Design of Compact Multiband Antenna

Avinash Gollapalli, P Sandeep Kumar*, G Rokkesh, S Nithish, Vishal Hirawat, and Rahul
Department of Electronics and Communication Engineering, SRM Institute of Science and Technology (Deemed University), Kattankulathur, Chennai, Tamil Nadu, India
Email: *sandeepp@srmist.edu.in

Abstract. This paper presents the design and analysis of a compact multi-band antenna employing multiple radiators, each radiator of different frequencies. The frequencies covered are 900MHz, 1800MHz, 2600MHz, 3500MHz, and 5500MHz. The height of each radiator is different for each frequency. The higher the frequency, the shorter the radiator. For example, the radiator's height of 5500MHz is only 13mm, while 900MHz is 83mm. The ground plane is placed on the backside of the substrate. The main challenge is to fit all the radiators on the single substrate while keeping the substrate's size constant, compact.

Keywords: Impedance Matching, WLAN, Radiation Pattern, Multiband, SAR

1. Introduction
An antenna is a device used to transmit information in electromagnetic waves through a medium such as space. The antenna is used with a transmitter and a receiver. The transmitted information is electric current; it is converted into electromagnetic waves for transmission and then again converted into the receiver end's electric current. With the rapid development and testing being done on the fifth generation of mobile communication, it is believed that the existing 4G devices will not be able to tap into the services of 5G. It is practical to develop cheap portable devices that can operate on 5G while still operating in 2G/3G/4G and WLAN. Without getting into the technicalities of the transmission, reception, and tuning of the signals, we aim to develop a novel design that can operate at the frequencies of various generations of mobile communication, such as 2G, 3G, and 4G 5G and WLAN.

The final design of the radiators is arrived upon after making multiple adjustments. Much help, inspiration was taken from the literature survey. The antenna in [1] uses arc-shaped radiators, which was the inspiration for radiator four's design. Authors of paper [2] talk about a defect in the ground plane. After studying the paper, we understood how introducing a defect in the ground plane improves the bandwidth and the antenna's gain. Authors in [3] and [4] talk about meandering. We found that the radiator one, having the lowest frequency, was also the longest of all the five radiators. However, with meandering, we could fit the radiator while leaving ample space on the substrate for the rest of the radiators. The antenna also has a small defect in the ground plane. [5-7] were used to understand WLAN technology and arrive upon radiator five's design. Since patch antenna is generally small, we studied [8-11] to understand how to make our design compact. Paper [12] includes SAR simulation for their design and the parameters to generate a tissue model. Authors in [13-15] talk about miniaturization's effects on the antenna's design and the problems that arise.

The designed antenna will be analyzed, and various parameters like the gain, efficiency, the obtained bandwidth, S-parameters will be depicted in this report. The Specific Absorption Ratio (SAR) of the
antenna will be analyzed. The antenna's design and simulation antennas were also fabricated, and the S-parameters were tested for the same.

2. Antenna Design
The antenna was structurally designed using the software CST Suite 2018. The antenna was designed using a technique called the loading technique. The antenna consists of the following elements, (i) substrate, (ii) ground plane, (iii) feed, (iv) radiators. The substrate material that was chosen for the base substrate is FR-4. The substrate is of dimensions 20 x 30 with a thickness of approximately 1.6 mm. The front plane has been depicted in Figure 1, and the ground plane has been depicted in Figure 2. The substrate contains five radiators; each radiator pertains to a frequency. The length of the antenna was calculated using the formula. The values have been listed in Table 1. The shorter the antenna, the higher is its resonating frequency. The antenna was designed to work with the frequencies of 0.9 GHz (2G), 1.8 GHz/3G, 2.6 GHz/4G, 3.5 GHz/5G, 5.5 GHz (WLAN). So, the radiator of WLAN is the shortest, with a frequency of 5.5 GHz. The radiators’ shape was arrived upon through multiple simulations, examining the results and making necessary adjustments since the design's compactness was of primary importance. A defect was introduced in the ground plane to improve the bandwidth. The resonant frequencies have been shown in Figure 3.

![Figure 1: Front Plane of Antenna](image1)

![Figure 2: Ground Plane of Antenna](image2)
Figure 3: Resonant Frequency

Table 1: Radiator length calculation concerning frequency

| Frequency (MHz) | (mm) | /4(mm) |
|-----------------|------|-------|
| 900             | 333.33 | 83.3  |
| 1800            | 166.66 | 41.6  |
| 2600            | 115.38 | 28.8  |
| 3500-4700       | 85.72 - 63.8 | 21.43 – 15.95 |
| 5500            | 54.54  | 13.6  |

3. Evolution of the Antenna Design

As mentioned earlier, the final design was arrived at after making multiple adjustments to the radiators’ shape and structure. The design starts with designing the 0.9 GHz radiator and then adding other corresponding radiators while making parallel adjustments to the design to get the required graph. A shift in the frequency had been observed each time a new radiator was added. Based on the shift, changes were made to the length and the shape of the radiators. The length of the radiators in the design differs from the theoretical values because of this very reason. This evolution has been depicted below.

Figure 4: Radiators
Figure 4 shows radiator one that corresponds to 900 MHz. In figure 5, radiator 2 was added to radiator 1, and a frequency shift was observed, along with the introduction of an unwanted frequency, which can be seen in the figure.

In figure 6, radiator 3, radiator 4 and radiator 5 can be observed. These radiators gave the frequency response shown in figure 7, and radiators 4 and 5 gave the frequency response shown in figure 8 and figure 9.
Figure 7: Radiators 4, 5

Figure 8(a): 0.9GHz, 1.8GHz

Figure 8(b): 3.6 GHz

Figure 8(c): 3.6 GHz
4. Simulated Results

The antenna was designed and simulated using CST software, and CST was selected for ease in simulation. The simulations were conducted for each radiator separately and then with all the five radiators collectively. The purpose of this was to understand how the frequency shifted because of mutual coupling when the radiators were added. Starting with radiator 1, we added radiator 2, radiator 3, radiator 4, and radiator 5 to understand the frequency shift and make changes to the design accordingly. Initially, there was a shift in the original frequency (900 MHz) corresponding to radiator 1 when radiator 2 (1800 MHz) was introduced to the design. When the other radiators were introduced, this shift was reflected in all the simulated frequencies. New frequencies were introduced in the frequency plot because of mutual coupling, even in the radiator's absence corresponding to the frequency. Based on the shift in frequencies, the radiators' shapes were adjusted to secure the target frequencies.

The final design was agreed upon, and the required simulations were run to check for the parameters. The return losses for the simulation are plotted in the figure. Good impedance match was found for all five frequencies, 900 MHz, 1800 MHz, 2600 MHz, 3500 MHz, 5500 MHz, with suitable bandwidth as given in Table 2.

Table 2: Bandwidth of the designed antenna at respective frequencies

| Frequency (MHz) | Bandwidth (MHz) |
|-----------------|-----------------|
| 900             | 23              |
| 1800            | 42              |
| 2600            | 122             |
| 3500            | 822             |
| 5500            | 330             |

The radiation patterns for all five frequencies were generated and observed. After generating the E-plots for the frequencies, a pattern close to a dumbbell was observed for all the frequencies. In an electromagnetic signal, the E-field is radiated perpendicular to the plane of the antenna. The field radiates in the positive y-axis and negative y-axis, assuming the x-axis lies parallel to the antenna's plane, hence the dumbbell shape.

While observing the H-field radiation patterns, we see that instead of a dumbbell, there is a singular circular-shaped radiation pattern. In the design, the ground plane extends up to 7mm. Since the H-field radiates parallel to the x-axis, no radiation can be observed above the parallel to the ground plane. The gain and efficiency were also calculated for the five frequencies. They have been listed in Table 3 below.

Table 3: Gain and Efficiency of the designed antenna

| Frequency(MHz) | Gain(dB) | Efficiency (%) |
|----------------|----------|----------------|
| 900            | 0.11     | 79.4           |
| 1800           | 0.786    | 77.6           |
| 2650           | 0.739    | 77.23          |
| 3500           | 0.656    | 66.06          |
| 5500           | 2.29     | 99.9           |

5. Specific Absorption Rate
In general, electromagnetic waves are absorbed by the human body. The measure of the extent to which the human tissue absorbs these waves is known as the specific absorption ratio or SAR. After designing the antenna and the subsequent simulations, the specific absorption ratio (SAR) was calculated for the antenna, which was done by designing a model of the first three layers of the biological tissue, namely the skin, fat, and muscle layers, which is shown in Figure 9. The SAR was calculated for one gram as tissue. The thickness of each of the three layers is given in Table 4, the body model parameters. The permissible value of SAR should be under 1.6. Upon completing the simulations, the values obtained were verified to be below the minimum permissible limit.

| Layer  | Thickness (mm) | Loss Tangent |
|--------|----------------|--------------|
| Skin   | 0.4            | 41.4         | 0.418 | 1100 |
| Fat    | 30             | 5.46         | 0.186 | 1100 |
| Muscle | 69.6           | 55.0         | 0.342 | 1040 |

It was observed that the lower the frequency, the higher the penetration power of the signal. For 900 MHz, the penetration was the highest, with the signal reaching the third layer, the muscle layer. There is a gradual decrease in the penetration power, with the lowest penetration power for 5500 MHz. The absorption patterns for every frequency have been depicted from figure 10 to figure 14.

![Tissue Model](image1.png)

**Figure 10:** Tissue Model

![0.9GHz](image2.png)

**Figure 11:** 0.9GHz

![1.8 GHz](image3.png)

**Figure 12:** 1.8 GHz
6. Results

The designed antenna was fabricated. The fabricated antenna can be seen in Figure 15.

Figure 13: 2.65 GHz

Figure 14: 3.5 GHz

Figure 15: 5.5 GHz

Figure 16: Fabricated antenna
The simulated design was fabricated, and the frequency response was calculated using a vector network analyzer (VNA) as shown in figure 16. During testing, five operational dips were obtained for -10 dB. As seen in Figure 17, a difference between the simulated (red color) and tested (blue color) results can be observed. This difference in the results can be attributed to various losses, namely, the transmission losses that might arise.

Due to an imperfect ground plane or connector losses (3dB or more), and other losses that might arise during the antenna's fabrication, the design was compared with the antenna dimensions of all the reference papers concerning the wavelength, and the concluding results have been published in the table 5. This design came out to be the smallest design.

### Table 5: Comparison of Antenna Size concerning the minimum frequency

| Paper | Size   | Minimum Frequency | Antenna size w.r.t |
|-------|--------|-------------------|--------------------|
| Paper 1 | 32 x 25 | 2.38 GHz          | 126 mm            | 0.25 x 0.19 |
| Paper 2 | 28.3 x 24 | 4.74 GHz          | 63.2 mm            | 0.44 x 0.37 |
| Paper 3 | 38 x 35 | 1.78 GHz          | 168 mm            | 0.22 x 0.2  |
| Paper 4 | 23 x 20 | 2.39 GHz          | 125 mm            | 0.184 x 0.16 |
| Paper 5 | 68 x 50 | 1.43 GHz          | 209 mm            | 0.33 x 0.23 |
| Paper 6 | 30 x 20 | 900 MHz           | 333 mm            | 0.9 x 0.6  |

### 7. Conclusion

In this paper, a novel design of a multi-band antenna operating at five different frequencies has been depicted. The total size of the antenna is 20 x 30 x 1.6. An FR-4 substrate was used during the antenna's fabrication with the radiators and the ground plane on opposite sides; the antenna consists of five radiators of different shapes. Each radiator corresponds to a frequency. The targeted frequencies are 900 MHz, 1800 MHz, 2650 MHz, 3500 MHz, and 5500 MHz corresponding to the second, third, fourth,
fifth generations of mobile communication and wireless LAN, respectively. A defect was introduced in the ground plane to improve the bandwidth of the signal. Various simulations were run in the software to calculate the reflection coefficient (\( \Gamma \)), the efficiency, the gain, the specific absorption ratio. Radiation patterns were also generated and observed. A prototype was fabricated, and the reflection coefficients were measured for the fabricated prototype. The difference between the simulated and the tested results were observed. These differences arose because of various losses. To conclude, the antenna can find suitable applications in 2G, 3G, 4G, 5G, and WLAN.

References

[1]. Zaman, W, Ahmad, H, Mehmood, "A miniaturized meandered printed monopole antenna for tri-band applications," *Microwave and Optical Technology Letters*, vol. 60, pp. 1265–1271, 2018.

[2]. Brar R S, Saurav K, Sarkar D, Srivastava K V, "A quad-band dual-polarized monopole antenna for GNSS/UMTS/WLAN/WiMAX applications," *Microwave and Optical Technology Letters*, vol. 60, pp. 538–545, 2018.

[3]. Ali T, Biradar R C, "A compact multi-band antenna using \( \lambda/4 \) rectangular stub loaded with metamaterial for IEEE 802.11N and IEEE 802.16E," *Microwave and Optical Technology Letters*, vol. 59, no. 5, pp. 1000-1006, 2017.

[4]. Chen S, Fang M, Dong D, Han M, Liu G, "Compact multi-band antenna for GPS/WiMAX/WLAN applications," *Microwave and Optical Technology Letters*, vol. 57, no. 8, p. 1769–1773, 2015.

[5]. Boukarkar A, Lin X Q, Jiang Y, Yu Y Q, "Miniaturized Single-Feed Multiband Patch Antennas," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 2, p. 850–854, 2017.

[6]. Manjunatha, K. A. and Agarwal, V., 2020, December. ISM band Integrated Distributed Antenna Systems for Industry 4.0: A Techno-Economic Analysis. In GLOBECOM 2020-2020 IEEE Global Communications Conference (pp. 1-6). IEEE.

[7]. Sezgin, I.C., Aabel, L., Jacobsson, S., Durisi, G., He, Z.S. and Fager, C., 2021. All-Digital, Radio-over-Fiber, Communication Link Architecture for Time-Division Duplex Distributed Antenna Systems. *Journal of Lightwave Technology*.

[8]. Wu, Z., Cao, C., Zeng, X., Feng, Z., Shen, J., Yan, X., Wang, B. and Su, X., 2020. Filterless radio-over-fiber system based on polarization multiplexing to generate an 80 GHz millimeter wave. *Applied Optics*, 59(24), pp. 7455-7461.

[9]. Noweir, M., Helaoui, M., Oblak, D. and Ghannouchi, F.M., 2020. Linearized Full duplex Radio-over-Fiber-over-Space Mixless Transceiver Architecture. *IEEE Photonics Technology Letters*.

[10]. Asha, D.S., 2021. A comprehensive review of Millimeter wave-based radio over fiber for 5G front haul transmissions. *Indian Journal of Science and Technology*, 14(1), pp. 86-100.

[11]. Liang, D., Shi, T. and Chen, Y., 2021. Photonic Generation of Multi-Band Linearly Frequency-Modulated Signal Based on a Dual-Parallel MZM. *IEEE Photonics Technology Letters*, 33(5), pp. 275-278.

[12]. Chen, Wenjuan, Dan Zhu, Jiang Liu, and Shilong Pan. "Multi-Band RF Transceiver Based on the Polarization Multiplexed Photonic Los and Mixers." *IEEE Journal of Selected Topics in Quantum Electronics* 27, no. 2 (2020): 1-9.

[13]. Fan, X., Zhu, S., Du, J., Li, M., Zhu, N.H. and Li, W., 2021. Photonic generation of quadruple bandwidth dual-band dual-chirp microwave waveforms with immunity to power fading. *Optics Letters*, 46(4), pp. 868-871

[14]. Kamalaveni A, Ganesh Madhan M, "A compact TRM antenna with high impedance surface for SAR reduction at 1800 MHz." *AEU - International Journal of Electronics and Communications*, vol. 70, p. 1192–1198, 2016.

[15]. A. Bashir and D. Faroze, "A full-duplex 40 GHz radio - over - fiber transmission system based on frequency octupling," *Opt. Quantum Electron.*, vol. 51, no. 10, pp. 1–11, 2020.