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Slot Engineering in Patch Antennas for Energy Harvesting Applications

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Abstract:

In this paper, the impact of slots on the patch antenna performance for energy harvesting applications is studied. The aim of this study is to exploit the role that slots play in patch antennas to control and adjust the resonant frequency of energy harvesting systems. This feasibility allow the designer to target the available source of electromagnetic energy. Three types of patch antennas were employed these are rectangular patch with inset feeding and one slot on the front patch, rectangular patch with double slots and UWB circular patch. CST MWS is used to simulate the proposed structures. The results showed that changing the dimensions of the slots and varying the distance between them have a direct and significant impact on the resonant frequency of the antenna.

Keywords: Patch Antennas, Slots, UWB, Energy Harvesting.

1 Introduction

In recent years, there is an enormous demand for portable wireless devices operating in L, C and S in application band. Due to this increased demand for wireless equipment in all aspects of today's life, RF energy harvesting can be a fit and practical remedy for solving the problem of continues replacing of batteries in handheld, portable devices. The concept of RF energy harvesting developed during 20th century and entails conversion of electromagnetic waves present in environment to direct current (DC) electricity (Brown, W.C., 1984). Nowadays, there are a number of approaches for generating energy from environment "RF/microwave, signals, pressure, heat, light motion" or another source of energy like human body "finger strokes, body heat, foot strike" have been put forth (Sudevalayam, S. and Kulkarni, P., 2011; Valenta, C.R. and Durgin, G.D., 2014) . The envisioned antennas have the benefits of small antenna size, broad bandwidth and effective radiation efficiency. Various antenna structures have lately been suggested in the literature for RF energy harvesting applications where set sources are found like, UMTS, GSM, LTE, WLAN, Bluetooth and 5G networks. Widely reported literature works with the goal of boosting systemic effectiveness and reducing complicity (Derbal, M. C. and Nedil, 2020; Le et al., 2021; Singh et al., 2018; Bakytbekov et al., 2018). Dual band and wide band antennas were previously employed for energy harvesting applications due to their ability to harvest as much energy as possible from surrounding sources (Sabaawi et al., 2022; Sabaawi et al., 2021; Nishimoto H. et al.,2010; Vyas, R. J. et al., 2013; Shigeta, R., 2013; Parks, A. N. et al., 2013; Pinuela, M. et al., 2013). Thus, we are propelled in our objective of planning a straightforward RF-EH circuit plan that can power up any sensor node on an extensive variety of cell and unlicensed groups without changes at the circuit level. This paper proposes a method for designing and optimizing slot antennas for RF energy harvesting applications. The designed antennas were simulated using CST Studio Suite. Three different design of antennas, rectangular patch with single slot, rectangular patch with double slot and slotted UWB circular patch were implemented.

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2 Slot Structure

In this section a slotted rectangular patch antenna with inset feeding is designed and simulated.

2.1 Single Slot Structure

In this section a slotted rectangular patch antenna with inset feeding is designed and simulated. The antenna structure has two slots: the first slot has a rectangle shape and lies on the front patch (copper), while the second slot lies on the ground plane (copper). The antenna is placed on FR-4 substrate with εr = 4.3, a thickness of 1.6 mm and a loss tangent (δ) of 0.02. A study is conducted into the effect of the slot location on the antenna performance. Three parameters was chosen to study the slot location impact. These are H1, H2 and L3 which are illustrated in Fig. 1. The reflection coefficient (S11) versus frequency for the case of varying H1 over a range 8-16 mm as shown in Fig.2. It can be seen from the results that the antenna exhibits dual band performance and when H1 was increased the resonant frequency of the lower band was increased. On the other hand, it is noted that increasing H1 leads to decreasing the resonant frequency of the upper band. In addition, it is found that H1 has a direct impact on the value of the reflection coefficient, which make this parameter a controller over the impedance matching. The antennas are affected weather the slot is placed vertically or horizontally.

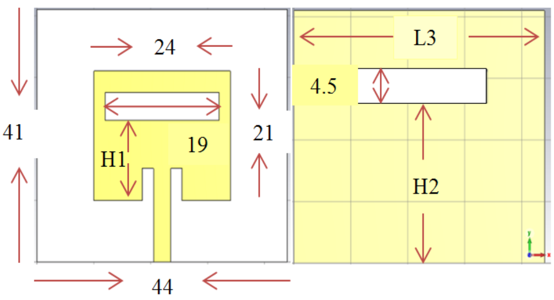

Fig.1: Single slot patch antenna. (a) Front view and (b) back view. All dimensions are in mm.

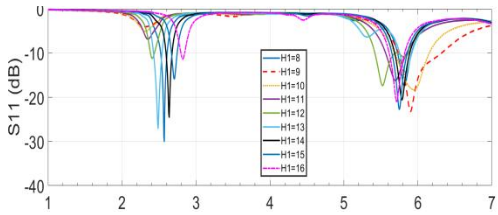

Fig 2: Effect of H1 on the antenna performance.

It can be clearly seen that changing the slot location (H1) slightly affects the antenna directivity.

Furthermore, the impact of parameter H2, which is the location of the back slot is studied. The simulated S11 of varying H2 from 20 to 30mm is shown in Fig.3. It is seen that H2 affects the lower band significantly where increasing H2 leads to increasing the lower band resonant frequency. This impact of H2 is quite important to control the resonant frequency at this frequency range in particular as there are several communication systems operate around 2 GHz. In contrast, H2 has shown a trivial impact on the upper band.

Table 1: Effect of H1 on the Directivity.

Frequency	**Slot location (H1)**	**Directivity**
5.8 GHz	H1=16	**5.110 dBi**
5.8 GHz	H1=16	**6.807 dBi**
2.4 GHz	H1=13	**5.068 dBi**
5.8 GHz	H1=13	**6.713 dBi**
2.4 GHz	H1=10	**5.118 dBi**
5.8 GHz	H1=10	**6.035 dBi**
2.4 GHz	H1=6	**5.192 dBi**
5.8 GHz	**H1=6**	**6.413 dBi**

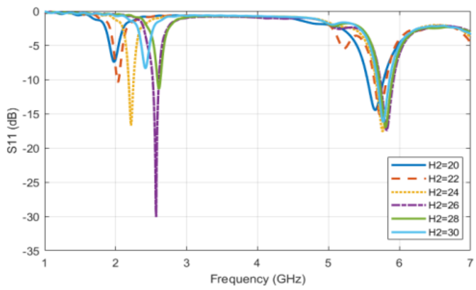

Fig 3: Effect of H2 on the antenna performance.

Finally, the impact of L3 was also studied to observe the impact of moving the back slot horizontally. The value of L3 was changed from 8 mm to 16 mm. Fig.4 shows the variation of S11 versus frequency and depicting the impact of L3. It is observed that varying L3 would decrease the lower band frequency and increase the upper band frequency. In other words, changing L3 value leads to increase the gap between the two frequency bands of the antenna.

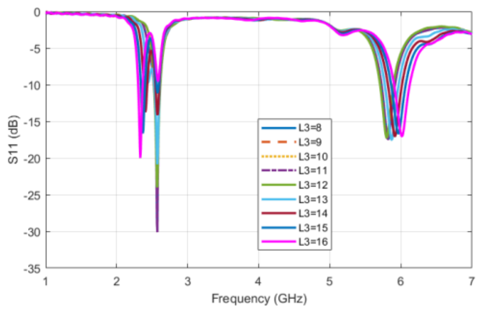

Fig 4: Effect of L3 on the antenna performance.

2.2 Double Slot Structure:

For the rectangular patch with double slot design, the impact of the distance between the two slots was also studied to observe the impact of moving the slots horizontally (shown in Fig.5). The reflection coefficient of the designed antenna for the case of increasing the distance D at distances of 1 mm, 4.5mm and 8 mm is illustrated in Fig.6. It is found that when the distance between two slots is reduced, the lower band frequency is increased while the upper band frequency decreases significantly with a decrease in return loss (S11) value in both cases.

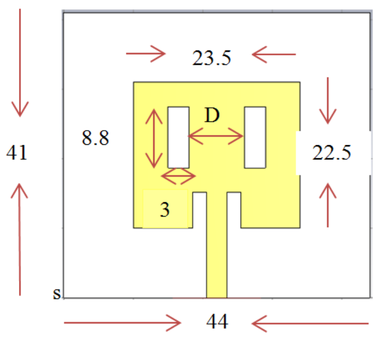

Fig 5: Double slot rectangular structure. All dimensions are in mm.

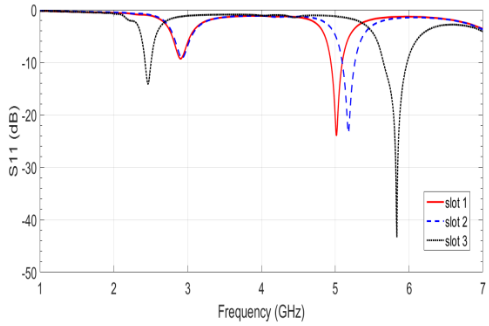

Fig 6: Double Slot Structure

2.3 Sloted Uwb Circular Patch Antenna:

An ultra-wide band (UWB) circular patch antenna is designed and simulated without slot at the beginning. Two slots are then added to the structure to study the impact of adding slots to the patch antenna structure as shown in Fig.7.

The circular patch antenna without slot exhibits a wide frequency band of operation starts from 2.4 GHz to 5.9 GHz as depicted in Fig. 8. This frequency of operation is utilized in several communication systems. In addition, in slotted UWB circular patch, it was noticed that the slots add another frequency band centered around 6.2 GHz. The distance between the two slots are varied by 2mm, 4mm and 8mm and its impact was observed. The results showed that varying the distance between slots can only affect the center frequency of the newly added band as illustrated in Fig.9. This means that the engineering the slots could adjust the frequency of operation around the frequency band of interest.

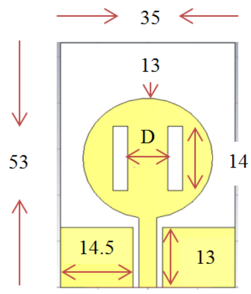

Fig 7: Slotted UWB circular patch antenna. All dimensions are in mm.

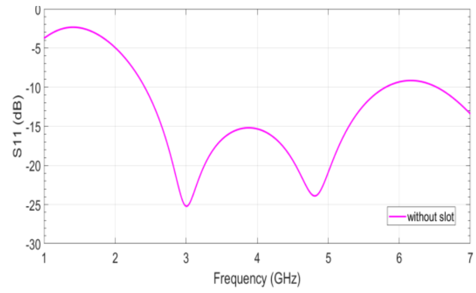

Fig 8: UWB circular patch antenna.

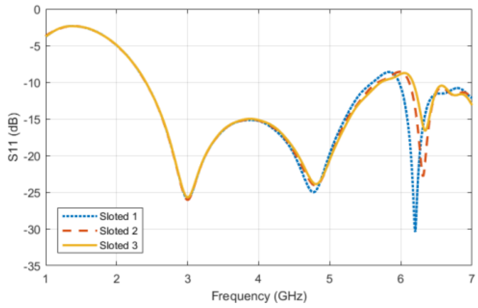

Fig 9: Slotted UWB circular patch antenna.

3 Conclusions

In energy harvesting application, it is quite important to design antennas that operates at a very specific frequency. This allows the user to target the center frequency of the abundant source of energy. To this end, the impact of slot size and location in three types of structures is studied (single slot, double slot and UWB with double slot). The results showed that slots offer the feasibility of controlling the frequency band of operation as well as offer the fine tuning capability to smoothly adjust the antenna resonant frequency.

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