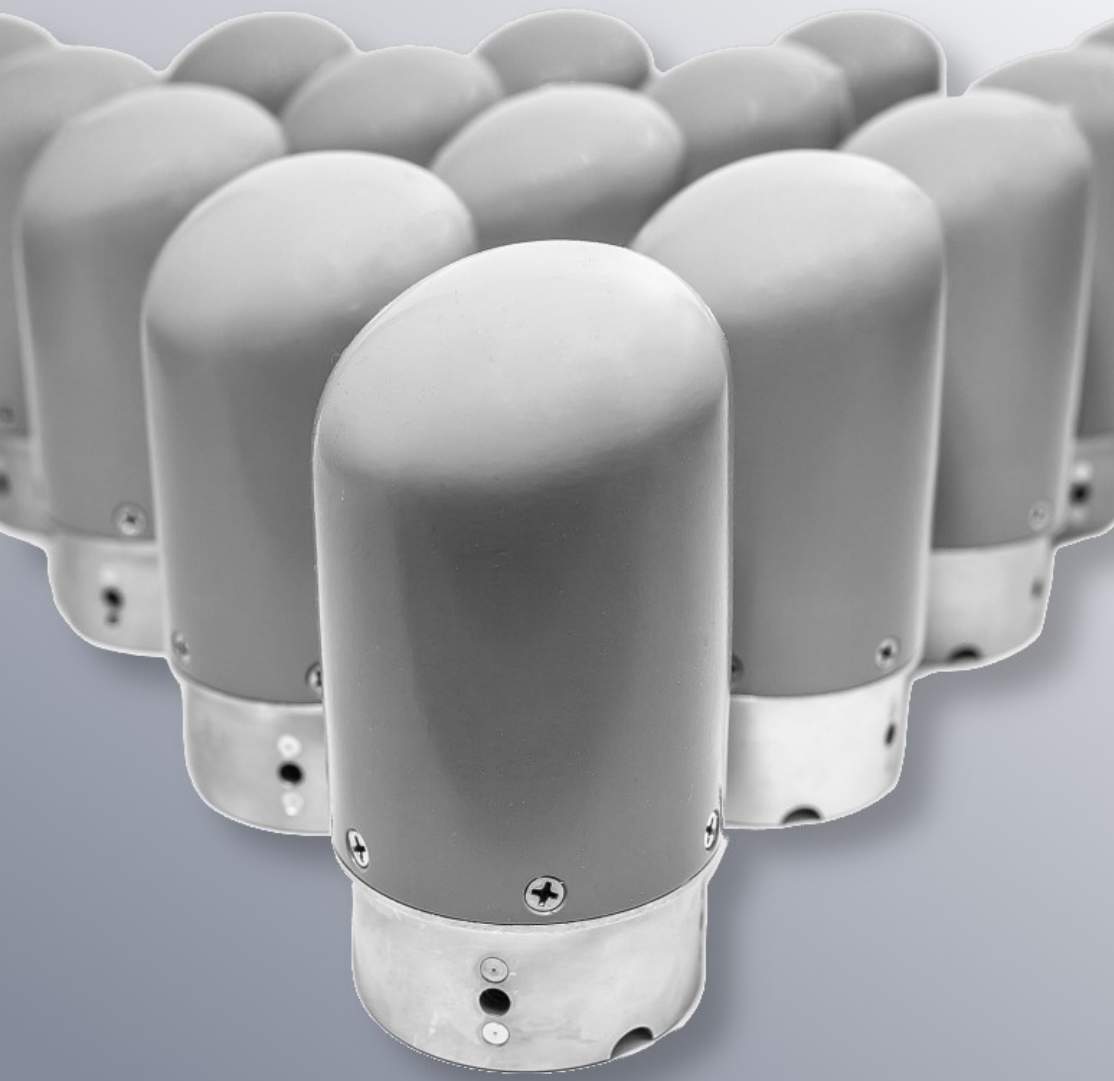# Spiral Antenna Design with MATLAB

Marcos Fioravante Buccella Espinoza

Consultants: Dr. Jaume Anguera Pros
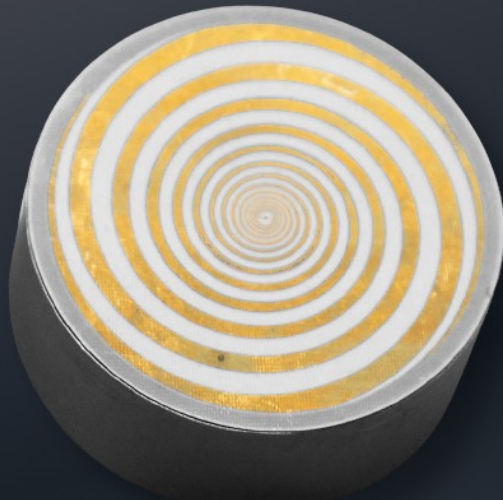Dr. Aurora Andújar Linares

Agenda

1.

Introduction

—

What is this about and why is it important?

Break down of the topic

This project presents a quantitative analysis of spiral antennas based on designs and simulations performed in the MATLAB software suite.

Spiral antennas are a type of planar antenna with diverse applications and ongoing research. MATLAB is a computer suite based on the application of numerical computation with many integrated applications.

At the end of the project, results have been obtained in graphical form that have served to determine how the application works in the study area.

**Key words:** Spiral, frequency-independent, simulation.

Overview of the topic

Like any research project, certain phases must be fulfilled for its successful development. To determine whether spiral antennas are useful and can be simulated in MATLAB, these three phases have been followed:

Bibliographic research

It is essential to understand how spiral antennas work and knowing their applications.
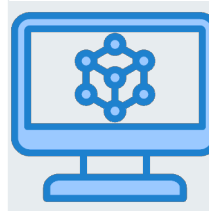
Parameterization and simulation

Preliminary calculations of the antenna generator parameters have been performed for subsequent simulation.

Analysis of the results

The results obtained must be analyzed to determine the feasibility of the hypothesis.

Why is this important?

Spiral antennas have numerous applications especially due to their frequency-independent behavior, so having a simulation software that allows easy modeling of them becomes necessary.

The simulation process can be complex since the time and computational requirements are significantly increased based on the frequency range under study. This project was born out of this need.
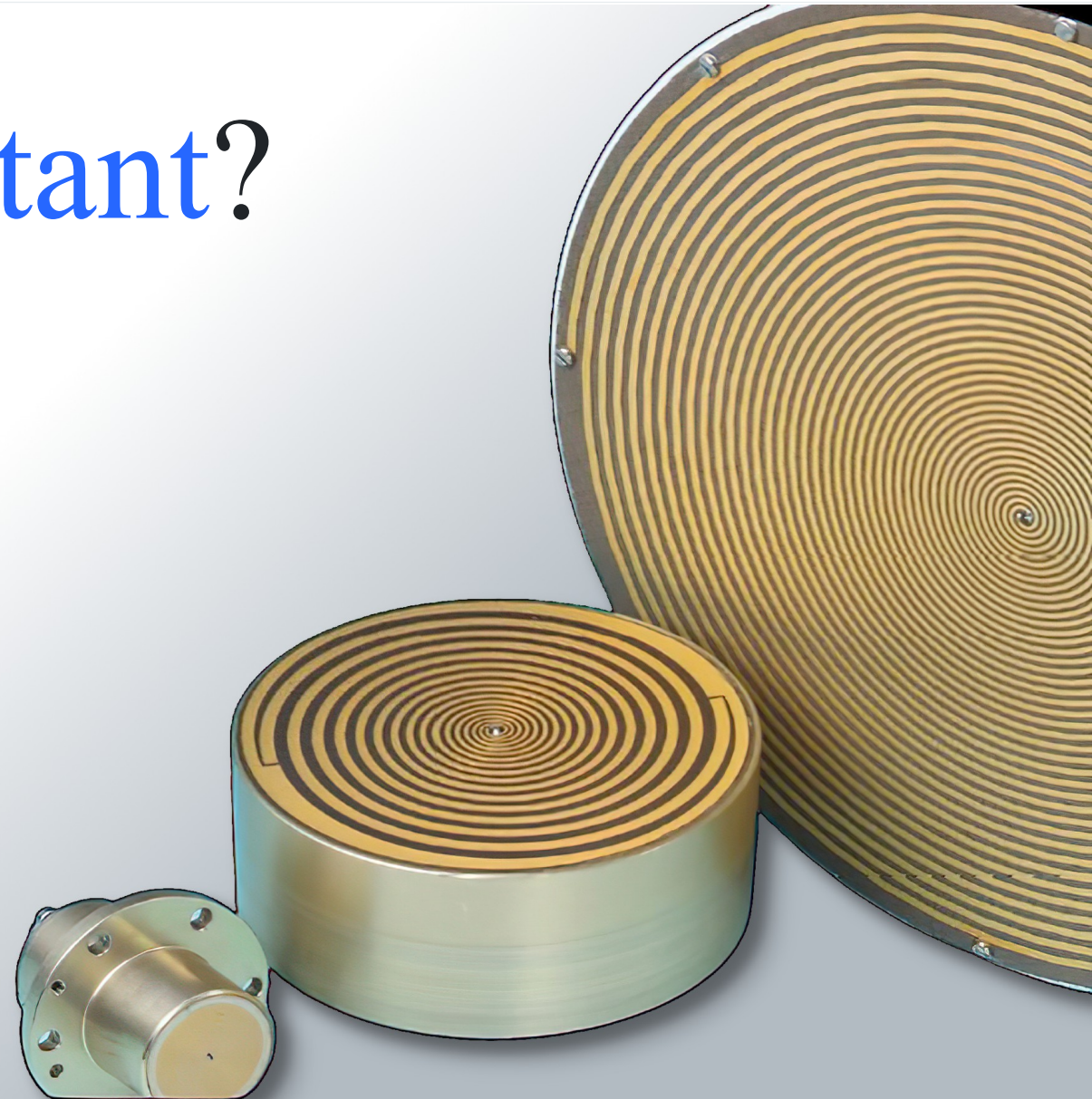
Topic

Spiral antenna design, analysis and simulation

Question

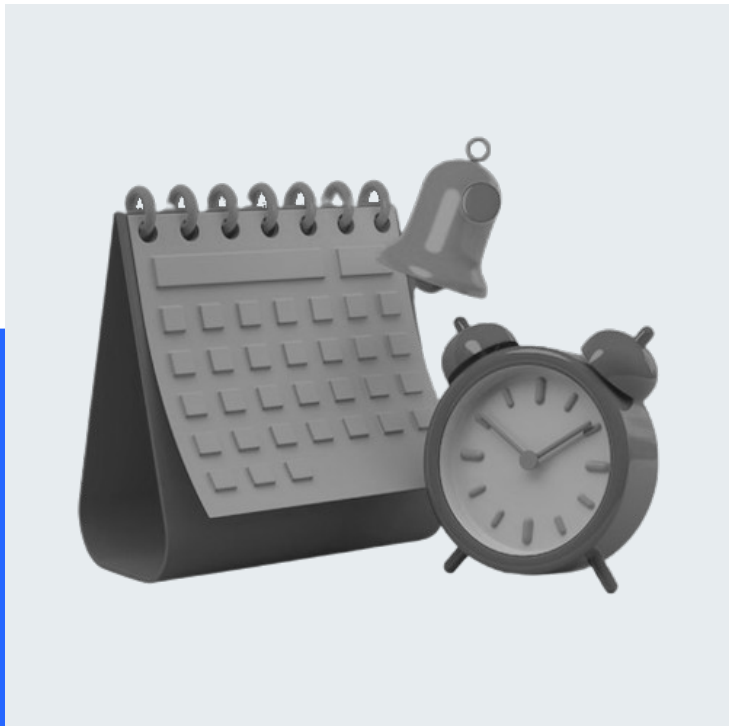Can spiral antennas be designed and simulated in MATLAB?

Answer

Yes. Different tests carried out satisfactorily prove this.

Objectives

1. To understand how spiral antennas work.
2. To simulate different configurations of spiral antennas in MATLAB.
3. To determine if the chosen tool is suitable for this type of simulations.

Project History

09/15/2022

Begin of scientific bibliography review and training.

10/15/2022

Started simulating spiral antennas.

12/15/2022

Finished the simulation and analysis, which included:

- First simulation of an equiangular spiral with a frequency range set.
- Simulation of a rectangular spiral antenna and comparison with the equiangular one.
- Analysis of the effect of the number of turns of the spiral.
- Effect of including a reflector plane under the antenna.

Start of the project drafting process.

01/15/2023

Completed research project

Products obtained

Literature review:

- Basic functionality of spiral antennas.
- Frequency independency.
- Applications of spiral antennas.
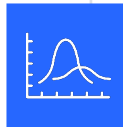
Graphical results:

- Corresponding to each simulation.
- Detailed analysis.
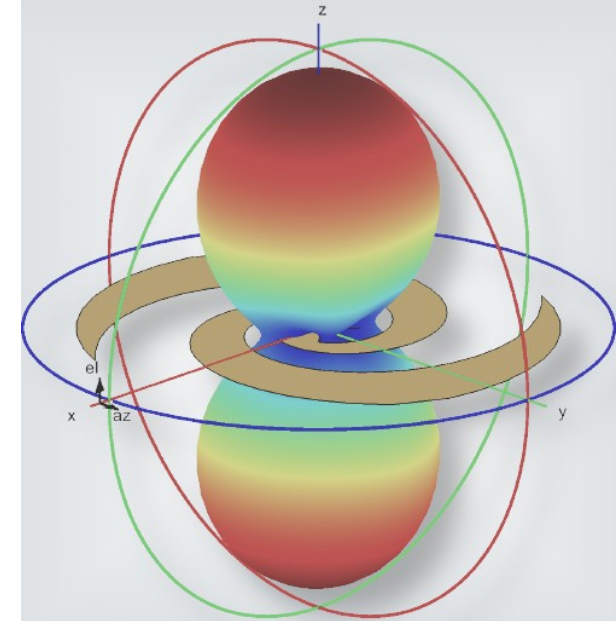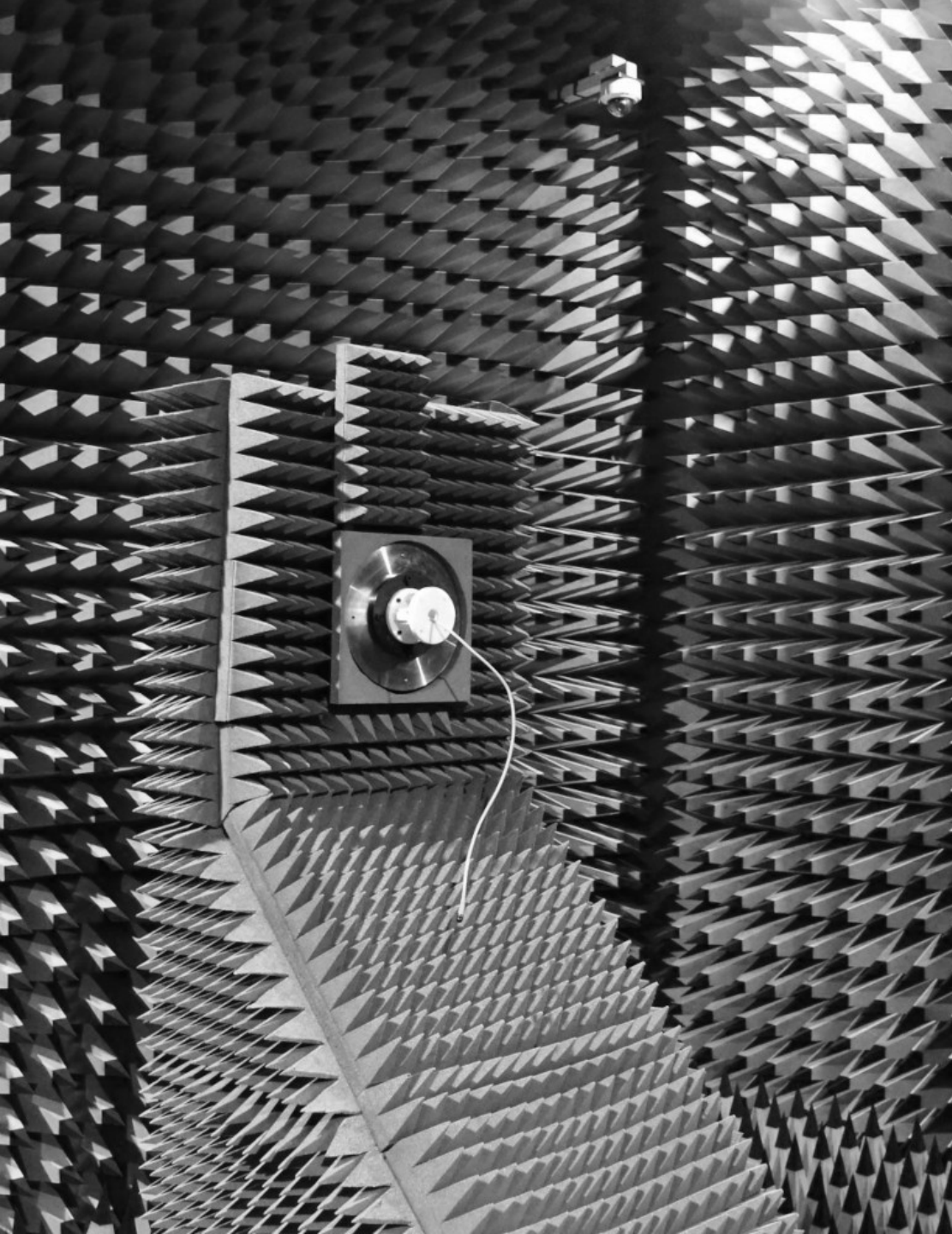- Adjusted to each simulated parameter.

Simulation's code:

- To generate every simulation carried out.
- Explanation of its usage.
- Easy adaptability.

Thesis memory:

- Reflection of results.
- Based on the UOC standard.
- Basis for future developments.

2.

The research project

—

What happened.

What are spiral antennas?

They are planar antennas with arms coiled in a spiral shape. Numerous geometries have been studied with different results. They acquire importance because if their geometry meets certain parameters, they behave as frequency-independent elements.

> " If an antenna is self-scalable, its properties will be independent of frequency. "

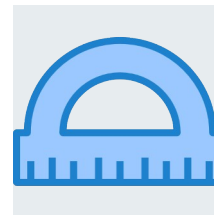**Victor H. Rumsey**
English electrical engineer

What makes a structure self-scalable?

τ=1.55

Truncable

They must be able to have a finite size and not grow to infinity.

Self-complementary

A structure is self-complementary when it and its complement have the same shape.

Defined by angles

They are defined by a polar coordinates equation: .

Scientific articles review

In-depth analysis:

- Operation basics and parameters review.
- Feeding structures.
- Electromagnetic analysis (Green function).

Applications:

- Space launcher communication.
- DF systems based in the angle of arrival (AoA) estimation.

Research and development:

- Usage of shallow cavities with resonant material to obtain unidirectional radiation.
- Application of SMD resistors to generate unidirectional radiation.
- Usage of parasitic elements (metallic posts) to increase bandwidth.
- Use of a resonant element as a notch filter.
- Aplication of dielectric lenses to increase the directivity of the antenna.
- Non-uniform structures that allow miniaturization.
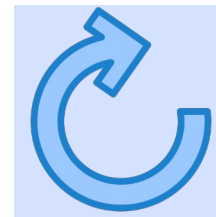
Equiangular spiral antenna parameters
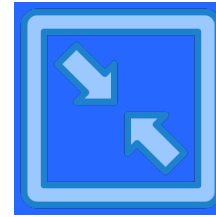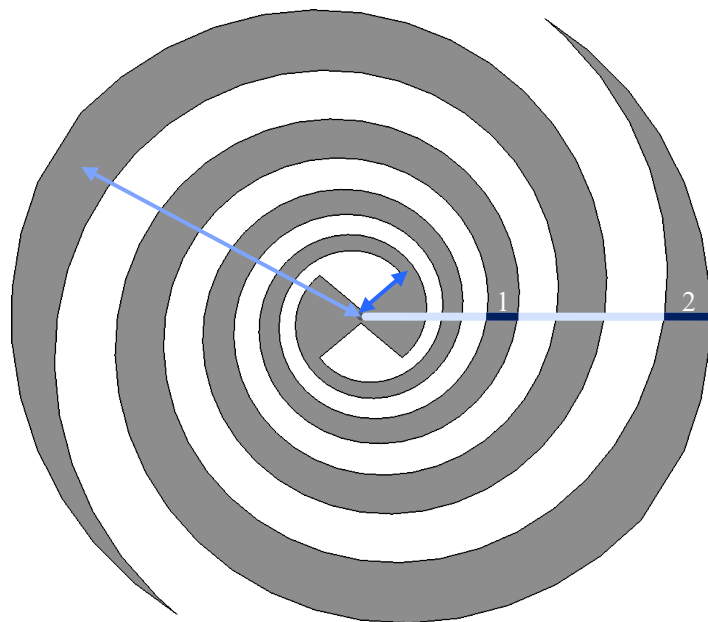
Inner radius

Distance from the center to the center of the innermost turn. Sets the maximum operating frequency of the antenna.

Outer radius

Distance from the center to the center of outermost turn. Sets the minimum operating frequency of the antenna.

Growth rate

Defines how fast the antenna is wound up. This is directly related to the number of turns the spiral will have.

First simulation set

- Equiangular spiral antenna to operate in the 1GHz-6GHz band.
- Default growth rate (0.35).

spiralEquiangular antenna element

2D Radiation diagrams

Results according to the expected:
- Almost no radiation to the sides of the antenna.
- Bidirectional radiation pattern.
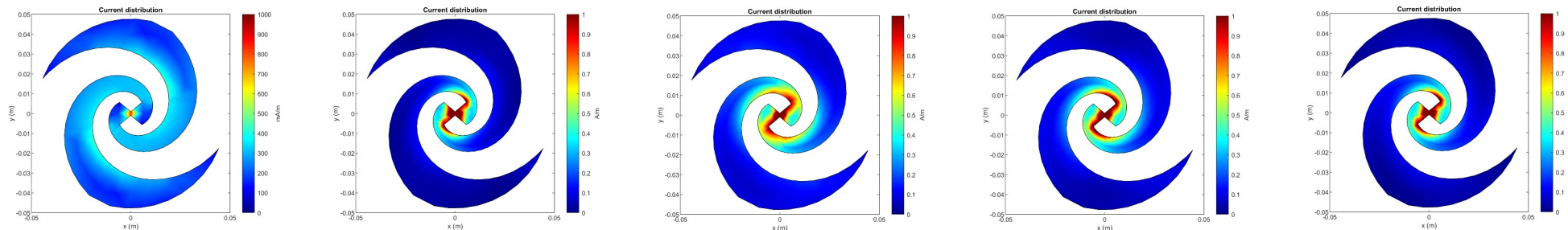- Extremely consistent results, aside from the lowest frequency.

Azimuth plane Gain (dBi)

Elevation plane Gain (dBi)
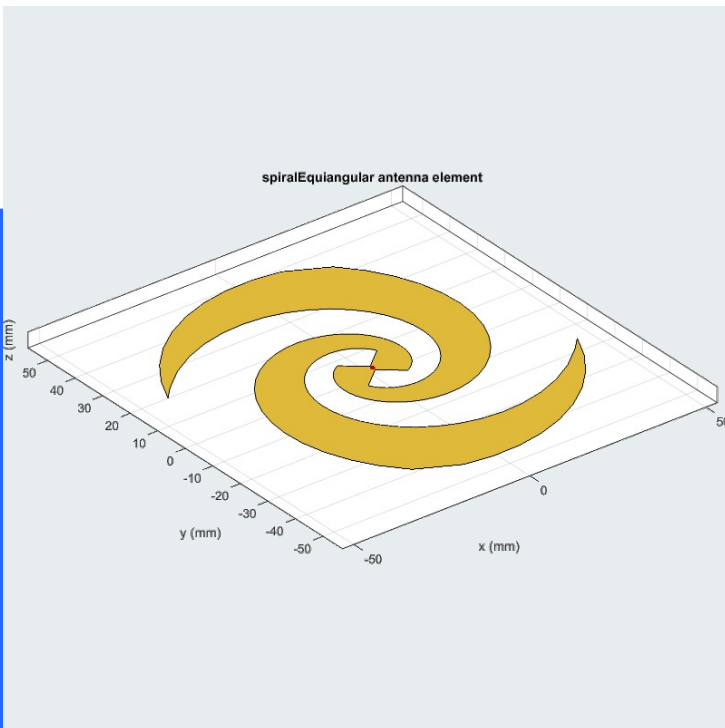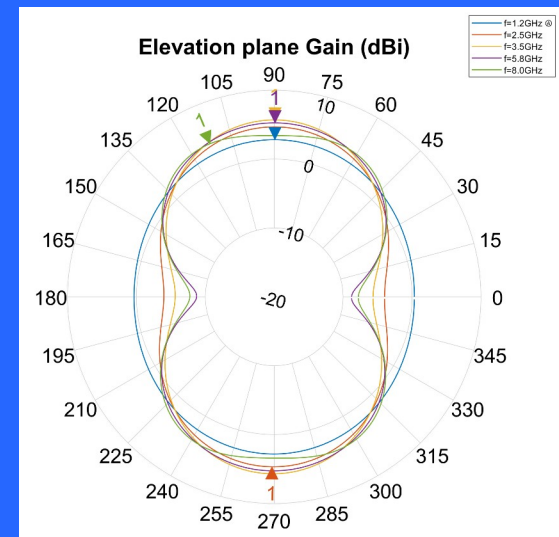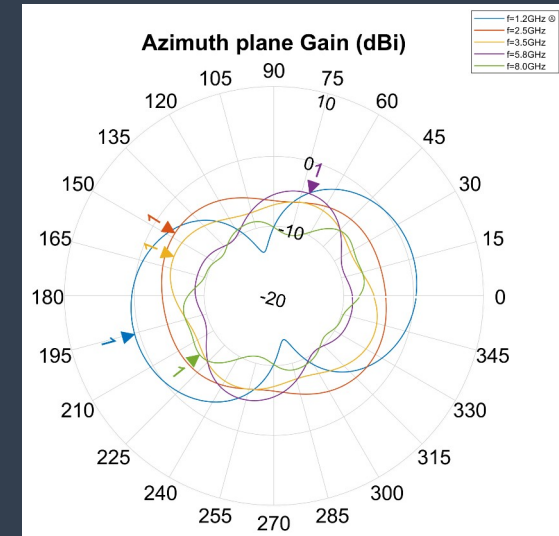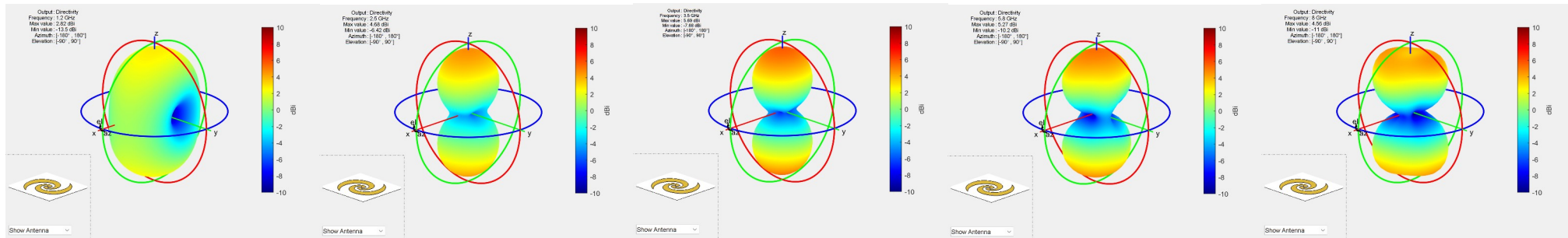
1.2 GHz   2.5 GHz   3.5 GHz   5.8 GHz   8 GHz

3D Radiation diagrams: Again, the results are extremely consistent, aside from the first frequency studied which shows radiation in the X coordinate direction.
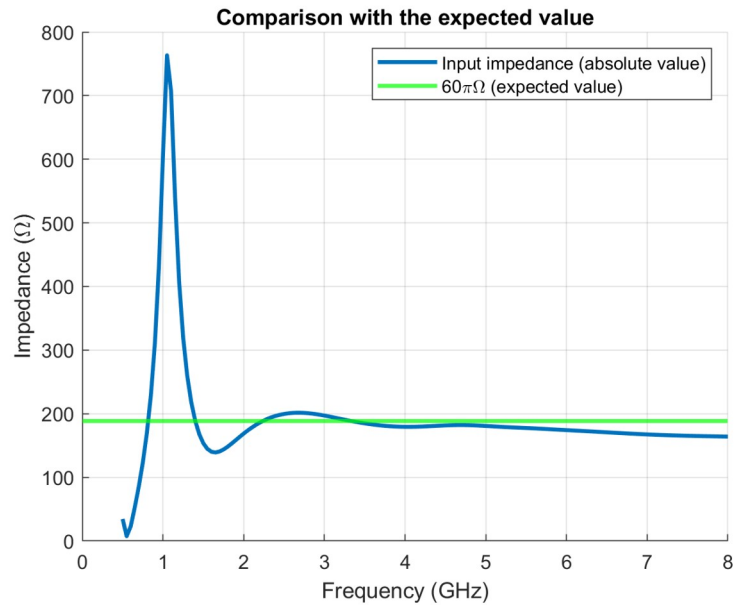

1.2 GHz   2.5 GHz   3.5 GHz   5.8 GHz   8 GHz

Surface currents distribution: The currents remain near the source. The lowest frequency had currents more evenly distributed over the arms.

Input impedance: The input impedance remained somewhat constant beyond 2GHz and consistent with the expected value for self-complementary structures. A spike appears around the lowest frequency selected.
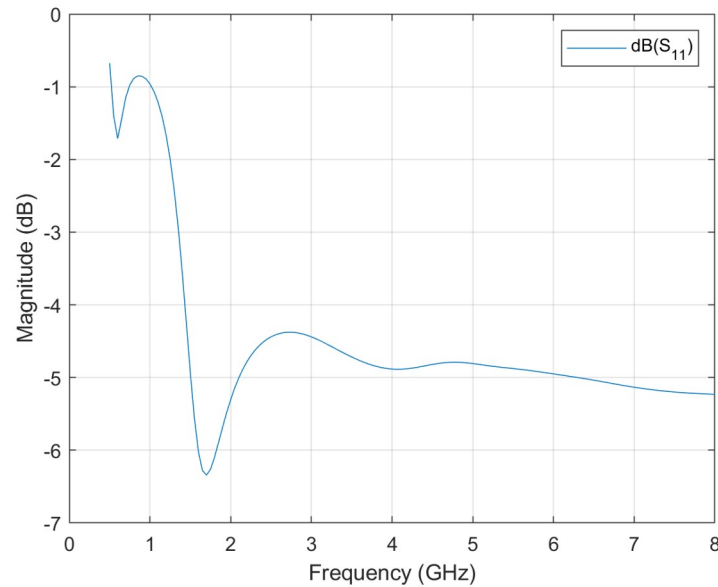
S₁₁ parameter: The results are the expected as seen in the input impedance plot. The value of the parameter remains below -5dB beyond 1.5GHz.
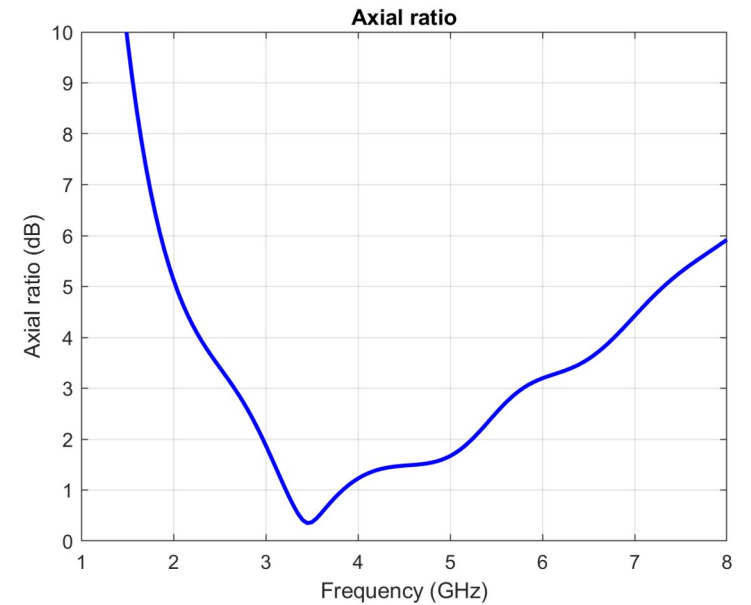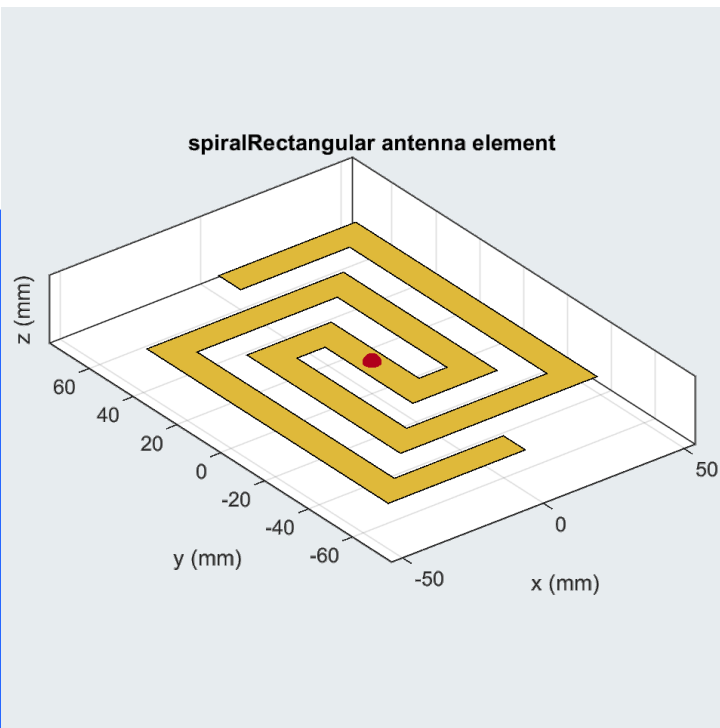
Axial ratio: The antenna shows an axial ratio below 2dB in the range of 3 to 5.2GHz, indicating a very good circular polarization in that range. The best value is obtained exactly in the center frequency (3.5GHz)

Second simulation set

Rectangular spiral antenna with matching dimensions of the previously simulated equiangular spiral.

2D Radiation diagrams

- Comparable (very little) radiation to the sides of the antenna.
- Again, a bidirectional radiation pattern in obtained. Gains are comparable, but better than those of the equiangular antenna.
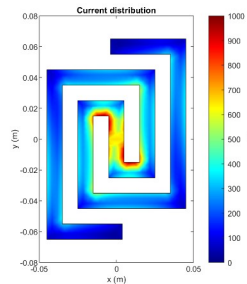- Apparent good stability, but not as good as the equiangular spiral.
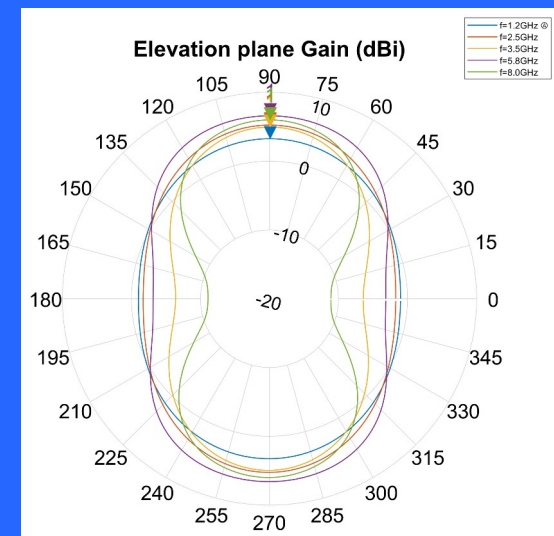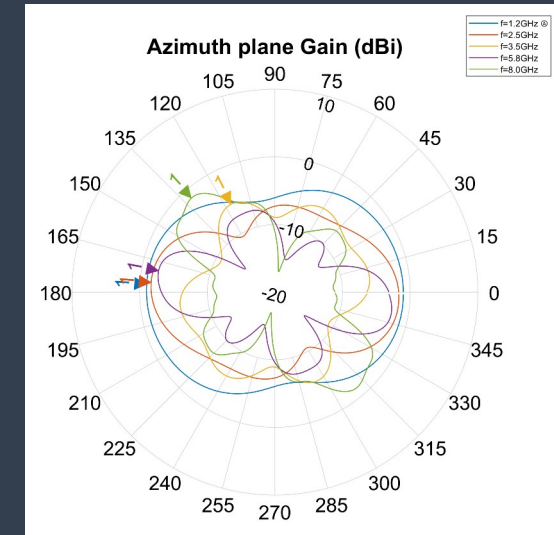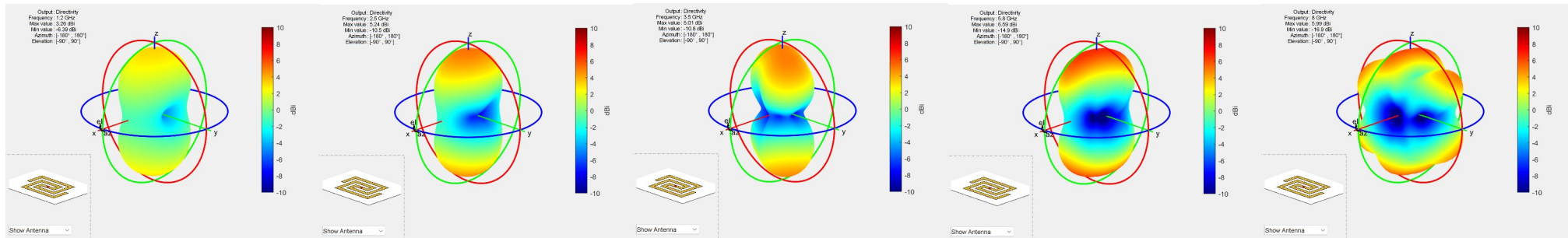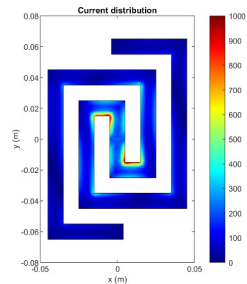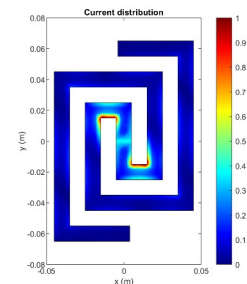
1.2 GHz   2.5 GHz   3.5 GHz   5.8 GHz   8 GHz

3D Radiation diagrams: The antenna performs better than the equiangular one at lower frequencies but significantly worse at the higher. The diagram is not as stable either.
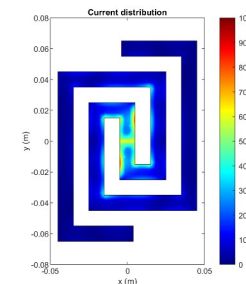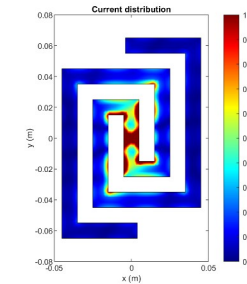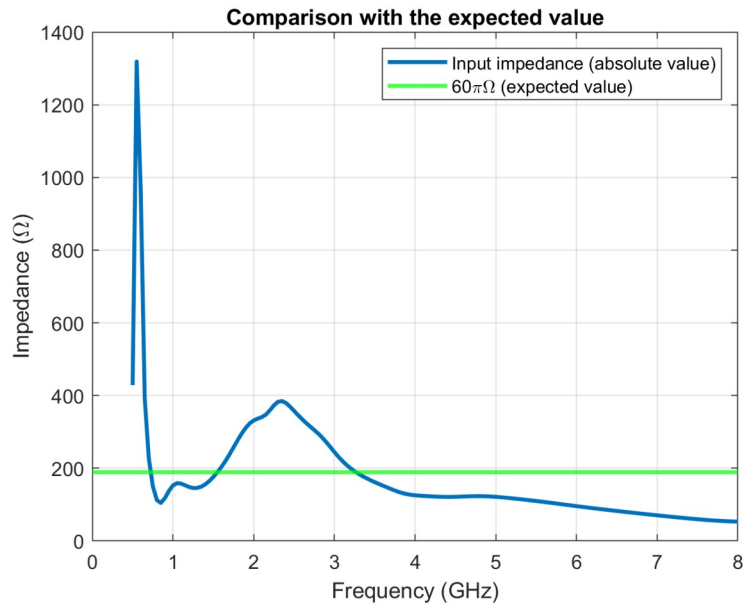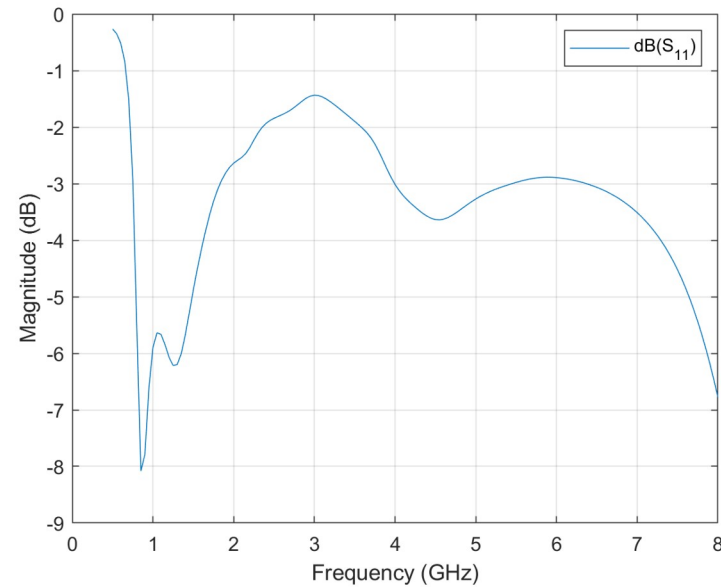

1.2 GHz   2.5 GHz   3.5 GHz   5.8 GHz   8 GHz

Surface currents distribution: The currents remain near the first turns when the antenna appears to perform better. At the higher frequency, large densities appear around the source.

Input impedance: The input impedance is extremely variable in the range under study, performing much worse than the equiangular spiral.

S₁₁ parameter: The voltage reflection coefficient is also very unstable, keeping over the -5dB mark for good part of the frequency range.
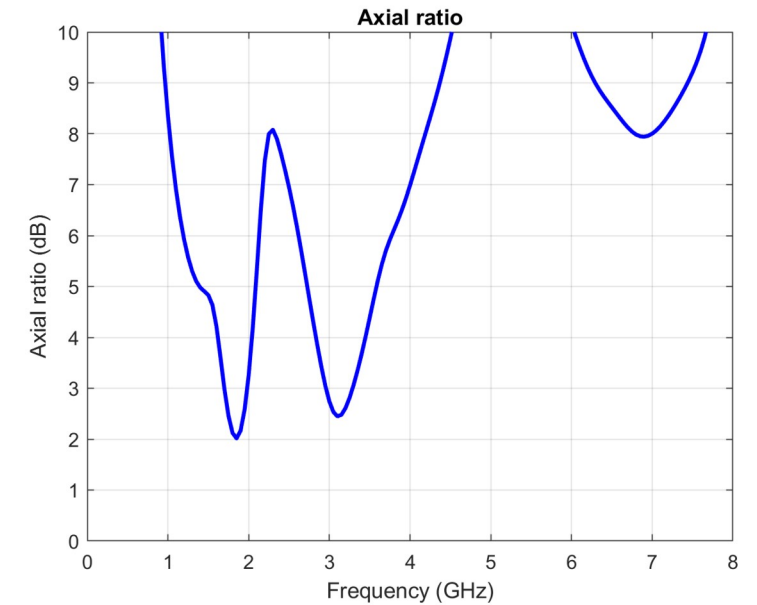
Axial ratio: Aside from a single frequency just under the 2GHz mark, the antenna fails to reach the 2dB mark that is acceptable for having a good circular polarization, representing again a clear disadvantage over the equiangular antenna.

Third simulation set

The number of turns of the equiangular antenna was changed varying the growth rate parameter in order to analyze its influence.

2D Radiation diagrams

Extremely consistent values obtained for the three configurations tested. The number of turns does not seem to affect significantly the gain of the antenna. The lower number of turns produced more radiation in the azimuth plane, but the values are almost insignificant (always below the 0dBi mark).
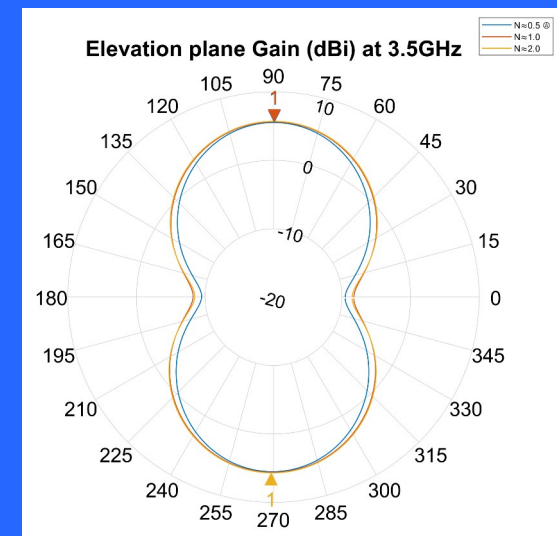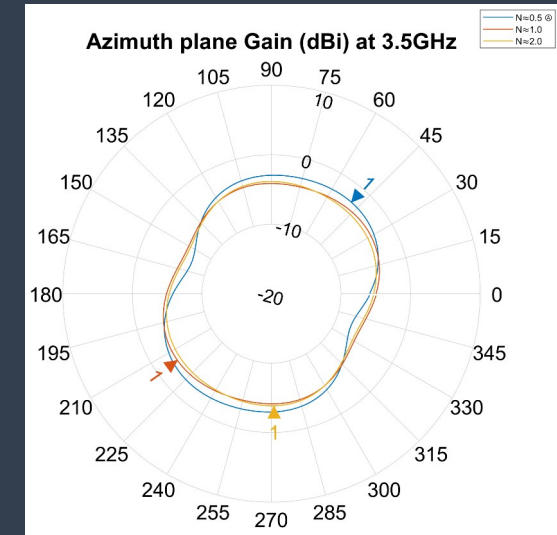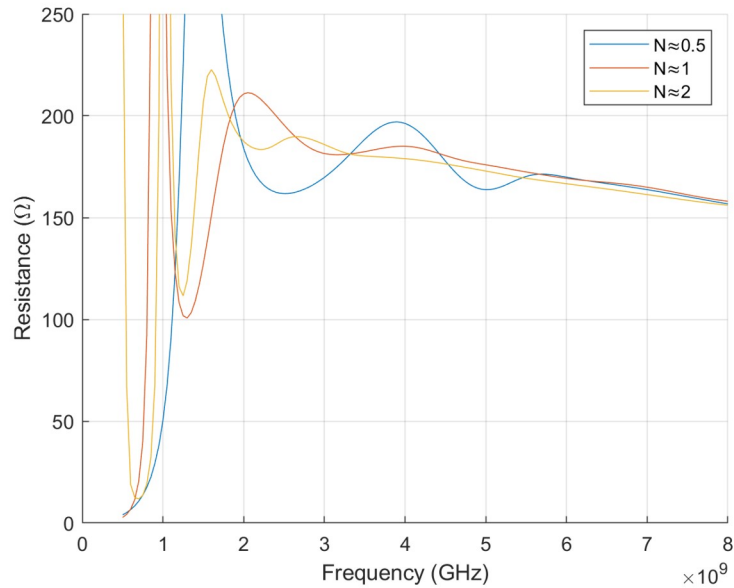
Input impedance: As the number of turns the antenna made increased, an improvement to the input impedance performance was seen. The curve became more stable, and the last peak moved down in the frequency range.
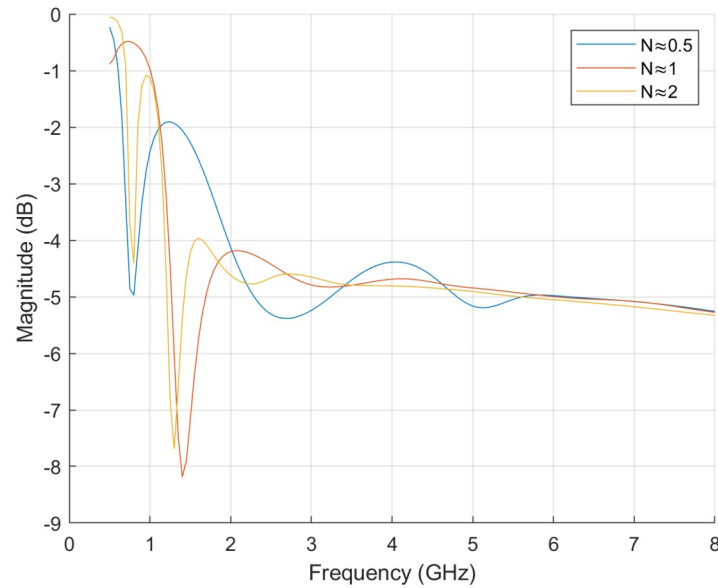
S₁₁ parameter: Again, the input voltage reflection coefficient showed better results as the number of turns was higher. The curve became stable at a faster rate.
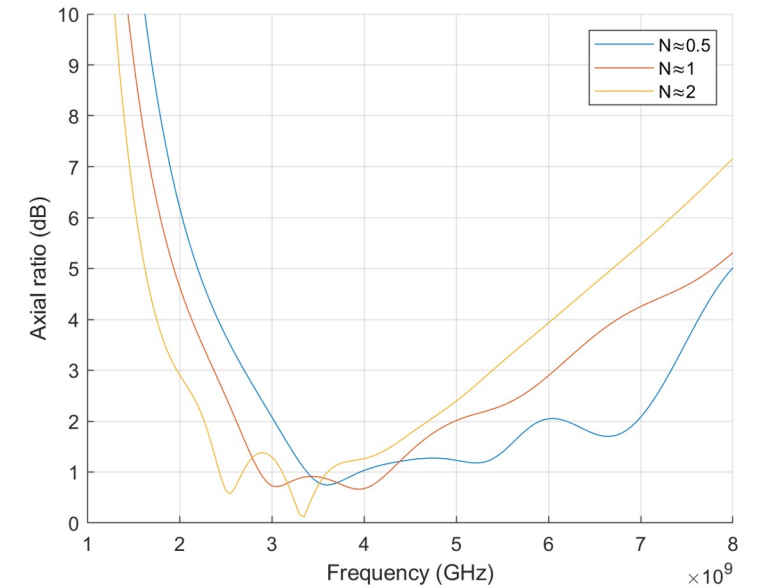
Axial ratio: While plot with two turns reaches the 2dB mark faster than the others, it was the 0.5 turns one that showed a higher bandwidth of circular polarization, going from 2.5GHz to 4GHz, a significant variation.

Optimization

The growth rate parameter was then optimized to obtain the highest possible gain using the built-in MATLAB Antenna Toolbox.
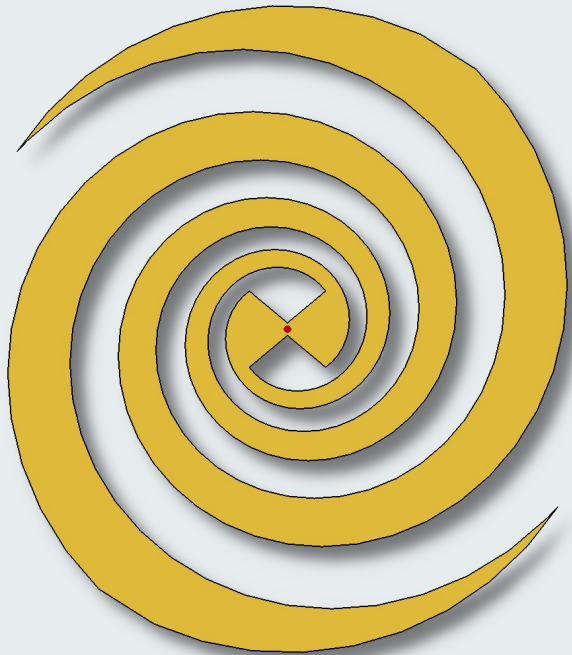
The parameter was iterated 100 times around the values of 0.1 and 1. After a short while, the optimization tool obtained an optimal value for the growth rate of 0.16, which produced a gain of 5.7dBi at the center frequency (3.5GHz). This result was used in the next section.

A manual for the usage of this tool is included in the memory of the project as an appendix.
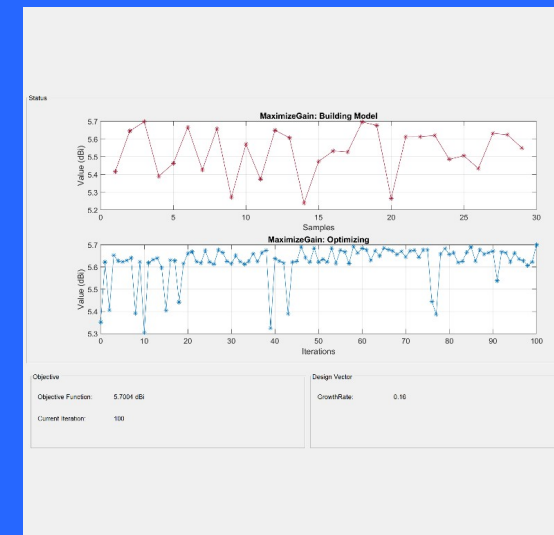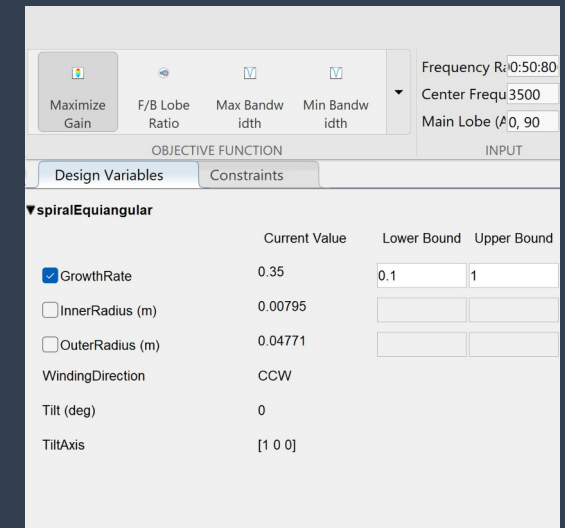
Fourth simulation set

An infinite PEC reflector plane element was added to the antenna to obtain a unidirectional radiation pattern. Its effect on the radiation was studied.

2D Radiation diagrams

Gain in the azimuth plane was exceedingly small, always below -34dBi, which is expected, as the reflector plane further concentrates the radiation perpendicularly to this plane.

The elevation plane diagram shows the desired unidirectional diagram with improved gains. However, the higher frequency (outside of the design limits) shows undesirable lobes.
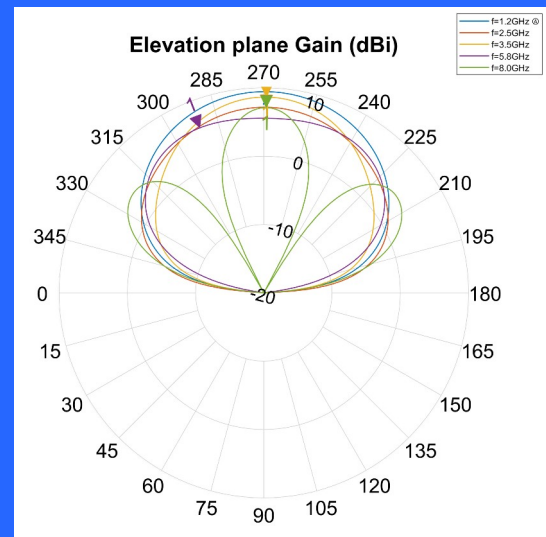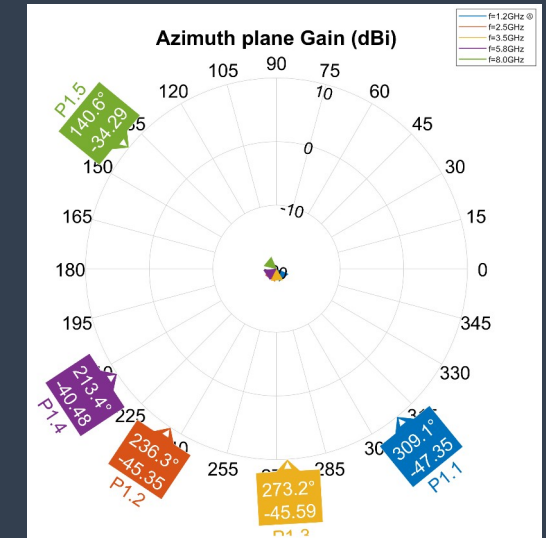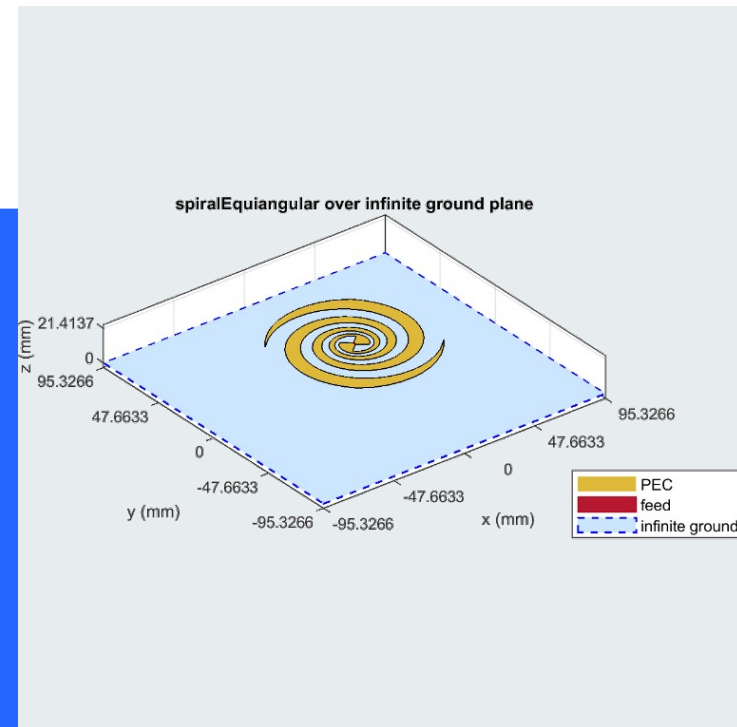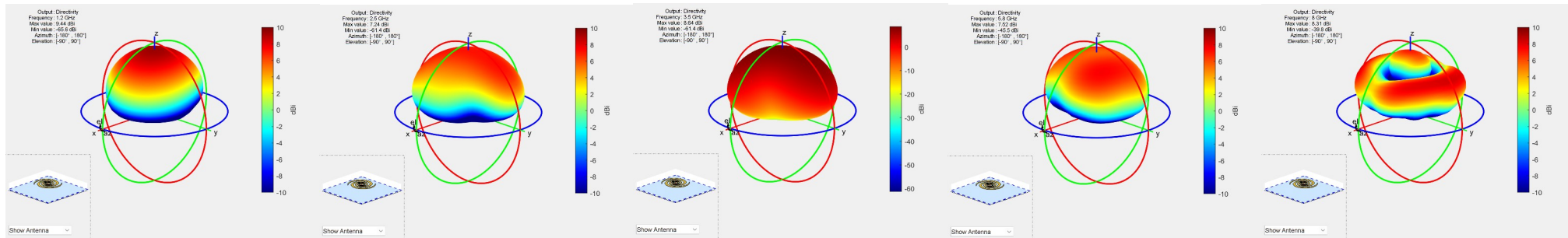
1.2 GHz   2.5 GHz   3.5 GHz   5.8 GHz   8 GHz

3D Radiation diagrams: The radiation diagram is consistent in the operating frequency range. However, the diagram from the highest frequency shows lobes, making it perform worse.
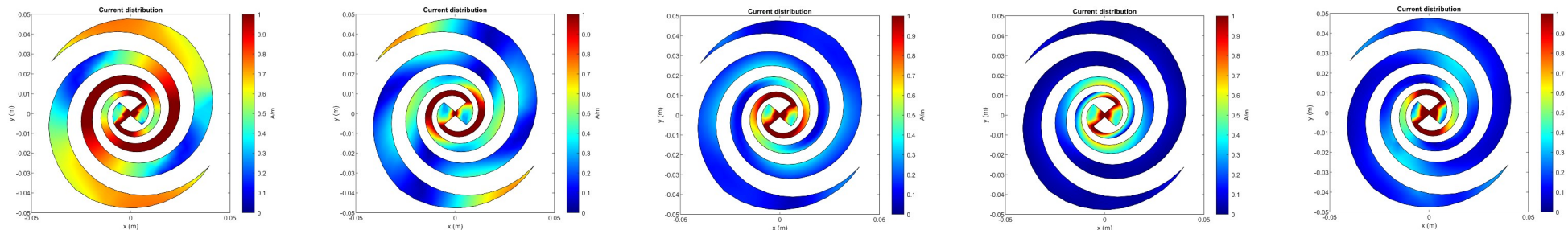
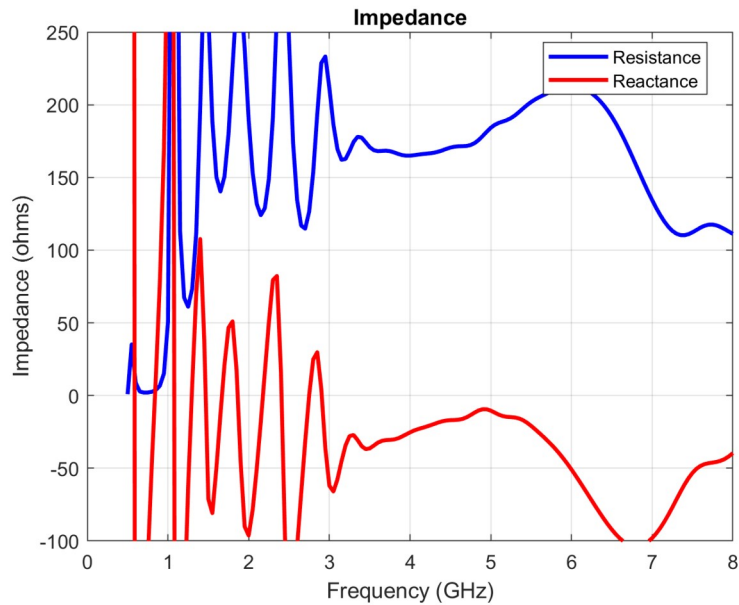1.2 GHz   2.5 GHz   3.5 GHz   5.8 GHz   8 GHz

Surface currents distribution: The reflector caused high current densities around the arms in the lower frequencies. This means that the antenna is not behaving as a self-scaling structure.

Input impedance: The lower frequencies display an erratic behavior, with many oscillations. The only relatively stable frequencies are found in the 3-6GHz range. This is consistent with the surface currents results.
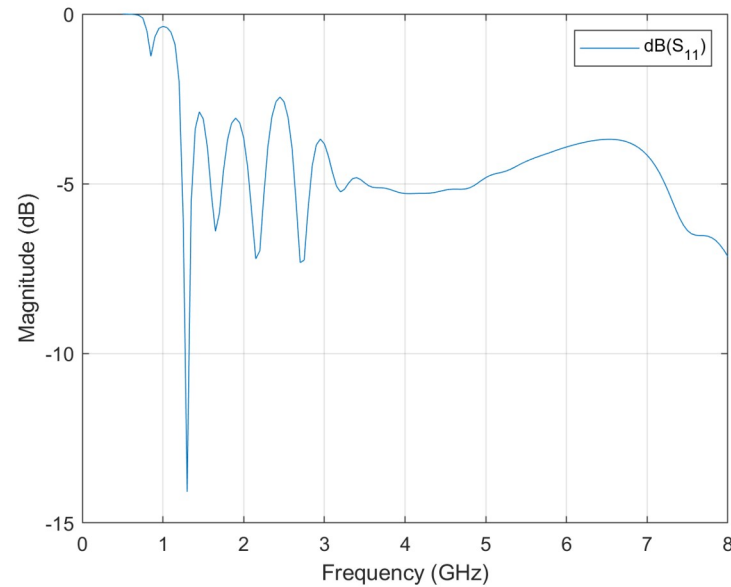
S₁₁ parameter: The system shows good impedance matching past the 3GHz mark, near -5dB. Before that, the oscillations make it extremely unstable.
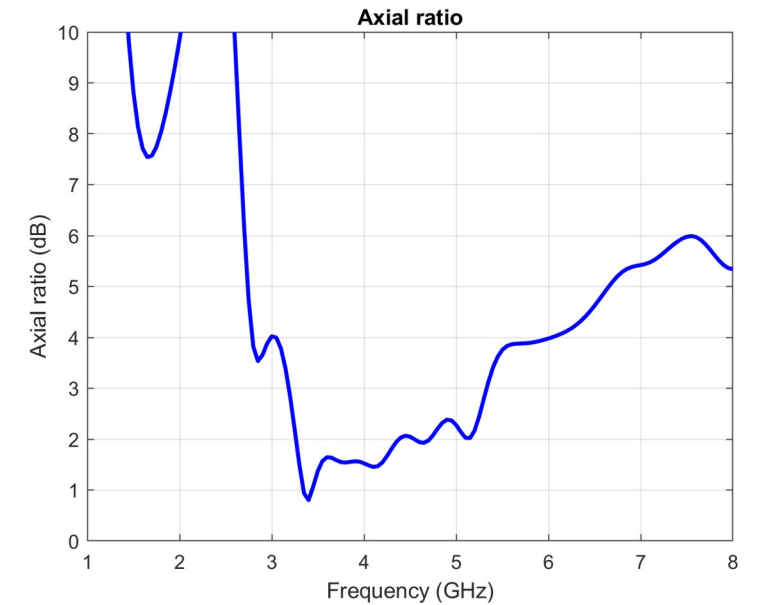
Axial ratio: The circular polarization range, where the axial ratio keeps below 2dB is also reduced with the use of the reflector plane. Now, it is seen only consistently around 3.2GHz to about 4.8GHz.

3.

Conclusion and proposed future research

___

What have we learned.

Conclusion

Conclusion 1

Equiangular spiral antennas are frequency independent.

- They show very good stability in all parameters.

- Its characteristics can be easily adjusted.

- Other types of spiral antennas do not work as well in any sense.

Conclusion 2

Reflector planes can be used to obtain unidirectional radiation.

- The radiation diagrams maintained their behavior.

- The antenna bandwidth is reduced with its use.

- The gain greatly improves.

Conclusion 3

MATLAB is a viable option to simulate spiral antennas.

- It allows simulations to be performed using both code and a graphical interface.

- It generates results both in graphical form and in data tables.

- Allows parametric optimizations to be performed.

Future research

Some proposed future research topics include:

- Feasibility and sustainability studies for the use of equiangular spiral antennas in integrated applications.

- Exploration of the use of other geometries for frequency-independent antenna design.

- Continue the work developed by the authors cited in this paper in areas of research and development to create improvements to spiral antennas.

Thank you.

Questions?