The Geometry Effect of Regular Polygonal Wire on Its Inductance for Antenna Application

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Abstract. One important parameter of an antenna is its inductance. Inductance is the nature of a conductor which is related to its magnetic characteristics when alternating electric current is flowed. There are several factors that affect the inductance of a conductor wire, such as the size (dimension of the wire), the geometric shape of the wire, the permeability of material around the wire, and others. In this paper, we will discuss the effect of wire geometry on the value of the wire inductance. The wire diameter of regular polygonal wire is very thin. In determining the inductance of regular polygonal wire, some restrictions do for simplification in the calculation. Some of these restrictions are (1) the length of wire or circumferential polygon is fixed, (2) the diameter of the wire is considered very thin, (3) the distribution of the magnetic field is considered homogeneous, (4) the effect of external magnetic fields on the wire ignored. The results of calculations and analysis show that the change in geometry of regular polygonal wire from rectangular wire to decagonal wire causes the wire's inductance value to increase.

1. Introduction
Nowadays communication and information are becoming the main needs of modern society. Wireless technology is closely related to communication technologies and information and continuously developed. The need for wireless technology is increasing, due to the increasing need for communication and data transmission [1, 2]. One of the main components in wireless technology is the antenna. Antenna acts as a component of sending and receiving signals or electronic data. Antennas must be more reliable in performance so that communication and data transmission can run smoothly and quickly [3, 4].

Reliable antenna characteristics will be obtained if the design and manufacturing process is done very well. The purpose of making an antenna design is to obtain an antenna characteristic such as gain, bandwidth, range, return loss of certain value [5, 6]. These characteristics can be obtained by adjusting or engineering various antenna design parameters such as antenna material, antenna structure and antenna geometry. Another important characteristic of antennas is the large antenna inductance. This characteristic is important because it determines the working frequency and bandwidth of the antenna [7, 8].

In this paper, an approach model will be discussed to calculate the inductance of a regular polygonal wire. This calculation model is important to be developed because it will be useful in the process of designing an antenna in the form of a looping wire. Using this calculation model, an inductance calculation of polygonal wire is carried out starting from the rectangular wire to the decagonal wire.
2. Method

2.1. Calculation Model Approach
In the calculation model for determining the inductance of regular polygonal wire, some restrictions are made for simplification in the calculation. Some of these restrictions are
(1) The length of the wire or the circumference polygon is fixed
(2) Wire diameter is considered very thin
(3) The distribution of magnetic fields is considered homogeneous
(4) The effect of the external magnetic field on the wire is negligible

2.2. Research Object of Polygonal Wire
In this research, the calculation of the inductance of regular polygonal wire has been carried out from the rectangular wire to the decagonal wire or there are seven types of wires. In Figure 1 only three of the seven geometric shapes of the polygonal wire are shown. The three geometric shapes of the wire are the rectangular wire, the heptagonal wire and the decagonal wire.

![Figure 1. The shape of a regular polygon wire: (a) rectangular, (b) heptagon, and (c) decagon](image)

Wire length or circumference of polygons used in the study is 10 cm. The diameter is considered to be very thin so that its influence can be ignored in the calculation of inductance. The distribution of the magnetic field is assumed to be homogeneous and the magnitude is equal to the magnitude of the magnetic field at the centre of polygon. The wire is in the air medium and the external magnetic field in the wire is not considered or ignored.

2.3. Computer Program for Inductance Model Calculation
In this research, the calculation of wire inductance is mostly done using a computer program. Algorithms and formulas in this computer program are based on the basic theory of electricity and magnetism in the regular polygonal wire model. In this computer program, the number of sides (n) as the program input. A set of values of many parameters form will be a set of inputs in the program. While the output from the program is the inductance (L) of the polygonal wire. The sequence of steps to be used in the inductance calculation model program is as follows
(1) Enter the number of polygon sides (n) as the program input
(2) Convert a polygonal wire geometric shapes into a number of parameter values as program input
(3) Calculated wire inductance value based on the basic theory of electricity and magnetism using the magnetic field homogeneous approach to the entire area of the polygonal wire
(4) Saving data of wire inductance (L) as a result of program output

Mathematically, a computer program of this polygonal wire inductance calculation models can be expressed as a function:

\[ L = f(n) \]  

(1)
With

\[ f(n) = \frac{\mu_0 ns}{4\pi} \sin\left(\frac{\pi}{n}\right) \]  \hspace{1cm} (2)

\( n = \) number of polygonal wire sides  
\( s = \) circumference of polygonal wire = 10 cm  
\( \mu_0 = \) permeability of a vacuum or air medium  
\( L = \) inductance of polygonal wire in µH

The theoretical calculation results using this method of inductance calculation of the wire can be compared with the experimental data (simulation results and measurement results). Experimental data, both simulation results data and measurement data directly on the wire have been obtained in previous studies. This comparison is carried out to measure the reliability of the polygonal wire inductance calculation model.

3. Results and Discussion

3.1. The Data from Calculation Result

Wire inductance value of the polygonal wire from the rectangular wire to the decagonal wire is shown in Table 1 below.

| Number of sides | Inductance (µH) |
|-----------------|-----------------|
| 4               | 2.8284          |
| 5               | 2.9389          |
| 6               | 3.0000          |
| 7               | 3.0372          |
| 8               | 3.0615          |
| 9               | 3.0782          |
| 10              | 3.0902          |

From Table 1, it can be seen that the regular rectangular wire has an inductance of 2.8284 µH and the regular decagonal wire has an inductance of 3.0902 µH. It has a higher inductance than the rectangular wire. Based on the data in the table, we can make inductance graphs of the polygonal wire from the rectangular wire to the decagonal wire. The shape of the wire inductance graph with respect to the number of sides of the wire as shown in Figure 2.
3.2. Discussion
The calculation result of polygonal wire inductance is shown in Table 1 and visualized in Figure 2 shows that the greater number of polygonal wire side, the wire inductance value will increase. Based on the inductance calculation model used in the study, there are two major factors that determine polygonal wire inductance, namely
(1) Magnetic fields magnitude arising at a central point polygon.
(2) The area of loop polygonal wire.
The stronger the magnetic field arising at the center of the polygon will lead to the greater inductance of the polygonal wire. The wider the area of loop polygonal wire will cause the greater the wire inductance.

The strength of the magnetic field at the centre of the polygonal wire depends on how much distance each side of the wire to the centre point of wire loop. The farther this distance will cause the smaller the magnetic field strength. On a rectangular wire, the distance of its sides to the centre of the rectangle is the closest compared to other polygons. On the decagon wire, the distance of the sides to the centre of the decagon is the farthest compared to the other polygons in this study. This means that the magnetic field strength at the centre of the polygon is the factor that contributes positively to the inductance. These results are shown in Table 1 and the graph in Figure 2.

The opposite occurs in the second factor, which is the loop area of the regular polygonal wire. The farther the distance to each side of the wire to the centre point of the polygonal wire will lead to the greater the loop area of the polygonal wire. In rectangular wire, the distance of its sides to the loop centre of the rectangle is the closest, so that the area of the rectangular wire is the smallest. In decagonal wire, the distance of its sides to the centre of the decagon is the farthest, so that the loop area of the decagonal wire is the largest. This means that the greater number of polygon sides will cause the wider polygon. Based on this, it means that the area of the polygon is the factor that contributes negatively to the inductance. These results are shown in Table 1 and the graph in Figure 2.

4. Conclusion and Recommendation
The result of calculation using the inductance model calculation in this study shows that change in the geometry of the polygonal wire from the rectangular wire into the decagonal wire cause an increase in inductance value of the regular polygonal wire.
To measure the reliability of the polygonal wire inductance calculation model, it is necessary to compare the theoretical calculation result data with the experimental result data, both the simulation result data and the measurement result data directly on the regular polygonal wire.

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