A Design of Switched-Beam Yagi-Uda Antenna for Wireless Sensor Networks

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Abstract - **In this paper, we present a design of the Yagi-Uda antenna, which can be switched to achieve radiation patterns toward different angles with a step of 45 degree. The antenna covers the ISM band for SRDs with a center frequency of 2.45 GHz. There are eight Yagi-Uda antennas combined in a circle form. Each Yagi-Uda antenna consists of a bended reflector, a bended driven and a bended director. The bended reflector is shared for different Yagi-Uda antenna by PIN diodes. Simulated results show that eight switching beams covered all directions in E plane with particular direction beam-width around of 60 degree. The gain of the main lobe is greater than 5.5dBi, whereas the side lobe is kept 11dB smaller than the main lobe. Thanks to the pattern switchable ability and its simple design, the antenna can be used for the master sensors in wireless sensor networks, or for communicating devices in cognitive radios.**

Keywords: *printed Yagi-Uda antenna, switched-beam, reconfigurable radiation pattern.*

I. INTRODUCTION

Wireless sensor networks (WSN), recent years, receives a number of research attentions because of various potential applications [1]. In agricultural applications of a wireless sensor network, the slave and master nodes might be placed on different complex areas. The life-time of this network depends on how much the energy of each node used. Moreover, the quality of one's data transference is affected strongly by the interference among slave, master nodes. To solve these problems, it is necessary to utilize directional antennas for nodes. For the slave nodes, a directional antenna is good enough because it might only need to communicate forward its master node. However, the master nodes should be able to connect to all of the slave nodes. For such master nodes, a switched-beam antenna is necessary for to save energy and enhance data throughputs.

Four main reconfiguration technique for antennas up to present have been introduced including optical variations [2] [3], physical movement schemes [4], material change mechanisms [5] and electrical switches [6][7]. Among these techniques, electrical switches using PIN diodes tend to be a good candidate in terms of cost and simplicity. An example of switched-beam antenna for WSN nodes for energy saving is introduced in [6]. The antenna is designed based on composing of four arrays of two L-shaped quarter-wavelength printed slot antenna elements arranged in a symmetrical planar structure. The steering of its radiation pattern is implemented by controlling the feeding of the antenna elements. This design achieved the switched beam in eight possible different directions in the azimuth plane. An advanced point of this design is that its size is compact and the side lobe about -14 dB compared to main lobe which is around 4.9 dBi. However, it remains some disadvantages such as the half power beam width (HPBW) is nearly 70 degree, which causes a large overlapping area. It is also difficult for this design to develop a structure that has more than eight radiating directions.

In [7], the authors present a reconfigurable radiation pattern for short-range radio communication devices. The main beam is switched flexibly in a quad-directional operation. The antenna can perform well within a compact size and limited necessary PIN-diodes for switching. Yet, the developed antenna can only switch its beam toward four-fixed directions. It would be difficult for master nodes to communicate in other directions.

In this study, we will present a design of Yagi-Uda antenna, which can be used to switch radiation patterns toward multiple angles. The PIN-diodes are used for switching and controlling elements of the antenna. The proposed fundamental Yagi-Uda antenna consists of a bended reflector, a bended driven and a bended director. The bended reflector is shared for other Yagi-Uda antenna in different directions by PIN diodes. By selecting the state ON/OFF of the PIN-diodes attached on the feeding line and reflector elements, we can activate single Yagi-Uda antenna toward a given direction, thus steering its main beam.

The rest of this paper is organized as follows. In section II, the fundamental design of a single antenna, the configuration of the proposed switched-beam antennas, and the PIN diode scheme are illustrated and analyzed. Some simulation results of the proposed antennas will be shown in sections III, followed by concluding remarks in section VI.

II. DESIGN AND ANALYSIS

The proposed antenna is designed base on printed Yagi-Uda antennas. In order to achieve switched-beam ability, several fundamental Yagi-Uda antennas are combined in a circle form and switched by PIN diodes. We intend to design the antenna working at the center frequency of 2.45 GHz in ISM bands for SRDs [8]. The FR4 PCB epoxy PCB (related permitivity of 4.4 and loss tangent of 0.02) is selected as the substrate. For practical feeding issue, two arms of the driven element will be placed on the both sides of the substrate.

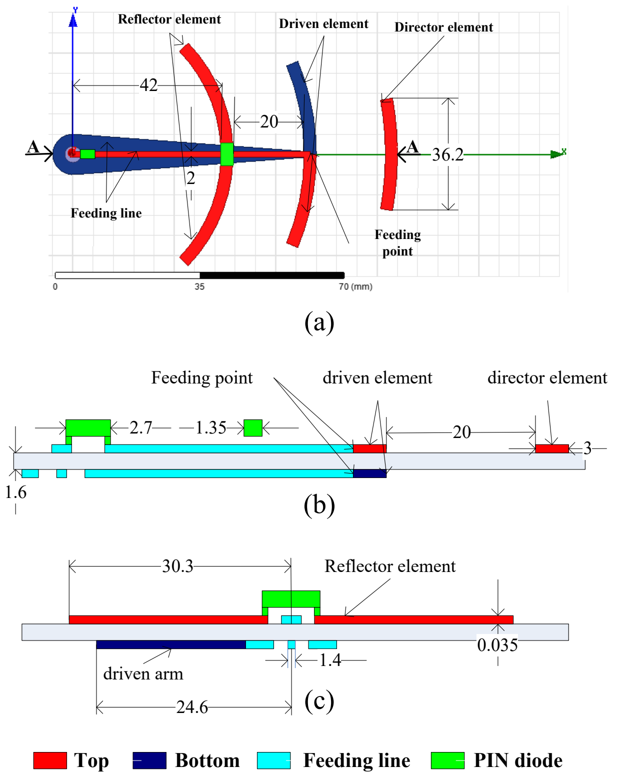

Fig. 1 Configuration of single Yagi-Uda antenna; a) XY plane b) A-A side view c) YZ plane. All dimensions are in mm.

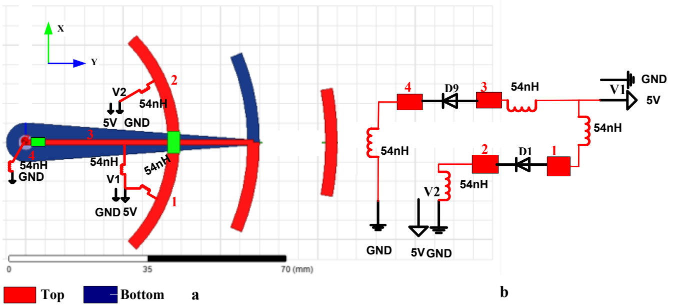

Fig. 2 Diode controlling circuit; a) actual circuit integrated in the antenna board b) equivalent circuit [7]

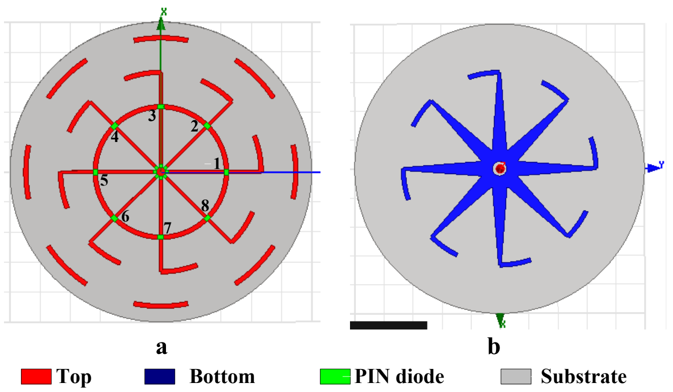

Fig. 3 Proposed switched-beam antenna consisting of 8 fundamental single antennas; a) the top layer b) The bottom layer

The proposed design of the fundamental antenna is shown in Fig. 1, which has three main parts: Yagi-Uda antenna, transmission feeding line and PIN diodes.The Yagi Uda antenna consists of a bended reflector, a bended driven and a bended director. One arm of this driven element is on the bottom side and the other is on the top side as illustrated in Fig. 1(a). By bending the elements of the Yagi-Uda antenna, it is possible to combine many fundamental antennas in the circle easily and reducing the antenna's size by reusing the reflector elements. The reflector elements can be shared for different Yagi-Uda antenna toward in different directions. They are connected or disconnected by PIN diodes. At each connection, the PIN diode here also plays as a bridge over the top-layer transmission feeding line as shown in Fig. 1(c) to isolate the transmission feeding line to the reflector elements.

In order to feed the driven element of Yagi-Uda antenna, we design a transmission feeding line laying on top and bottom sides of the substrate. The top transmission line will be fed to the top arm of the driven, whereas the bottom line is connected to the bottom arm of the driven. The other terminal of the feeding line is connected to a 50-Ohm SMA connector. The top feeding line and SMA pin are also connected or disconnected by PIN diodes attached on.

Fig. 2 shows the schematic of the PIN diodes for selecting actual active Yagi-Uda antenna in particular directions. The locations of the PIN diodes as well as RF components of the controlling circuit are highlighted. In Fig. 2(b), the PIN diode D1 is in ON-state because of the 5voltage-Biasing between V1 and V2 (V1, V2 are connected to 5V and GND respectively). Similarly, the PIN diode D9 is ON-state. Therefore, two parts of the reflector element are connected together and the driven element is fed by SMA connector. On the other hand, PIN diodes D1 and D9 are in OFF states when the V1 is connected to GND. Therefore, in this cause, this particular antenna is not active.

Now, we can combine several the fundamental bended Yagi-Uda antennas with switched-beam ability. In this research, we proposed a combination of eight fundamental single antennas. The proposed antenna can switch its main radiation patterns toward different angles with a step of 45 degree. Fig. 3 illustrates the configuration of the proposed antenna structure. Here, eight sectors are numbered from one to eight. Apart from this configuration, it would be possible to develop with more than eight switched beams such as 16, 32 or even more switched beams with narrower beam-width. The methodology is as simple as adding more fundamental antennas in a circle from. However, there might appear some drawbacks such as bigger antenna size, lager amount of PIN diodes required and increased complexity.

For the case of eight switchable beams as shown in Fig. 3, in total, sixteen PIN diodes are used and placed on the reflector circle and feeding lines (top layer). They are numbered by D1, D2… to D16. Detailed information of diode locations are shown in Fg. 4. The steering of these eight beams is implemented by changing the state ON/OFF of eight PIN diodes placed on the reflector circle and 8 PIN-diodes attached on the top feeding line. The PIN-diodes (BAP50-03) is utilized to realize this design. All of the diodes are located on the top metallization as shown in the Fig. 4. A controlling PIN-diode circuit is proposed in the Fig. 5. It is as similar to the controlling circuit of the fundamental antenna. The controlling the particular direction of this design is carried out through the DC-voltages, (5V or 0V), are connected to V_N, where N=1, 2,…,8 respectively. The sector operation of this antenna is indicated in the Fig. 5 and Tables 1. For instance, the sector 1 is chosen when the V_N DC-Voltages are set as "$V_1V_2V_3V_4V_5V_6V_7V_8$"= “10000000”, in which “1” and “0” indicate the high voltage level (5V) and low voltage level (0V), respectively. In this case, a pair of diodes, D1, D9 as Fig. 4 is in ON-state and the others are in OFF-state. Therefore, one fundamental Yagi-Uda antenna is active in the radiating sector 1 and the other do not work.

There are eight radiation patterns which are directed respectively forward 90, 45, 0, 315, 270, 225, 180, 135 degree in the E plane. Correspondingly, only one pair of the diodes, (D1-D9), (D2-D10), (D3-D11), (D4-D12), (D5-D13), (D6-D14), (D7-D15), (D8-D16) is in ON-state, while all of other pairs are in OFF-state. Table I shows the description of this performance with specified codes for controlling the DC-voltages V_N.

III SIMULATION AND RESULTS

We model the antenna configuration and simulate it using the computational software Ansoft’s HFSS. In simulation, the diodes are assumed as ideal switches with no delay durations and no loss part energy.

Fig. 6 shows the reflection coefficient of one active Yagi-Uda antenna. As can be seen from this figure, the proposed antenna offers a wide -10dB bandwidth, covering the frequency band from 2.39 to 2.55 GHz with a center frequency of 2.45 GHz. The relative bandwidth of the antenna is about 6.47%. Such bandwidth is usually reasonable for sensors in general wireless sensor networks.

Figs. 7 show the simulated radiation pattern of an active Yagi-Uda antenna in the proposed antenna. We can see that the antenna is directional with low back lobe level. The main lobe of the radiation pattern is about 5.7 dBi, while the side lobe is kept 11dB smaller than the main lobe in E-plane. The half power beam width (HPBW) is 59.3 degree. Thanks to the symmetric design, all Yagi-Uda antennas in the whole design should have similar performances regardless to its directions.

Fig. 8 shows the radiation pattern of different active Yagi-Uda antennas of the proposed antenna. As we can see from this figure, the main beam can be switched in E-plane in different directions, with a step of 45 degree. Each beam corresponds to different pairs of controlling PIN diodes (as shown in Table I).

Thanks to excellent performances of the proposed switched-beam antenna, it can be a good candidate in developing hardware for wireless sensor networks, especially where require energy saving in performance. Fabricating the proposed antenna and validating its characteristics is an important work in our near futures. To put it in actual applications, evaluations on the effects of the PIN diodes will be also interesting discussions.

TABLE I. DIODE STATE IN SELECTING BEAMS

Sec-tor	The division of radiation pattern regions		
	"$V_1V_2V_3V_4V_5V_6V_7V_8$" *“1”-5V; “0”-0V*	*ON-state*	*OFF-state*
1	“10000000”	*D1,D9*	The others
2	“01000000”	*D2,D10*	The others
3	“00100000”	*D3,D11*	The others
4	“00010000”	*D4,D12*	The others
5	“00001000”	*D5,D13*	The others
6	“00000100”	*D6,D14*	The others
7	“00000010”	*D7,D15*	The others
8	“00000001”	*D8,D16*	The others

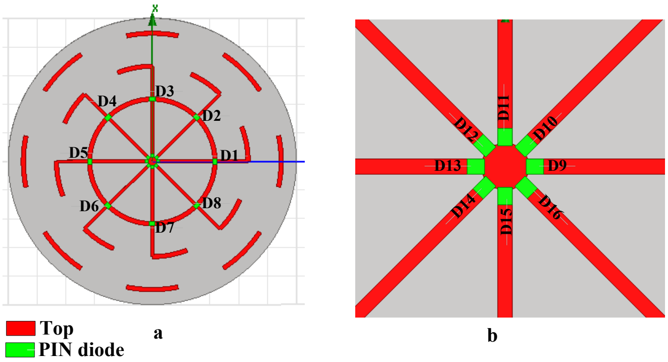

Fig. 4 Location of PIN diodes; (a) on reflector circle (b) on the top feeding lines

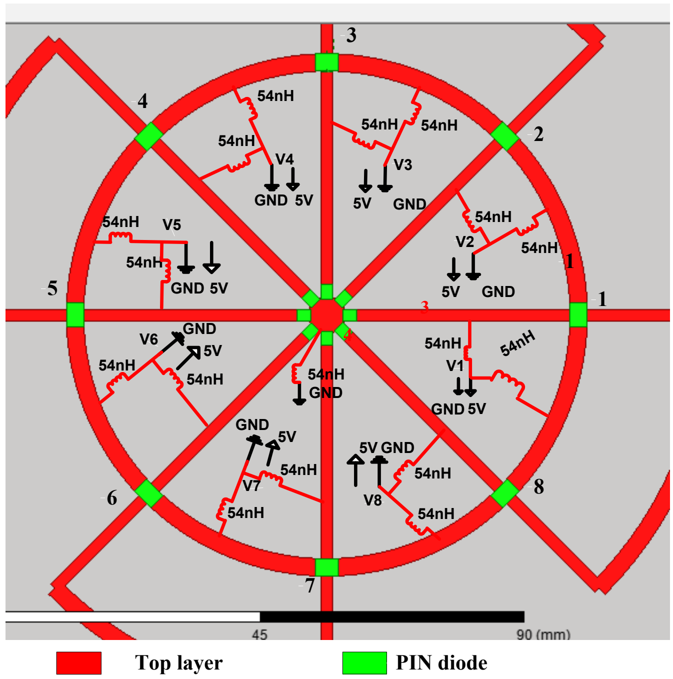

Fig. 5 Diode controlling circuit for eight radiating directions

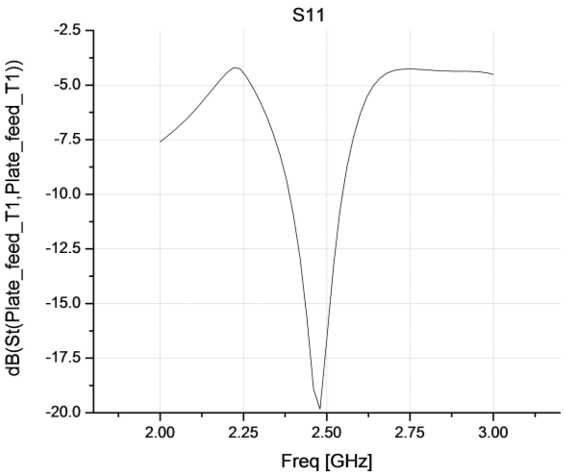

Fig.6 Simulated S11 of one active Yagi-Uda antenna

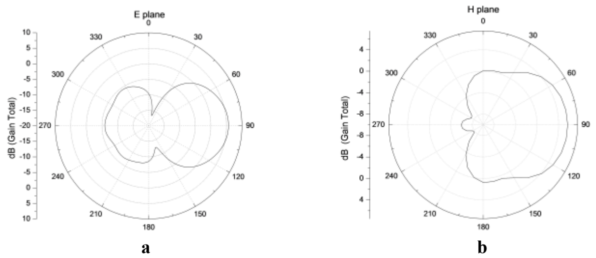

Fig.7 The simulated result Gain vs. phi in 90^0- direction main beam; a) in E plane, b) in H plane

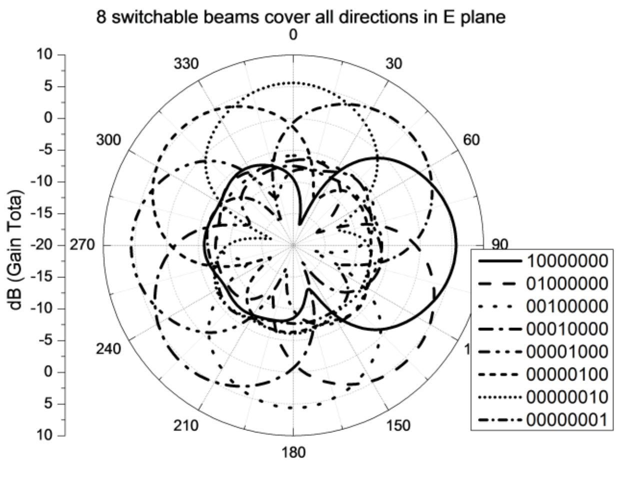

Fig. 8 Switched beams (in E plane) in different directions corresponding to different pairs of controlling PIN diodes

IV. CONCLUSIONS

We present in this paper a switched-beam Yagi-Uda which can be used for wireless sensor networks. The proposed fundamental antenna is with bended the reflector, driven and director of Yagi-Uda antenna. A group of 8 fundamental Yagi-Uda antennas are formed in a circle configuration, where the segments of reflectors are shared. PIN-diodes are utilized to connect or disconnect segments of reflector, and to control the feeding of each fundamental Yagi-Uda antenna. This proposed antenna can offer eight directional beams toward different directions, making it suitable for sensing or communicating in sensor networks and cognitive radios. This design offers good gains, wide bandwidth and beam-width in a simple configuration. In the next works, we will focus on fabricating the antennas, and measuring its characteristics. In addition, we will be also addressing the issue of inward propagating radiation pattern and potential interesting applications in near future.

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