Study, Design and Simulation of a Pointing Controller Switch for Beam Switching Antenna Systems

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Abstract

In this paper, we propose the study, design and simulation of a pointing controller circuit (selector of beam position) for beam-switching antenna systems. This circuit is an active switch-based PIN diode (one input / eight output), designed with microstrip technology and capable of controlling eight beam pointing positions.

The frequency band considered is the UMTS band, the design is performed with the substrate Fr4 (Er = 4.5 tgδ = 0.02 h = 1.6 mm) and simulations are realized with the ADS software.

Keywords: *A microstrip antenna array, SP4T switches SP8T switches, switched beam system, reconfigurable antennas.*

1. Introduction

The switched beam Antenna systems, which falls into the category of beamforming systems are a systems that form multiple fixed beams with increased sensitivity in certain directions. Very beneficial for a lot of applications such as the base stations of mobile networks where the quality of coverage is a requirement and the radar systems where the quality of detection is paramount.

This type of antenna systems measure the intensity of the signal and choose a bundle of several fixed beams plotted. This is done using weighted signal antenna with the highest power output combinations. These choices are determined by techniques of digital signal processing in the baseband or RF signal.

Despite the wide variation of this kind of antenna systems, the necessary elements that constitute them are the same. These are:

- Radiant sources: an array of planar antennas (c).
- The beamforming network: which distributes the power supply sources under any law of amplitude and phase for forming the lobe (b).
- The control circuit (or the beam position selector): this circuit acts as a control circuit and controlling of beam pointing direction (a).

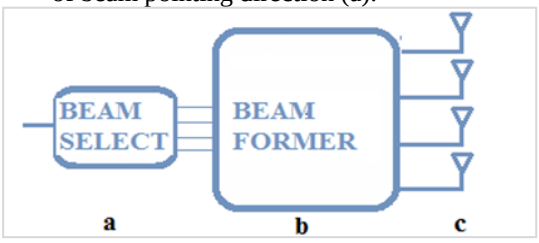

Fig. 1 Beam-switching antenna system

In this paper we propose the study, design and simulation of a control pointing circuit (selector of beam position) for beam-switching antenna systems. This circuit is an active switch-based PIN diode (one input / eight output), designed with microstrip technology and capable of controlling eight beam pointing positions.

The frequency band considered is the UMTS band, the design is performed with the substrate Fr4 (Er = 4.5 tgδ = 0.02 h = 1.6 mm) and simulations are realized with the ADS software.

2. SPST Switch Based on PIN Diode

2.1 The PIN Diode

The PIN diode (Positive - Intrinsic - Negative) is used in many applications ranging from UHF to microwave

frequencies. It works like a variable resistor in RF and microwave frequency being controlled by its bias current direct [1]. A microwave PIN diode is a semiconductor device that operates as a variable resistor at RF and Microwave frequencies. A PIN diode is a current controlled device in contrast to a varactor diode which is a voltage controlled device. Varactors diodes are design with thin epitaxial I-layers (for a high "Q" in the reverse bias) and little or no concern for carrier lifetime (Stored Charge). When the forward bias control current of the PIN diode is varied continuously, it can be used for attenuating, leveling, and amplitude modulating an RF signal. When the control current is switched on and off, or in discrete steps, the device can be used for switching, pulse modulating, and phase shifting an RF signal. The microwave PIN diode's small physical size compared to a wavelength, high switching speed, and low package parasitic reactances, make it an ideal component for use in miniature, broadband RF signal control circuits. In addition, the PIN diode has the ability to control large RF signal power while using much smaller levels of control power [2].

- PIN diode in reverse bias

In reverse bias the electrical equivalent circuit of the diode is then a parallel circuit composed of a capacitance Ct and a resistance of losses Rp in series with parasitic self Ls The defining equation for Ct is:

$$Ct = \varepsilon A/W \qquad (1)$$

Where ε is the dielectric constant of silicon, A=Diode Junction Area.

- PIN diode in forward bias

The electrical equivalent circuit of the diode is a resistor Rs in series with a low inductance Ls. The PIN diodes are characterized in forward bias by the value of the RS resistance and in reverse bias by the Ct value of the capacity [3].
The Rs vs If relationship is described as:

$$Rs = W^2/(\mu_n + \mu_p)Q \quad \text{(Ohms)}$$

$$Rs = W^2/(\mu_n + \mu_p)I_f\tau \qquad (2)$$

Where: W=I-region width, If= Forward bias current, τ is the minority carrier lifetime μ_n is the electron mobility, μ_p is the hole mobility[4].
For most of the PIN diodes, Rs varies from 0.6 to 6 ohms and the capacitance from 0.02 to 1 pF, all applications and operating frequencies combined.

2.2 Switches based on PIN diodes

The Diode switches normally employ a semiconductor device called a PIN diode as the active element of the circuit. Indeed, this diode has the distinction of playing the role of a switch with two properties; in reverse bias the signal passes and in forward bias is reflected [3].
The switch Single Pole Single Throw SPDT shown in Fig4 is considered as the basic circuit of the SPNT Switches architectures (Single Pole Throw N). It can transmit or block the microwave signal.

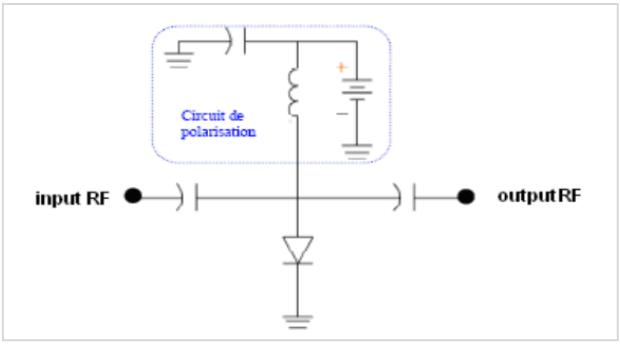

Fig. 2 SPST Switch –based on PIN diode

when the voltage is positive the diode is conducting and the load resistor in the output circuit is short circuited and thus the input signal is blocked. When the bias voltage is negative, the diode is blocked and the input signal is routed to the output [5].

3. SP4T Switch Based on PIN Diode

To make a SP4T switch (single pole four throw) suitable for our application [6], we started from the architecture of SPST (single pole single throw) parallel shown in Figure 3.

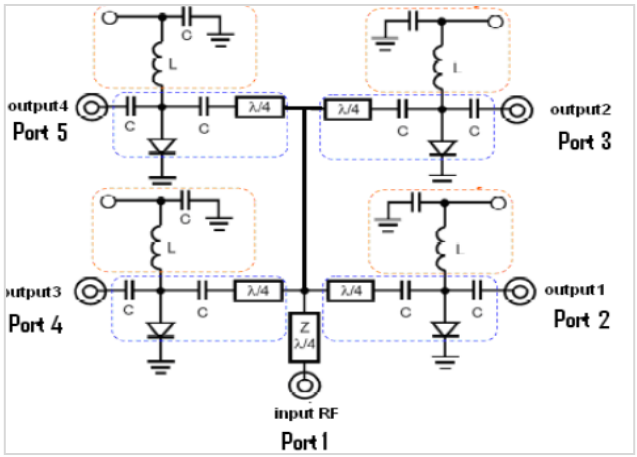

Fig. 3 SP4T Switch -based on PIN diode

Thus, the switch has four output branches where diodes are connected in parallel. Each branch has its own bias circuit. All these branches are connected to a common point where link capacities are added to prevent any return to the DC inputs and outputs. Figure 3 shows the schematic of the switch [7].
The circuit has four diodes, twelve capacity, RF input and four outputs. This switch will therefore allow us to route the input signal to an output of four. The selected sound will be activated by biasing the biasing circuit in reverse. The other outputs inactive are directly polarized [8].

4. Proposition and validation of an SP8T switch architecture based on PIN diode

4.1 Proposition of an SP8T switch architecture based on PIN diode

The proposed architecture of the switch is based on the architecture of SP4T (one input four outputs).
It consists of eight separate branches, a branch of the eight be active while the others are inactive. to select the port dispatcher who will receive the signal indicating the pointing direction of the beam. The proposed architecture is represented by figure 4.
This architecture consists of two SP4T (one input and four output) and an elbow that will interconnect. The SP4T is already validated; we have to validate the elbow connecting the two switches and the total system.

4.2 Validation of the elbow circuit

The elbow role is the activation of a SP4T switch among two, therefore consisting of two SPST switches based PIN diode. We proposed the following scheme with ADS (figure 5)

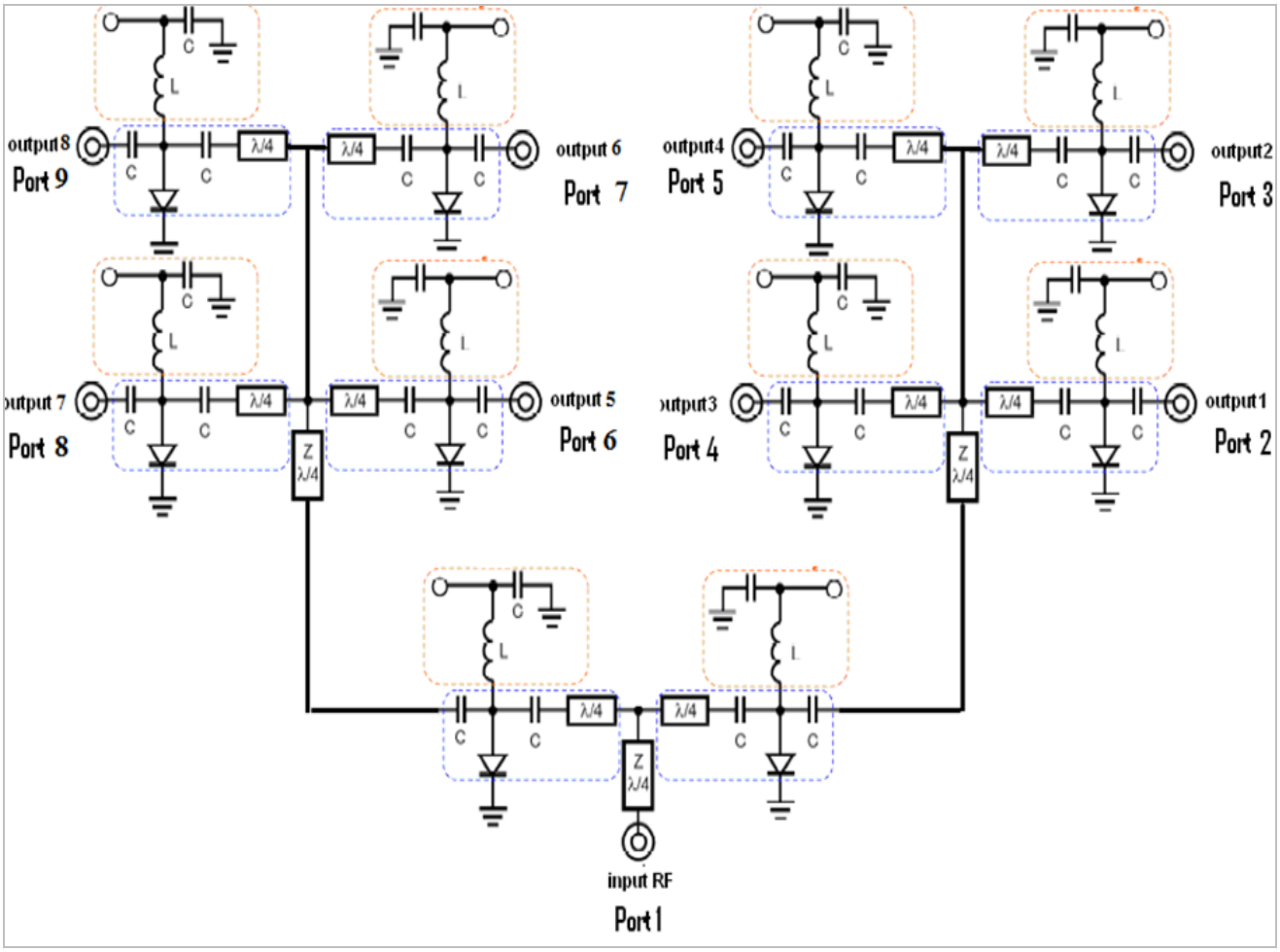

Fig. 4 SP8T Switch -based on PIN diode architecture

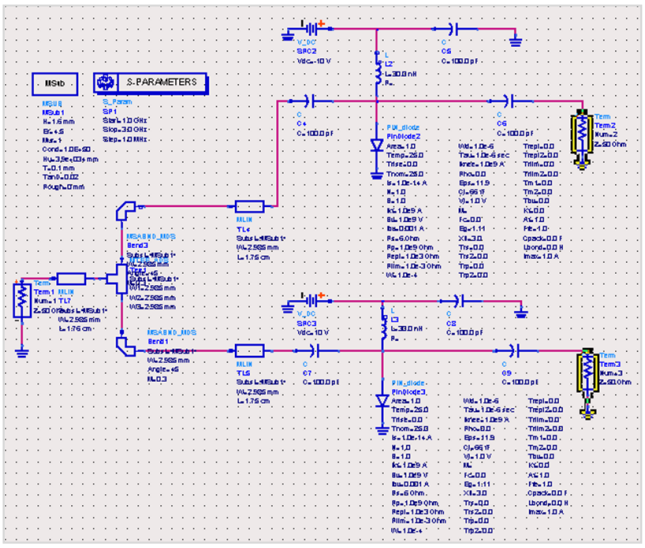

Fig. 5 Architecture of the elbow based PIN diode, designed with ADS

The simulation results shown in the following figure at 2GHZ, verify; a reflection coefficient of -25 dB bandwidth of 1.5 GHz and a transmission coefficient of -0.5 dB for the active branch, and -21.5 dB for the inactive branch.

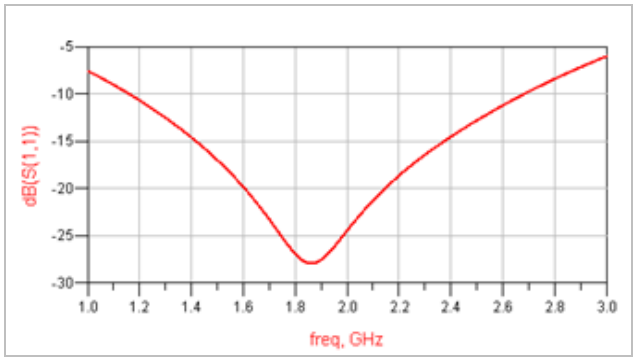

Fig. 6 S11 Simulation results for the elbow based on PIN diode designed with ADS

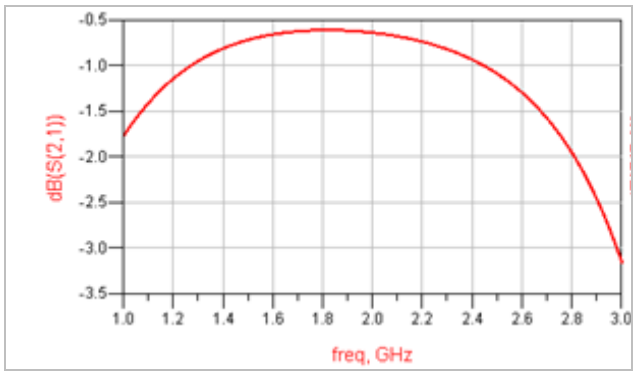

Fig. 7 S21 Simulation results for the elbow based on PIN diode designed with ADS

Fig. 8 S31 Simulation results for the elbow based on PIN diode designed with ADS

The results are satisfactory, so we can pass to validate the total system.

4.3 Validation of the SP8T switch architecture based on PIN diode

The architecture translated with ADS software is given by figure 9:

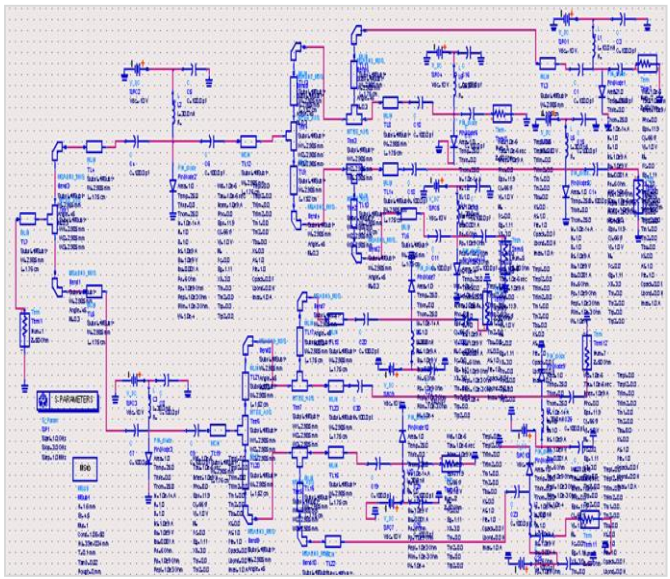

Fig. 9 SP8T switch architecture based on PIN diode

Simulation results show (2GHz); a reflection coefficient of -40 dB, a 0.4 GHz bandwidth, and a transmission coefficient of -2 dB for the active branch and between -20 and -50 dB for inactive branches.

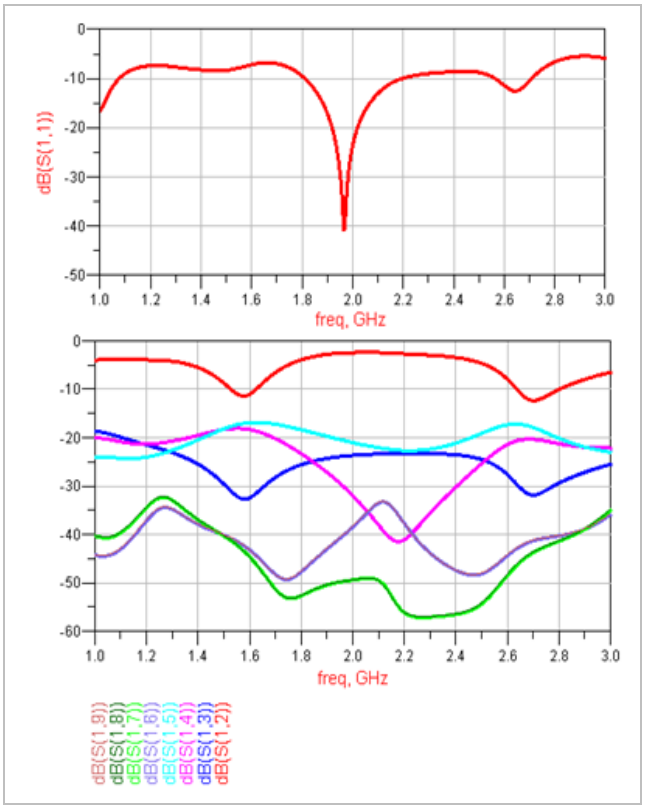

Fig. 10 Simulation results for the SP8T based on PIN diode designed with ADS

The results are satisfactory, so we can proceed to the generation of the LAYOUT. The LAYOUT generated using ADS is given by the following figure:

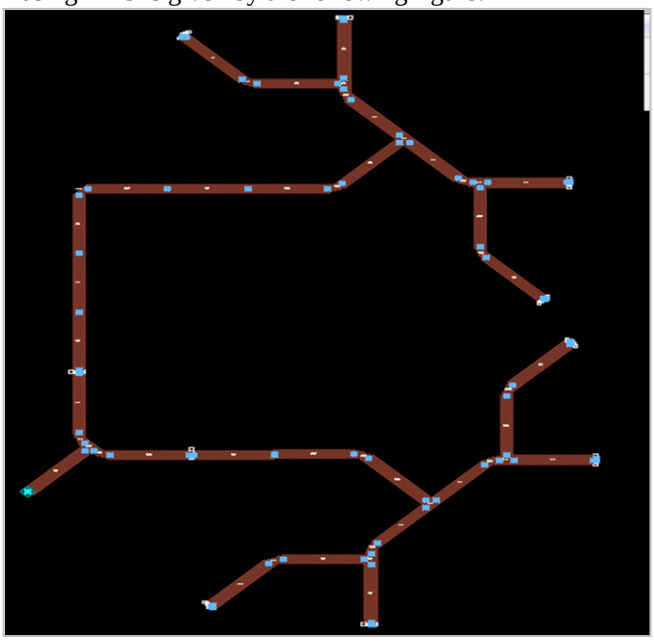

Fig.11 LAYOUT of the SP8T based on PIN diode generated by ADS

The LAYOUT is the final step before the implementation of the circuit.

5. Conclusion

In this paper we have proposed the study, design and simulation of a new SP8T active switches architecture based on PIN diode (one input / eight outputs), designed with microstrip technology and capable of controlling eight positions of pointing beam. The frequency band is considered for UMTS band, the design is performed with the Fr4 substrate (Er = 4.5 tgδ = 0.02 h = 1.6 mm) and simulations are realized with the ADS software.
The results allowed by this new architecture simulation are at 2GHz; a reflection coefficient of -40 dB, a 0.4 GHz bandwidth and a transmission coefficient of -2 dB for the active branch and between -20 and -50 dB for inactive branches.

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