Multi-Layers Strip Dipole Antenna by Using Flexible Copper-Clad Laminate for UHF RFID Tags Antenna

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Abstract: This article presents the design of multi-layers strip dipole antenna by using flexible copper-clad laminate for UHF RFID tags antenna. The purpose of the paper is to design a flexible copper-clad laminate stacked; call Multi-Layers that suitable for curved on the cylindrical objects for UHF RFID system. The designed antenna will reduces the effect of curving based on relative changes in length on each layers. Caused by curving of the antenna is not the same for each layer of antenna, so result of an extended length will prove a resonance frequency of antenna and make it has better efficiency compares to modern antenna when it is curved or attached to cylindrical objects. The multi-layer strip dipole antenna is designed at 920 MHz for UHF RFID applications.

Key words: Multi-layers strip dipole antenna, Flexible copper-clad laminate, UHF RFID tags antenna.

INTRODUCTION

The current system of Radio Frequency Identification (RFID) has been used in many aspects of daily life including the logistic system, object tracking system, inventory management, human monitoring and electronic money (Finkenzeller, 2010). RFID is a very valuable technology tool that holds the promise of replacing existing identification technologies like the bar code because it can provide longer reading distance, fast reading speed, and large information storage capability. RFID systems consist of reader and tag. A reader broadcasts a radio signal in its wireless transmission range for queried information contained in tag. After that, the tag will reply with required information. The detection range and accuracy are directly dependent on the performance of reader / tag antennas. However, RFID tag antenna has a lot of different types and shapes applicable for various kinds of products. The tag antenna can be printed onto flexible substrates (or so-called inlays). The flexible substrates of the tag antenna have been affected by various distortions when applying with different packages with non-flat surface. This distortion in the structure will usually change the performance of the RFID tag antenna and the performance degradation in the RFID system especially when operating in very high frequencies.

In this article, we introduce a novel structure of copper clad laminate with dielectric substrate stacking on layer by layer that has more efficiency than single layer for UHF RFID tag antenna and suitable for RFID applications. However, the tag RFID is mostly used as strip dipole antenna (Chen, 2007; Dobkin, 2007). Practically, strip dipole antenna property and efficiency including resonance frequency will be changed depending on the surface of the object it is lying on, may be rough or curved surfaces (Svanda and Polivka, 2007).

The analysis of curving the RFID tag antenna models by using a multi-layer antenna will be discussed. The result of curving will change the resonance frequency of antenna. Multi-layer antenna will reduce the effect of curving based on relative changes in length on each layers. Caused by curving of the antenna is not the same for each layer of antenna. So, result of an extended length will prove a resonance frequency of antenna and better efficiency compares to modern antenna.

This paper is organized into three sections. The first section is an introduction of RFID as already mentioned above. The second section is a demonstration of the antenna structural design and discussion on single-layer strip dipole antenna and multi-layer strip dipole antenna. In simulation section, a reflection coefficient of curved antenna in various radiuses and difference type of antenna are presented by result of simulations. The last section is the conclusion of the paper.

Basic Concept of Multi-Layers Strip Dipole Antenna:

Basically, rectangular strip antenna can be classified into two main categories depending on their length-to-width ratio. An antenna with a narrow rectangular strip (typically strip width less than $0.05\lambda_0$) is called a microstrip dipole and a broad rectangular antenna is called microstrip patch.
Microstrip width has a minor effect on the resonant frequency and radiation pattern of antenna. A larger strip width increases the power radiated and thus decreases resonance resistance, increases bandwidth and increases radiation efficiency (Salonen and Rahmat-Samii, 2007). We can model a microstrip dipole antenna or we can call strip dipole antenna with required properties related to thin-wire dipole model.

![Fig. 1: Schematic of microstrip dipole antenna.](image1)

Microstrip dipole as shown in Fig. 1 can be designed for the lowest resonant frequency using transmission line model. Thus, and gap between each arm of antenna is too small compare to total length of antenna. However, The CST-Microwave Studio high frequency simulator is used as the simulation tool (CST-Microwave Studio, 2009). So, the final dimensions are optimizing by simulation results.

a) Single-layer straight  b) Single-layer curved  c) Double-layers straight  d) Double-layers curved

![Fig. 2: Schematic of copper strip dipole antenna.](image2)

Figures 2(a) and 2(b) present a structure of strip dipole antenna called single-layer strip dipole antenna. Single-layer strip dipole antenna can add more layer stack into a structure that called double-layers strip dipole antenna, as shown in Fig. 2(c) and 2(d). Each layer has the same length when it is straight but the inner layer will be little longer than outer layer because the radius of each layer is not the same when it is curved. So, we can implement this changeable characteristic for suitable tuning properties of antenna. Normally, when a strip dipole has more length, its resonance frequency will decrease as well (Garg, et al, 2001). On the other hand, if the length is shorter than the original, the resonance frequency will increase. So, we design a double-layer strip dipole antenna that uses this physical change to compensate curving of antenna. Normally, double-layer strip dipole antenna has been designed to have shorter outer layer than inner layer as shown in Fig.3 (Saetiaw, et al, 2011).

![Fig. 3: Double-layers strip dipole antenna schematic.](image3)

From Fig. 4, the Schematic created to demonstrate how we can calculate effective length of double-layer strip dipole antenna when it is straightened and curved as

\[ L_{\text{eff}} = 2(L_{11} + \Delta L_1 + T_1 + L_{22}) \]  \hspace{1cm} (1)

where \( L_{mn} \) is the length of strip on layer \( m \) section \( n \) and \( T_{mn} \) is thickness of strip on layer \( m \). From Eq. 1, the effective length (\( L_{\text{eff}} \)) of antenna is the same on left arm and right arm. However, \( \Delta L_1 \) is an expanded length on layer 1 that came from effect of difference curving on each layer will show as
\[
\Delta L_1 = T_1 \theta_1 = \frac{T L_{21}}{R_2}
\]  
(2)

where \( L_{21} = R \theta_1 \) and \( T \) equal to an antenna thickness on inner layer.

From Fig. 4(b), the length of section \( L_{11} \) was fixed by physical structure. So, it would make section \( L_{12} \) move away from center rather than section \( L_{22} \). This functioning affects on extension of length \( \Delta L_m \) occurred on layer \( m \). A positive sign of \( \Delta L_m \) in Eq. 1, the normal length has been extended.

In this paper, we used a flexible copper-clad laminate as raw material. It has many types of material that normally used in industrial. So, we selected model AP9121R that is one of commonly used (DuPont™, 2013). It has dielectric constant, dielectric thickness and copper clad thickness equal to 3.4, 0.051 millimeters and 35 micrometers (1 ounce per square foot), respectively.

However, it seems that flexible copper-clad laminate has a very small thickness to make a lot of extend length compare to double-layers strip dipole made from pure copper sheet when it curved. So, it is possible that we can stack it to make a multi-layer strip dipole antenna with this material that will make more thickness to a value that make a good response compares to an original design with double-layers. However, when it has a lot of layers, it makes a bit longer process to make an antenna. This means to a limitation of multi-layers which will be decided for how many layers for fabrication to be capable to perform with good economic value.

Figure 5 shows a single-layer of flexible copper-clad laminate strip antenna. However, if we stack a flexible copper-clad laminate more than two layers, we can call them in general term as a multi-layers strip dipole. So, a demonstrate diagram to calculate effective length of triple-layers strip dipole antennas shown in Fig. 6.

From Fig. 6, the schematic created to demonstrate how we can calculate effective length of triple-layers strip dipole antenna as

\[
L_{\text{eff}} = 2(L_{11} + \Delta L_1 + L_{12} + \Delta L_2 + T_2 + L_{22})
\]  
(3)

where

\[
\Delta L_1 = \frac{T L_{21}}{R_{C2}}
\]  
(4)

and
\[ \Delta L = \frac{T_c L_1}{R_{c3}} \]  

(5)

Fig. 6: Triple-layers strip dipole antenna schematic.

The thickness of each layer (T_i) can be calculated by total thickness of flexible copper-clad laminate that equals to thickness of copper layer (T_{CM}) plus thickness of dielectric substrate (T_{SM}) where M is number of layers. Otherwise, a radius of curved on each layer can be used as a radius of copper layer (R_{CM}). So, we can find out an extend length of each layer of triple-layers strip dipole antenna by Eq. 3 to Eq. 6. This triple-layers strip dipole antenna is used to demonstrate a multi-layer to compare with a single-layer. On the edge of each layer on the center side will be joined to another layer to make a physical contact on entire antenna. So, we implement this diagram to design the best performance of multi-layer strip dipole based on thin copper sheet with dielectric substrate.

**Simulation Results:**

Figure 6 shows a structure of the multi-layers strip dipole antenna simulated by using CST-Microwave Studio high frequency simulator. The antenna is laid on XY-plane and curve in XZ-plane. Some of antenna parameters affected the resonance frequency of the antenna. The comparable result found that only one parameter changed when the other was fixed. By the way, the strip width will mostly effect to frequency bandwidth (Garg, et al., 2001).

![Fig. 7](image)

Fig. 7: Resonance frequency of single-layer strip dipole antenna with difference width (mm.).

Typically, strip width less than 0.05\( \lambda \) for a strip dipole that is around 16.3 millimeters for center frequency at 920MHz. Figure 7 shows effects of strip width that make antenna bandwidth extend. So, a strip width is set to 10 millimeters for a proper size to use and has enough bandwidth to cover in UHF-RFID standard (850 – 960 MHz). The bandwidth of UHF-RFID standard in Thailand is 920-925 MHz (www.gs1.org, 2013). Otherwise, this design will not affect with the overlap length. If they are changed the overlap length vary from 5, 7.5, 10, 12.5 and 15 millimeters, respectively. The resonance frequency still the same at 920MHz as shown in simulation result in Fig. 8.
The total length of antenna used quarter wavelength equal to 81.25 millimeters. Flexible copper-clad laminate has copper layer 0.035 millimeters in thickness; the substrate thickness is 0.051 millimeters, the length of all section of all type is shown in Table 1, where antenna type is a single-layer strip dipole antenna and triple-layers strip dipole antenna.

The simulation result of using different curved radius is equal to a curving ratio multiplied by wavelength ($\lambda_c$) of center frequency. In this case, center frequency is 920MHz. So, a wavelength is equal to 325 millimeters that converts to actually curving radius as shown in Table 2.

![Figure 8: Resonance frequencies of triple-layer strip dipole antenna with difference overlap length (mm.).](image)

**Table 1:** The dimension parameters of multi-layer strip dipole antenna (Unit: millimeter(s)).

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Single-layer</th>
<th>Triple-layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>$T_{C_{1-C_3}}$</td>
<td>0.035</td>
<td>0.035</td>
</tr>
<tr>
<td>$T_{S_{1-S_3}}$</td>
<td>0.051</td>
<td>0.051</td>
</tr>
<tr>
<td>G</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$O_{1-2}$</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>$L_{11}$</td>
<td>71.25*</td>
<td>10.00</td>
</tr>
<tr>
<td>$L_{21}$</td>
<td>-</td>
<td>10.00</td>
</tr>
<tr>
<td>$L_{22}$</td>
<td>-</td>
<td>10.00</td>
</tr>
<tr>
<td>$L_{31}$</td>
<td>-</td>
<td>20.00</td>
</tr>
<tr>
<td>$L_{32}$</td>
<td>-</td>
<td>61.25*</td>
</tr>
</tbody>
</table>

*approximate from quarter wavelength at 920MHz

**Table 2:** Curving ratio and actual curving radius.

<table>
<thead>
<tr>
<th>Curving ratio</th>
<th>Actual curving radius* (mm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2$\lambda$</td>
<td>65</td>
</tr>
<tr>
<td>0.4$\lambda$</td>
<td>130</td>
</tr>
<tr>
<td>0.6$\lambda$</td>
<td>195</td>
</tr>
<tr>
<td>0.8$\lambda$</td>
<td>260</td>
</tr>
<tr>
<td>1.0$\lambda$</td>
<td>325</td>
</tr>
</tbody>
</table>

* $f_c = 920$ MHz, $\lambda = 325$ mm.

The radius of curve has been changed in order to observe the reflection coefficient (S11) and resonance frequency. The result of the simulation with different curving ratio of single-layer strip dipole antenna and multi-layers strip dipole antenna. The single-layer and triple-layers strip dipole antennas are shown in Fig. 9 and Fig. 10, respectively.

According to these results, it could be summarized that resonance frequency of antenna and curving ratio are more stability when we used more layers. For example, on single-layer strip dipole antenna, the resonance frequency has been changed from 920 MHz to 936.5 MHz when it curved. It resonance frequency has shift more than 16.5MHz. Then, the resonance frequency for triple-layers strip dipole antenna has been changed from 920 MHz to 929 MHz when it is curved with curved ratio 0.2 or 65 millimeters. It shows that the resonance frequency only change less than 9 MHz when it curved.
Conclusion:
This paper presents a novel design of multi-layer using flexible copper-clad laminate call multi-layer strip dipole antenna to improve the performance of bendable antenna suitable for RFID tags. The simulation of improvement achieved when the RFID tag antenna has curving characteristic. A design of antenna and effects of size on frequency (or the responded frequency of antenna) have been presented. The results of simulation will be implemented to design the appropriate and efficient antenna. According to the simulation, the multi-layer strip dipole antenna is more attractive than single-layer strip dipole antenna because it has higher stability of resonance frequency while curving. Resonance frequency decreasing is affected by curving. Increasing of resonance frequency for multi-layer strip dipole antenna is less than the single-layer strip dipole antenna with curved ratios equal to 0.2 wavelengths or 65 millimeters. Hence, the antenna has to be designed to match specific characteristics of object surfaces including material properties in order to improve RFID system performance.

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REFERENCES

CST-Microwave Studio, 2009.