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DESIGN OF A COMPACT MICROSTRIP PATCH ANTENNA FOR WIRELESS SENSOR NODES

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Abstract

This paper presents the design of a compact micro strip patch antenna at 2.4 GHz for wireless sensor networks (WSNs) applications. Wireless sensor networks (WSNs) consist of nodes with a limited power source with compact size. In this paper, two compact micro strip patch antennas are designed and simulated by using Zeland Inc's IE3D software. The performance is then measured in terms of gain, bandwidth and polarization. Although energy consumption and dimensions are reduced, the efficiency of the antenna together with its performance, should not be significantly degraded. Transmission line model is used to determine the length and width of the antenna, where the first antenna is the size of 39mm long and 47mm wide and the second design produces an antenna with 28.6mm long and 37.7mm wide. It is observed that the two antennas are still able to maintain the performance and received a good level of efficiency. Still, several important parameters are found decline due to antenna miniaturization.

Keywords: Microstrip antenna, Transmission line model, Wireless sensor network.

1. Introduction

Future market demands for the internet of things (IoT) devices and wireless sensor nodes are predicted trillion “things” to be connected by 2025 [1]. Smart system solutions are typically required embedded sensing, signal processing, power generation and energy management. However, these technologies are needed to be addressed before dissemination [2]. Wireless sensor network (WSN) platforms are formed by a large number of sensor nodes to support automation of infrastructures, home and office to enhance services. Each node of WSN is equipped with a sensor to measure, monitor, tracking, or physical surveillance phenomena [3].

Characteristics of being light, small and planar structure microstrip antenna have the advantage of being easy to apply to wireless sensor nodes at low production cost [4]. In order to design a compact microstrip patch antenna, substrates with higher dielectric constants must be used, which is less efficient and resulting in a narrower bandwidth. Among the parameters affected due to this size reduction are the gain of the antenna will be lower, the bandwidth will be narrower, more critical tuning, a higher level of sensitivity to the components and other external factors [5]. Hence, a trade-off must be realized between the antenna dimensions and antenna performance. Generally, the miniaturization process of a microstrip patch antenna can be achieved by several approaches [6], such as:

i. Use of high substrate dielectric constant (Permittivity).

ii. Modification on common shapes of microstrip patch elements.

iii. Use of a stacked short-circuited method, short-pin method and short-wall mounted method.

iv. Any combination of the above methods.

This paper describes the design and simulation process, which began by designing two different sizes microstrip patch antennas at 2.4 GHz for WSN applications. Design and simulation are carried out using a Zeland IE3D. Comparison is then made between the two antennas, and the performance is evaluated in terms of gain, bandwidth and polarization.

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore, they are extremely compatible with embedded antennas in handheld wireless devices such as cellular phones and pagers. Another area where they have been used extensively is in satellite communication. In its most fundamental form, a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Fig. 1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate [7].

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape, as shown in Fig. 2. In this design, a rectangular patch has been chosen where for this type of shape, the length, L of the patch is usually $0.3333\lambda o < L < 0.5\lambda_o$, where λ_o is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda_o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda_o \leq h \leq 0.05\lambda_o$. The dielectric constant of the substrate (or permittivity), ε_r is typically in the range of $2.2\leq \varepsilon_r \leq 12$ [4].

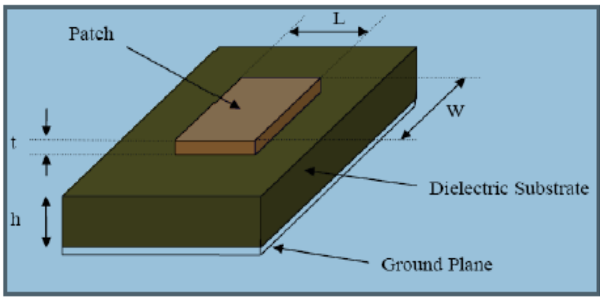


Fig. 1. Structure of a microstrip patch antenna.

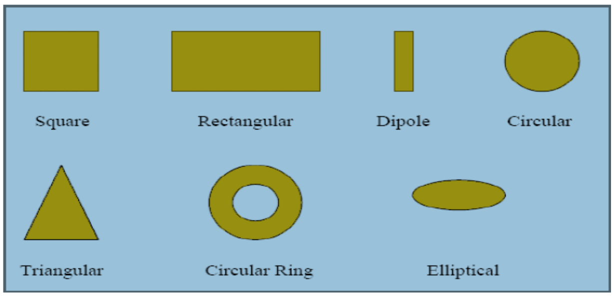


Fig. 2. Common shapes of microstrip patch elements.

A variety of methods can feed microstrip patch antenna. The four most popular feed techniques used are the microstrip line inset-feed, coaxial probe, aperture coupling and proximity coupling. The microstrip line inset-feed is used for this design. This is one of the easiest feeding schemes as it gives simplicity in modelling thus simple to fabricate. This technique uses a conducting strip which is connected directly to the edge of the microstrip patch, as shown in Fig. 3. The conducting strip is smaller in width as compared to the patch, and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure [4].

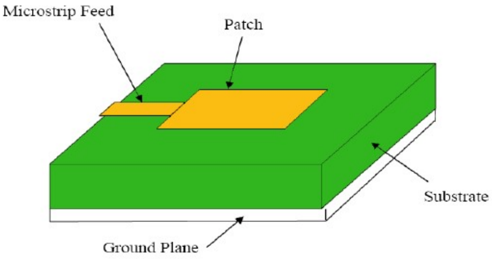


Fig. 3. Microstrip line feed.

2. Design Principles

A principle of the transmission line model has been used in designing and analyzing the performance of both antennas. This is by far the simplest model, and it gives good physical insight even though it is less accurate. Other designs and analysis methods that can be used are cavity model and full wave model. Based on this transmission line model, all necessary designs for these two antennas are calculated at operating frequency, f_o = 2.4 GHz. The patch is in a rectangular shape as it simplifies the analysis and performance prediction. Substrate height is h, dielectric constant of the substrate (or permittivity) is ε_r and substrate material chosen is FR4. Formulas used to calculate the width, W and the length, L are shown below:

2.1. The patch width, *W*

For a rectangular shape patch, the width is calculated using the equation given by Eq. (1). Patch width,

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

2.2. The patch length, *L*

As the actual length of the patch is directly related to the value of effective length, L_{eff} given in Eq. (3) and extended length, ΔL as shown in Eq. (4), the following Eq. (2) is used to determine the actual patch length, L. Patch length,

$$L = L_{eff} - 2\Delta L \tag{2}$$

where,

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \tag{3}$$

and,

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

2.3. The effective dielectric constant, ε_{reff}

Equation (5) shown below is the formula to calculate the effective dielectric constant, ε_{reff} which is based on the height, chosen dielectric constant and the calculated width of the patch antenna.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{5}$$

The detailed specifications for both designs are shown in Table 1.

Table 1. Specifications of antenna.

	Antenna No. 1	Antenna No. 2
Operating Frequency, f_o	2.4 GHz	2.4 GHz
Substrate dielectric constant (permittivity, ε_r)	2.47	4.5
Height, *h*	1.6 mm	1.6 mm
Feeding Technique	Microstrip line inset-feed (Fi) 13.2 mm	Microstrip line inset-feed (Fi) 12.2 mm
Length, *L* × Width, *W*	39 mm × 47 mm	28.6 mm × 37.7 mm

2.4. Design structure

Figures 4 to 7 depict the design for both antennas according to the parameters stated in Table 1. Simulation by IE3D was then conducted to verify the design of both antenna and to see whether objectives are achieved or not. The two antennas are designed and simulated by applying a classical scheme as a meshing scheme. There are two types of meshing scheme in IE3D; classic and contemporary. Both give good and exact simulation [5]. From the simulation, parameters such as return loss S11, gain and polarization form can be identified. Next, a comparison has been done between these two designed antennas to see the impact of antenna's dimension on the efficiency and performance of the antenna.

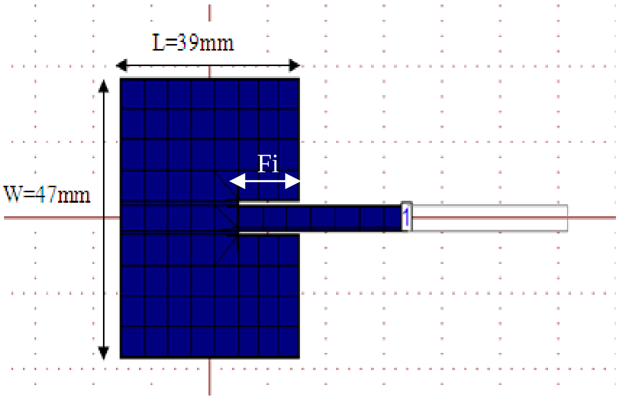


Fig. 4. Design structure of antenna 1 (2d top view).

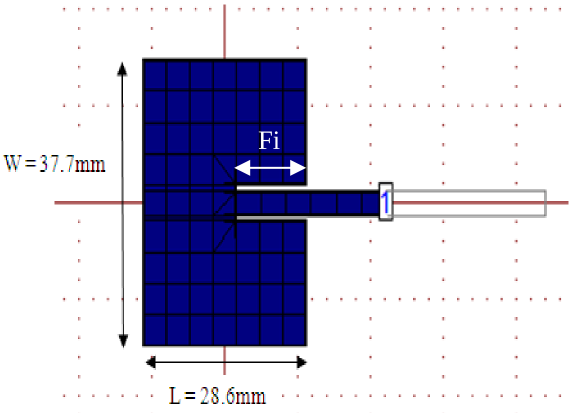


Fig. 5. Design structure of antenna 2 (2d top view).

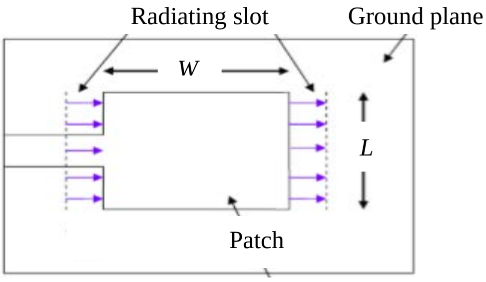


Fig. 6. Top view of antenna.

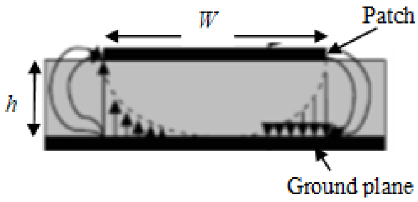


Fig. 7. Side view of antenna.

3. Results and Analysis

Both antennas are designed with the same height *h* but the different value of permittivity, ε_r. The use of a low permittivity as in the first designed antenna is recommended as it contributes to the better antenna efficiency. Unfortunately, it will also result in larger antenna size. The second antenna has been designed with a higher permittivity and this contributes to a much smaller dimension of antenna.

3.1. Return loss S_{11}

The corresponding simulation return loss S_{11} against frequency is shown in Figs. 8 and 9. Both antennas exhibited return loss value less than -10 dB. The obtained return loss shows the ability of both antennas to operate effectively in 2.4 GHz.

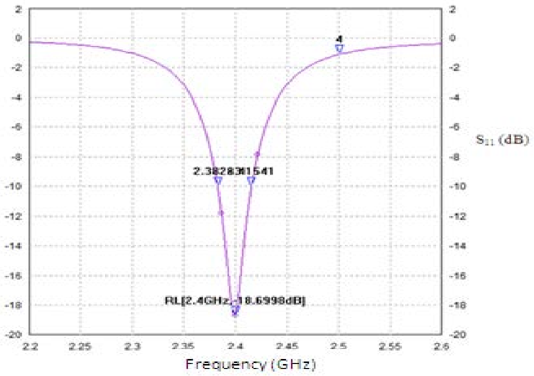


Fig. 8. Frequency vs return loss S_{11} for antenna 1.

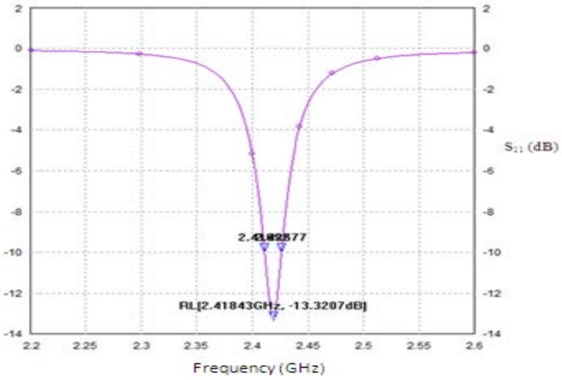
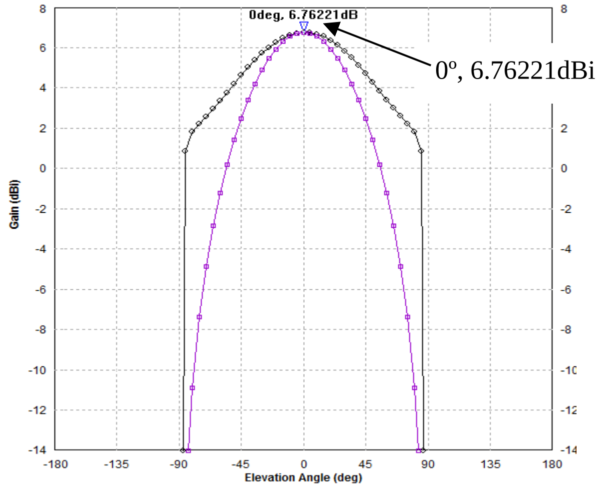


Fig. 9. Frequency vs return loss S_{11} for antenna 2.

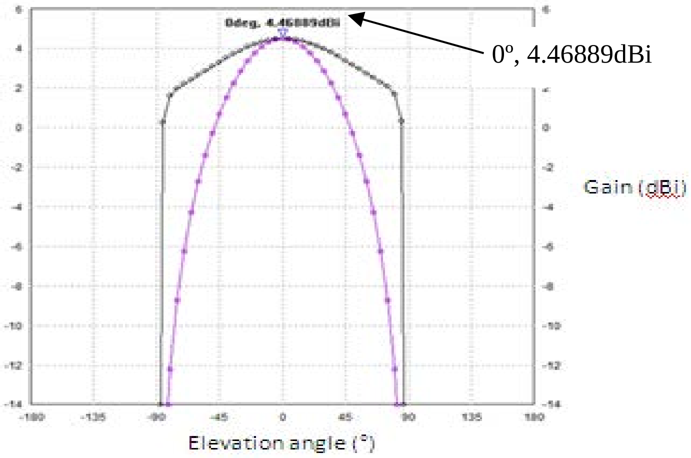
3.2. Gain

The microstrip patch antenna radiates normal to its patch surface. Thus, the elevation pattern for φ=0° and φ=90° are important for the measurement. Figures 10 and 11 show the simulated elevation pattern gain displayed in the 2D Cartesian plot for both antennas. Antenna 1 produced a gain of 6.76 dBi at 0° while antenna 2 produced a gain of 4.46 dBi at 0°.



0º, 6.76221dBi

Fig. 10. Elevation patterns gain for antenna 1.



0º, 4.46889dBi

Fig. 11. Elevation patterns gain for antenna 2.

3.3. Polarization

Antenna polarization is a very important parameter when choosing and installing an antenna. Most communications systems use either linear polarization (vertical or horizontal) or circular polarization. A linear polarized antenna radiates an electric field that varies in only one direction. In a circular polarized antenna, the plane of polarization rotates in a circle making one complete revolution during one period of the wave. An antenna is said to be horizontally polarized (linear) when its electric field (by current distribution plot) is perpendicular to the Earth's surface.

In IE3D, the 3D current distribution plot gives the relationship between the co-polarization (desired) and cross-polarization (undesired) components. Moreover, it provides a clear picture as to the nature of polarization of the fields propagating through the patch antenna. Figures 12 and 13 clearly show that both antennas are horizontal linearly polarized.

Horizontal polarization was initially chosen in TV broadcasting because there was an advantage not to have TV reception interfered by vertically polarized stations such as mobile radio. Also, human-made radio noise is predominantly vertically polarized, and the use of horizontal polarization would provide some discrimination against interference from noise [8].

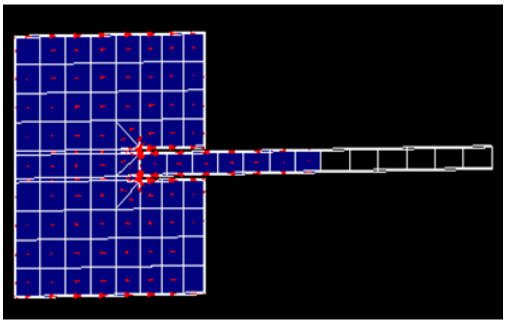


Fig. 12. 3D Current distribution plot for antenna 1.

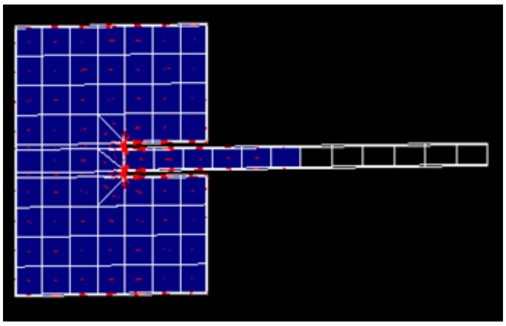


Fig. 13. 3D Current distribution plot for antenna 2.

4. Discussion

Table 2 summarizes the results by a comparison between the first and second designed antenna. It can be seen that with a greater bandwidth = 1.25%, the first designed antenna exhibits a good performance level and higher efficiency as compared to the second antenna. However, antenna 1 is larger in size compared to antenna 2. To obtain a compact antenna, the second antenna is designed with a higher value of permittivity, almost double than permittivity in the first antenna. This results in a reduction of size as explained in section 3. Along with the size reduction, the performance and efficiency of the second antenna deteriorate accordingly. However, the antenna is still able to operate at the desired frequency range for WSN applications.

Return loss for both antennas find less than -10dB at around 2.4 GHz and this indicates that the two antennas do not produce a lot of energy loss during signal transmission took place. The first antenna has a bandwidth that is much higher than the second antenna. This is expected because when the antenna size decreases, the bandwidth will be narrower. Bandwidth and antenna size are generally two parameters that are closely and directly related to each other and introduce conflicts, in which the improvement of one of these parameters will result in a further deterioration of another parameter [9]. With the reduction in the size of the second antenna, it is noticed that the gain is also affected. The gain becomes much lower than the first antenna and this is also expected because it is one of the effects of the miniaturization.

Table 2. Simulation results for antenna 1 and 2.

	Antenna No. 1	Antenna No. 2
Operating Frequency, f_o	2.4 GHz	2.4 GHz
Substrate dielectric constant (permittivity, ε_r)	2.47	4.5
Height, h	1.6 mm	1.6 mm
Width, W	47 mm	37.7 mm
Length, L	39 mm	28.6 mm
Gain	6.76 dBi	4.46 dBi
Efficiency, η	89.11 %	64.52 %
Bandwidth	1.25 %	0.41 %
Return loss, S_{11}	-18.69 dB	-13.32 dB

5. Conclusions

The antennas are designed and simulated successfully. Both antennas cover the operating frequency for WSN applications with good return loss characteristics. Simulation approach has implemented the first approach - the use of high substrate dielectric constant (permittivity). It has been noticed that several antenna parameters deteriorate with the miniaturization process. A comparison between two designed antennas is made and the result shows that with the use of low substrate permittivity, it will increase the bandwidth of the microstrip patch antenna thus produce a good performance and high efficiency antenna.

Results also show that size is a critical criterion to get insights when designing an antenna, especially for WSN applications. Miniaturization process of a microstrip patch antenna is difficult to realize since its resonant frequency is primarily determined by the dominant mode of the cavity of microstrip patch element. With the same substrate's thickness, the second antenna is designed with a higher permittivity and this creates a much smaller antenna size. Unfortunately, the gain, efficiency and overall performance decrease. Thus, the design of a compact microstrip patch antenna where the size reduction is needed depends on the actual needs and the required bandwidth of the antenna itself.

Nomenclatures

f_o	Operating frequency or resonant frequency, GHz
Gain	Gain, dBi
h	Substrate height, mm

L	Patch length, mm
L_{eff}	Effective length, mm
ΔL	Extended length, mm
S_{11}	Return loss, dB
W	Patch width, mm

Greek Symbols

ε_r	Substrate dielectric constant (permittivity)
ε_{reff}	Effective substrate dielectric constant (effective permittivity)
η	Antenna efficiency
λ_o	Free-space wavelength, m
φ	Elevation angle (Fig. 10 and 11), deg.

Abbreviations

2D	2 Dimension
3D	3 Dimension
FR4	Substrate material grade designated by NEMA known as ‘flame retardant-4’.
Fi	Feeding technique - Microstrip line inset-feed
IoT	Internet of Things
WSN	Wireless Sensor Node

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