**Lab Title: Antenna Simulation and Design Exercise**

**Student’s name: Wanqing Shao**

**Course: MSc Communication Engineering**

**Lab Supervisor: Dr Laith Danoon**

**Date: Nov 11st, 2024**

**Introduction**

The aim of this report is to investigate the design and performance characteristics of a dipole antenna using simulation tools. The primary focus of the study is to explore how different parameters, such as resonance frequency, S11, bandwidth, gain, and directivity, affect the dipole antenna's performance. A dipole antenna is one of the simplest and most fundamental antenna types, widely used in a range of applications due to its simplicity and efficiency. By modeling and simulating the dipole antenna, this report provides insights into its behavior under varying design parameters and aims to optimize its characteristics for effective operation. The simulation also examines how changes in dimensions influence key performance indicators, such as radiation pattern and bandwidth.

**Background Theory**

A dipole antenna consists of two equal-length conductive elements, typically in a half-wave form, with each element about a quarter wavelength of the resonance frequency. Key parameters include resonance frequency, S11 (reflection coefficient), bandwidth, gain, and directivity.

Resonance frequency is the frequency where the antenna radiates effectively. S11 measures power reflection, with lower values indicating better impedance matching. Bandwidth represents the effective frequency range. Gain is the ability to focus energy in a direction, and directivity measures the concentration of power in that direction.

These parameters are essential for optimizing antenna performance. By simulating different dipole configurations, a comparative analysis of how design changes influence antenna characteristics is provided.

**Procedures**

1. **Model Design**
   * Create a dipole antenna model with specified dimension.图示

     描述已自动生成
   * Define key parameters: L1 (element length), a (element radius), and g (gap).
   * Select materials and describe the type of port used.
2. **Simulation Setup**
   * Set up the simulation environment and define the frequency range (e.g., 1-2 GHz).
   * Specify observed parameters: S11, radiation pattern, gain, resonance frequency, and directivity.
   * Set boundary conditions and radiation box for free space simulation.
3. **Simulation Execution**
   * Run simulations for different dipole configurations.
   * Record resonance frequency, S11, gain, and radiation patterns for each configuration.
4. **Parameter Variation**
   * Repeat simulations with different values of "a" (1 mm, 5 mm, 10 mm).
   * Document changes in antenna characteristics.
5. **Data Collection**
   * Collect data for each configuration, including S11 plots, radiation patterns, gain, and directivity.
   * Save figures of antenna models and results.
6. **Analysis**
   * Analyze data to determine the impact of parameter variations on performance.
   * Compare results for different values of "a" and generate a comparison table.

**Simulation Results, Discussion, and Analysis**

The following section presents the simulation results for the dipole antenna with three different configurations, corresponding to different values of the parameter "a": 1 mm, 5 mm, and 10 mm. The analysis includes the resonance frequency, S11, bandwidth, gain, and radiation pattern for each configuration. Comparisons are made to evaluate the impact of changing the dipole element radius on antenna performance.

1. **Simulation Results for a = 1 mm**
   * The antenna was simulated with L1 = 50 mm, a = 1 mm, g = 2 mm, and a frequency range of 1 GHz to 2 GHz.

图片包含 图表

描述已自动生成

* + The S11 response was examined over the frequency range, and the frequency (f\_min) at which |S11| had a minimum value was located. f\_min=1.342GHz

图表, 折线图

描述已自动生成

* + The frequency corresponding to the input resistance R = 50 Ohms (fR) and the frequency at which input reactance X = 0 Ohms (fX) were also identified. fR = 1.21322GHz; fX = 1.35829GHz

图表, 折线图

描述已自动生成

* + The -10 dB and -6 dB bandwidths of the antenna were determined, which are 141 MHz and 281 MHz
  + Far-field monitors were set to observe radiation patterns at fmin, and electric and magnetic field monitors were used to observe fields at fmin on the XoY and XoZ planes.

气泡图

低可信度描述已自动生成电脑屏幕的照片

低可信度描述已自动生成

图片包含 游戏机, 鱼

描述已自动生成

The directivity/gain of the antenna at fmin was noted, and the electric and magnetic field distributions were observed.

* + The radiation patterns, and the electric and magnetic field distributions at the frequency set.

气泡图

中度可信度描述已自动生成

背景图案

描述已自动生成图片包含 游戏机, 鱼

描述已自动生成

1. **Simulation Results for a = 5 mm**
   * The antenna was simulated with L1 = 50 mm, a = 5 mm, g = 2 mm, and a frequency range of 1 GHz to 2 GHz.

图片包含 室内, 飞机, 桌子, 站

描述已自动生成

* + The S11 response was examined over the frequency range, and fmin, and fR were located as in the previous configuration, while fX is invalid, since the curve never reached to 0 Ohms in y-axir. f\_min=1.342GHz; fR=1.201GHz

图表, 折线图

描述已自动生成 图表, 折线图

描述已自动生成

* + The -10 dB and -6 dB bandwidths were determined for this configuration, which are 192 MHz and 455 MHz.
  + Far-field monitors and electric/magnetic field monitors were set to observe radiation patterns and field distributions at fmin.

气泡图

中度可信度描述已自动生成电脑屏幕的照片

描述已自动生成图片包含 徽标

描述已自动生成

The directivity/gain of the antenna at fmin was noted, and the electric and magnetic field distributions were observed.

* + The radiation patterns, and the electric and magnetic field distributions at the frequency set.

图片包含 示意图

描述已自动生成 图示

描述已自动生成 电脑的屏幕

描述已自动生成

1. **Simulation Results for a = 10 mm**
   * The antenna was simulated with L1 = 50 mm, a = 10 mm, g = 2 mm, and a frequency range of 1 GHz to 2 GHz.

图片包含 室内, 桌子, 飞机, 站

描述已自动生成

* + The S11 response was examined over the frequency range, and fmin were located as in the previous configurations, while fR, and fX is invalid, since those curve never reached to 50 and 0 Ohms in y-axir. fmin = 1.221GHz

图表, 折线图

描述已自动生成 图表, 折线图

描述已自动生成

* + The -6 dB bandwidths were determined for this configuration, which is 239 MHz. However, since the min of S-Para is greater than -10 dB, the -10 dB bandwidths is 0.
  + Far-field monitors and electric/magnetic field monitors were set to observe radiation patterns and field distributions at fmin.

图片包含 游戏机, 球

描述已自动生成 电脑萤幕

中度可信度描述已自动生成

图片包含 表面图

描述已自动生成

The directivity/gain of the antenna at fmin was noted, and the electric and magnetic field distributions were observed.

* + The radiation patterns, and the electric and magnetic field distributions at the frequency set.

图片包含 游戏机

描述已自动生成 图片包含 游戏机

描述已自动生成 电脑屏幕的照片上有字

低可信度描述已自动生成

1. **Comparison and Analysis**
   * A comparison table summarizing the key performance metrics for the different values of parameter "a" is provided below.

|  |  |  |  |
| --- | --- | --- | --- |
| a (mm) | **resonance frequency (dB)** | **Bandwidth (MHz)** | **Directivity (dBi)** |
| 1 | 0.07803 | 281 | 2.645 |
| 5 | 0.1357 | 455 | 2.792 |
| 10 | 0.09645 | 239 | 2.820 |

* + The results show that as the radius "a" increases, the resonance frequency generally shifts. For a = 1 mm, the resonance frequency is 0.07803 GHz, increasing to 0.1357 GHz for a = 5 mm, and then decreasing to 0.09645 GHz for a = 10 mm. This suggests that the resonance behavior of the antenna is influenced by the dipole element's radius, with both increases and decreases depending on the specific value of "a".
  + The bandwidth shows significant variation across the different radii. For a = 1 mm, the bandwidth is 281 MHz, increasing to 455 MHz for a = 5 mm, and decreasing to 239 MHz for a = 10 mm. This indicates that a moderate increase in radius (e.g., 5 mm) yields a broader bandwidth, while a further increase reduces it.
  + The directivity of the antenna also increases with the radius. For a = 1 mm, the directivity is 2.645 dBi, increasing to 2.792 dBi for a = 5 mm and slightly further to 2.820 dBi for a = 10 mm. This suggests that larger radii contribute to better directionality.

1. **Discussion**
   * The results indicate that the radius of the dipole element significantly affects the antenna's performance characteristics. As the radius increased from 1 mm to 5 mm, the resonance frequency increased, and the bandwidth widened, reaching its peak at 455 MHz. However, with a further increase in radius to 10 mm, the resonance frequency decreased, and the bandwidth also narrowed to 239 MHz. This demonstrates a non-linear relationship between radius and antenna performance, indicating an optimal radius that balances these metrics.
   * The observed increase in directivity with increasing radius highlights a trade-off between bandwidth and directionality. While larger radii lead to improved directivity, they may also impact bandwidth and resonance stability. The moderate increase in radius (from 1 mm to 5 mm) yielded the highest bandwidth, indicating a potential optimal configuration for applications requiring broader frequency coverage.
   * The S11 response and impedance characteristics suggest that a balanced approach is required when selecting the radius of the dipole element. Improved impedance matching was noted with increasing radius, enhancing power transfer and radiation efficiency. However, the narrowing bandwidth at higher radii implies limitations for applications needing broad frequency operation.
   * In conclusion, optimizing the dipole element radius is crucial for achieving desired performance metrics, including resonance frequency, bandwidth, and directivity. The analysis suggests that a radius of around 5 mm provides a good compromise between bandwidth and directivity, making it suitable for a variety of applications. For applications where higher directivity is prioritized, a larger radius may be preferable, whereas applications requiring wider frequency coverage might benefit from a more moderate radius.

**Conclusion**

In this report, the design and performance characteristics of a dipole antenna were analyzed using simulation tools. The study focused on investigating how varying the dipole element radius affected key parameters, including resonance frequency, S11, bandwidth, and directivity. The results showed that the radius of the dipole significantly influences these performance metrics, with notable trade-offs between bandwidth, gain, and directivity.

It was found that increasing the radius generally improved impedance matching and directivity but also influenced the resonance frequency and bandwidth in a non-linear manner. The optimal configuration was observed for a radius of 5 mm, which provided a balanced combination of broad bandwidth and sufficient directivity. This makes it suitable for applications requiring efficient radiation over a wide frequency range.

Ultimately, the findings highlight the importance of optimizing the dipole element dimensions based on specific application requirements. Depending on the desired performance—whether it be broader frequency coverage, higher gain, or increased directionality—a suitable balance must be achieved. The study serves as a useful reference for designing dipole antennas to meet specific performance criteria in various RF applications.

**References**

1. Balanis, C. A. (2016). *Antenna Theory: Analysis and Design*. Wiley.
2. Kraus, J. D., & Marhefka, R. J. (2002). *Antennas for All Applications*. McGraw-Hill.
3. Stutzman, W. L., & Thiele, G. A. (2012). *Antenna Theory and Design*. Wiley.
4. Pozar, D. M. (2011). *Microwave Engineering*. Wiley.
5. CST – Computer Simulation Technology AG. (2016). CST MICROWAVE STUDIO 2016: Workflow and Solver Overview. Retrieved from CST MICROWAVE STUDIO documentation.