Design and Simulation of Henna-based Composite Substrate for UHF-RFID Application on Dielectric Properties

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Abstract. This paper presented the effect of dielectric properties of henna-based composite towards the performance of the tag antenna for UHF-RFID application. The dielectric properties focused in this work were dielectric constant and loss tangent. Henna-based composite was developed with different amount of henna loading as the substrate for RFID passive tag. The design of antenna was optimized using CST Microwave software to achieve resonance frequency at 915 MHz. The output parameters from this work were reflection coefficient (dB), bandwidth (MHz), gain (dB), directivity (dBi), antenna efficiency (%) and voltage standing wave ratio (VSWR). In conclusion, dielectric properties of the substrate affect all the output parameters significantly except for directivity value.

1. Introduction

Radio-Frequency Identification (RFID) gain its attention across the world since 1990’s [1]. It is a system that can be used for item identifications, tracking activities and logistic purposes due to its flexibility, ready-ability and longer read range compared to barcode. RFID system is generally composed of three main components which are computer host, reader and tag. RFID tags can be divided into three categories based on type of their power supply which are active tag, semi-active tag and passive tag. As the reader send the electromagnetic wave to the passive tag, the antenna will inductively couple with IC chip, instruct the IC chip to reply its ID and the ID will be sent back to the reader via backscattering signal and finally, the data will be displayed in the computer host. The passive tag has become the most friendly-user because of its low cost, low maintenance and small in size since no battery is needed. Meanwhile, the performance of passive RFID tag depends on the properties of its antenna and substrate.

In RF application, the most popular commercial substrates are Rogers and FR-4. Rogers has a higher dielectric constant and remain stable although with higher frequencies and lower dissipation factor compared to FR-4. However, due to its expensive price, FR-4 is more affordable and commonly chosen for mass production. FR-4 is made from laminated epoxy with woven fiberglass sandwiched by copper sheet on both sides and has dielectric constant of 4.3. This rigid value of dielectric constant for FR-4 drives the researchers to look forward for flexibility by applying plant loading in the polymer during fabrication of substrate. The value of dielectric properties can be altered depending on the amount of plant loading since the plant contains higher weightage of carbon element.

The dielectric properties of the composite are depending on the polarization of the material [2] and amount of plant fiber loading [3]. This is due to interfacial and orientation polarization between filler (plant fiber) and matrix (polymers). As known, plant has permanent-polar molecule from the hydroxyl...
group which contributes to high hydrophilic characteristics while most of the polymers are non-polar [4]. Due to these circumstances, this will lead to interfacial and orientation polarization in the composite. The interfacial polarization occurred due to the difference of conductivity between two materials; the higher the differences of conductivity, the higher the interfacial polarization [5][6]. At the same time, orientation polarization occurred because of the existence of polar molecules in plant structure which is lignin, contributing to poor adhesion between filler and matrix [7]. Error! Reference source not found. shows the example of composite with different type of plants.

| Composites              | Weightage (%) | Frequency (Hz) | Dielectric Constant (e') |
|-------------------------|---------------|----------------|--------------------------|
| Jute/Bamboo/Polyester   | 15:15:70      | 3.0 – 6.0      | 3.50 – 5.50 [2]          |
| Sisal/Polyester         | 50:50         | 0.7 – 4.2      | 3.25 – 3.55 [5]          |
| Jute/Polypropylene      | 55.9:44.1     | 3.0 – 6.3      | 3.10 – 7.10 [4]          |
| Kenaf/Epoxy             | 14:86         | 12.4G – 16.4G  | 0.50 – 2.50 [6]          |

One of the methods to enhance adhesion between plant and polymer is chemical treatment such as sodium hydroxide (NaOH) or potassium permanganate (KMnO₄) [8][9]. The chemical treatment will help to remove the lignin structure from the plant and increase the roughness of the surface and will simultaneously reduce the hydrophilic nature of plant [10]. Reducing of OH⁻ in fibers will decrease the interfacial and orientation polarization occurred between fillers and composites. Thus, this work will discover the potential of henna-based composite for UHF-RFID application at 915 MHz with various value of dielectric constant and loss tangent.

2. Methodology

2.1. Preparation of Henna-based Composite Substrate
Henna particles were oven-dried, sieved and treated with sodium hydroxide solution for 12 hours with a ratio of 1:20. The size of henna particles was kept constant not exceeding 150 µm. Then, the treated henna particles were dried in the oven for 24 hours after had been washed by tap water for 3 times. Next, henna particles was mixed with epoxy polymer with different proportion before mixing with hardener for curing process. Finally, the mixture was poured in silicon mould for solidification process.

2.2. Dielectric Testing
The dielectric testing towards henna-based composite substrates was conducted using Agilent 85070 coaxial probe method based on ASTMB150 standard. They were placed between the fixtures which composed of a few holes and screwed up to tighten it. Then, the frequency was set between 860 – 960 MHz specifically for ultra-high frequency. As the probe placed within the hole, the dielectric constant and loss tangent were measured and exported as raw data.

2.3. Simulation Work
CST Microwave Software is the software to run the simulation especially for RF application to observe the behaviour of the antenna. The result of dielectric testing was implemented in CST Microwave software for simulation stage and the antenna design was optimized to maintain the resonance frequency at 915 MHz. Figure I and Table II show the design of the antenna using pure copper deposited on the henna-based composite. In order to determine the effect of dielectric properties towards the performance of tag is approaching accuracy, only m dimension was adjusted during optimization process and the resonance frequency was maintained at 915 ± 0.5 MHz (can refer Table III). This antenna design composed of capacitive loading, meandered line, T-matching loop, 18 Ω IC chip and a lumped element which is 0.8 pF capacitor. Each substrate is specified with an ID
number based on dielectric constant value followed by loss tangent value. For example, the substrate that has 4.3 dielectric constant and 0.025 loss tangent is specified as 4325.

3. Result and Discussions
In RFID application, the properties of the antenna really exert an impact towards the performance of tag. Nevertheless, the dielectric properties of the substrate also contribute to the tag performance although it is just a medium where the antenna, IC chip and lumped element are deposited. This is because the higher permittivity value of the substrate helps to reduce the dissipation of the RF wave. Hence, the main parameters of the dielectric properties that will be considered in this research are dielectric constant and loss tangent.

3.1. Effect on Reflection Coefficient and Bandwidth
In this context, the reflection coefficient or return loss describes the ratio of the complex amplitude of wave reflected from the tag antenna to the complex amplitude of wave transmitted from the reader where the reflection coefficient is considered accepted when it can go down below than -10 dB. Same goes to bandwidth, the bandwidth can be calculated by the difference between higher frequency and lower frequency where reflection coefficient is at -10 dB or VSWR is 2 which its value tells the amount of data can be transmitted. Figure 2 shows result of reflection coefficient with various value of dielectric constant and loss tangent. As the value of dielectric constant increases, the value of reflection coefficient decreases which is good for performance of the tag. Higher dielectric constant and lower loss tangent values will shift the resonance frequency to the left. Hence, the m dimension needs to be increased so that the resonance frequency at 915 MHz can be achieved. Lowest reflection coefficient was experienced by 4335 and followed by 3825. Meanwhile, the calculation of the bandwidth had been calculated and tabulated in Table III. By comparing various value loss tangent, it
shows that bigger bandwidth could be obtained by applying higher loss tangent. This can be observed by comparing 4345 with 4325 and 4335.

3.2. Effect on Gain, Directivity and Antenna Efficiency

Antenna directivity describes the degree of the RF wave transmitted where antenna gain refers to the intensity of the RF wave in particular degree. The product of directivity and antenna efficiency can be expressed as the value of gain. In other word, the value of gain depends on the value of directivity and antenna efficiency. Figure 3 and Figure 4 show the radiation pattern of gain and directivity for each substrate respectively with omnidirectional pattern since it is dipole antenna. Based on Table III, it is clear that higher gain can be obtained by applying lower loss tangent substrate. The directivity value keeps increases as the value of dielectric constant and loss tangent also increase but not very significantly. This is proven that dipole antenna has omnidirectional properties of radiation compared to directive antenna such as Yagi. However, the highest gain and antenna efficiency was achieved by 3825 and followed by 3325.

Figure 3. Various value of gain where a) 3325, b) 3825, c) 4325, d) 4335 and e) 4345.
3.3. Effect on VSWR

VSWR stands for Voltage Standing Wave Ratio describes the efficiency of the power received from the reader to the antenna. As the power received decreases, the antenna might have not enough power to transmit back. The ideal value of VSWR with 0% reflected power is 1:1. Hence, the best VSWR that can be achieved in this research is 1.07 experienced by 4325 and 4335. Table I showed the summarization of simulation result.

| ID    | Dielectric Constant | Dielectric Loss Tangent | Reflection Coefficient (dB) | Bandwidth (MHz) | Gain (dB) | Directivity (dBi) | Antenna Efficiency (%) | VSWR |
|-------|---------------------|-------------------------|-----------------------------|-----------------|-----------|-------------------|------------------------|------|
| 3325  | 3.3                 | 0.025                   | -21.63                      | 102.27          | 1.80      | 2.30              | 78.26                  | 1.18 |
| 3825  | 3.8                 | 0.025                   | -27.79                      | 203.44          | 1.82      | 2.31              | 78.79                  | 1.09 |
| 4325  | 4.3                 | 0.025                   | -29.46                      | 175.97          | 1.72      | 2.32              | 74.14                  | 1.07 |
| 4335  | 4.3                 | 0.035                   | -29.68                      | 195.75          | 1.52      | 2.35              | 64.68                  | 1.07 |
| 4345  | 4.3                 | 0.045                   | -22.02                      | 205.09          | 1.33      | 2.36              | 56.36                  | 1.17 |

4. Conclusion

The amount of henna loading can give different value of dielectric properties which contributes to flexibility of substrate in UHF-RFID application. Based on these simulation result, (1) lowest reflection coefficient experienced by 4334, (2) bigger size of bandwidth can be achieved by implementing higher loss tangent, (3) highest gain and antenna efficiency was achieved by 3825 (4) directivity has changed but not so significant due to properties of dipole antenna which radiated omnidirectional wave and (5) the best VSWR was obtained by 4325 and 4335. In conclusion, higher dielectric constant contributes to stability of overall performance as the value of reflection coefficient significantly decreased.
Author’s contribution
Nadzeefah Zamil¹: Idea & concept generation, first draft and manuscript writing, data collection and simulation work, analyses of data and interpretation. M N M Ansari¹ ² - Idea & concept generation, suggestion and advice on the simulation studies, suggestion on interpretation of the data, supervision of the project and manuscript editing. Y E Jalil² - suggestion and advice on the simulation studies, simulation and analytical tools application, interpretation of the data, co-supervision of the project and manuscript editing. Noor Afeefah Nordin¹ - project management, suggestion and advice on the analyses, manuscript editing and revision. Zainudin Yahya – co-supervision of the project. A A Azlan³ - Idea on the design of the antenna, simulation and analytical tools application, co-supervision of the project and manuscript editing.

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