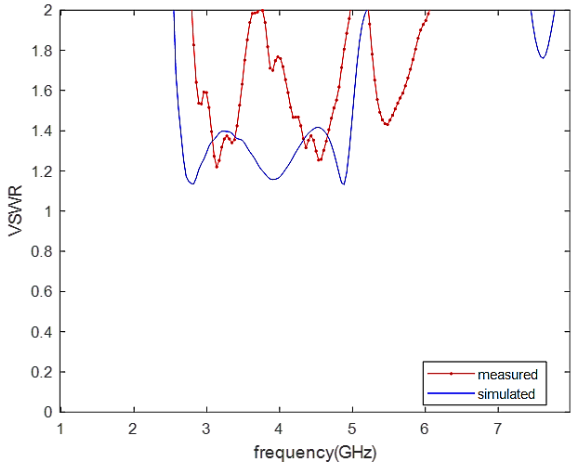

Figure 8. Simulated and measured VSWR characteristics of the SRR loaded patch antenna

4. Multiple-Linear Regression Analysis

Multiple linear regression is a statistical technique used to model the relationship between a dependent variable and multiple independent variables. In the context of determining the relative permittivity of substrate materials for 5G antenna applications, multiple linear regression can be used to develop a predictive model that relates the electric and magnetic fields to the relative permittivity of the substrate material. The relative permittivity, also known as dielectric constant, is an important parameter that characterizes the ability of a material to store electric energy in an electric field. In the case of 5G antennas, the substrate material used in the antenna design can significantly impact the antenna's performance and efficiency. Therefore, accurate determination of the relative permittivity of the substrate material is critical to achieving optimal antenna design. By using multiple linear regression, one can develop a model that relates the electric and magnetic fields to the relative permittivity of the substrate material. This model can then be used to predict the relative permittivity of different substrate materials based on their electric and magnetic fields. The variables selected as electric and magnetic fields can be obtained through simulations or experiments. Multi-linear regression technique is an approach for determining the relationship between variables affecting systems. Multiple linear regression equation is depicted as:

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$$Y = X_0 + b_1 X_1 + b_2 X_2 + \cdots + b_m X_m + \epsilon \tag{1}$$

where X_0 is a constant, and Y stands for the dependent variable. X_1, X_2, X_3,…, X_m represent the independent variables of the systems. b_1, b_2, b_3, …, b_m are referred to as the regression coefficients and ϵ is the error term.

In this study, multiple linear regression analysis is used to determine the relationship between the relative permittivity of the substrate material and electric-magnetic field distributions. Initially, spatial coordinates (x, y, z), and the real and imaginary parts of the Electric and Magnetic Field Components (E, H) are selected as the input parameters (attributes). Relative permittivity of the substrate material (εr) is attained as the output. The relative permittivity values are 2.2 (Rogers 5880), 4.4 (FR-4), 3.66 (Rogers 4350), 1.6 (Cotton), and 1.9 (Polyester). Spatial coordinates are varied with 3.25 mm intervals in the range as $-40.625 \leq x \leq 40.625$, $-45.5 \leq y \leq 45.5$, and $20.325 \leq z \leq 21.925$. 52780 instances are obtained by changing the substrate material via CST Microwave Studio program. This means that the proposed data set has (10556×5) instances with 16 attributes for each substrate material. It is found that linear regression technique has mean absolute error (MAE) of 0.0748 and correlation coefficient of 0.9758. The results are presented in Figure 9.

Correlation coefficient	0.9758
Mean absolute error	0.0748
Root mean squared error	0.2309
Relative absolute error	7.4926 %
Root relative squared error	21.8663 %
Total Number of Instances	52780

Figure 9. Data Mining Results Obtained by Multiple Linear Regression Analysis

5. Conclusions

This study presents the design and analysis of a circular patch antenna loaded with Split Ring Resonator for 5G communication systems. Return Loss, VSWR, Radiation Pattern and radiation efficiency are examined in the sub 6 GHz range. The antenna covers n77, n78, and n79 bands with a bandwidth of 2.58 GHz from 2.55 GHz to 5.13 GHz. The simulation results are confirmed with the experimental analysis. It is verified that the proposed antenna is a good candidate for 5G communication systems. Additionally, multiple linear regression analysis is used to estimate the substrate material of the designed antenna. In the regression analysis, the spatial coordinates (x, y, z) and the real and imaginary parts of the electric and magnetic field components are selected as the input parameters (attributes). Relative permittivity of the substrate material (ε_r) is the output parameter. Thus, the data set has 52780 (10556 x 5) instances and 16 attributes. After the analysis, the mean absolute error (MAE) is determined as 0.078 and correlation coefficient is 0.9758. Therefore, the permittivity of a substrate material can be accurately estimated by the proposed model. In summary, multiple linear regression is an important tool for determining the relative permittivity of substrate materials for 5G antenna applications. It allows for the development of a predictive model that relates the electric and magnetic fields to the relative permittivity, which can then be used to optimize antenna performance and efficiency.

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