# A Compact Design of Switched Line Phase Shifter for a Microstrip Phased Array Antenna

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**Abstract**— This paper presents a 1×4 microstrip Phased Array Antenna (PAA) with a uniquely designed switch line phase shifter to obtain steerable beam pattern. The antenna is designed on a Rogers RT/Duroid $6006^{TM}$ dielectric substrate with a relative permittivity of 6.15. Each element of the probe fed PAA are connected to a phase shifter on a different dielectric substrate. The phase shifter has four equal length microstrip lines placed on a circular fashion around a via that connects the antenna. The circular phase shifter network feeds the antenna through the via at the center. This design is useful if a phase shifter must be integrated with an antenna in a tight space. A diode switch is placed between the microstrip traces to change the length of the transmission line. An addition of each transmission line provides a phase shift of 90°. The Arduino controlled switches can be turned ON and OFF to steer the antenna beam pattern. The maximum steering angle obtained was ±45°. The antenna is appropriate for Wi-Fi application that requires directional beam pattern, Multiple Input Multiple Output (MIMO) communications, scanning radar, and other applications requiring steerable beam pattern.

## 1. INTRODUCTION

Phased array antennas are widely used for various applications requiring fixed or steerable beam pattern. These antennas provide control over the direction and beam pattern without mechanically adjusting the antenna position. The beam produced by the antenna can be steered in a desired angle by changing the phase of individual antenna element. The PAA provides flexibility to receive signal from a direction where the signal path is not obstructed and transmit signal in any preferred direction. The application of traditional PAA were limited to aerospace and military use due to high cost, complexity, and the size of the antenna. The use of such antenna is found mostly in spaceships and satellites for space communications [1] and military radars [2]. To obtain a directional antenna pattern, each antenna element in an array must be fed through a phase shifter. The realization of a mechanical phase shifter on each antenna element makes an antenna costly and bulky. Therefore, the implementation of such antenna on a small electronic device is difficult due to area constraint.

The research advancement in patch antenna and microstrip base phase shifters made it possible to realize antenna arrays for wide range of applications. Today antenna arrays are employed on Wi-Fi, LTE technology [3], and health care applications [4]. In this paper, we design a phase shifter for a four-element linear patch antenna array. The antenna is designed at 4.9 GHz, public safety band; however, the concept of phase shifter can be applicable for diverse applications. Our goal is to design a phase shifter small enough to fit within the antenna element spacing so that its realization is possible under each antenna unit.

To reduce the size and bulkiness of an antenna, electrical phase shifters are more realized on an antenna than mechanical phase shifters. Butler Matrix and switch line phase shifter are some of the popular electrical phase shifter used in antenna arrays. To reduce the size of an antenna, a dual band Butler matrix are found to be implemented on phased arrays [5]. As the number of antenna element increases, the number of such phase shifter must increase. As a result the size of the antenna gets bigger. The increasing uses of Butler matrix in modern wireless communications [6] and 5G technologies [7] can be substituted with the proposed design to reduce the overall antenna dimension. The number of input and output ports in a Butler matrix are equal. Excitation of each input ports provides directional beam pattern of an antenna. The direction of an antenna beam can be controlled using this method, however the phase shift on each antenna element cannot be controlled independently. Therefore, a broadside beam cannot be obtained using this method. A Butler matrix can be formed with 4, 8 or 16 input/output ports. Hence, an antenna array with different number of antenna element cannot be realized. The Butler matrix must be stacked up if they are used to feed a planar array, thus by increasing space and complexity.

In a switch line phase shifter, the input signal is routed through different length transmission line so that the signal reaches the antenna at different time. A true time delay is obtained using switch line phase shifter as in [8] and [9]. A four-bit switched line phase shifter is realized in [8] using

Micro-electro-mechanical switches (MEMS) where different length transmission lines are switched to obtain desired phase shift. In [9] a constant phase shift is produced by switching a reference transmission line with a phase shifting line. In current designs, the length of the transmission lines switched to obtain phase shift are longer and does not fit within antenna element spacing. In our proposed design, the phase shift is provided by extending a transmission line using RF switches along a circular path around the via that feeds the antenna. If this circular traces are branched at four equal lengths to feed the coaxial fed antenna at the center, four phases of 0°, 90°, 180°, and 270° should be achieved.

## 2. DESIGN

A probe fed four elements rectangular patch antenna is designed in High Frequency Structural Simulator (HFSS). The dimension of the antenna depends on the resonance frequency, relative permittivity of the material, and its height. The antenna is designed for a frequency of 4.9 GHz. A Rogers RT/Duroid 6006$^{TM}$ is used as a dielectric material. The height of the dielectric substrate is 1.524 mm and the relative permittivity is 6.15. The higher value of dielectric constant minimizes the size of the antenna. This kind of material is very suitable for antenna that has area constraint. The length of each antenna element is 11.37 mm and the width is 20.78 mm. The antenna elements are placed on a substrate of length 80.1128 mm and width 161.7784 mm. The antenna elements are placed half wavelength apart and a space of quarter wavelength is established between the antenna element and the edge of the substrate. A ground plane is placed on the other side of the dielectric substrate. The phase shifter for the antenna is placed on a different dielectric substrate. The phase shifter and the antenna are on a separate substrate. The isolation of phase shifter from antenna substrate provides higher gain and reduces spurious effect. It also helps to suppress side lobe level of antenna radiation pattern. The research conducted by M. T. Ali et al. on two different antenna structures shows that the antenna with separate feeding substrate is more advantageous than the antenna with feeding network on a same substrate. They found that the ratio of main lobe to side lobe was −11.9 dB for an antenna with separate feeding network. Whereas, a ratio of −5.35 dB was obtained for an antenna with feeding network on a same substrate [10].

The design of phase shifter is shown below in Figure 1. The phase shift is obtained by delaying an input signal by increasing the length of the transmission line. The design shows four equal length transmission line placed around a via. Each of the traces are connected to the via and can be switched to provide different phase shift. A phase difference of 90° is expected from each

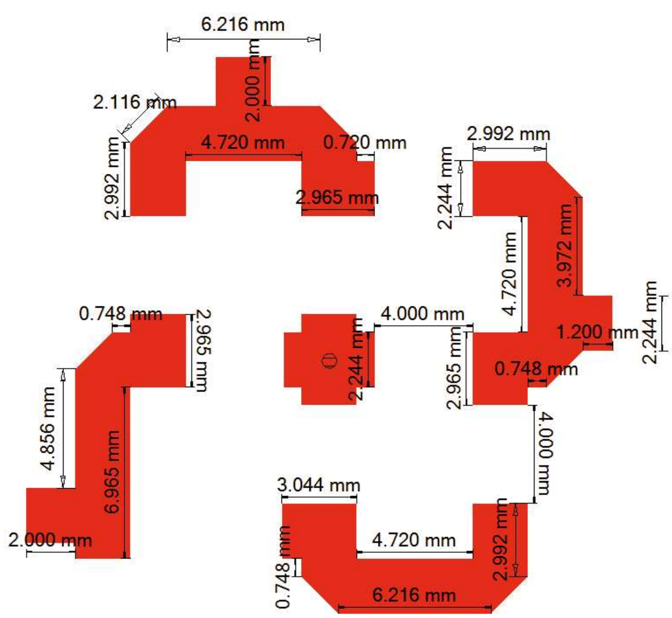


Figure 1: Dimension of transmission lines on a phase shifter.

additional transmission line. Each traces of transmission line are matched to 50 Ω impedance using single open stub. The dimension of the transmission line and the stubs are shown in Figure 1 below. The transmission lines are mitered to minimize the loss due to sharp corners. A gap of 4 mm is placed between the transmission line. A diode switch will be placed in each gap to extend the transmission line. The diode switches are turned ON and OFF with an Arduino to obtain a desired phase shift. For simulation purpose, these gaps will be filled with a lumped component to provide the effect of a diode switch.

Each of these phase shifters are placed under each antenna element on a different dielectric substrate. The phase shifter connects to an antenna through a coaxial cable. A corporate feed network is then connected to these phase shifters as shown in Figure 2 below. The antenna is fed through the input port of a corporate feed network.

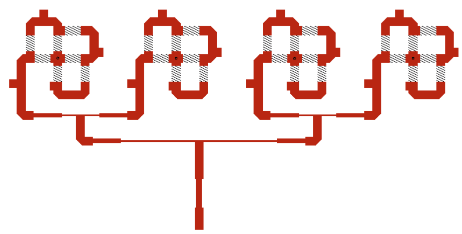

Figure 2: Corporate feed network connected to phase shifters.

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The proposed antenna with antenna elements and the phase shifter are shown below in Figures 3 and 4.

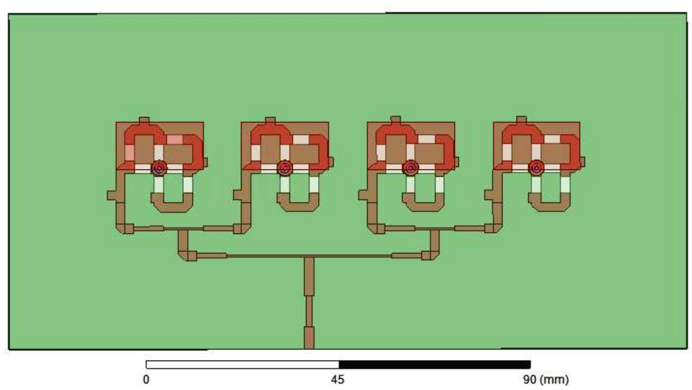


Figure 3: Top view of proposed phased array antenna.

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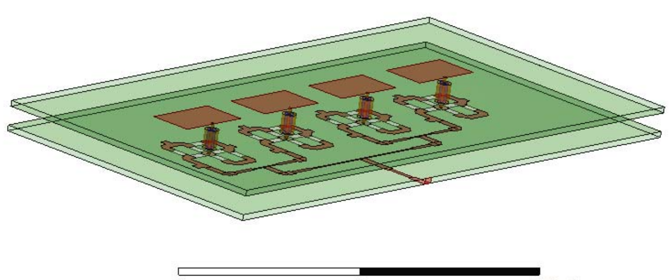


Figure 4: Slant view of proposed phased array antenna.

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## 3. RESULTS

The simulation was performed using High Frequency Structural Simulator (HFSS). The proposed phase shifter is first simulated with a single antenna element to validate the expected phase shift from each arm of the microstrip lines. We projected that an addition of each transmission line would provide a phase increment of 90°. The phase of reflection coefficient obtained from each arm of the transmission line is shown in Figure 5 below. The simulation shows that the result is in a close agreement with the projected phase shift. In reference to the first transmission line, an addition of 2nd, 3rd and 4th traces provide 87°, 59°, and 63° phase shift respectively. The error in the result is probably due to the stubs of unequal length on each transmission line and signal on which the measurement is taken. The phase shift is measured on a reflection coefficient instead of a forward gain signal. The measurement of phase shift was not possible on a forward signal without removing an antenna from the simulation. The phase shifter with an antenna at the end acts as a one port network and does not provide all $s$-parameters.

The antenna is simulated by enclosing it in a Perfectly Matched Layer (PML) boundary. The wave reaching the radiation boundary are absorbed perfectly if the incident angle of the wave is normal to the radiating surface. For a phased array antenna, the radiated energy is steered at

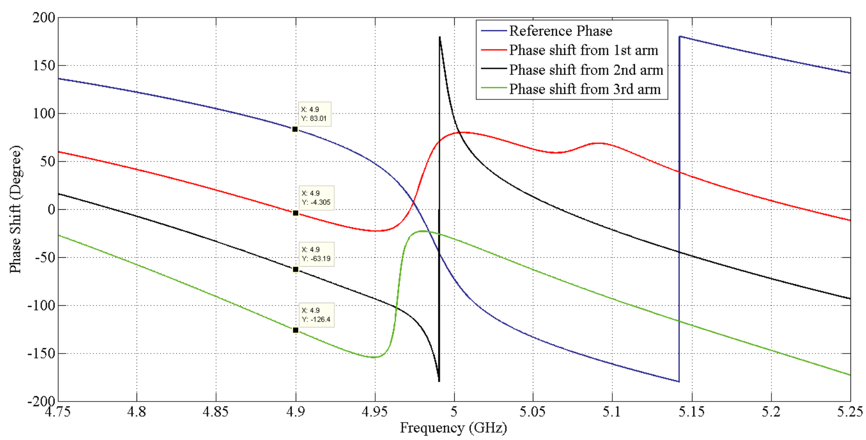


Figure 5: Phase difference between four transmission lines on a phase shifter.

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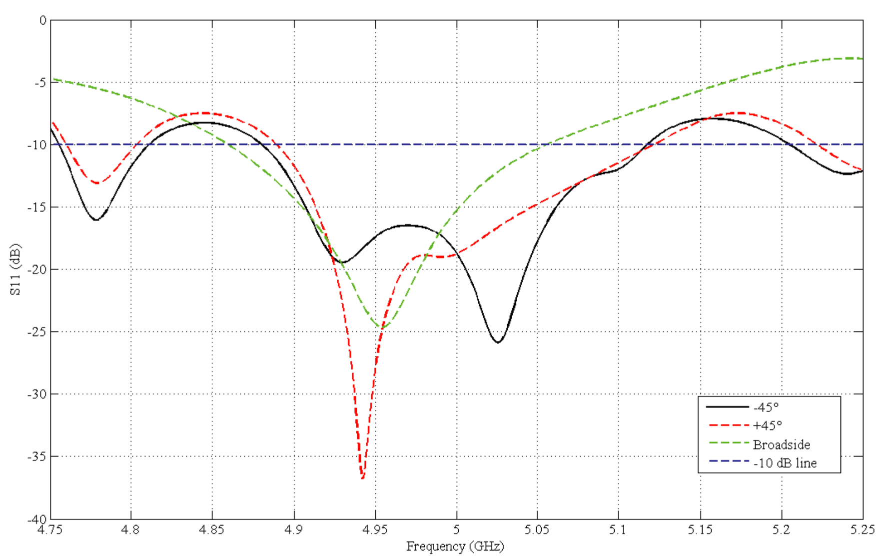


Figure 6: $S$-parameter for three different phase shifter configurations.

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different angles. The wave is not absorbed as desired if the incident angle is not normal to the boundary. Therefore, a PML boundary is used while simulating antenna structures that produces oblique radiation pattern. The antenna is simulated at a frequency of 4.965 GHz. This is the center frequency of 4.9 GHz public safety band. The simulation was performed to obtain beam steering at three different angles. First, the simulation was run with the reference line of the phase shifter connected to the first antenna element and addition of 2nd, 3rd and 4th lines for each consecutive antenna elements. The second simulation was performed with transmission lines in reverse order. Third was performed with the reference line on each phase shifter connected to each antenna element. The result of $s$-parameter for each case is shown below in Figure 6. The two-dimensional radiation pattern of $E$-field on Figure 7 shows that a beam steering of $\pm 45°$ and 0° were obtained from the simulation.

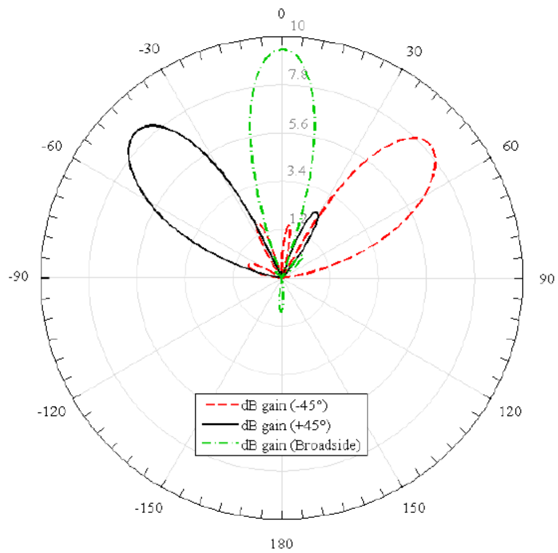


Figure 7: 2D-Radiation pattern with three different phase shifter configurations.

## 4. CONCLUSION

The performance of the designed phase shifter for an antenna array produced a good result and met the design expectation. An addition of each transmission line segment to the reference line provided a phase shift close to 90°. A beam steering of $\pm 45°$ with minimum reflection was obtained at the desired frequency band. The phase shifter was designed to fit within the space of antenna element spacing. This method of phase shifting can be applied and can perform very well with other applications as well. This method of phase shifting is very useful for antenna arrays in small electronic devices that have area constraint. The designed antenna covers 11 channels (7, 8, 9, 183, 184, 185, 187, 188, 189, 192, and 196) of 5 GHz Wi-Fi. The phase shifter has a potential use in diverse applications including MIMO communication, scanning radar, and other beam steering technologies.

## 5. FUTURE WORK

The antenna is on a process of fabrication. The switching between transmission line on a phase shifter will be controlled by an Arduino. Diode switches will be used to switch between the signal paths. A future publication will address mutual coupling effect and optimized antenna performance results.

## REFERENCES

1. Sarabandi, K. and F. Wang, "Phased array of large reflectors for deep-space communication," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 43, No. 1, 251–261, 2007.
2. Kinghorn, T., I. Scott, and E. Totten, "Recent advances in airborne phased array radar systems," *2016 IEEE International Symposium on Phased Array Systems and Technology (PAST)*, 1–7, 2016.

3. Bashri, M. S. R., T. Arslan, and W. Zhou, "A dual-band linear phased array antenna for WiFi and LTE mobile applications," *2015 Loughborough Antennas Propagation Conference (LAPC)*, 1–5, 2015.
4. Latif, S. I., D. A. Nelson, and V. La, "An on-body conformai printed array antenna at mmWave frequencies for healthcare applications," *2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, 1–2, 2016.
5. Ren, H., J. Shao, R. Zhou, B. Arigong, H. S. Kim, C. Li, and H. Zhang, "A compact phased array antenna system based on dual-band Butler matrices," *2013 IEEE Radio and Wireless Symposium*, 214–216, 2013.
6. Kapusuz, K. Y. and U. Oguz, "Millimeter wave phased array antenna for modern wireless communication systems," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, 1–4, 2016.
7. Huang, F., W. Chen, and M. Rao, "Switched-beam antenna array based on butler matrix for 5G wireless communication," *2016 IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition (iWEM)*, 1–3, 2016.
8. Huang, Y., J. Bao, X. Li, Y. Wang, and Y. Du, "A 4-bit switched-line phase shifter based on MEMS switches," *10th IEEE International Conference on Nano/Micro Engineered and Molecular Systems*, 405–408, 2015.
9. Zhang, J. and S. W. Cheung, "Design of 90° switched line phase shifter with constant phase shift using CRLH TL," *PIERS Proceedings*, 1655–1658, Guangzhou, August 25–28, 2014.
10. Ali, M. T., T. A. Rahman, M. R. Kamarudin, M. N. Md Tan, and R. Sauleau, "A planar antenna array with separated feed line for higher gain and sidelobe reduction," *Progress In Electromagnetics Research C*, Vol. 8, 69–82, 2009.