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# A multiband and wideband frequency reconfigurable slotted bowtie antenna

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**ABSTRACT**

A multiband and wideband frequency reconfigurable antenna is presented. A wideband from 3.5 GHz to 9.0 GHz is achieved by introducing one stripline in the middle of a slotted bowtie antenna, whereas multiband is obtained by integrating an additional two slotted arms at the end of bowtie-shaped. As a result, the antenna operated at multiband mode (1.7 GHz and 2.6 GHz) and wideband mode (3.5 GHz to 9.0 GHz) simultaneously. The reconfigurability of the antenna is attained through switches. Five states are achieved with three pairs of switches configurations. All results are presented and discussed, including S11, current distribution, radiation pattern, and gain. The antenna is suitable to be used in multimode communication systems.



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## 1. INTRODUCTION

Advancement in modern communication systems nowadays has experienced an increase in reconfigurable antennas with frequency agility. An antenna is a core element for any wireless communication system including Global System for Mobile Communications (GSM), Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE) and etc. However, increasing in demands for frequency bands raised an issue on a shortage of available radio frequency spectrum [1]. Also, it is quite challenging to fit multiple antennas in one small and compact systems [2]. Therefore, reconfigurable antenna is the solution to solve the spectrum usage problem. In addition, frequency reconfigurable antenna has been realized with the ability to tune or switch the operating frequency in one single antenna. Thus, the frequency reconfigurable antenna can offer a smaller communication system compare by using a conventional antenna.

Frequency reconfigurable antenna can be divided into several types such as narrowband, multiband and wideband mode of configurations. The configurations can be switched between the same mode or to another type of mode. For example, narrow-to-narrowband [3], narrow-to-wideband [4, 5], multi-to-multiband [6-10], multi-to-wideband [11-18], wide-to-wideband [19] and wide-to-narrow-to-multiband [20, 21] configurations have been proposed and discussed. However, in this paper, we only focus on configurations of narrow-to-wideband and multi-to-wideband.

There are two types of techniques to obtain reconfigurabily. First, by switching in and out the radiator on antenna structure. Second, by changing electrical properties of the antenna itself. Antenna proposed in [7, 19] used the first technique while antenna in [16, 17] used second technique to reconfigure their antenna's frequencies. Both of the techniques are commonly used to achieve reconfigurability. However, some of the antennas used filter to allow only certain band to operate as reported in [4, 6, 18].

Ellipse wideband antenna with bandpass filter in [4], allows the antenna to operate in wideband mode ranging from 3.5 GHz to 5.97 GHz. The activation of the bandpass filter produces a narrowband centered at 5.8 GHz. Antenna in [5] is able to have a narrowband mode to be passed at 4.8 GHz and wideband mode ranging from 2.0 GHz to 6.0 GHz.

Tapered slot antenna offers wide-to-multiband reconfiguration ability is presented in [11]. Wideband mode ranging from 1.0 GHz to 3.8 GHz, a dual-band and triple-band modes are achieved. The dual-band and triple-band modes are operated within the wideband range. A pentagon-shaped antenna with an electromagnetic bandgap (EBG) is presented in [14]. The antenna provides dual-band mode at 1.8 GHz and 5.2 GHz, and a wideband mode at 1.6 GHz to 2.37 GHz. All antennas presented in [2, 3, 8-15] have switched multi or narrowband mode within the wideband frequency range. If the multi or the narrowband mode is outside the wideband range, narrow-and-wideband modes can be operated simultaneously as shown in [22]. U-slot Fractal Koch curve microstrip antenna is able to have a narrowband mode around 1.8 GHz to 2.0 GHz and wideband mode ranging from 2.5 GHz to 6.8 GHz, simultaneously. By having five switches, the antenna can provide 4 states of configurations. Only one of them operates in wideband mode whereas the others operate in narrow-and-wideband mode. This type of antenna offers more functionality compared to [2-16] by covering wider operating bands.

Normally, a monopole antenna is used to offer a wide frequency range. However, in this paper, bowtie antenna is proposed to produce a wide range of frequency. Unlike conventional bowtie antenna in [23, 24], frequency range of a bowtie antenna can be increase by modifiying the antenna structure itself as proposed in [25-27]. For example, a rectangular box is inserted before the triangular bowtie-shape in [25]. The box will reduce the reflection of triangular bowtie-shape thus make the antenna has a wider bandwidth. The modification on the antenna structure gives a wide range of frequency from 5.3 GHz to 14.2 GHz.

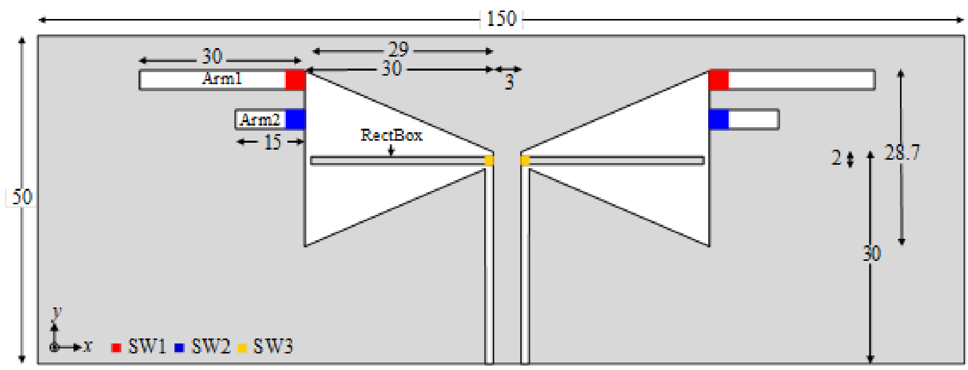
In this paper, a frequency reconfigurable slotted bowtie antenna is proposed. The antenna is using ideal switches to switch the operating frequency over a wide range of bands. The slotted bowtie antenna is able to operate in a wideband mode from 3.21 GHz to 9.0 GHz, by inserting a stripline in a bowtie-shaped design. Extra features are added by providing a dual-band mode to the antenna compared to the antenna in [22]. Dual-band is realized by inserting dual-pairs of slotted arms at the end of bowtie-shaped design. Therefore, the antenna is able to achieve dual-band and wideband modes working simultaneously at a time. Moreover, the proposed antenna can have up to five different states, based on its switches configurations. The proposed antenna is suitable for multimode communication system applications.

## 2. ANTENNA DESIGN

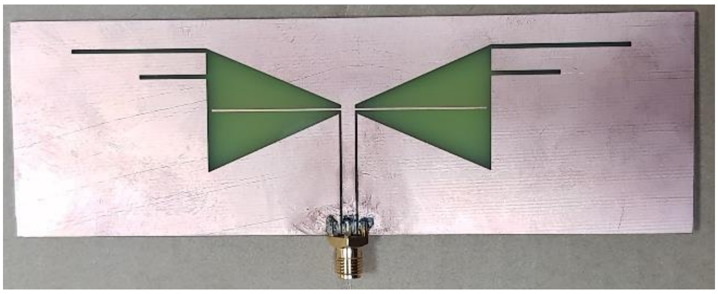
The proposed antenna geometry is shown in Figure 1(a) with three pairs of switches to achieve frequency reconfigurability while the fabricated antenna in state one is shown in Figure 1(b). The proposed antenna consists of a slotted bowtie antenna with a stripline in the middle of bowtie-shaped and two pairs of slotted arms. the stripline is called as a rectangular box (Rectbox). The proposed antenna is implemented using an FR4 board with the height, h of 1.6 mm, permittivity, $\varepsilon r$ of 4.3 and tangent loss, $\tan\delta$ of 0.002. Stripline (Rectbox) width is 0.5 mm and the slotted arms width is 1.0 mm. The width of the feed-line and the gap of the 50Ω Coplanar waveguide (CPW) feed-line are 3.0 mm and 0.5 mm, respectively.

A reference slotted bowtie antenna is shown in Figure 2, produces a dual-band mode at 3.35 GHz and 6.92 GHz. By introducing a rectangular box as shown in Figure 3, the antenna is able to operate in wideband mode ranging from 2.73 GHz to 9.0 GHz. Two pairs of slotted arms are added into the antenna structure to produce dual-band modes. This dual-band mode can be separated into low-band and high-band. The first arm, the longest length, operates at 1.7 GHz known as low-band while the second arm, shortest length, operates at 2.6 GHz known as high-band. Therefore, it enables the antenna to operate in dual-band and wideband modes simultaneously.

The switches configurations are presented in Table 1. Five states are achieved by switching on and off the switches. Switch OFF indicates that the switch is replaced with a vacuum block in the simulation process, while switch ON indicates that the switch is represented as a copper block. In state one, all radiators (Arm1, Arm2, bowtie and Rectbox) are functioned allowing the antenna to produce a dual-and-wideband mode. In state two, only Arm1, bowtie and Rectbox are activated, producing a single-band at low-band and wideband modes to works simultaneously. In state three, only Arm1 is decoupled while the others are activated, allowing the antenna to operate at single-band (high-band) and wideband states simultaneously.

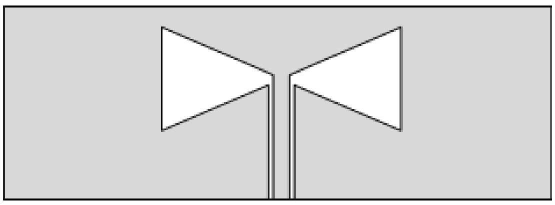



(a)

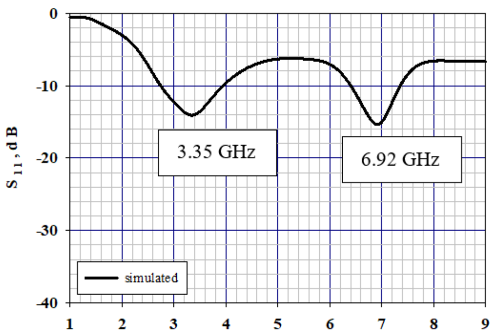


(b)

Figure 1. Antenna (a) geometry (b) fabricated antenna in state one

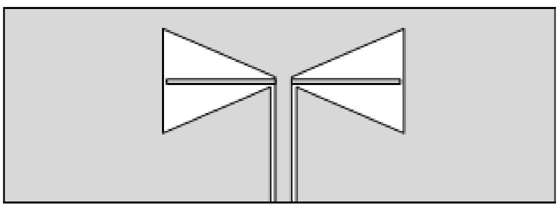


(a)

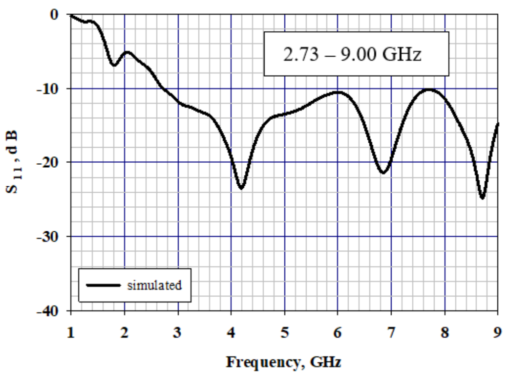



(b)

Figure 2. Reference slotted bowtie antenna (a) geometry (b) $S_{11}$



(a)




(b)

Figure 3. Reference slotted bowtie antenna with rectangular box (a) geometry (b) $S_{11}$

In state four, the wideband mode is obtained by decoupling Arm1 and Arm2. This can be referred to in Figure 3. Lastly, in state five, quad-band is achieved by decoupling the Rectbox. In this state, $S_{11}$ results in Figure 2 can be as reference data as to how the quad-band is obtained from the antenna.

Table 1. Switches configuration

| State | SW1 | SW2 | SW3 | Mode |
|---|---|---|---|---|
| One (1) | OFF | OFF | ON | Dual-band and wideband |
| Two (2) | OFF | ON | ON | Single-band and wideband |
| Three (3) | ON | OFF | ON | Single-band and wideband |
| Four (4) | ON | ON | ON | Wideband |
| Five (5) | OFF | OFF | OFF | Quad-band |

## 3. RESULTS AND ANALYSIS

Figure 4 shows $S_{11}$ results for all states, both simulated and measured results. For simulated results black straight line, in Figure 4(a), dual-band resonances at 1.74 GHz and 2.63 GHz, as well as wideband states ranging from 3.21 GHz to 9.0 GHz is observed and operated simultaneously. Bandwidth for the dual-band mode at 1.74 GHz and 2.63 GHz are 110 MHz (1.68 GHz - 1.79 GHz) and 170 MHz (2.57 GHz - 2.74 GHz), respectively. In Figure 4(b), single-band mode at 1.75 GHz and wideband mode ranging from 2.90 GHz to 9.0 GHz are achieved. Bandwidth for single-band mode at 1.75 GHz is 110 MHz (1.69 GHz -1.80 GHz). In Figure 4(c), single-band and wideband configurations are obtained however, the single-band operating frequency is 2.21 GHz and the bandwidth is 190 MHz (2.11 GHz - 2.30 GHz) while the wideband mode is ranging from 3.11 GHz to 9.0 GHz.

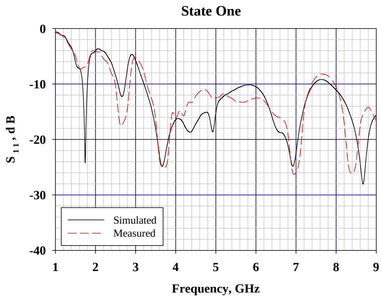
In Figure 4(d), the wideband configuration is achieved from 2.65 GHz to 9.0 GHz. Finally, in state five, quad-band mode is achieved at 1.52 GHz, 2.6 GHz, 3.64 GHz and 6.93 GHz as in Figure 4(e). The bandwidths of the quad-bands are 80 MHz (1.48 GHz - 1.56 GHz), 410 MHz (2.54 GHz - 2.95 GHz), 640 MHz (3.39 GHz - 4.03 GHz) and 710 MHz (6.58 GHz - 7.29 GHz).

Generally, the measured results agree well with the simulated results as shown in Figure 4. However, there are two major differences that we can notice. First, all lower frequency operates in 1.5 GHz to 1.7 GHz such as in states one, two and five, the $S_{11}$ value is lower compared to the simulated result. For example, in state one, the $S_{11}$ value for simulated at 1.7 GHz is -12.8 dB but the measured value is -7.0 dB only. In state two, simulated $S_{11}$ at 1.7 GHz is -11.6 dB while the measured $S_{11}$ value is -6.6 dB. In state five, -11.8 dB of $S_{11}$ value at 1.5 GHz is obtained in simulated value and -7.3 dB is achieved in measured result. Even though the measured value is lower, the antenna still operated because more than 70% of power still transmitted [28].

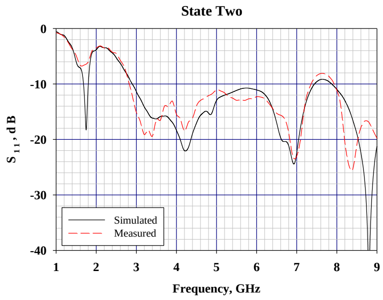
Second, there is a shifting frequency in state three. In simulated, the antenna is operated from 2.11 GHz to 2.30 GHz. However, in the measured result, the antenna is operated from 2.2 GHz to 2.6 GHz. Problems in the measurement value may occur due to the fabrication error or coming from the board itself. Based on the result shown in Figure 4, a filter can be introduced in order to get another mode such as single-band and dual-band only as reported in [29].

In Figure 5, current distributions for state one is shown. In Figure 5(a), current for 1.7 GHz is mainly located around the first arm. While the current for 2.6 GHz is located at the second arm as in Figure 5 (b). Obviously, it can be seen that arm1 and arm2 have contributed to the narrowband operation. The wideband mode current distributions are shown in Figure(c-e). Figure 5(c) shows the current distribution at 3.5 GHz. While in Figure 5(d), at 5.8 GHz and in Figure 5(e), at 7.5 GHz. The explanation of the wideband state is mentioned in [30]. Mostly, all current distributions for all frequencies and states are the same as described for state one.

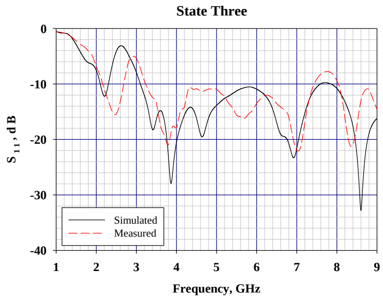
In Figure 6, radiation pattern results are presented for state one. From the figure, the H-plane pattern (black line) looks omnidirectional for all frequencies while in E-plane pattern (red line) is bi-directional type. The radiation pattern shows satisfactory performance over the entire frequency range, in all states for both simulated and measured results. Only the measured result for H-plane is different from the simulated ones. Almost in all states, at 90° and 270° directions have a difference. The error is probably due to the placement of antennas during the measurement process.



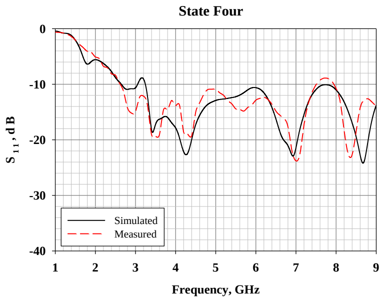
(a) State one



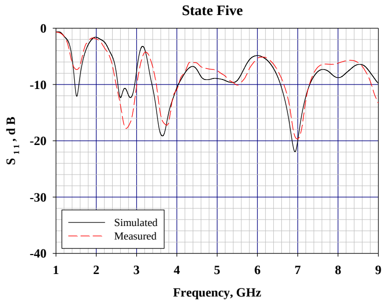
(b) State two



(c) State three

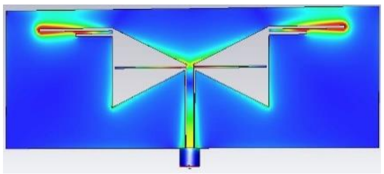


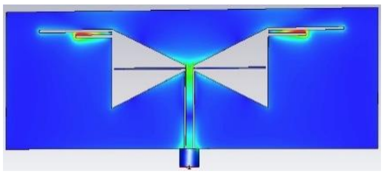
(d) State four

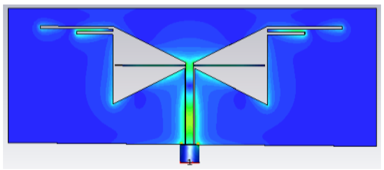


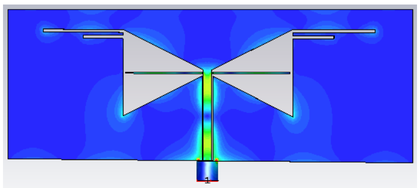
(e) State five

Figure 4. Simulated and measured $S_{11}$ results


(a) 1.7 GHz


(b) 2.6 GHz


(c) 3.5 GHz


(d) 5.2 GHz

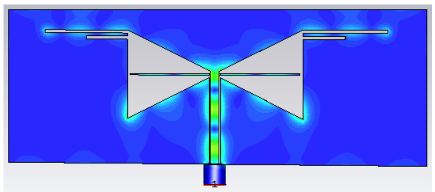
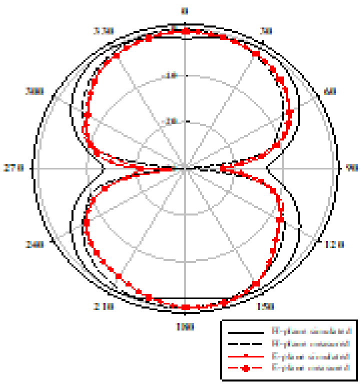
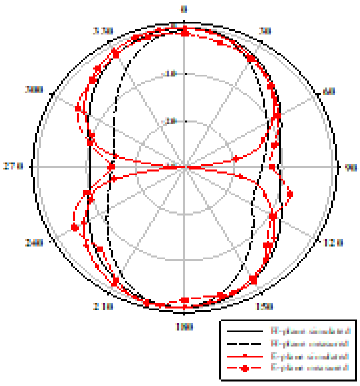
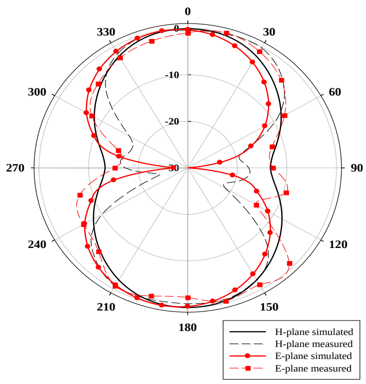

(e) 7.5 GHz

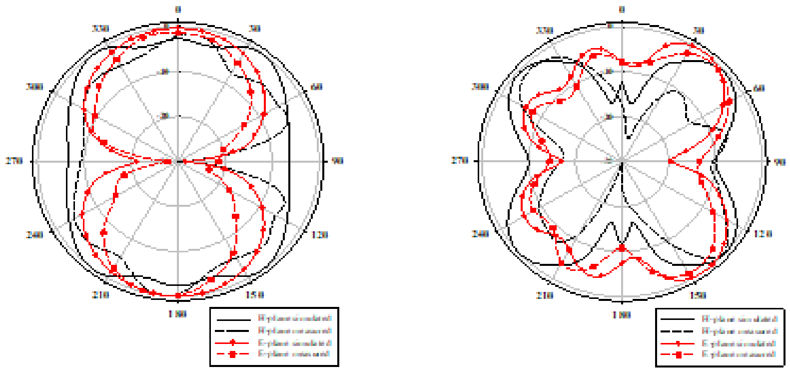
Figure 5. Simulated current distribution results


(a) 1.7 GHz


(b) 2.6 GHz



(c) 3.5 GHz



(d) 5.2 GHz (e) 7.5 GHz

Figure 6. Simulated and measured radiation pattern results for state one (straight black line: H-plane simulated, dashed black line: H-plane measured, straight red line circle symbol: E-plane simulated, dashed red line square symbol: E-plane measured)

Table 2 tabulates the gain result for all states. Currently, only measured $S_{11}$ and radiation patterns can be showed since there are no sufficient tools to measure the gain value. Simulated gain is recorded at the maximum direction in 3D-plane. The highest gain is recorded at 3.5 GHz with a value of 6.24 dBi while the lowest gain at 1.7 GHz with a gain value of 0.4 dBi. As in the table, gain at lower frequency is lower compared to others. This might be due to the coupling effect or mismatch losses.

Table 2. Gain results for all states

| State | Mode | F1, GHz (Gain, dBi) | F2, GHz (Gain, dBi) | F3, GHz (Gain, dBi) | F4, GHz (Gain, dBi) | F5, GHz (Gain, dBi) |
|---|---|---|---|---|---|---|
| One (1) | Dual-band and wideband | 1.7 (0.40) | 2.6 (4.68) | 3.5 (5.33) | 5.2 (5.16) | 7.5 (2.43) |
| Two (2) | Single-band and wideband | 1.7 (0.65) | - | 3.5 (6.24) | 5.2 (5.35) | 7.5 (2.51) |
| Three (3) | Single-band and wideband | - | 2.2 (5.25) | 3.5 (5.62) | 5.2 (5.24) | 7.5 (2.72) |
| Four (4) | Wideband | - | - | 3.5 (5.97) | 5.2 (5.42) | 7.5 (3.19) |
| Five (5) | Quad-band | 1.5 (1.19) | 2.6 (3.94) | 3.5 (4.57) | - | 6.9 (5.20) |

## 4. CONCLUSION

The slotted bowtie antenna with additional structures provides the multi and wideband characteristics. By using the switches, the antenna has frequency reconfigurability to switch from one frequency to another. Additional features or modes can be added to the antenna by integrating the filter, to filter out unwanted frequencies. The simulated results are agreed well with the measured result in terms of $S_{11}$ and radiation patterns. This antenna is suitable for future multimode wireless communication networks. The ideal switches will be replaced by real switches such as pin-diode and MEMS switches, in order to be implemented in a real environment.

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