The Effect of Shorting Pin Locations on the Performance of a Pattern Reconfigurable Yagi-Uda Patch Antenna

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***Abstract*—This paper presents a linearly polarized Yagi-Uda patch antenna deployed with rectangular parasitic elements. In this work, the effect of shorting location or switching location towards the performance of beam tilt angle and reflection coefficient is investigated. By varying the shorting location, the direction of a main beam can be tilted to various angles. However, since the beam patterns overlap with each and other, only four shorting locations are proposed to achieve three sets of directive beam patterns which have maximum separation between them. The antenna is capable to steer the main beam to three different directions at theta of +30°, 0° and -30° at H-plane while sustaining a constant reflection coefficient bandwidth of 274 MHz around center frequency of 5.8 GHz. Operating around 5.8 GHz frequency, this antenna is capable to be used for WIFI and WIMAX applications.**

Keywords—Pattern reconfigurable; Yagi-Uda; RF swicth

I. INTRODUCTION

In recent days, antenna design has to satisfy the demand of various types of wireless application and need to overcome different types of propagation issues delivered by the ever-growing modern wireless communication systems. Antenna reconfigurability can be considered as the solution to this demand since it is capable to cope with the changes of application or propagation characterisitic in order to enhance or sustain the quality of the communication. Reconfigurable antenna can be defined as an antenna that can modify on or more property of the antenna without pertubing the other properties of the antenna. The antenna properties that are usually involved in reconfigurable antennas are such as radiation pattern, frequency and polarization. Since many applications today require portable or mobile devices, radiation pattern reconfiguration could be useful in improving the signal quality while reducing the effects from interference. The main challenge in radiation pattern reconfiguration is to maintain the other properties of the antenna. Such a scenario usually can be noticed in the design of patch-type reconfigurable antenna. The majority of works reported [1-3] unable to maintain the reflection coefficient (in other words resonant frequency) of the antenna when the reconfiguration is applied. Unlike these antenna design techniques, the antenna design with Yagi-Uda parasitic patch able to change the radiation pattern while sustaining the operating frequency of the antenna [4]. There are two possible techniques that can be employed to achieve the beam tilt with Yagi-Uda patch antenna. First, the beam pattern can shifted/altered by changing the dimension of the parasitic element as reported in [5]. Using switches, the length of the parasitic element can varied thus it provides imbalance impedance between the driven element and parasitic elements, where such characteristic able to produce the changes in the radiation pattern. Secondly, any of the parasitic elements can be shorted to the ground to act like a reflector and the remaining parasitic element works as a director. With the aid of the reflector and director (pushing and pulling effect), the radiation pattern is tilted towards the director, or opposite to the reflector. This paper adopts the later method where the radiation pattern reconfiguration of Yagi-Uda parasitic patch antenna is investigated with respect to the balanced shorting pins location on the parasitic element. For the sake of simplicity, the shorting locations are assumed as the switching lcoation. The presence of the shorting pin can be considered as the ON condition and the absence of the shorting pin can be considered as the OFF condition. The following section provides the antenna model and the operation principle of the Yagi-Uda patch antenna. Then, Section 3 and 4 carries out investigation to identify the optimum locations of the shorting pins to obtain the best directive beam patterns and tolerable S_{11} bandwidth. Section 5 presents the final and optimized antenna design with four shorting pins. Finally, some conclusion remarks are given in Section 6.

II. ANTENNA STUCTURE AND RADIATION MECHANISM

Fig. 1 depicts the physical structure of the Yagi-Uda patch array antenna. The antenna consists of three parallel patches on a full grounded Taconic dielectric substrate with a thickness of 1.6 mm and a dielectric constant (ε_r) of 2.2. The driven element or the center rectangular patch has a width of *W* mm and length of *L* mm. The antenna is fed through a SMA probe from the back of the antenna. The feed location *a* is optimized to achieve a desired input impedance. The parasitic elements are smaller with respect to the driven element where the width and length are denoted as *W′* and *L′* respectively.

Each parasitic element is connected to the ground plane at the back of the antenna through a switch, where shorting pin represent as the artificial switch.. The location of the shorting pin is crucial in determining main beam with optimum tilt. As depicted in Fig. 1, the shorting pin is located at the coordinate of (-*u*,-*v*) and (*u*,-*v*) with respect to the origin. First, the *v* value is optimized to enable a good beam tilt. To investigate the performance of beam steering and the changes in radiation pattern, the *u* value is varied from 12 to 28 with a step size of 2. All the related parameters that refer to the antenna dimension are tabulated in Table I.

TABLE I. BEAMFORMING CHARACTERISTICS BASED ON SWITCHING CONDITION

Antenna parameters	Size (mm)
a	3
u	[12:2:28]
v	6
g	2
W	19
W'	0.9**W*
L	16.1
L'	0.98**L*

The presence of the shorting can be considered as ON condition while the absence of the shorting pin can be assumed as OFF condition. Both parasitic elements are physically of the same electric length, switching their states between short and open circuit results them to act as a reflector and a director, respectively. In these configurations, the radiation patterns are controlled by the coupling between the driven element and the two parasitic elements. When S1 is ON and S2 is OFF, the beam will be tilted to –θ direction in *xz* plane. The complementary configuration will tilt the beam towards +θ in *xz* plane.

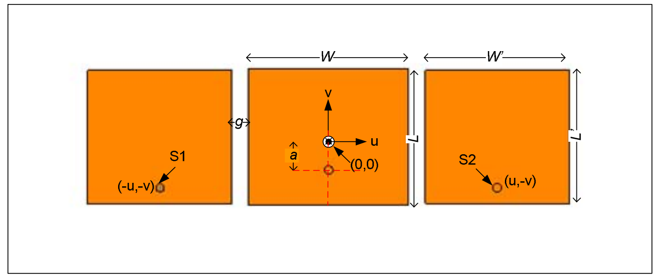

Fig. 1. Pattern reconfigurable Yagi-uda patch array antenna

III. INVESTIGATION ON THE RADIATION PATTERN OF THE ANTENNA WITH DIFFERENT SHORTING PIN LOCATIONS

The simulation is carried out to investigate the beam tilt produced by the configuration S1-OFF and S2-ON. Meanwhile, S1-ON and S2-ON configuration is applied to produce beam tilt angle at θ=0° direction. In what follows, the analysis has been carried out to compare the effect of the shorting location to both configurations namely, i) S1-OFF & S2-ON and ii) S1-ON & S2-ON. Based on the results obtained, the final switching configuration will be selected for the optimized antenna design.

A. Directive radiation pattern at -θ direction

The result of beam tilt angle by the S1-OFF & S2-ON configuration is presented here. Fig.2 depicts that the direction of the main beam varies as the shorting location is varied from *u* = ±12 to *u* = ±28. Careful observation reveals that at the nearest or the furthest location of the shorting pin, the largest beam tilts can be produced.

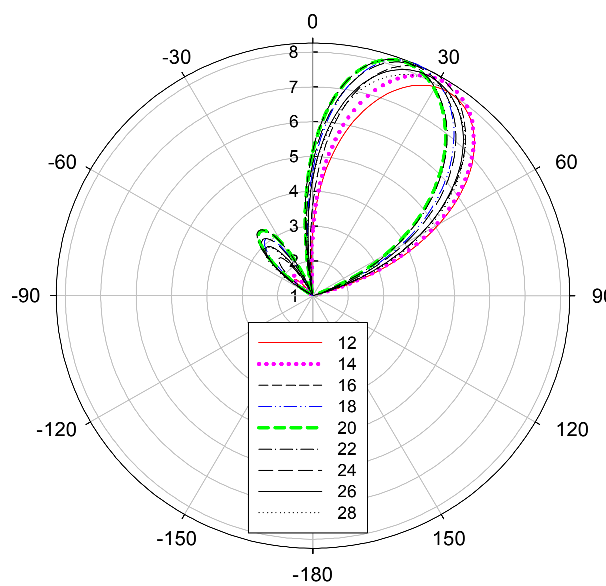

Fig. 2. Polar radiation patterns for different locations of shorting pins when S1=OFF and S2=ON

B. Directive radiation pattern at θ=0° direction

Fig.3 shows the result of polar radiation pattern obtained by the different shorting pin locations for the case of both S1 and S2 are ON. It shows, when the shorting pins are located at *u* = ±20, it produces a directive beam pattern with the highest realized gain. Furthermore, careful observation reveals that a directive beam pattern unable to be produced when the shorting location at $u \leq 18$. It can be noticed that the antenna produce a divisive beam pattern when the shorting location is at $u = \pm 12$, although this location produce the largest beam tilt angle in the previous configuration of the switch.

TABLE II. BEAMFORMING CHARACTERISTICS BASED ON SWITCHING CONDITION

Switch Mode	$\pm u$	Maximum gain, G	Tilt angle, θ_m	HPBW	S11 Bandwidth
S1=OFF ; S2=ON	12	8.0	33	53.3	5.785 – 5.892 (107 MHz)
	14	8.2	31	52.4	5.747 – 5.918 (171 MHz)
	16	8.3	27	51.8	5.669 – 5.944 (275 MHz)
	18	8.3	24	50.8	5.647 – 5.965 (318 MHz)
	20	8.2	21	50.5	5.608 – 5.973 (365 MHz)
	22	8.2	22	50	5.632 – 5.973 (341 MHz)
	24	8.2	24	52.6	5.646 – 5.972 (326 MHz)
	26	8.1	27	54.5	5.668 – 5.967 (299 MHz)
	28	8.0	30	56.1	5.676 – 5.974 (298 MHz)
			$\theta=0^{O}$		
S1=ON ; S2=ON	12	3.08	0	-	-
	14	6.2	0	107.2	5.752 – 5.870 (118 MHz)
	16	6.8	0	91.2	5.667 – 5.911 (244 MHz)
	18	8.1	0	67.7	5.599 – 5.943 (344 MHz)
	20	8.6	0	60.4	5.569 – 5.950 (381 MHz)
	22	8.4	0	64.6	5.583 – 5.947 (364 MHz)
	24	7.9	0	75.9	5.606 – 5.944 (338 MHz)
	26	7.0	0	94.8	5.626 – 5.946 (320 MHz)
	28	6.7	0	101.6	5.629 – 5.954 (325 MHz)

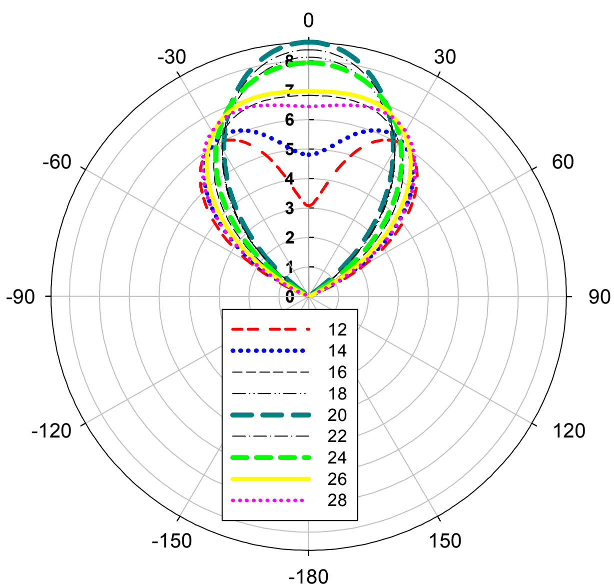

Fig. 3. Polar radiation patterns for different locations of shorting pins when S1=ON and S2=ON

IV. INVESTIGATION ON THE REFLECTION COEFFICIENT OF THE ANTENNA WITH DIFFERENT SHORTING PIN LOCATIONS

In antenna design, the most commonly referred parameter is S_{11}. S_{11} represents how much power is reflected from the antenna, therefore it is known as the reflection coefficient [6]. For instance, if S_{11}=0 dB, it means that all the power is reflected from the antenna and no power is radiated. To ensure that the power delivered to the antenna is at least 70 %, the S_{11} of the antenna should be <-10 dB. Although most of the previously designed reconfigurable antennas [2, 3] fail to achieve the common S_{11} bandwidth level for all switches configuration, this work aims to achieve this S_{11} level with a bandwidth of at least 200 MHz. Through simulations, it has been also identified that the S11 bandwidth by the antenna is affected by the shorting locations and the configuration of the switch. Table II tabulates the result of S_{11} bandwidth obtained when the shorting pin locations for the case of both S1 and S2 are ON; and S1 is OFF and S2 is OFF. The antenna unable to obtain a tolerable S_{11}<-10 dB when the shorting locations are very near to the driven element. A tolerable S_{11} bandwidth approximately of 300 MHz can be obtained for the shorting locations at $u \geq 18$.

V. Optimized Antenna Design Parameters and Modes of Operation

From Table II, it can be seen that at S1=OFF & S2=ON configuration, the maximum tilt angle of 33° can be obtained with the shorting pins are located at u = ±12. However, at these locations, the antenna only manages to obtain S_{11} bandwidth of 107 MHz. The next configuration that can offer tolerable tilt angle and S_{11} bandwidth is at the shorting location of u = ±28. Therefore this configuration is selected to attain the best performance for steering operation. On the other hand, the optimum shorting pin locations to get the directive beam pattern at θ=0° are at u = ±20. At these shorting locations, the antenna is able to have the highest gain and the largest S_{11} bandwidth. The similar shorting location that is selected for S1=OFF & S2=ON configuration (u = ±28) cannot be used for S1=ON & S2=ON configuration because at these shorting location the antenna attain reduced gain and narrow S_{11} bandwidth. Overall, it can be concluded that, to attain the best performance at each steering angle, four shorting locations are necessary. Two switches are necessary to obtain steered directions at -30° and +30°, where these switches are located at u = ±28. Meanwhile two switches are required at u = ±20, to produce the directive beam pattern at 0°. Working with the four shorting locations, the antenna will have a common bandwidth from 5.676 MHz to 5.950 MHz. The final design consists of four switches or shorting locations to obtain three directive beam patterns at +30°, 0° and -30°. The directive beam patterns of the three directions with the respective ON/OFF condition of the shorting pins are tabulated in Table 3. Note that, the tilt angle of -30° is obtained with complementing the switch condition of +30°.

TABLE III. Beamforming Characteristics based on Switching Condition

Switch Mode				Direction of the main beam, θ
S1	S2	S3	S4	
OFF	OFF	ON	ON	-30°
ON	ON	OFF	OFF	+30°
OFF	ON	ON	OFF	0°

VI. Conclusion

This paper presents an investigation of the shorting pin locations towards the beam steering characteristics and S_{11} bandwidth of a Yagi-Uda patch antenna for 5.8 GHz operating frequency. Thorough investigations reveal that the different locations of the shorting pins with different operating mode yields various beam patterns. Based on the optimum results for each of the configuration, four shorting pin locations are selected for the final antenna design. Based on the selected shorting pins, three modes can produce directive beam pattern to three different directions at θ = -30°, 0° and +30° with an average peak gain of ~8 dBi in all directions. Apart from that, the antenna is able to provide 274 MHz common bandwidth of S_{11} < -10 dB regardless the mode of antenna operation. Different shorting pin location may be chosen for the antenna to improve the bandwidth but with the trade-off of reduced beam tilt angle and vice versa. Dimension wise, the proposed antenna is compact and can be easily installed at portable wireless devices.

Acknowledgement

The authors would like to thank the contributions of Universiti Malaysia Perlis (UniMAP) and the Ministry of Malaysian Higher Education (MOHE) of Malaysia for the Ph.D. scholarship of the author which enabled the production of this article.

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