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TRANSPARENT ENERGY HARVESTING ANTENNA FOR VEHICLE WINDSHIELD APPLICATION

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Abstract -- *This paper presents a transparent energy harvesting antenna for a vehicle windshield application. The antenna is designed using AgHT-4 with a thickness of 0.175 mm and the glass substrate (ε_r= 4.82) with a thickness of 2 mm. The antenna has dimensions of 46.238 x 35.4 mm. The antenna is designed and simulated in CST simulation software. It shows that the return loss of -32.76 dB obtained at 2.2412 GHz with broad directional pattern and a gain of 5 dBi. The rectifier circuit of RF energy harvesting will charge the energy storage by utilizing the ambient RF signals from the environment, convert it to the DC signal, and using the DC signal to charge the energy storage. This antenna is intended to be mounted on a car windshield to provide Wi-Fi signals to passengers.*

Keywords: *Energy Harvesting; Transparent antenna; Windshield.*

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INTRODUCTION

Energy harvesting replaces the need for conventional resources and cables or replacement batteries. Many products have been introduced, that instead of using electric batteries, will use environmental energy and turn it into electrical power. This device uses electromagnetic, solar, thermal, or mechanical energy, vibration, pressure, etc. as a source to generate electricity (Dasm et al., 2019; Obaid & Fernando, 2017).

This electrical energy is stored in durable cells such as capacitors or MEC and is used later. The development of ambient energy harvesting has been integrated with photovoltaic solar cells. The photovoltaic solar cell is applied as a layer above the surface and is used in various aspects such as smartphones, smart watches, mobile services. By utilizing the transparency of photovoltaic, it is applied not only on the surface of the car but also on the windshield (De Pinto et al., 2016). By utilizing solar cell photovoltaic capabilities and RF energy harvesting antenna to obtain ambient energy, it is expected that in the future there will be many self-sustainable standalone devices and vehicles.

Energy harvesting technology is possible to obtain energy from environmental energy resistance such as heat and electromagnetic waves converted into DC energy. RF energy harvesting can convert RF signals into electricity which can be a renewable energy alternative that can be implemented in various fields. RF harvesting is not like a wireless network that is only limited to energy; it can be taken from an environment that can also transmit and receive RF signals (Lu et al., 2015).

Since the 1990s transparent antennas have been investigated (Ito & Wu, 1991; Yurduseven et al., 2012; Song et al., 2008; Simons & Lee, 1997) from semi-transparent to transparent antennas that using Transparent Conductive Oxide (TCO) material. This investigation allows the integration of transparent antennas with photovoltaic solar cells that can harvest energy from the sun as well as from the radio environment. This integration between the antenna and solar cells provides a sharing of the benefits of use which can reduce the size, weight, and costs required.

TCO is an essential material for the application of antennas. TCO transparent solar cells are appropriately installed on glass and plastic. TCO has the advantage of a smaller weight volume, less costly and has more flexibility. In general, the antenna type of transparent conductors used is indium tin oxide (ITO, AgHT-4, PEDOT). A high degree of transparency is suitable for use on transparent designs on the surface (Kroener, 2012).

There are several studies about antenna application on the car (Wen-bo et al., 2013; Van Hoang et al., 2017). The antenna (Wen-bo et al., 2013) studies for SDARS and GPS applications. The FR4 as the substrate and mounted on the surface of the windshield. The antenna is dual-band working on 1.5 - 1.62 GHz and 2.25 - 2.40 GHz. The antenna proposed in the paper (Van Hoang et al., 2017) is used for RIFD tag applications on vehicles. The antenna is mounted on the windshield of the vehicle. The antenna operated across the frequency band of 865 – 868 MHz with a gain of 3.0 dBi and the distance covered is around 12m.

In this paper, the proposed antenna is intended to provide a 2.4 GHz Wi-Fi signal. The implementation of the proposed antenna is for on car-applications. The antenna is mounted on car windshield faced to the inside of the car so it can provide 2.4 GHz Wi-Fi signal to the passenger and it is also used as harvesting RF energy.

MATERIAL AND METHOD

Mathematical Explanation

The geometry of the proposed antenna was calculated with the following formulas (Manchanda et al., 2014). The thickness of the substrate can be calculated from the following equation. However, in this design, the substrate's thickness of 2 mm is specified.

$$h_s \le \frac{0.3c}{2\pi f\sqrt{\varepsilon_r}} \quad (1)$$

Where,
h_s = Thickness of the substrate
f = frequency in GHz.
c = velocity of light in m/s.
ε_r = substrate dielectric constant.

The length of the substrate can be calculated by:

$$L_s = L_p + 6h_s \quad (2)$$

The width of the substrate can be calculated by:

$$w_s = w_p + 6h_s \quad (3)$$

The width of the patch can be calculated from the following equation:

$$w_p = \frac{c}{f}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (4)$$

Also, the length of the patch can be calculated from the following equation:

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad (5)$$

Where ε_{eff} = effective permittivity which is given by:

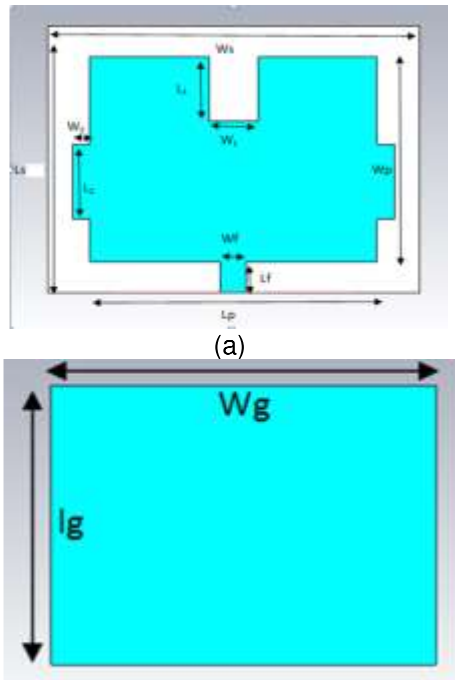
$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right)\left(\frac{\varepsilon_r - 1}{2}\right)\left(\frac{1}{\sqrt{1 + \frac{12h_s}{w_p}}}\right) \quad (6)$$

while ΔL = physical length which is given by:

$$\Delta L = h_s\left[\frac{0.412h_s\left(\varepsilon_{eff} + 0.3\right)\left(\frac{w_p}{h_s} - 0.264\right)}{\left(\varepsilon_{eff} + 0.258\right)\left(\frac{w_p}{h_s} - 0.8\right)}\right] \quad (7)$$

Antenna Configuration

In this proposed transparent antenna, the material used is glass as the substrate with a given thickness of 2 mm. AgHT-4 is used as the patch material that has 0.175 mm of thickness. This material also has high transparency that can be used on many application like building window, car windshield, and small devices. Dimensions of the antenna are listed in Table 1 and shown in Fig. 1.



(a)

(b)

Figure 1. The proposed antenna geometry. (a) the front side of the antenna (b) the back side of the antenna.

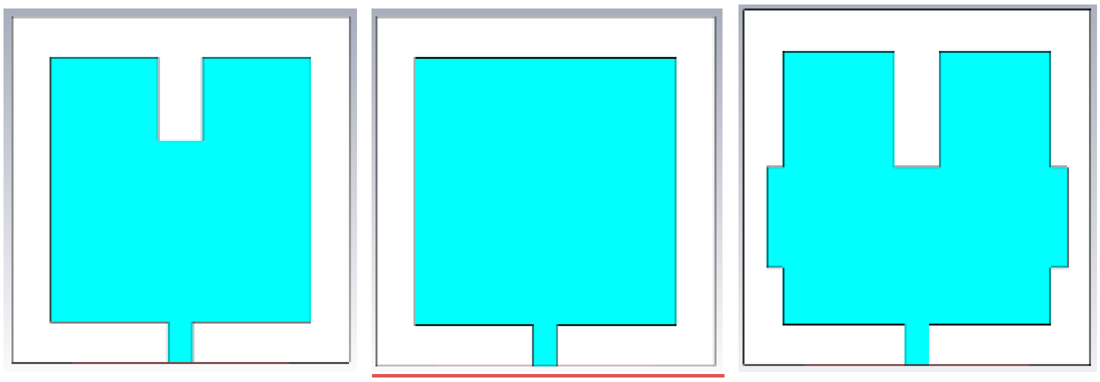
Table 1. Antenna Geometry Dimension

Parameter	Value (mm)
h_s	2
L_f	4.8
L_g	35.4
L_p	27.231
L_s	35.4
T	0.175
W_f	3.245
W_g	46.238
W_p	35.638
W_s	46.238
W_1	6
L_1	9
W_2	3
L_2	10

RESULTS AND DISCUSSION

Characterization is needed to get the desired antenna specification. The different shape and dimension of the slot have a different effect; it can affect the frequency, return loss, and radiation pattern of the antenna (Rahayu et al., 2010; Rahayu et al., 2018). Cutting the slot is to optimize the results.

Three steps of parametric studies have been performed to obtain the desired frequency as shown in Fig. 2.



(a) (b) (c)

Figure 2. Antenna parametric studies.
(a) step 1 (initial antenna design), (b) step 2(cutting edge on the top of the patch), (c) step 3 (final antenna design).

Fig. 2(a) shows the initial design of the antenna. The cutting edge is added at the top of the patch as shown in Fig. 2(b). As shown in Fig. 2(c) rectangular are added to the side of the patch.

As shown in Fig. 3, the simulated return loss provides -10.99 dB at 2.3424 GHz as shown in step 1, the Cutting edge is added at the top of the patch as shown in step 2. The frequency is shifted to 2.358GHz with -12.97 dB as shown in step The lowest return loss at 2.412 GHz of 32.76 dB.

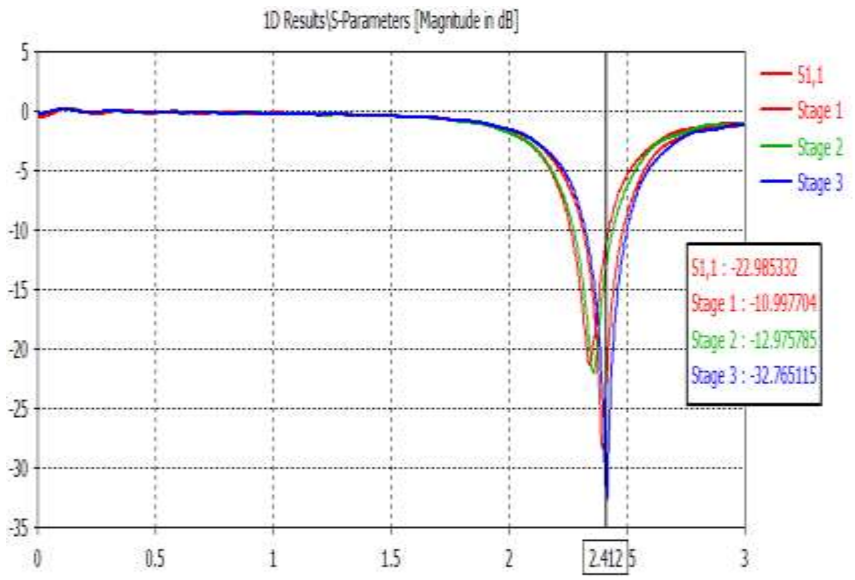
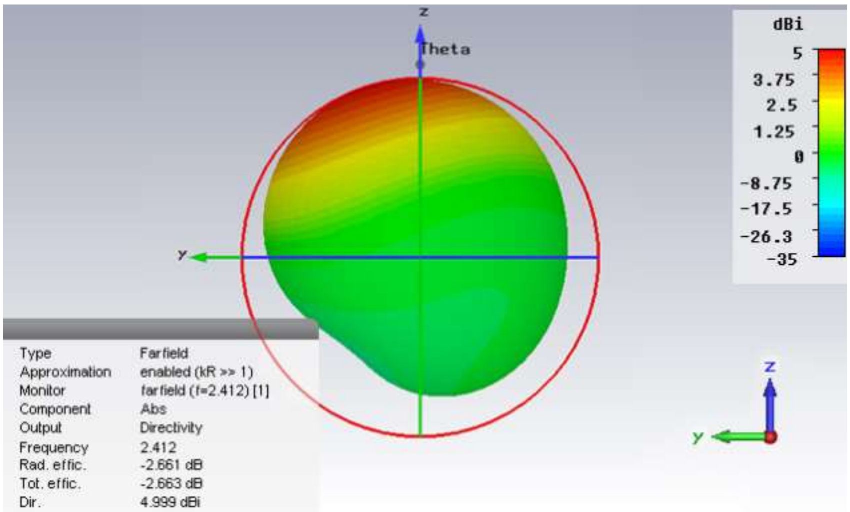
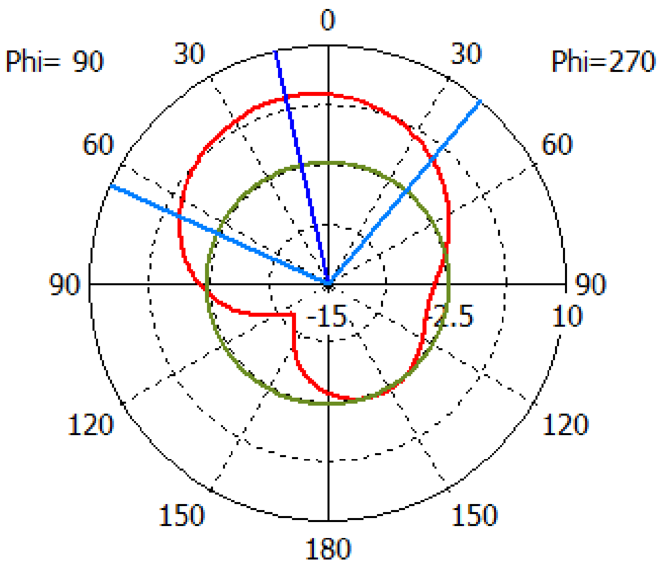


Figure 3. The return loss of the parametric studies



(a) 3D view



(b) 2D view

Figure 4. The simulated radiation pattern of the antenna

Fig. 4 shows the simulated radiation pattern of an antenna with a gain of 5 dBi at 2.4GHz.

To develop an RF energy harvester, there are needs three main blocks are required: first, an antenna is to harvest the electromagnetic energy from the environment, a high AC to DC converter and a storage element.

The diagram block of the system is shown in Fig. 5. The antenna captures the RF signals generated by a source such as Wi-Fi and Bluetooth. The matching network is used for the antenna along the rectifier. The rectifier circuit will charge the energy storage by utilizing the ambient RF signals from the environment; convert it to the DC signal, and using the DC signal to charge the energy storage.

The antenna used is 2.4 GHz in this paper. The impedance of each block must be matched to get the maximum of the antenna output power to the rectifier as shown in Fig. 6. The rectifier is based on a single stage Villard voltage multiplier (Jabbar et al., 2010).

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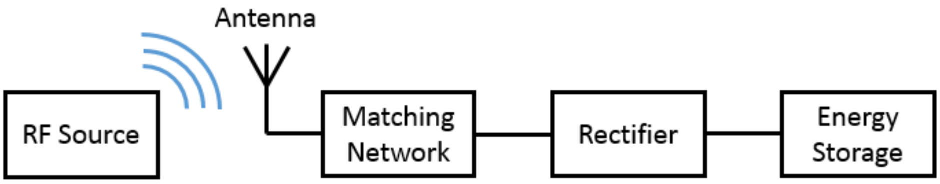

Figure 5. Schematic of the RF energy harvesting

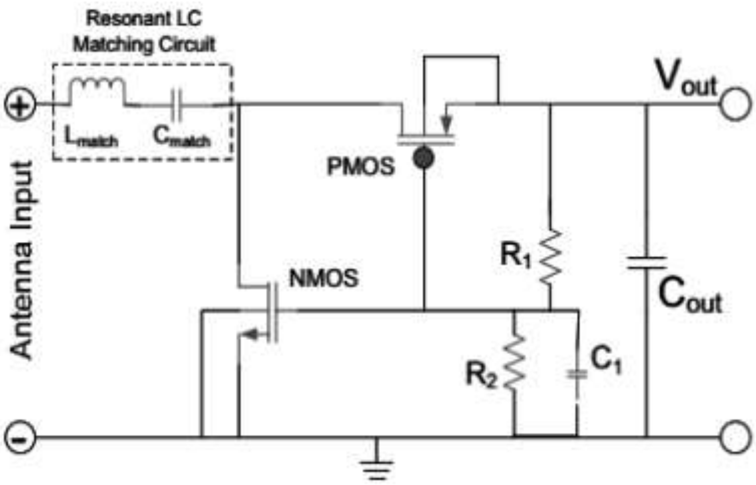

Figure 6. Single stage Villard voltage multiplier for energy harvesting

Villard voltage multiplier is designed using the technology of CMOS; efficiency of the circuit is 22.97% at 66µW input. The output voltage is 1.5V. The output is stored on the 220μF capacitor as the storage.

CONCLUSION

This paper presents the design of a transparent antenna for the windshield. This antenna works at 2.4GHz and as RF energy harvesting. The proposed antenna uses AgHT-4 with a thickness of 0.175 mm and the glass substrate (ε_r= 4.82) with a thickness of 2 mm. The proposed antenna return loss is -32.76 dB obtained at 2.412 GHz with broad directional radiation pattern and a gain of 5 dBi. The antenna is intended to mount on the windshield of the car, for Wi-Fi application.

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