Analysis of Diameter Changes Effect on Radiation Element to Improve Characteristics of Fullwave Loop Antenna

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Abstract. The article explained about the analysis of effect changes the diameter of radiating elements to the improvement of antenna characteristics. The antenna radiating element studied was solid copper wire and the type of antenna observed was an antenna that had a circular contour called the Full Wave Loop antenna. This antenna is used for digital television broadcast receiver applications and has a circle radius of 16 cm. Improved antenna characteristics were analyzed for 3 types of radiation element diameter, namely; 3.5 mm; 2.5 mm and 2.0 mm. The Antennas were operated in a working frequency of 586 MHz, which is for digital television receiver broadcast channels. Based on the test data on the 3 diameter antenna elements and calculation analysis, it is known that the improvement is characteristics VSWR occurs in the radiation element with 2.0 mm diameter, the VSWR value is 1.93, return loss is 7.6 dB, antenna impedance is 97 Ω, gain of 12.88 dBi and antenna bandwidth of 7.17% and gain of 12.86 dBi, while the antenna characteristics of the radiating elements that are 2.5 mm and 3.5 mm larger are worse, among others; for VSWR 2.7 and 3.63. Return loss is -6.9 dB and 4.9 dB. Antenna impedance was 135 Ω and 175 Ω. The antenna gain was 8.78 dBi and 7.1 dBi. The smaller the diameter of the radiating element in the Full Wave Loop antenna will improve the characteristics of VSWR, Return loss, input impedance, gain. On the other hand, the smaller the radiation element will reduce the antenna bandwidth, so it is necessary to look for other methods to improve bandwidth capacity without changing the four characteristics of the good antenna. Likewise, the equation for determining the physical size of the radiating element is re-defined.

1. Introduction

The Radiation elements on the antenna function send electromagnetic wave energy to the atmosphere. Full Wave Loop antenna is an antenna that has a circle contour. This antenna has an element of radiation with elements of radiation from hollow material, this antenna has characteristic such as 30% bandwidth, gain 3.14 dBi, impedance of 135 ohms and VSWR 2.0 [1].

Improving the characteristics of an antenna can be done in several ways, including; through the selection of antenna radiation element materials, Improvement of antenna characteristics by selecting antenna radiation element materials, secondly choosing antenna reflector element material, there are three reflective materials that are tested to test the improvement of antenna efficiency, namely;
material from aluminum, iron plate and copper. The results found that the copper material had an efficiency of 64.5% compared to two other materials [2].

In a study entitled Effects of Antenna Material on the Performance of UHF RFID Tags, We also found that deposited copper was highly conductive, about 86% that of bulk copper. This superior conductivity allows copper antennas to be considerably thinner. Our results show that for the thin deposited copper with narrow line widths (0.25 and 0.5 mm), that the thinner copper was always superior to thicker silver ink [3].

Another research is Performance of a Small Loop Antenna in the 3-10 MHz Bandwidth. Research has observed changes in the working frequency of loop antennas to the characteristics of bandwidth. The Chu bandwidth limit for an antenna of 1 m diameter indicates a theoretical maximum bandwidth of 0.19 kHz at 3.6 MHz, rising to 12 kHz at 10.1 MHz. Since Chu’s theory assumes arbitrary antennas of 100% radiation efficiency, the Chu limit should perhaps more properly be described as a bandwidth•efficiency limit. The present loop measurements give a calculated bandwidth-efficiency product of 0.028 kHz at 3.6 MHz and 2.6 kHz at 10.1 MHz [4][5][6].

In this paper, the results of the study will explain the effect of changes in the diameter of the radiating element on the characteristics of full wave Loop antennas. The analysis improvement characteristic improvement, includes 3 parameters, among others, impedance, bandwidth and gain. Is there a relationship between changes in the diameter of the radiating element and the improvement of these characteristics? This interesting problem is explained in the next section. There are 3 types of antenna diameters made for characteristic observations in this study, the 3 diameters are 3.5 mm, 2.5 mm and 2.0 mm. Research activities were carried out at the antenna laboratory and propagation of the Telecommunication Study Program Politeknik Negeri Lhokseumawe.

2. Another section of your paper

This section explains in detail about the research conducted. Obviously, it can be seen in figure 1. The figure shows that the antenna under study is the Full Wave Loop antenna, this antenna is designed for applications to receive digital TV broadcast wave signals indoor.

![Figure 1](image)

**Figure 1.** Description of research methodology

The main goal of the study is to explain the effect of changes in the diameter of the antenna radiating element on the improving of the characteristics of the antenna. Observation of improving characteristics of the Full Wave Loop antenna is done by varying the diameter of the radiating antenna element, which is denoted d, while the radius of circle D is fixed, seen in equations (1) and (2) and figure 2.
In this study, antenna radiating elements using solid conductor material from copper, not from a split conductor material like the origin. In the following description, the reference is used to review design physical dimension of Full Wave Loop and study the characteristics of the antenna. as for the 3 antennas referred to, shown in figure 2.

2.1. Physical dimension of antenna
Full Wave Loop antenna is a full circle antenna as shown in figure 3. In the figure 3 shows the physical dimensions of the antenna full wave loop. There are two parts to the physical dimension of the antenna, namely; radius of circle D (mm) and diameter of the radiating element d (mm).

Both physical measurements can be calculated using equation (1) and equation (2). n Where \( \lambda \) is the wavelength (m), \( \pi \) is the valuable Constanta is 3.14.

\[
D = \frac{\lambda}{\pi}
\]

and

\[
d = \frac{D}{2}
\]

2.2. Antenna characteristic f
In this sub-chapter, some reference reviews are explained about the main characteristics of an antenna. The full review is given below.
2.2.1. Voltage standing wave ratio

VSWR is defined as the ratio between the maximum voltage (Emax) and minimum voltage (Emin) along the transmission line. VSWR can be calculated using equation (3). If the antenna is suitable, meaning that the antenna impedance is equal to the impedance of the transmission line, then all the energy that reaches the antenna will be radiated to the free space. However, if both are not suitable, the antenna will not receive all the energy from the transmission line. The portion of power not received by the antenna will be reflected back towards the source or sender. This will form a wave pattern along the transmission line called the voltage standing wave ratio, VSWR.

\[
VSWR = \frac{E_{\text{max}}}{E_{\text{min}}} \quad (3)
\]

or calculated using the equation (4)

\[
VSWR = \frac{1+\Gamma}{1-\Gamma} \quad (4)
\]

where \(\Gamma\) is the magnitude of the reflection coefficient, its value can be calculated using the equation 5.

\[
\Gamma = \frac{V_r}{V_i} = \frac{Z_l - Z_o}{Z_l + Z_o} \quad (5)
\]

2.2.2. Return Loss

It is defined as the event of the loss of transmitted power from the sender to the channel and antenna. The best return loss value can be seen from the smallest value. Return loss is the difference between forward and reflected power, in dB, generally measured at the input to the coaxial cable connected to the antenna. If the power transmitted by the source is \(P_T\) and the power reflected back is \(P_R\), then the return loss is given by \(P_R\) divided by \(P_T\). For maximum power transfer the return loss should be as small as possible. This means that the ratio \(P_R/P_T\) should be as small as possible, or expressed in dB, the return loss should be as large a negative number as possible. For example, a return loss of -40 dB is better than one of -20 dB [7]. This Return Loss, RL is determined in dB as equation follows (6).

\[
RL = -20 \log \left[ \frac{\Gamma}{1} \right] \quad (6)
\]

while,

\[
\left| \frac{P_R}{P_T} \right| = \frac{\left( Z_L - Z_o \right)}{\left( Z_L + Z_o \right)} \quad (7)
\]

Where, \(Z_L\), \(Z_o\) is load impedance or input impedance, \(Z_o\) characteristic Impedance.

2.2.3. Bandwidth antenna

The bandwidth is the antenna operating frequency band within which the antenna performs as desired. The bandwidth could be related to the antenna matching band if its radiation patterns do not change within this band. In fact, this is the case for small antennas where a fundamental limit relates bandwidth, size, and efficiency. The bandwidth of other antennas might be affected by the radiation pattern’s characteristics, and the radiation characteristics might change although the matching of the antenna is acceptable. We can define antenna bandwidth in several ways [8]. Ratio bandwidth (BWr) is.

\[
BWr = \frac{f_u}{f_l} \quad (7)
\]

where \(f_u\) and \(f_l\) are the upper and lower frequency of the band, respectively. The other definition is the percentage bandwidth (WB\(_r\)) and is related to the ratio bandwidth as.

\[
%\text{BW}_r = 200 \times \frac{f_u - f_l}{f_u + f_l} \quad (8)
\]
Or
\[
\% \text{BW}_r = 200. \frac{W_r - 1}{W_r + 1}
\]  

(9)

2.2.4. Antenna impedance
As electromagnetic waves travel through the different parts of the antenna system, from the source to the feed line to the antenna and finally to free space, they may encounter differences in impedance at each interface. The frequency response of an antenna at its port is defined as input impedance (Zin). The input impedance is the ratio between the voltage and currents at the antenna port. Input impedance is a complex quantity that varies with frequency as

\[
\text{Zin}(f) = \text{Rin}(f) + j\text{Xin}(f),
\]

(10)

where \( f \) is the frequency. The antenna’s input impedance can be represented as a circuit element in the system’s microwave circuit. The antenna can be represented by an equivalent circuit of several lumped elements, as shown in figure 4, from the picture it can be explained that the equivalent circuit of the antenna is connected to a source, Vs, with internal impedance \( Z_s \),as.

\[
Z_s = R_s + jX_s.
\]

(11)

The antenna has an input impedance \( Z_{in} \) of.

\[
Z_{in} = R_a + jX_a.
\]

(12)

The real part consists of the radiation resistance (\( R_r \)) and the antenna losses (\( R_l \)).

![Figure 4. Equivalent circuit of an antenna](image)

2.2.5. Antenna gain
Antenna gain is defined as the antenna's ability to deliver maximum power to the air, gain can be calculated by the equation (13).

\[
\text{Gain} = [E_1 - E_2] + 2,15
\]

(13)

Where \( E_1 \) is the measured power on the Device Under Test (DUT) antenna (dB) and \( E_2 \) is the standard antenna power (dB). antenna gain can also be calculated from the measurement results with the following equation 14.

\[
G_{\text{eff}}(dB) + G_{\text{an}}(dB) = 20 \log \left( \frac{4\pi R}{\lambda} \right) + 10 \log \left( \frac{P_R}{P_I} \right)
\]

(14)
Where, $G_{at}$ is absolute gain of the transmitter antenna (dB), $G_{ar}$ is absolute gain of the receiver antenna (dB), $\lambda$ is wavelength antenna (m), $P_T$ is measured power on the transmitter and $P_R$ is measured power at the receiver and $R$ is the minimum distance between the sending antenna and the receiving antenna (m). Antenna gain can also be calculated using substitution equations or combination equation method, such as equations (15), (16) and (17).

Antenna combination (1-2)

$$\frac{4\pi R}{\lambda} + 10 \log \left( \frac{P_R}{P_T} \right)$$

Antenna combination (1-3)

$$\frac{4\pi R}{\lambda} + 10 \log \left( \frac{P_R}{P_T} \right)$$

Antenna combination (2-3)

$$\frac{4\pi R}{\lambda} + 10 \log \left( \frac{P_R}{P_T} \right)$$

Where $P_{T1}$, $P_{T2}$, $P_{T3}$ is measured power on the transmitter first, second and third. $P_{R1}$, $P_{R2}$ and $P_{R3}$ is measured power on the receiver.

3. Experiment Results

In this paper, the experimental results explain the change in diameter of the radiating element in the antenna against the 4 main components of the antenna characteristics of Full Wave Loop. These four characteristics are VSWR, Return Loss, Presents Bandwidth, impedance and gain antenna. Briefly described below.

3.1. VSWR characteristics

Voltage Standing Wave Ratio (VSWR) is the ratio between the maximum amplitude and minimum amplitude along the transmission line, the VSWR value is also affected by the antenna input impedance. For VSWR we need a device that can measure the amount of voltage or power that travels from the source along the channel to the antenna and from the antenna to the next transmission line back to the source, the equipment is called base test station, BTS.

Measurements are carried out mechanism as follows, the antenna operates at a frequency of 2 86 MHz, the antenna is connected to BTS equipment via a 50 U RG transmission line coaxial cable. BTS is setup to measure VSWR, the test results on the three antennas is shown in table 1.

| Frequency (MHz) | Variations diameter (d) (mm) | VSWR    |
|----------------|------------------------------|---------|
| 586            | 3.5                          | 3.63    |
| 586            | 2.5                          | 2.70    |
| 586            | 2                            | 1.93    |
It is known that at a diameter of 3.5 mm, 2.5 mm and 2.0 mm each has a VSWR of 3.63; 2.70 and 2.43. From these results, it is known that the improving of VSWR characteristics occurs in the antenna that has a diameter of 2.0 radiating elements with a VSWR value of 2.43. For larger diameters, the VSWR gets bigger. From these results it is known that the improvement of VSWR characteristics occurs in the antenna that has a diameter of the radiating element of 2.0 mm with a VSWR value of 1.93; for radiating elements with a larger diameter, that is, 2.5 mm, 3.5 mm, the characteristics of VSWR are greater, the values are 2.7 and 3.63 respectively, or in other words the antenna that has the diameter of the radiating element d which gets bigger will have the characteristics of the increasingly poor VSWR, more details can see on the figure 5.

3.2. Return loss characteristic

In this study, the setup of the return loss test was doing the same as the VSWR characteristic measurement. Antenna working frequency is 586 MHz, BTS is setting with the aim of measuring the returns loss value on the three antennas for different diameter variations, more details can be seen on the table 2. These results indicating that the smallest return loss, resulting in power losses due to the signal being transmitted back to the PT source from PR occurs in the antenna element with the smallest diameter antenna. Next details can be seen on the figure 6.

Table 2. results of return loss calculation in three different radiation element diameters

| Frequency (MHz) | Diameter radiating element (mm) | Return loss (dB) |
|-----------------|-------------------------------|-----------------|
| 586             | 3.5                           | -4.9            |
| 586             | 2.5                           | -6.8            |
| 586             | 2                             | -7.6            |
3.3. Percent bandwidth

One important characteristic of Full Wave Loop antennas is Bandwidth. The physical dimension of the antenna full wave loop is determined by 2 parameters, namely the diameter of the circle, D and the radius of the radiating element on the antenna d, as shown in Figure 3. In this study, it will be observed, weather changes in the diameter of the radiating element in the antenna will enlarge or reduce bandwidth capacity. The diameter of the antenna radiating element based on the calculation of equation (1) and (2) is 2.5 mm.

In this test, D is made constant and the diameter of the radiating element d in the antenna is chosen with a diameter of one level larger than that, which is 3.5 mm and one level lower below it, which is 2.0 mm. The results of mapping the bandwidth changes in the antenna are shown in table 3.

| Diameter | \( f_U \) | \( f_L \) | % Bw |
|----------|---------|---------|-------|
| 3,5      | 556     | 616     | 10,24 |
| 2,5      | 563,5   | 608,5   | 7,68  |
| 2        | 565     | 607     | 7,17  |

Figure 6. Graph of the effect of return loss changes on the change in size of the antenna element

Figure 7. Graph of the results of the calculation of the bandwidth of the three different radiation element diameters
On the base of calculation of the percentage of bandwidth on the antenna, it was found that the bandwidth of each antenna will increase as the diameter of the antenna radiating element increases. At 3.5 mm diameter antenna, the resulting bandwidth percentage is 10.24%, at a diameter of 2.5 mm the percentage of bandwidth is 7.68% and at 2.0 mm diameter the percentage of bandwidth is 7.17%. This mapping can be clearly seen in Figure 7.

3.4. Antenna impedance characteristic

The frequency response of the antenna at its port is defined as input impedance (Zin). The input impedance is the ratio between the voltages and currents at the antenna port. Input impedance is a complex quantity that varies with frequency. In other word, the antenna frequency response is defined as input impedance (Zin). By using equation 7, the antenna impedance is recognized as shown in table 4.

| Frequency (MHz) | the diameter of the radiating element (mm) | Zin (Ω) |
|----------------|------------------------------------------|--------|
| 586            | 3.5                                      | 175    |
| 586            | 2.5                                      | 135    |
| 586            | 2                                        | 97     |

From table 4, it is known that the use of a smaller diameter radiation element will result in a smaller impedance, that is, the greater the element's diameter, the greater input impedance characteristic of the antenna. This condition describes the mismatching between the characteristic impedance of the transmission line or the coaxial cable with the antenna input impedance. At a diameter of 3.5 mm radiating element, it has a 175 Ω, has input impedance, at a diameter of 2.5 mm of the radiating element, it has characteristic impedance of 135 Ω and at the diameter of the radiating element 2.0 mm, the antenna impedance is 97 Ω. Furthermore, how the effect of the change in diameter of the antenna radiation element to improve the antenna impedance characteristics can be seen in the explanation in figure 8.

3.5. Antenna gain characteristic

To calculate the gain, we use a combination method like the approach described in equations (15), (16) and (17). The Tx and Rx are set to distance 2 m, Tx and Rx antenna operate at 586 MHz, the
antenna and measuring device are connected to the coaxial cable transmission line RG 58U with a character impedance is 50 ohms. Furthermore, to calculate the gain, we need data from the measurement results of the transmit power of $P_T$ and the results of the power measurement receive $P_R$. The result of analytic expression, antenna gain measurement is presented in table 5.

| $d$ (mm) | $f$ (MHz) | $G_1+G_2$ (dB) | $G_1+G_3$ (dB) | $G_2+G_3$ (dB) | $G_{tot}$ (dBi) |
|----------|-----------|----------------|----------------|--------------|---------------|
| 3,5      | 586       | 15,9          | 16,6          | 18,3         | 7,1           |
| 2,5      | 586       | 17,01         | 18,77         | 18,21        | 8,78          |
| 2        | 586       | 27,41         | 22,92         | 24,6         | 12,86         |

From table 5, antenna gain has been evaluated. The antenna gain that has a radiated element in diameter of 3,5 mm is 7.1 dBi, the antenna gain that uses a radiation element in diameter of 2.5 mm is 8.78 dBi, while the antenna gain with a radiation element diameter of 2.0 mm is 12.86 dBi. This discussion can be seen clearly in figure 9.

![Figure 9. Compare this gain base on the diameter radiating element](image)

We compare this antenna gain based on the diameter of the radiation element used. Comparison of gain obtained from our analysis is shown in figure 9. 1. Thus, it can be said that the antenna's ability to deliver power to the air is very good when using radiating elements with a type of solid copper wire in a small diameter.

4. Conclusion
The effect of changing the diameter size of the smaller radiating elements in the Full Wave loop antenna will cause the characteristics of the antenna, such as; VSWR, return loss, input impedance, gain gets better. In diameter sizes of small radiating elements, such as at 2.0 mm diameter, the ratio of the voltage wave forward to reversed voltage wave is smaller, this occurs because characteristic input transmission line and characteristic input impedance of the antenna matching, so the four antenna characteristics are very significant reducing power losses returning to the transmitter. This does not apply to the larger diameter sizes of the radiating elements which are 2.5 mm and 3.5 mm.

Another part, the characteristics of the next antenna are Bandwidth. The effect of improvement on bandwidth occurs with a larger diameter size of the radiating element, for example from the test results and calculations for diameter sizes of 2.0 mm, 2.5 mm and 3.5 mm, each of which has a bandwidth percentage of 10.24%, 7.68% and 7.17%. This condition is contrary to the four characteristics described earlier. Increasing the diameter, will cause the worsening characteristics of VSWR, return loss, input impedance and antenna gain.
In the small size of the diameter of the radiating element, the bandwidth size is narrower compared to the diameter size of a large radiating element. Thus, if desired to enlarge the bandwidth, it is necessary to find another method, not by increasing the diameter of the antenna radiation element, because increasing the diameter size of the antenna radiating element will cause the VSWR characteristics, return loss, input impedance and antenna gain to get worse.

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