Application Note AN-008: *High Power, High Isolation, Switching Solutions with NuSwitch PIN DIODE Technology*

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Introduction

The need to route RF signals through system switching networks while maintaining low insertion loss and high isolation continues to be increasingly demanding. Combined with the need for a robust device capable of handling high transmit level signals while maintaining strong signal integrity without the introduction of unwanted noise, it becomes clear that an RF Switch is a critical component to any RF system.

In the arena of RF switches, there are many different options and styles to choose from. Reflective or Absorptive? PIN Diode, FET, or Mechanical? Power consumption and device control? All of the possibilities can make finding the ideal switching solution for your individual needs a daunting task.

Within this application note, we will cover the different types of RF switches and how NuWaves' NuSwitch can offer an efficient, cost-effective solution for your specific system's needs.

Switch Technologies

RF Switches can be classified into two groups based on the mechanism in which the switch operates:

- **Electromechanical** switches rely on physical contacts moving to make or break the desired switch path such as a Relay.
- **Solid State** switches make or break signal paths using semiconductors such as a Diode or Transistor

Electromechanical switches employ physical metal contacts that can either be "Open", allowing no signal to pass through, or "Closed", completing the circuit to allow signal to pass through. This type of switch can be described by the number of "Poles" or common ports that can be connected and the number of "Throws or the possible positions each Pole can connect to. These possibilities are express by the number of "poles" to the number of "throws".

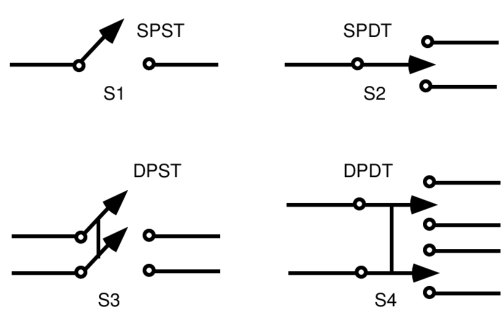

Figure 1. Schematic Examples of Mechanical Switches

An example of an Electromechanical Switch would be a *Single Pole, Single Throw* (SPST) switch where the switching mechanism is either open or closed through one path. Another example would be a *Double Pole, Double Throw* (DPDT) which is simply two SPST switches working simultaneously to either make or break two separate signal paths. It is important to note that when a switch of this type utilizes multiple poles the switching action moves in tandem across all poles. Meaning, both poles will always remain in the same state or position in relation to each other, not allowing for the 1st pole to be in the Make position while the 2nd in the Break position.

Because of its inherently low loss and high isolation, electromechanical switches can be used across a wide band of frequencies. Though, this style of switch does present some trade-offs due to the physical movement required to operate. Electromechanical switches are slower when switching paths and can introduce arcing between contacts. Further, electromechanical switches have a limited lifespan due to potential vibration damage, shock damage, and overall mechanical wear.

Solid State switches are semiconductor devices unbound by mechanical movements to perform changes in switch states. Not held to the same mechanical constraints, solid state switches are widely considered to be more durable and reliable compared to electromagnetic switches. Though, this increase in overall reliability comes with a potential for increased loss through the signal path.

Solid State switches are generally designed with two types of semiconductors, PIN Diodes or Field Effect Transistors (FETs) - or a combination of the two.

FET switches utilize semiconductor devices to control the conductivity of a channel in the semiconductor material. FETs are generally a 3-termination device with a through path between 2 terminations and the 3rd termination acting as an "On/Off" control. With the application of a bias voltage, the transistor will turn on and allow signal to pass through. Conversely, as the bias voltage decreases the FET will go into "Pinch-off" and the through path becomes open not allowing signal to pass.

FET switches can consume less current and have higher insertion losses than PIN Diode switches, but they are often unable to handle the RF power levels obtained by PIN diode switches.

Unlike PN Diodes, a PIN Diode has a 3rd region between the P-type and N-type junction called the Intrinsic region. This is an undoped region that has capacitive properties with the ability to store a charge allowing the diode to pass alternating signals when a forward bias current is applied. When this happens, the PIN diode acts as a variable resistor at RF and microwaves frequencies. PIN diodes can be controlled by very small amounts of current.

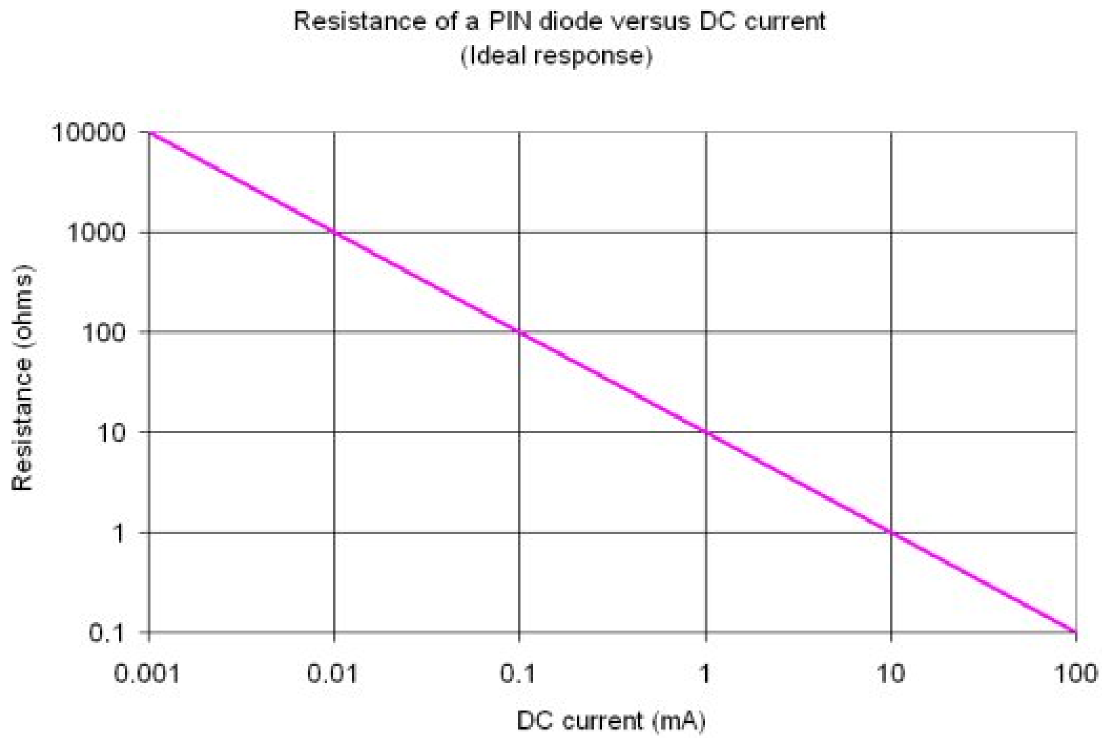

Figure 2. Bias Current VS RF Resistance

Figure 2 shows the bias current to resistance response of an ideal PIN diode. As you can see, it takes relatively low amounts of current to obtain a 50-Ohm impedance looking into the PIN diode easily conducting RF signals through. This characteristic makes PIN diodes ideal for RF Switches, Variable Attenuators, and Limiters.

PIN diodes also allow for higher RF power handling. The power handling capabilities of a PIN diode are controlled by three parameters:

- Upper operating temperature of the device
- Breakdown voltage
- Charge storage capability

Best reliability is achieved by keeping the junction temperature below 200C. Additionally, it is paramount that the breakdown voltage of the diode be at least twice the peak RF voltage and that the charge stored in the intrinsic region is not greater than the charge moved in one half-cycle of the RF waveform. These parameters will ensure that the diode does not exceed its breakdown voltage and that the intrinsic region does not deplete its charge.

Figure 3 (below) shows examples of three basic ways to design a PIN diode switch for passing an RF signal. Schematic (a) shows the diodes in a series configuration where biasing one side allows that signal path to become the through path while the opposite unbiased side is purely reflective. Schematic (b) shows the diodes in a shunt configuration with matched ¼ wave transmission lines on each arm of the switch path. This configuration operates in the reverse fashion of the series diode configuration. Biasing the shunt diode directs the RF energy to ground while the matched ¼ wave transmission line provides for a better isolation match. Schematic (c) shows a combination of the two previous configurations to create a Series-Shunt PIN diode switch with properties of both configurations.

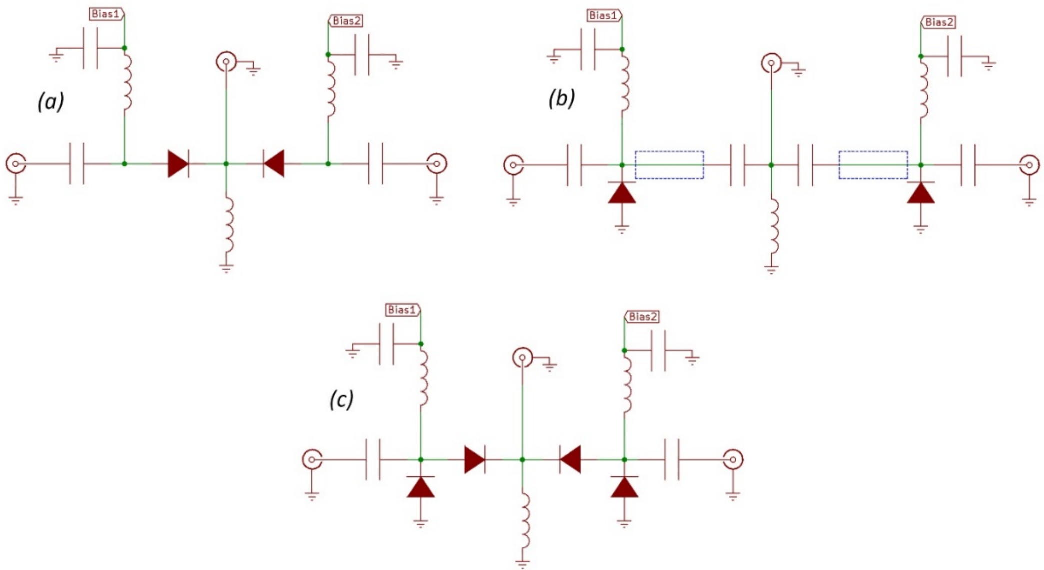

Figure 3. PIN Diode Switch Example Schematics – (a)Series, (b)Series-Shunt, (c)Shunt

Isolation & Loss

There are two circuit configurations to consider with PIN diode switches: Reflective and Absorptive. An Absorptive RF switch sends the unused path to a 50-Ohm load maintaining a good VSWR match. In most cases, an absorptive switch can be used instead of a reflective switch, but not vice-versa. A Reflective RF switch does ***not*** terminate the unused port to a 50-Ohm load. Essentially the act of "turning off" the diode presents nearly infinite impedance to the signal creating a high VSWR mismatch-hence the name, Reflective.

Switch Type	Isolation	Insertion Loss
Series	$10\,log_{10}\left[1+\frac{1}{(4\cdot\pi\cdot C\cdot Z_0)^2}\right]$	$20\,log_{10}\left[1+\left(\frac{R_s}{2Z_0}\right)\right]$
Shunt	$20\,log_{10}\left[1+\frac{Z_0}{2R_s}\right]$	$10\,log_{10}[1+(\pi\cdot f\cdot C\cdot Z_0)^2]$
Series-Shunt	$10\,log_{10}\left[\left(1+\frac{Z_0}{2R_s}\right)^2+\left(\frac{X_c}{2Z_0}\right)^2\cdot\left(1+\frac{Z_0}{R_s}\right)^2\right]$	$10\,log_{10}\left[\left(1+\frac{R_s}{2Z_0}\right)^2+\left(\frac{Z_0+R_s}{2X_c}\right)^2\right]$

Table 1. Isolation and Insertion Loss Equations for PIN Diode Configurations

Isolation is the amount of signal attenuation between ports of interest. In the example of a Single Pole, Double Throw switch the isolation would be the delta between the signal passing through the path in the Make position and the amount of that same signal on the path of the Break position.

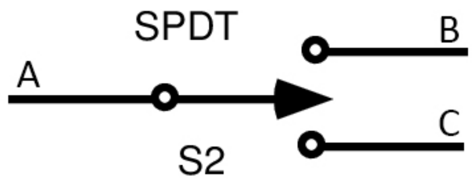

Figure 4. Isolation Example for SPDT

In this example, if the SPDT was configured that paths A and B were in the Make position and there was a 0dBm signal at some frequency passing through ports A to B but we were able to measure that same signal on port C at -40dBm, then the Isolation between Ports B and C is 40dB. In some cases, the Isolation between B and C could differ depending on the circuitry of the switch itself, where the Isolation from C to B is some different value than B to C dependent on which path configuration the switch is in.

In the case of a switch being used to separate Transmit and Receive signals, it is important to know how much isolation between the ports you have so as not to damage any equipment you may have connected. This is most critical when in a Transmit situation, typically dealing with higher RF powers.

Insertion Loss is another important component of any RF network. It is defined as the amount of initial signal lost through the transmission line or network. In the case of the RF switch example in Figure 4 the insertion loss is the amount of loss from port A to B when A to B is in the Make position and conversely, A to C when A to C is in the Make position. If we continue with the previous example of Isolation from Ports B and C when A to B is in the Make position, a 0dBm signal will have some amount of loss when traveling from A to B. If the input is 0dBm, the output will be lower. Dependent on the switch design this could be anywhere from 0.1dB of loss to upwards of 2 or 3 dB of loss.

Equations given in Table 1 allow the designer to calculate Isolation and Insertion Loss through each of the PIN Diode design configurations.

Switching Speed and Control

The speed at which the RF switch changes states can be relatively fast, usually measured in Micro or Nano seconds. In general, the faster your switch can operate the better. Switching speed is straightforward and defined by how long it takes from when the control line tells the switch to change positions until the change is complete. Electromechanical switches/relays can have very high switch times <15ms where Solid State switches can achieve much greater switch times < 10µs.

NuSwitch Solutions

NuWaves has developed a highly reliable reflective PIN Diode Switch for operation in the VHF/UHF bands. It employs PIN diode technology to achieve high power handling capabilities > 150 Watts between 50 – 512 MHz. The simple 5VDC power and TTL control lines allow for ease of use and operation. With the utilization of series-shunt PIN configurations, the NuSwitch VU150MH01 provides low insertion loss at a 0.25dB typical in Rx and 0.15dB typical in Tx. Including high isolation between ports, typically >50dB across the band. A typical switching speed of 4μs makes this switch a great addition to any UHF or VHF system.

About NuWaves

NuWaves Engineering is a premier supplier of RF and Microwave solutions for the Department of Defense (DoD), government, and industrial customers. An RF engineering powerhouse, NuWaves offers a broad range of design and engineering services related to the development and sustainment of key communications, telemetry and electronic warfare systems, as well as a complete line of commercially available RF products. NuWaves' products include wideband frequency converters, high-efficiency and miniature solid-state power amplifiers and bidirectional amplifiers, high intercept low noise amplifiers and miniature RF filters. NuWaves Engineering…Trusted RF Solutions™.

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