A Polarization Switchable Active Integrated Array Antenna with a Single-Lambda Slot-Ring Gunn Oscillator and PSK Modulator

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Abstract: A polarization switchable active integrated array antenna is proposed in this letter. The proposed antenna accommodates two microwave circuits; an oscillator and PSK modulator with antennas for both vertical and horizontal polarizations. Employing a PSK modulator in the horizontal feed line, it is possible to flip the horizontal polarization of the antenna and hence the polarization can be switched between $\pm \frac{\pi}{4}$. The basic concept of the proposed antenna is experimentally confirmed by using a 10-GHz band prototype antenna and better than 15-dB cross-polarization suppression is obtained.

Keywords: active integrated antennas, Gunn oscillator, PSK modulator, polarization switching, reconfigurable antenna

Classification: Antenna and Propagation

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1 Introduction

Due to the unprecedented development of wireless communications, the demand for faster communications, higher capacity, and higher frequency utilization efficiency spur a growing interest in active integrated antennas (AIAs). The AIA indicates that active circuitry is integrated with passive antenna elements on the same substrate. The AIAs have been the topic of interest in recent years due to their attractive features in millimeter-wave systems of lower transmission-line loss, higher antenna efficiency, and low cost. Due to the development of high-level of integration, AIA has found many applications such as power combining, beam switching, and retro-directive arrays [1, 2]. Several AIA design concepts and configurations like to provide oscillation function [3], frequency reconfigurability [4], switchable radiation patterns [5], voltage controlled oscillation [6], and amplification [7] integrated with antennas have been reported for different kind of applications. Besides, polarization diversity can be simultaneously used to effectively increase the system capacity and frequency reusability [8]. In [9, 10], polarization agile self-oscillating AIAs have been demonstrated. A ring-slot antenna integrating two microstrip Gunn oscillators with polarization modulators are studied in [9]. A 12-patch array antenna using a two-wavelength slot-ring Gunn oscillator has been used in [10], wherein two PSK modulators are integrated to present polarization agility.

In this letter, a simplified version of the previous work using a single-lambda slot-ring Gunn oscillator is newly proposed. The main benefit of this antenna is its simple layout which allows a single PSK modulator only to
switch the polarizations. For ease of impedance matching, the both-sided MIC technology is used to design the array feed network. A brief description of this proposed antenna has been discussed in [11].

2 Spatial Modulation Technique

Fig. 1 illustrates a conceptual idea of the spatial modulation communication systems. For any polarization propagating to the +z direction

\[ E(z,t) = i_x E_x \sin(2\pi ft - kz) + i_y E_y \sin(2\pi ft - kz + \varphi) \]  

(1)

where, \(i_x\) and \(i_y\) are unit vector of \(x\) and \(y\) directions, respectively. ±45° polarizations can be realized from Eq. (1), when

\[ E_x = E_y \quad \& \quad \begin{cases} \varphi = 0 : +45^\circ \\ \varphi = \pi : -45^\circ \end{cases} \]

Polarization agile spatially modulated communication systems carry infor- mation by switching between two orthogonal polarized waves, ±45° as shown in Fig. 1. Considering +45° and −45° as 0 and 1, respectively, the transmitted wave polarization changes to +45°, −45° and +45° for input signal 010. By detecting these polarized angles at the receiver, the transmitted signals can be recovered. Thus, a simple communication system using space-domain parameters can be realized.

3 Operating Principle and Configuration of the Antenna

Fig. 2(a) illustrates the basic block diagram of the proposed AIA. The proposed AIA consists of antenna elements for horizontal and vertical polarizations with two microwave circuits; an oscillator and PSK modulator. The

![Fig. 1. Illustration of spatial modulation communications.](image-url)
oscillator defines the oscillation frequency as well as provides power to the antenna elements. The purpose to employ the PSK modulator is to achieve 180° phase switching of the signals. Thus, employing a PSK modulator in the horizontal feed line, it is possible to flip the horizontal polarization of the antenna and hence the polarization can be switched between ±45° as shown in the vector diagram.

Fig. 2(b) shows the schematic structure and cross-sectional view of the proposed AIA. The antenna comprises 2×2 dual-polarized patch array, a Gunn oscillator with a single lambda slot-ring resonator, and a PSK mod-
Fig. 3. Measured and simulated results of the proposed AIA.

To excite each polarization separately, two output ports of the Gunn oscillator are used. Two PIN diodes D1 and D2 control the signal traveling path in the slot ring of the PSK modulator and thus the 180° phase switching. The placement of the PSK modulator and Gunn oscillator on the reverse side of the substrate makes the antenna compact.

Fig. 2(c) shows the photograph of the prototype antenna. The design center frequency is 10 GHz and the size of the antenna is 90 mm × 80 mm. The antenna is etched on a Teflon glass fiber substrate ($\varepsilon_r = 2.15$, thickness = 0.8 mm). During the simulation, ON and OFF conditions of the PIN diodes are realized by a short and open circuit, respectively, and two feed ports have been incorporated instead of the Gunn oscillator.

4 Results and Discussion

Fig. 3 shows the measured and simulated results of the proposed AIA. The antenna is designed and optimized by using the Momentum of Keysight Technologies’ Advanced Design System (ADS). Throughout the measurement, copper (Cu) wire was used instead of the PIN diodes and the distance between the proposed transmitting antenna and the receiving horn antenna was 130 cm to guarantee the required far-field condition.

Fig. 3(a) presents the normalized simulated and measured electric field intensity at θ = 0° with respect to the cutting plane angle.
intensity with respect to the cutting plane angle. The cutting plane angle $\phi$ represents the antenna rotation around its $z$-axis and $E_\theta$ represents the electric field intensity measured across the receiving horn antenna. For the diode D1 position’s short circuit, it can be seen that the measured maximum field intensity is obtained around $\phi = +45^\circ$ at 9.47 GHz, while $\phi = -45^\circ$ for D2 position’s short circuit, with better than 15-dB cross-polarization suppression in both cases. The discrepancy between the measured and simulated cross-polarization level is due to the polarization error caused by the measurement imperfection, fabrication errors, etc. The -20dB cross-polarization level corresponds to 5.7$^\circ$ polarization error from ideal $\pm 45^\circ$ polarizations. The polarization switching capability of the antenna is successfully confirmed.

Fig. 3(b) represents the simulated and measured radiation patterns of the antenna on $\phi = 0^\circ$ and $90^\circ$ planes. Here, the antenna was kept fixed at respective planes and then measured the radiated power level at each individual reception angle across the horn antenna to draw the radiation patterns. Referring to the graph, the measured radiation patterns on both these planes are similar compared to the simulated results.

Fig. 3(c) shows the simulated and measured radiation patterns on both $\phi = \pm 45^\circ$ planes of the antenna for both D1 and D2 short conditions. Here the red (triangle marks) and blue (circle marks) line represent the radiation patterns measured on $\phi = +45^\circ$ and $\phi = -45^\circ$ plane, respectively. When the diode D1 position is shorted, $+45^\circ$ polarized waves are excited and hence, the radiation patterns of $\phi = +45^\circ$ planes are dominant than the $\phi = -45^\circ$ planes and vice versa for D2 short. Due to the structural symmetry, the radiation patterns for both D1 and D2 short conditions are almost similar and half-power beam width in both figures is approximately 45 degrees.

5 Conclusion
In this letter, a polarization agile AIA using both-sided MIC technology has been proposed by employing a Gunn oscillator and PSK modulator. A prototype antenna has been fabricated and the performance has been measured to confirm the polarization switching concept. The demonstration clearly shows the polarization switching functionality and self-oscillating capability of the antenna. Hence, the concept is found to be feasible with better than 15-dB cross-polarization suppression. The simple and compact structure makes the proposed antenna attractive for various types of X-band high-speed communications.

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