Design and Simulation of a SP4T Switch Based on The PIN Diode Suitable For UMTS Use

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Summary
The aim of this work is the study and simulation of a SP4T switch based on PIN diode dedicated to the UMTS use. This switch will allow us to deliver RF energy via an output of four and will be integrated into a microstrip adaptive antenna array circuit. The following work is done between the signals, systems and components laboratory of FST-Fez and the microwave laboratory of the National Institute of Posts and Telecommunications of RABAT MOROCCO.

Key words:
SPNT Switch; SPDT Switch; SP4T Switch; PIN Diode; Adaptive Microstrip Antennas

1. Introduction

The Electronic pointing antennas have many forms and can have a wide variety of design, but they always include a switching device which can drive the beams needed. These devices are called the radio frequency switches, they are used to route the signal to go to one of N outputs. The Switches based on PIN diode have a very short switching time (some tens of nanoseconds). Extremely compact, these diodes can be used in the waveguide and coaxial structures or mounted on puce. These diodes can switch at low power (few milliwatts), and high power levels up to more KW at a much lower frequencies. In addition, these switches are available in several configurations of SPNT (Single Pole Throw N).

2. The PIN diodes

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].

2.1 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 (Fig 1).

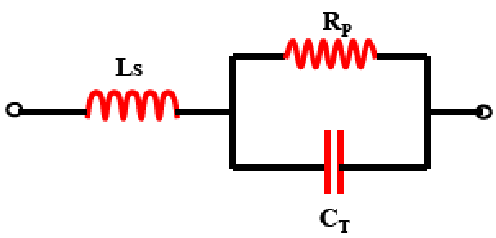

Fig. 1 Electrical equivalent circuit of a PIN diode polarized in reverse

The defining equation for Ct is:

$$Ct = \varepsilon A / W$$

Which is valid for frequencies above the dielectric relaxation frequency of the I-region, ie:

$$f \succ 1/2\pi\rho\varepsilon$$

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

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2.2 PIN diode in forward bias

The electrical equivalent circuit of the diode is a resistor Rs in series with a low inductance Ls (Fig 2).

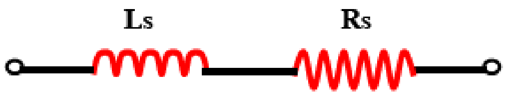

Fig. 2 Electrical equivalent circuit of a PIN diode polarized in direct

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:

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

Or

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

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.

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.

3. 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.
There are two different possible structure for this switch:
a- Series structure : when the voltage is positive the diode is conducting, the signal coming out of the microwave generator propagates to the load.In the opposite case when the control voltage is negative, the diode is blocked and behaves as a capacitor Ct.

Fig. 3 SP3T Switch -based PIN diode

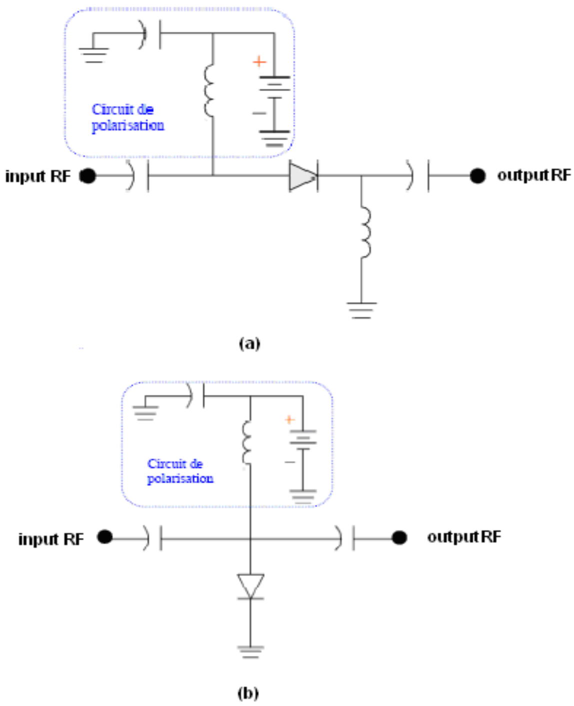

Fig. 4 SPST Switch -based PIN diode (a) in series (b) in parallel

b- Parallel structure: 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.

4. Study and architecture proposal for the switch Single Pole 4 Throw SP4T

The aim of the realization of this switch is to integrate it into a microstrip adaptive antenna array dedicated to UMTS application. The substrate used is FR4 with carracteristiques following: thickness: 1.6 mm εr: 4.5 and tgδ: 0.02.
The antenna consists of a network of circular patches fed by microstrip line and distributed in a tree structure that allowed a good performance [4]. The antenna array consists of two sub network; a subnet distribution and another subnet scanning using a Butler matrix including the need to integrate the study switch [5].

4.1 simulation of a SPDT parallel switch

The SPDT is the basic circuit that will allow us to pass to SP4T; this circuit will routing or blocking the RF signal.
The diode chosen for this application is PIN HPND 4028 sold by Hewlett-Packard [6]. In forward bias the diode is equivalent to a series resistance characterizing the loss of contact: Rs = 1.5Ω. In reverse bias, the equivalent circuit is a capacitance in parallel: Ct = 25fF.
The simulation is done with ADS (Advanced Design System) from Agilent, the circuit of the SPDT parallel switch is translated by the diagram in Fig. 5.

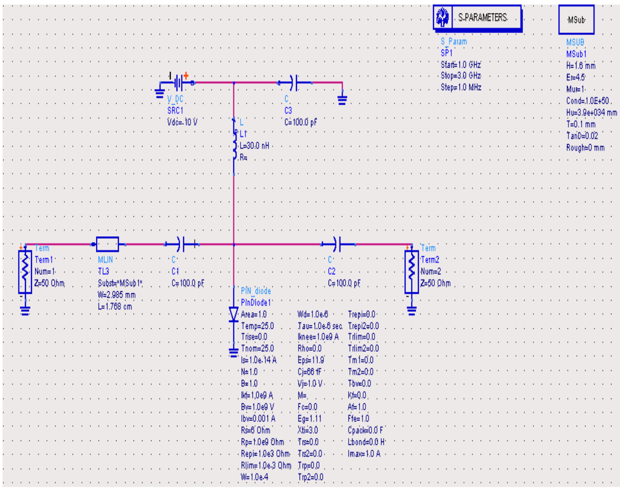

Fig. 5 SPDT Switch simulate by ADS

So when the circuit is in reverse bias the RF signal is transmitted to output (Fig. 6)

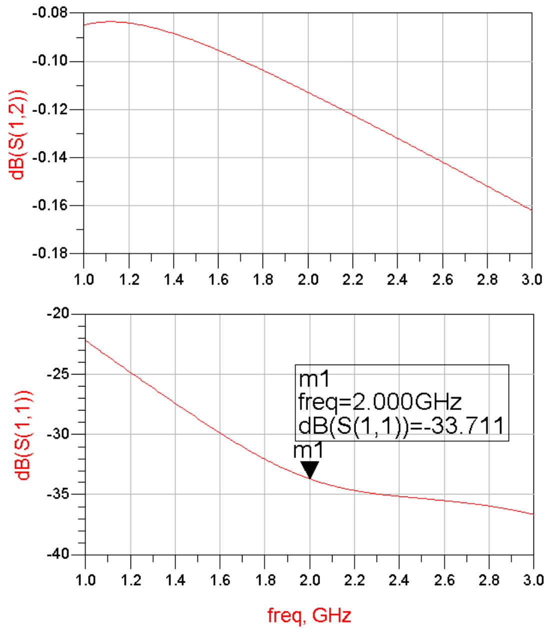

Fig. 6 Results of SPDT Switch simulation biased in reverse

When the circuit is biased in direct the RF signal is blocked (Fig. 7).

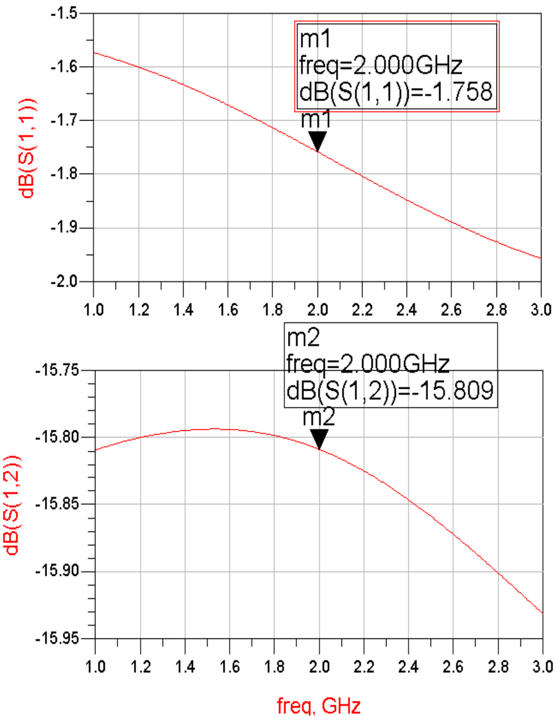

Fig. 7 Results of SPDT Switch simulation biased in direct

4.2 simulation of a SP4T parallel switch

The SPDT architecture is extended to make SP4T switch, the switch has four output branches in which the diodes are connected in parallel, each branch has its own bias circuit as is well illustrated in Fig. 8.

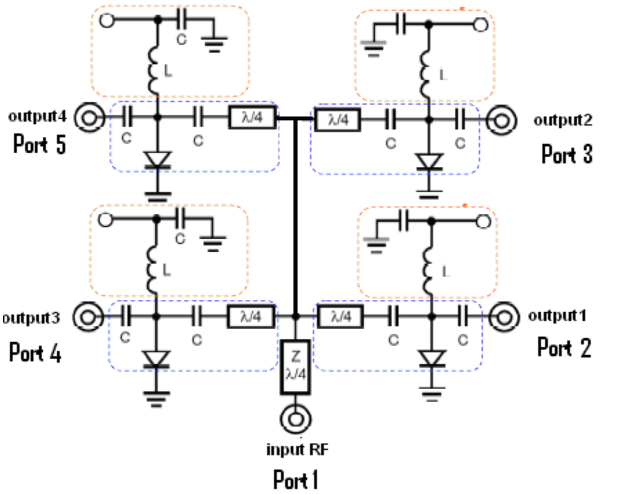

Fig. 8 Architecture of SP4T switch-based PIN diode in parallel

This switch can route the signal to a path of four. The switching time of these diodes is 2nsec. The bias voltage is -10V, 10V. The coupling capacitors are selected high value as not to disrupt the transmission of RF energy [7]. The circuit of the SP4T switch is translated by the diagram in Fig. 9

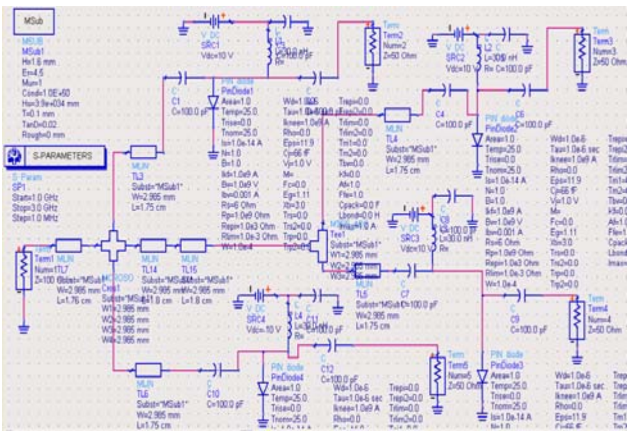

Fig. 9 SP4T Switch simulate by ADS

So when the branch 1 of the circuit is in reverse biased and the other branch are biased in direct. Fig. 10 shows that the transmission of RF energy is to output 1 while the others output are completely blocked. Bandwidth allowed by this switch is 700 MHz [1.9GHz, 2.6 GHz] and integrates well the UMTS band.

At 2 GHz (UMTS Frequency):

Output1 (port2) active

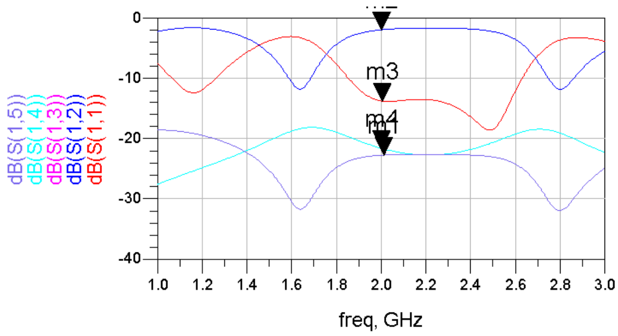

Fig. 10 Results of SP4T Switch simulation output1 active

S11= -13.8 dB S12= -1.9 dB S13 =-21.6 dB S14 = -21.6 dB S15=-22.7dB

Output2 (port3) active

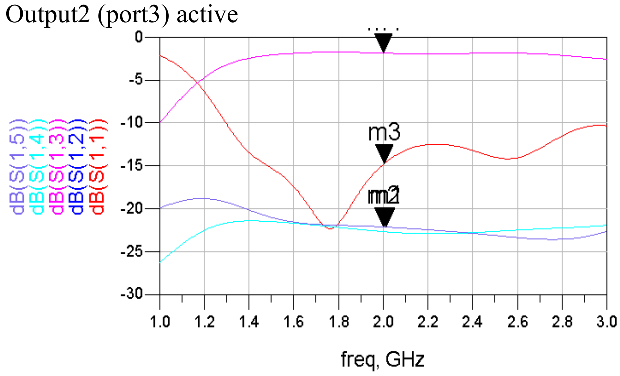

Fig. 11 Results of SP4T Switch simulation output2 active

S11 = - 14.7dB S12 = -22 dB S13 =-1.8 dB S14 = -22.6dB S15=-23 dB

Output3 (port4) active

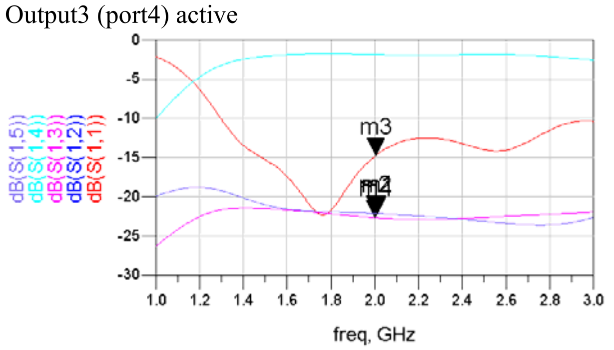

Fig. 12 Results of SP4T Switch simulation output3 active

S11 = - 14.7dB S12 = -22 dB S13 =-1.8 dB S14 = -22.6dB S15=-23 dB

Output4 (port5) active

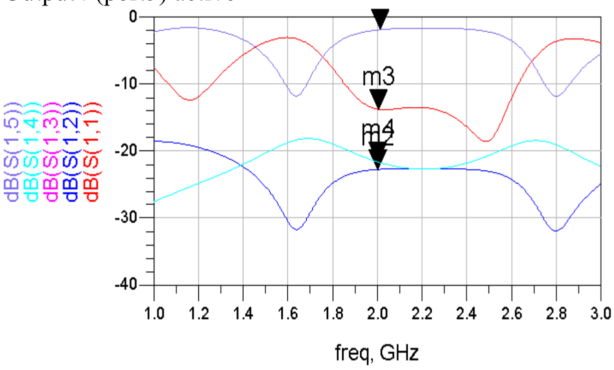

Fig. 13 Results of SP4T Switch simulation output4 active

S11 = -13.8 dB S12 = -1.9 dB S13 =-21.6 dB S14 = -21.6 dB S15=-22.7dB

6. Conclusion

Simulation results show that we may have realized architecture of SP4T switch used in the UMTS frequency band. This will allow us to integrate the switch in the antenna circuit.

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