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A NOVEL GREEN ANTENNA PHASE-SHIFT SYSTEM WITH DATA ACQUISITION BOARDS

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Abstract—A novel green phase shifter system is proposed in this research. The system is developed by a combination of reconfigurable beam steering antennas and data acquisition (DAQ) boards. A combination of two reconfigurable beam steering antennas, located side-by-side, forms a spatial configuration structure with a fabricated 'green' element plank of rice husk placed in between. The concept of a spatial configuration technique has been 'mutated' by shifting the structure of spiral feed line and aperture slots of first beam steering antenna by as much as 45°. The PIN diode switches connected to the DAQ boards enable the intelligent capability of the spatial antennas. The activation of certain degree radiation patterns of either the first beam steering antenna or the second beam steering antenna depends on the memory of the DAQ boards — Beam Manager. When an intruder comes from the cardinal angles of 0°/360°, 90°, 180°, or 270°, its range and angles' location will be automatically detected by the first antenna through the output ports of the 1st DAQ: P1.0, P1.1, P1.2, and P1.3. The second antenna is then activated by the output ports of the 2nd DAQ: P2.0 up to P2.3, to adaptively maneuver the beam towards four different ordinal directions of 45°, 135°, 225°, and 315°.

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As a result, this system collectively contributes to the development of eight angles of radiation patterns, which can be rotated in 45° steps within 0.01 ms and successfully cover 360° without any uncovered and overlapped angle; 0°/360°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. Moreover, a mutual coupling effect generated by the spatial configuration of both antennas is alleviated by the element plank of rice husk, whose width, length, and thickness are 45 mm, 150 mm, and 10 mm, respectively. Possessing the characteristics of an adaptive new phase shifter concept and assisted by the green element of a rice husk, this system is potentially an effective way to decrease the number of drop outs and lost connections, and provides larger coverage. It is a promising candidate for installation with a WiMAX application.

1. INTRODUCTION

A phase shifter is normally composed of a microwave circuit that is capable of controlling the phase shift or phase difference between two or more quantities of radio frequency signals that are neither transmitted nor received by an antenna. Inherently, a phase shifter appears as additional hardware to be connected to the antenna in order to change its phase [1–4]. Although this conventional system is already established, the combination of a separated phase shifter with an antenna leads indirectly to the complex and bulky structure as shown in Figure 1. Moreover, the phase shifter itself also poses a few challenges in that it requires a high biasing DC voltage and dielectric breakdown. It also has packaging issues, limited capacitance tunability, and lower inductors for filter designs. Hence, there's a crucial need to develop a new, efficient, and smaller phase shifter system.

Experimentally, antennas are only front-end transducers converting RF signals into electromagnetic waves that are moving through a sheltered cable [5]. There is no way an antenna's output phase can be controlled without the support of an external phase shifter. However, in this research, a fast phase shifter system has been invented by merging the spatial structure of reconfigurable beam steering antenna with Data Acquisition boards (DAQs) to become one single element. Hence, the effectiveness of this approach in reducing the dimensions of the overall structure is proven and its impact on beam steering tunability has been confirmed through measurements. Moreover, DAQs that are connected to PIN diode switches of spatial beam steering antennas allow a fast switching capability between their output phases within 0.01 ms [6].

Typically, spatial structure is one of several wireless diversity methods employed to improve the quality and reliability of a wireless link by using two or more antennas that are co-located toward each other [7–9]. In this research, the capability of this structure in producing pattern diversity (phase changing) with the support of the PIN diode switches has been exploited as a novel phase shifter for the beam steering antennas to cover 360° without any uncovered and overlapped angles; 0°/360°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. This system can direct its beam in both cardinal (0°/360°, 90°, 180°, and 270°) and ordinal directions (45°, 135°, 225°, and 315°) when the spiral feed line and slots of the first beam steering antenna have been perfectly 45° shifted to add on the phase shifter capability of the second beam steering antenna.

However, the combination of the spatial structure with the PIN diode switches creates greater mutual coupling effects, which exist due to the electromagnetic (EM) interaction between the adjacent antenna elements [10–15]. Eventually, the high value of mutual coupling results in a reduction of efficiency and a distortion of the antenna's radiation angle.

Ferrite tiles (NiZn), foam polyurethane, and polystyrene are categorized as absorbent materials that have the capacity to eliminate the mutual coupling effects. The electrically thin ferrite tiles (NiZn) are used regularly for low-frequency range applications between 30 MHz up to 1 GHz. Meanwhile, foam materials such as polyurethane and polystyrene are specially made for higher frequency applications between 1 GHz and 40 GHz [16–18]. These foam materials are suitable for this proposed phase shifter as its operating frequency is at 2.3 GHz, but the exorbitant price has served to limit its deployment [17–19].

Hence, in this research rice husk, which is agricultural waste originally from paddy fields (Oryza Sativa), is investigated for use as an RF absorbent. The 35.77% composition of carbon contained in the rice husk allows for the potential development of new 'green' and natural absorbent since it has the ability to suck up the RF signals. Rice husk also consists of silica, which undoubtedly contributes to the

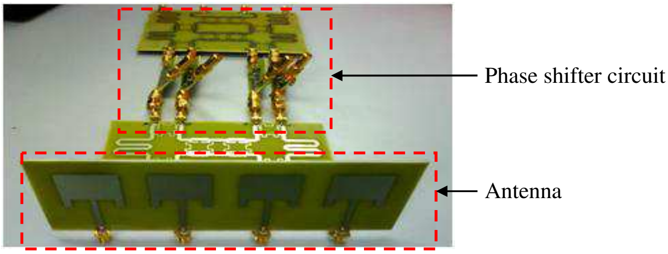


Figure 1. Phase shifter with array antenna [1].

lightweight material.

Furthermore, around 350,000 tons of rice husks are produced annually and traditionally burnt as these materials are considered 'waste' in Malaysia. This open burning is undoubtedly harmful to the environment [20]. Indirectly, instead of inventing a new green absorber, deployment of the rice husk is cheaper, easy to get, and harmless to the environment. The proposed phase shifter antenna, which is separated by the rice husk element plank, holistically contributes to the development of eight significant high gain beam steering radiation patterns without distorting and overlapping one another. Besides, it no longer needs an external circuit compared to the conventional phase shifter.

The paper is organized as follows: In Section 2, we explain the antenna design, which is a combination of spatial reconfigurable RLSA beam steering antennas, and we investigate the effects of the rice husk element plank structure. The results of the measurements are revealed in Section 4. Section 5 presents the conclusion.

2. SPATIAL RECONFIGURABLE RLSA ANTENNA STRUCTURE

In this research, the novel phase shifter's ability is realized through the spatial configuration structure of two reconfigurable radial line slot array antennas: R-RLSA 1 and R-RLSA 2, which are physically located besides each other. Each R-RLSA has been developed using an aperture coupled formation consisting of two different layers of substrates: the top and bottom layers. The top substrate is etched with a radiating element, while the bottom substrate is printed with feed line and aperture slots as shown in Figure 2. Relative permittivity (ε_r) of 4.7 FR-4 dielectric substrates with a loss tangent (δ) of 0.019 has been applied to form both substrates.

In this research, spatial means the two R-RLSA beam steering antennas, RLSA 1 and RLSA 2, are co-located next to each other

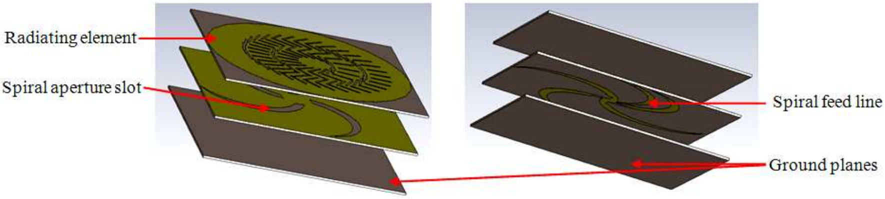


Figure 2. Configuration of single beam steering RLSA antenna.

Figure 3. Fabricated spatial R-RLSA antenna radiating surface.

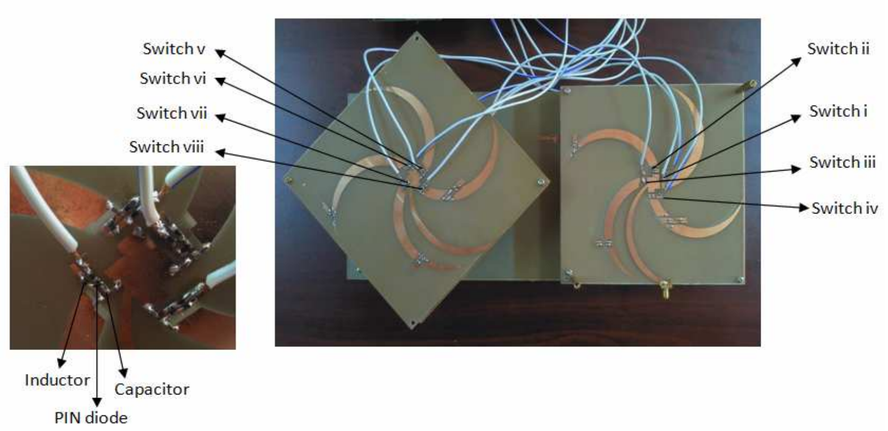


Figure 4. Fabricated spatial R-RLSA antenna feed line with PIN diode switches.

but separated by some distance as depicted in Figure 3. The spiral feed line of RLSA 1 has been perfectly 45° shifted to add on the phase shifter capability of the RLSA 2, as shown in Figure 4. Both feed lines of R-RLSA 1 and R-RLSA 2 are integrated with PIN diode switches in order to decide whether cardinal or ordinal directions are being activated. The R-RLSA 1 is only capable of steering its beam in four cardinal directions; 0°/360°, 90°, 180°, and up to 270°. The ordinal directions are the intermediate points between four cardinal directions which cover 45°, 135°, 225°, and 315°, and which belong to a shifted 45° of R-RLSA 2.

Each antenna of R-RLSA 1 and R-RLSA 2 has four PIN diode switches and each diode has been surrounded by two inductors and two capacitors to form the completed biasing switching circuit shown in Figure 4. This biasing circuit is crucial to control the degree of steering beam radiation patterns. Both R-RLSAs have four arms of spiral feed line with radius lengths of 70 mm, 60 mm, 50 mm, and 40 mm. The longer the arm of the spiral feedline is, the stronger the magnetic field will be. The longest arm has the greatest magnetic field and is thus able to 'force' the shorter arm's magnetic field. In the meantime, the spiral aperture slots act as a 'subway' to determine the amount of magnetic field transmitted from the spiral feed line to the R-RLSA radiating surfaces. When these circumstances continue to be replicated, the radiation pattern will move harmoniously to those magnetic field sequences and eventually enabled the beam steering capability.

However, the performance of those antennas might be impaired by the mutual coupling effects generated from side-by-side radiating elements and the biasing circuit. Hence, a 'rampart' line made of rice husk material has been introduced exactly in the middle of both antennas. Naturally, 35.77% of carbon has been identified as being contained in the rice husk materials, and with such a high percentage, the husks can be fully utilized to absorb radio frequency (RF) signals to counter those mutual coupling effects.

However, the raw rice husk has to go through some processes to strengthened its structure. By mixing the rice husk with resin chemicals usually composed of Urea Formaldehyde (UF) and Phenol Formaldehyde (PF) chemicals, a strong structure called element plank is produced as depicted in Figure 5. This element plank needs to be heated up to 180°C in a high-pressure machine for at least 10 minutes to manufacture the solid, stronger, and robust structure of element plank shown in Figure 5. After heating, this structure is stripped to the appropriate width, length, and thickness of 45 mm, 150 mm, and 10 mm. This plank is now ready to be applied to the spatial R-RLSA antennas as depicted by Figure 6. The plank has a relative permittivity of 1.6 and a loss tangent of 0.085.

Figure 5. The solid element plank of rice rusk.

Figure 6. The spatial R-RLSA antennas with rice husk element.

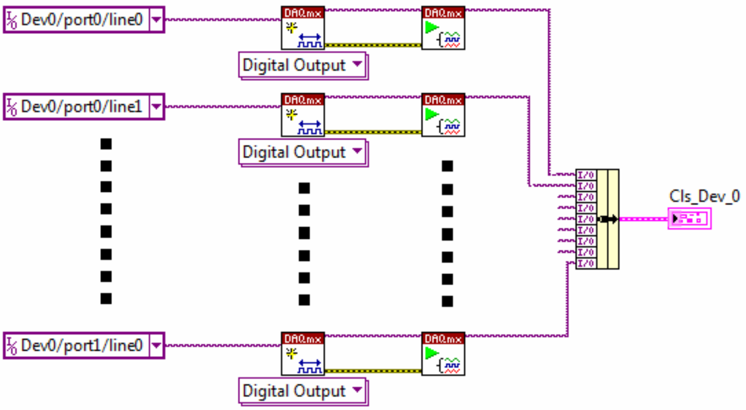


Figure 7. Assigning control state to digital output ports.

3. INTELLIGENT PHASE SHIFTER USING NATIONAL INSTRUMENTS DATA ACQUISITION MODULE (NI-DAQ) WITH LABVIEW SOFTWARE

The LabVIEW software used in this research controls a digital output port by creating a virtual channel corresponding to the actual output port. By creating this virtual channel, the operating system knows that the actual hardware is not in the system hardware. In this particular implementation, NI-DAQs (1st NI-DAQ and 2nd NI-DAQ) are connected to the system through the Universal Serial Bus (USB) port of the laptop. Each NI-DAQ can provide up to 12 digital input/output lines which are categorized under Port 0 and Port 1. Port 0 consists of eight digital input/output lines (named line 0 through 7) and Port 1 consists of four digital input/output lines (named line 0 through 3). Since this is a digital port, it will only provide an output value of 0 or 1 (0 volts and +5 volts respectively).

The design of the schematic diagram using LabVIEW software acts as an 'engine' in this research. The control of virtual channels has been divided into three stages: initializing, writing, and clearing. These processes are about assigning task functions to available digital input/output ports of the NI-DAQs. Figure 7 shows LabVIEW's schematic that provides the capability of assigning output ports. In Figure 8, the NI-DAQs, NI-DAQ 1 and NI-DAQ 2, are connected with PIN diode switches of R-RLSA 1 and R-RLSA 2 through its output

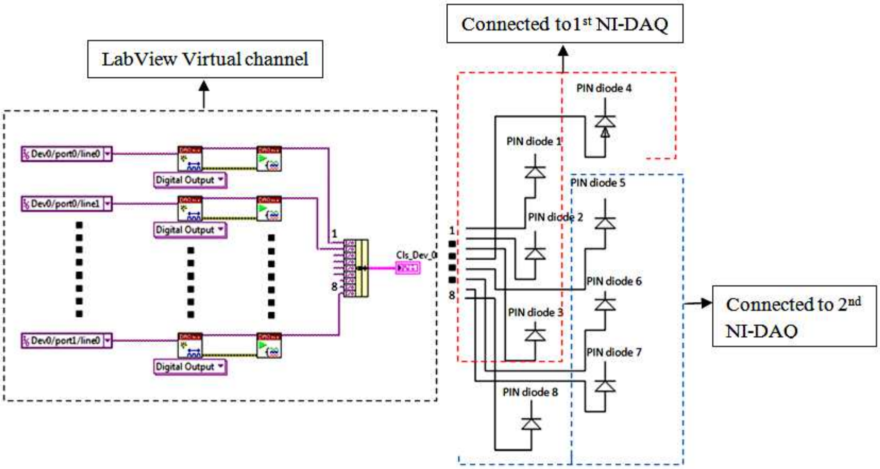
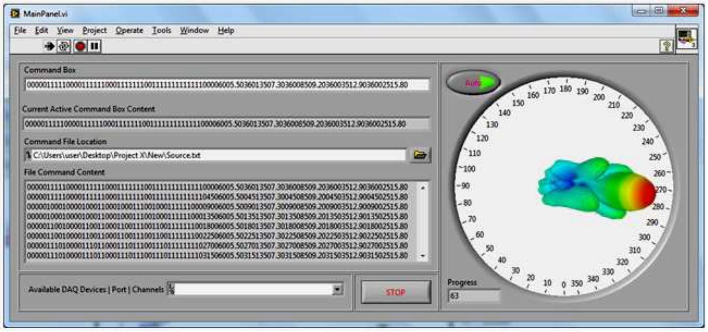


Figure 8. The schematic integration PIN diode of R-RLSA antennas into NI-DAQs.



Command Box
00000111110000111111000111111100111111111111100006005.5036013507.3036008509.2036003512.9036002515.80

Current Active Command Box Content
00000111110000111111000111111100111111111111100006005.5036013507.3036008509.2036003512.9036002515.80

Command File Location
C:\Users\user\Desktop\Project X\New\Source.txt

File Command Content
```
00000111110000111111000111111100111111111111100006005.5036013507.3036008509.2036003512.9036002515.80
00000111110000111111000111111100111111111111104506005.5004513507.3004508509.2004503512.9004502515.80
00000100010000100011000100011100100011111100009006005.5009013507.3009008509.2009003512.9009002515.80
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00000111010000111011000111011100111011111111031506005.5031513507.3031508509.2031503512.9031502515.80
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Available DAQ Devices | Port | Channels

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Figure 9. The GUI of the control system in LabVIEW software.

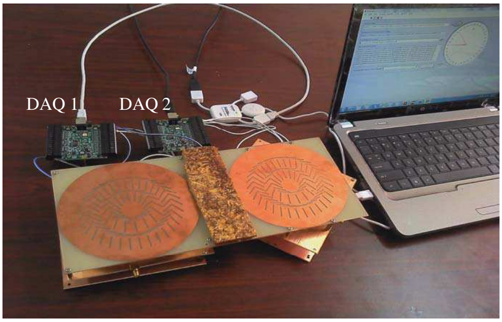


Figure 10. The fabricated integration of reconfigurable RLSA antennas into NI-DAQs.

ports of A1–A4 and B1–B4. The process of extracting the appropriate ASCII character, comparing it, and assigning it to the respective digital output port will be delivered by this schematic. Instead of manually activated switches, the output phase of both antennas could be inter-changed through the invented graphical user interface (GUI) of LabVIEW software as depicted in Figure 9. Figure 10 shows the completed integration of spatial antennas with DAQs and LabVIEW software.

4. RESULTS AND DISCUSSION

In this research, a novel phase shifter structure effectively steers the beams when used in spatial diversity configurations, and should provide performance similar to angle diversity. However, the effects of mutual coupling significantly distort the antenna patterns when deployed in such a configuration. The distortion in patterns will tend to decrease the performance of two closely spaced antennas. A left shifting of 15°, 45°, and 25° for the angles of 45°, 135°, 225°, respectively, is experienced by the R-RLSA antennas without involvement of the element plank. And a right shift of 60° has occured when it is supposed to be at an angle of 315°. It is clearly shown that mutual coupling effects have significantly twisted the radiation beam angles and consequently led to the overlapping beams and uncovered areas shown in Figure 11.

A number of patterns are obtained through proper phase and magnitude values by the presence of the rice husk element plank. The proposed R-RLSA antennas support a minimum beamwidth of 55°, which can be rotated in 45° steps, yielding a total of eight fine main beam patterns which successfully cover all 360° without any uncovered and overlapped angles. In order to realize a fast switching between beam radiation patterns, the novel phase shifter system crucially necessitates the storing of a set of patterns produced from a combination of a few PIN diode switches in the NI-DAQs' memory called 'Beam Manager'. The NI-DAQ's Beam Manager is programmed to be responsive in sensing any changes of required phase angle, depending on the user's needs. Once the location of the phase

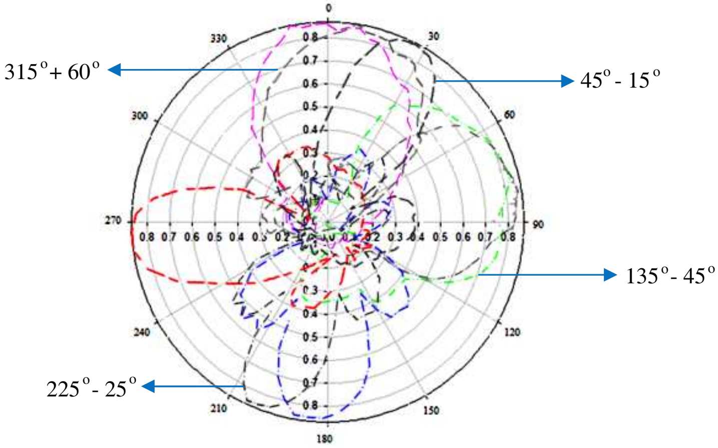
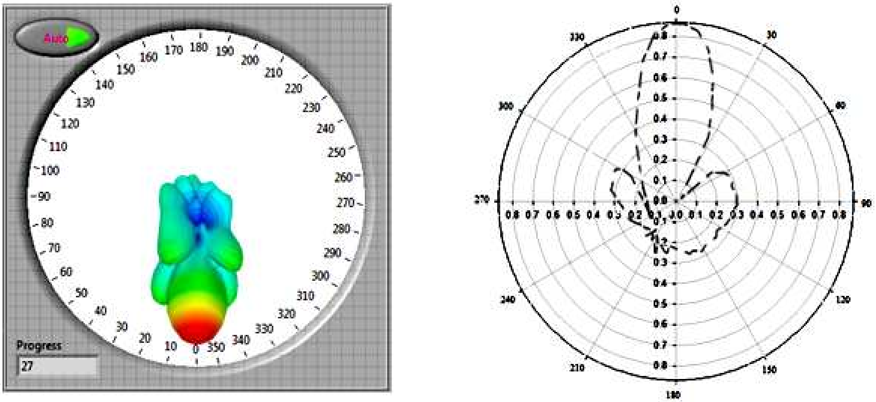


Figure 11. Measured mutual coupling effects on radiation patterns.

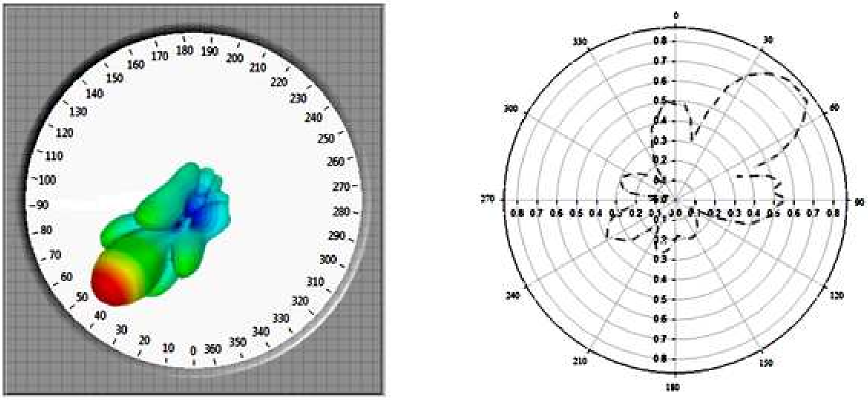


(a) (b)

Figure 12. The radiation patterns at 0°. (a) Virtually in LabVIEW. (b) Measured.

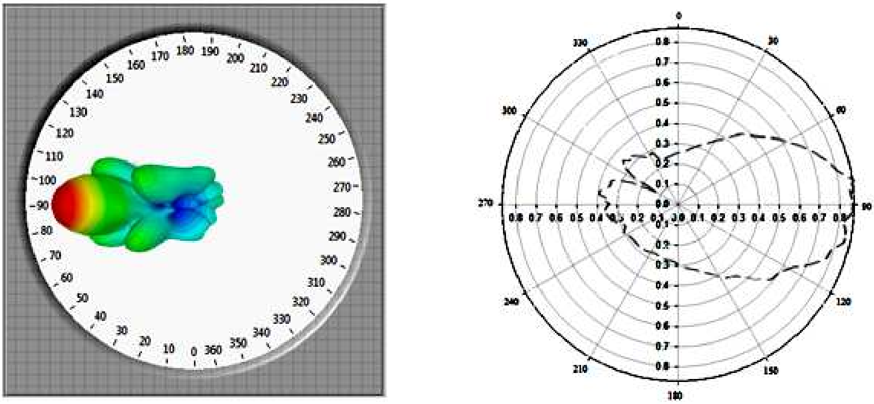
angle has been locked, the Beam Manager responds adaptively by activating the PIN diodes of particular R-RLSA antenna through its output port of A1–A4 and B1–B4.

The R-RLSA antennas' particular radiation patterns were made possible through the activation of particular switch configurations. Figure 12 shows a novel phase shifter system located the beam direction virtually and measured it through the LabVIEW interfacing software



(a) (b)

Figure 13. The radiation patterns at 45°. (a) Virtually in LabVIEW. (b) Measured.

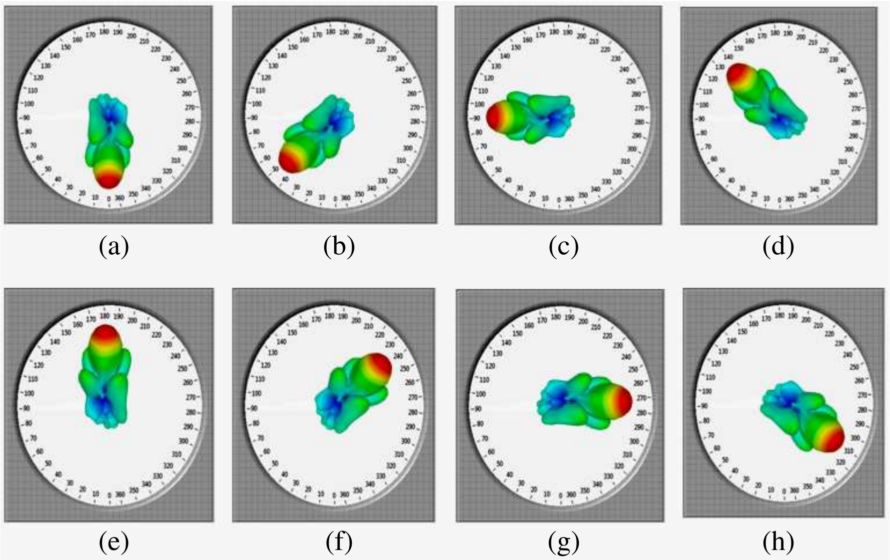


(a) (b)

Figure 14. The radiation patterns at 90°. (a) Virtually in LabVIEW. (b) Measured.

and R-RLSA antennas, respectively. The system has a radiation pattern at 0°/360° with a gain of 9.14 dB and HPBW of 40°, when the first up to the third PIN diode switches of R-RLSA 1 are activated. If any object is detected at a 45° angle, it means the NI-DAQ's Beam Manager has already activated from the fifth up to the eighth switches of R-RLSA 2 simultaneously to strike a radiation pattern at 45° with a gain of 9.22 dB and HPBW of 50°, as shown in Figure 13. In Figure 14, the main beam radiation pattern is exactly at 90° with gain of 9.5 dB and HPBW of 65° when turning ON the first switch of R-RLSA 1.

Meanwhile, the pattern is pointed at an angle of 135°, with a beamwidth of 60° and gain of 9.67 dB when the fifth switch of R-RLSA 2 is turned ON. The direction of 180° with 9.81 dB gain and a HPBW of 35° is achievable by activating the first and second switch of R-RLSA 1. The beam direction is pushed to another 45° to become 225° when turning ON the first up sixth switches of the R-RLSA 2. A smaller beamwidth of 55° with gain of 9.71 dB is achieved simultaneously during that particular angle. The beam would be pushed off to 270° with the gain increased up to 9.98 dB and a HPBW of 43° when the first up to the third switches of the R-RLSA 1 are turned ON. Activating the fifth, sixth, and seventh switch of the R-RLSA 2 allows the beam to lead to an angle of 315°, with a beamwidth of 52° as well as gain of


(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 15. The LabVIEW radiation patterns at (a) 0°/360°, (b) 45°, (c) 90°, (d) 135°, (e) 180°, (f) 225°, (g) 270° and (h) 315°.

Table 1. Configuration of PIN diode switches of the proposed measured antenna.

Number of RLSA	Number of PIN diode switch	PIN Diode status							
RLSA 1	i	ON	OFF	ON	OFF	ON	OFF	ON	OFF
	ii	ON	OFF	OFF	OFF	ON	OFF	ON	OFF
	iii	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF
	iv	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF
RLSA 2	v	OFF	ON	OFF	ON	OFF	ON	OFF	ON
	vi	OFF	ON	OFF	OFF	OFF	ON	OFF	ON
	vii	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON
	viii	OFF	ON	OFF	OFF	OFF	OFF	OFF	OFF
Gain (dB)		**9.14**	**9.22**	**9.5**	**9.67**	**9.81**	**9.71**	**9.98**	**9.85**
HPBW (°)		**40**	**50**	**65**	**60**	**35**	**55**	**43**	**52**
Main Lobe Direction (°)		**0**	**35**	**90**	**130**	**180**	**230**	**270**	**315**

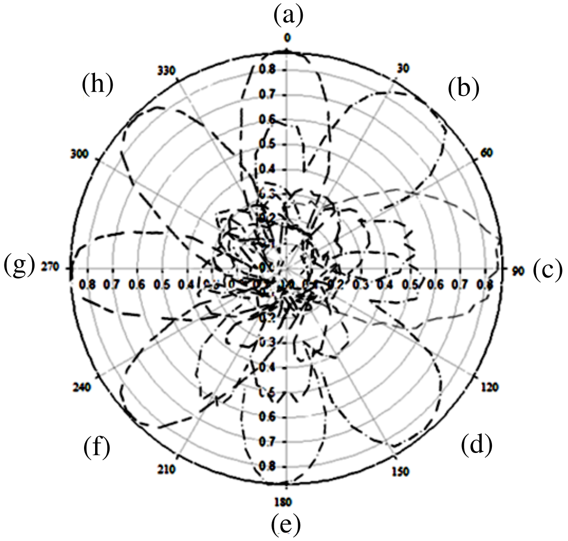


Figure 16. The measured radiation patterns at (a) 0°/360°, (b) 45°, (c) 90°, (d) 135°, (e) 180°, (f) 225°, (g) 270° and (h) 315°.

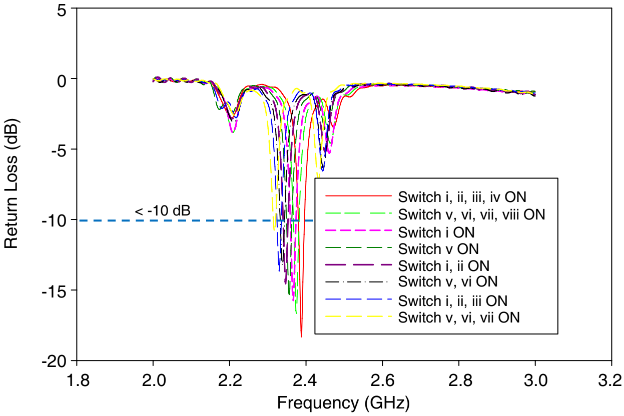


Figure 17. The measurements of return loss.

9.85 dB. The outputs of the PIN diodes' switching scheme, known as the Beam Manager, are summarized in Table 1.

In all, this novel phase shifter system efficiently covers a wider angle of space with the ability to change the phase angle of the beams within 0.01 ms, depending on the user and the environment. Note that the phase shifter system effectively achieves the desired angles, which are 0°/360°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°, as shown in Figures 15 and 16. Such a feature is unattainable if the antennas are directly connected without the element plank of rice husk. All the radiation patterns of the proposed antenna are relatively at frequency 2.3–2.39 GHz as depicted by Figure 17.

5. CONCLUSION

This research introduces a novel phase shifter system consisting of a spatial configuration of R-RLSA antennas, an element plank of rice husk, and NI-DAQs. The element plank of rice husk has significantly assisted the spatial R-RLSA antennas to provide coverage at the cardinal directions of 0°/360°, 90°, 180°, 270° and ordinal directions of 45°, 135°, 225°, and 315°, respectively. The rotation of 45° steps through eight different angles of radiation patterns are potentially to reduce the number of drop outs and lost connections and indirectly to provide wider coverage. The 'Beam Manager' embedded in NI-DAQs' memory contributes to the capability of the system, which can be fully controlled by a laptop. Hence, the system could respond to any changes of environment by providing the angles of the particular beam required within 0.01 ms, and having them activated manually or automatically. Through the concept of spatial structure, a new phase shifter has been successfully discovered as one single element rather than the current phase shifter that always comes with two elements. Moreover, instead of a smaller in size, this proposed phase shifter system is better in terms of maintenance and power consumption and is cheaper in price.Together with the deployment of green element technology, the proposed system has great potential to be instigated as a front-end transmitter and multi-receiver for WiMAX application.

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