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Parametric analysis of a broadband Archimedean spiral antenna with cavity

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Abstract

In this article an Archimedean spiral antenna is designed and analyzed that has good operation in broadband application. By analyzing this design, the effects that different parameters have on antenna operation will be studied and ways of optimization will be found. Influences of cavity height and number of turns to obtain good matching and gain in a frequency interval of 4 to 18 GHz will be discussed. In addition, using cavity wall around the antenna, side lobes are decreased or deleted. By tapering the arms at feeding center, better matching will be attained. For making S_{11} bandwidth better, increasing the cavity height or reducing the number of turns can be used. Changing number of turns does not have a significant effect on the gain. To improve the antenna gain, the cavity height needs to be adjusted such that the reflected wave from cavity and radiated wave from spiral arms are constructing.

Keywords: Archimedean spiral antenna, cavity, broadband antenna, gain, babinet principle

1. Introduction

The ever increasing demand for broadband military communication, satellite communication services and antenna arrays require enhanced performance from antennas. The Archimedean spiral antenna is a suitable candidate for the above mentioned applications because of its performance characteristics such as broadband width, high gain, wide beam width and circular polarization [1].Therefore, in order to achieve an optimized performance of spiral antenna; a parametric study of spiral is developed. The performances of the spiral antenna due to the wire feeding and size (radius) to the radiation pattern have been analyzed before in [2, 3].in [4] effects of change in inner radius, arm width and distance between arms have been analyzed, too but other parameters don't have been analyzed. However, this paper investigates parametric study of two arm Archimedean spiral antenna parameters including cavity height and number of arm turns and their effect on gain and S_{11}. The radian sphere is a hypothetical sphere whose diameter $2r$ is equal to the largest linear dimension ($r = \lambda/2\pi$), of the antenna that it encloses [5]. This is very important so the antenna provides the optimum performance on the other hand small enough to any mobile applications. If the electrical size is less than one wavelength ($r \leq \lambda/2\pi$), the antenna is categorized as an electrically small [5] which exhibits low radiation resistance, high reactance, low efficiency and narrow bandwidth. In some cases, the performance of the antenna can be further improved if the size is larger than one wavelength ($r > \lambda/2\pi$). Therefore, having known these limitations, a parametric study based on the radiansphere technique is performed so a proper optimization on the antenna performance versus the electrical size can be carried out suitable for UWB applications.

2. Geometric antenna design

One of the important spiral antenna, is Archimedean. Although Archimedean spiral is a broadband antenna, it should be considered like a quasi-frequency independent antenna since, from the geometric perspective, it cannot be defined and specified by just using angles. So, due to its high similarity to frequency independent antenna in specifications and form, Archimedeans can be categorized in this group. Bandwidth for Archimedean spiral antenna in this article is from 4 to 18 GHz.

The Design of proposal antenna is shown in figure.1. As we see in figure.1 this antenna is formed with two arms and cavity. Conductor walls around the antenna are placed in order to decrease or delete side lobes. The Feeding of this antenna is embedded in between of two arms.

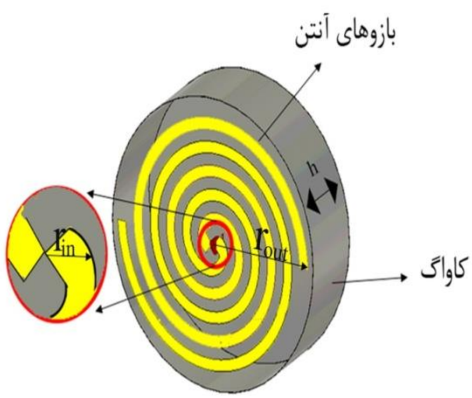

Figure.1 - antenna design and tapering at feed center

According to babinet principle, since the antenna is designed as self-complementary, impedance will be calculated as below:

$$Z_{air} Z_{ant} = \frac{\eta^2}{4} \quad (1)$$

Z_{ar} is the specification impedance of antenna complementary and Z_{ant} is antenna input impedance. Shape of complementary antenna is the same as the shape of original antenna. So input impedance is equal to complementary impedance. Therefore we will have this:

$$Z_{in} = \frac{\eta_0}{2} = 188.5\Omega \quad (2)$$

Internal and external radius of spiral antennas respectively is calculated by maximum and minimum broadband such as below:

$$r_{in} = \frac{c}{2\pi f_{low} \sqrt{\varepsilon_{eff}}} \quad (3)$$

$$r_{out} = \frac{c}{2\pi f_{high} \sqrt{\varepsilon_{eff}}} \quad (4)$$

In the above equation C represents the speed of light, f_{low} minimum frequency, f_{high} maximum frequency, r_{in} internal radius, r_{out} external radius and ε_{eff} substrate effective permeability constant.

Width and distances between arms would be calculated by internal and external radius. Thickness of cavity and arms are taken so thin. To review each cavity height parameters and number of turns effects, separate antennas. Has been considered.

2.1. First antenna: Effects of change in number of turns

Structure of the first antenna is a spiral with two arms and feeding from center. Substrate in this antenna is air. Cavity height (*h*) is 3.9 mm, internal radius (r_{in}) is 1.7 mm, and external radius (r_{out}) is equal to 33.3 mm. change of turn numbers are from 1.5 to 6.5. In this case, by fixing the internal and external radiuses, turn number is changed.

2.2.Second antenna: effect of the change in cavity height

Also in this case, Structure of the second antenna is a spiral with two arms and feeding from center. Substrate in this antenna is air.

Number of turns is 2.5, internal radius (r_{in}) is 1.95 mm, and external radius (r_{out}) is equal to 33.3 mm. change of cavity height (h) is from 5 to 11 mm. in this case, by fixing the number of turns, other parameters are changed.

3. Simulation result:

Parametric review of Archimedean spiral antenna with two arms, is done by help of CST simulation software 2014. In this section at first the effect of change in number of turns on gain and S11 will be studied. Then, the effect of cavity height on mentioned feature will be discussed.

3.1. Effect of change in turn number on gain and S11:

A- First evaluation is related to the amount of S11 in term of turn number changes. The figure.2 shows that by increasing the number of turns, S11 bandwidth will be decreased.

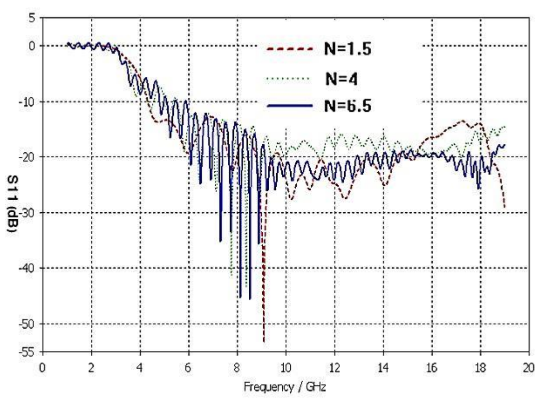

Figure.2- S11 in term of frequency for different turn number in first antenna

This occurs because of the changes in input impedance of antenna which is due to the change in turn numbers. According to the fact that internal and external radius are fixed, by changing the turn number, only arms width and arms distance will be altered. As a result, the input impedance will be altered, too. It means, with the changes that have been done, input impedance cannot be considered equal to 188.5 ohms.

B- Result of turn number change on gain are illustrated in figure.3. As this figure shows, after 4 GHz, increase or decrease of turn number, do not have remarkable effect of antenna gain.

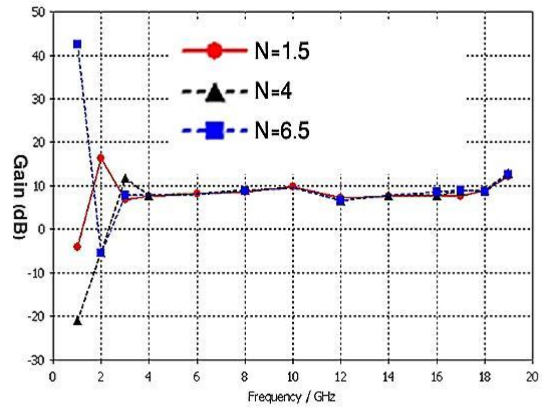

Figure.3- Gain in term of frequency for different turn number in first antenna

3.2. effect of change in cavity height on gain and S11:

A- First section of this part is about reviewing influences of changes in height on S11.by looking at the simulation result that is illustrated in figure.4, the effectiveness of height on S11can be concluded. By the increment in height, matching is improved which is due to direct effectiveness of cavity height on input impedance. As figure.4 shows, in lower frequencies that wavelength is longer, cavity height is more effective on input impedance. Consequently, as the frequency increases, wavelength will decrease and its effect on input impedance will decrease, too.

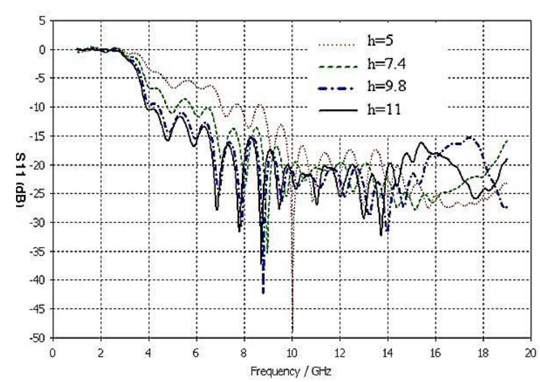

Figure.4- S11 in term of frequency for different cavity height in second antenna

B- Effect of changes in height on gain is illustrated in figure.5. By analyzing figure 5, it can be concluded that the effect of the changes in height depends on the reviewed frequency. By analyzing that whether the wave that reflected from cavity and the wave that radiated from spiral have constructive or destructive interference, we can find out that how big antenna gain on that frequency is. The more in-phase interference of waves reflected from the cavity and radiated from spiral, the higher gain in that frequency will be attained.

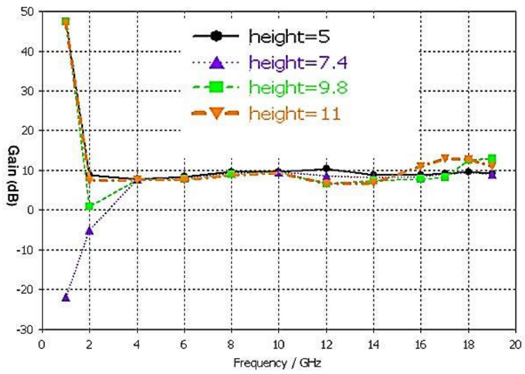

Figure.5-Gain in term of frequency for different cavity height in second antenna

According to figure.5, in 4 to 10 GHz interval the gain change is too low and in 10 to 18 GHz interval it has 2.5 dB changes. In figure.6, antenna radiation pattern in 10 GHz frequency can be seen.

4. Conclusion:

Parametric study of Archimedean spiral antenna with cavity was presented which can be used for spiral antenna optimizations. In the designs, cavity walls were used to reduce or delete side lobes of pattern and tapered arm at feeding center in order to attaining a better matching. From the results it can be concluded that the effect of height on S11 is more than the effect of turn number in antenna. For improving S11 bandwidth, the height can be increased or the turn number can be reduced. Changes in turn number do not have any significant effect on gain. To improve the antenna gain, the cavity height needs to be adjusted such that the reflected wave from cavity and radiated wave from spiral arms are constructing. Knowing the effect of changes in parameters on specifications of antenna radiation helps a lot in optimizing the antennas.

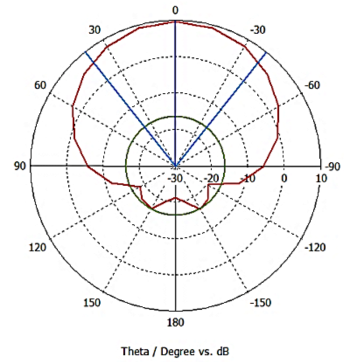

Figure.6- radiation pattern of antenna in 10 GHZ

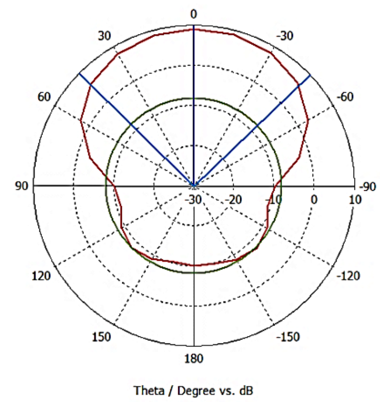

Figure.7- radiation pattern of antenna in 10 GHZ without cavity

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