High Power PIN Diode Switches for Aerospace and Defense Applications

By Rick Puente, Skyworks Solutions, Inc.

Designers of high power transceivers or radios for low frequency aerospace and military applications are typically restricted to design with proven technologies with high reliability. These transceivers require a way to switch the antenna to the transmitter output and the receiver input. A typical radio transceiver is shown in Figure 1. Designers must comply with demanding specifications. The switch must be robust enough to handle the RF input power in the transmit mode, as well as exhibiting low insertion loss in the receive mode to reduce added noise figure to the LNA. In the past, high power RF switching up to 100 W and operating frequencies of 30 MHz to 2000 MHz limited radio designers to use mechanical switches and relays to direct high power transmit signals to the antenna and prevent that signal from entering the sensitive front end of the local receiver. While mechanical switches typically have a lower ON resistance and less harmonic distortion, they are larger in size, slow switching and more expensive. Radio designers needed a highly reliable, integrated, low cost switch solution.

The solution is PIN diode technology. PIN diode technology has been available for over 60 years. A PIN diode operates as a variable resistor at RF and microwave frequencies. Its “ON” resistance varies from less than 1 ohm (ON) to more than 10 KΩ (OFF) depending on the bias. While PIN diodes do not operate well below a few MHz and require more current to operate compared to IC switches, they are ideal for higher power levels used in military, SATCOM or base station applications.
Typically PIN diode switches consist of a mixture of series and/or shunt diodes depending on the circuit requirements. Series PIN diodes can function within a wide bandwidth limited by the biasing inductors and DC blocking capacitors, while shunt diodes feature high isolation relatively independent of frequency. Skyworks packaged switches use a combination of both shunt and series PIN diodes to achieve optimal insertion loss and isolation performance in a small QFN package. This integrated diode switch solution improves max power handling and minimizes board space and circuit complexity while reducing cost over a discrete diode design.

Figure 2: QFN 16 Lead 4.0 x 4.0 x 1.5 mm

Figure 3: The SKY12208-478LF Circuit
PIN diode packaged switches provide a low cost, high power handling capability, low-loss connection between the antenna and the receiver, high isolation in the deselected transmission path, high linearity, fast switching speed, and simple bias control, all with a small physical size. For low frequency aerospace and military switching applications, Skyworks has developed a line of high power PIN diode SPDT QFN packaged switches, as shown in Figure 2.

![Figure 4: The SKY12212-478LF Circuit](image)

**High Power Handling Solid State T-R Switches**

The SKY12208-478LF (50 W) and SKY12212-478LF SPDT (100 W) switches utilize a series, shunt diode on the RX side and one or two series PIN diodes to achieve high-power handling of 50 or 100 watts CW, low insertion loss of 0.4 dB typical and high ANT-RX isolation of >40 dB. Both switches can be used in many applications, but their primary application is as a transmit-receive switch.
The SKY12208-478LF and SKY12212-478LF operate in the frequency range of 0.02 to 2.7 GHz and are particularly useful in military and aerospace communication system applications, JTRS, SDRs (software defined radios), VHF, UHF, land mobile radios and public safety radios. Both devices are provided in a 4 x 4 x 1.5 mm, 16-pin quad flat no-lead (QFN) package.

The internal circuitry of the SKY12208-478LF is shown in Figure 3. The internal circuitry of the SKY12212-478LF is shown in Figure 4. The SKY12212-478LF incorporates an additional series diode on the TX side compared to the SKY12208-478LF to dissipate additional RF power. Both circuits are reflective, single pole double throw switches with asymmetrical sections. The common antenna port is labeled “ANT.” The TX side incorporates a series diode(s) capable of handling high RF power. The RX side utilizes a low resistance single series diode and a shunt diode for low loss and high isolation. A small MIS chip capacitor connected to the shunt diode provides an AC-ground return as well as RF tuning while the switch operates in the ANT-RX isolation state. The SKY12208-478LF and SKY12212-478LF are constructed with maximum ANT-RX isolation below 2.0 GHz.
Both switches are operated in one of two discrete switch states as shown in Figure 5. In ANT-TX mode, the series diode on the TX side and the RX_BIAS shunt diode on the RX side of the switch are forward-biased, resulting in low impedance and low insertion loss between the antenna port and the TX port. At the same time, the series RX diode is in the reverse-bias state, which provides high impedance, resulting in high isolation between the RX port and the antenna port.

In ANT-RX mode, the series diode on the RX side of the switch is forward-biased, resulting in low impedance and low insertion loss between the antenna port and the RX port. At the same time, the series TX diode and the RX_BIAS shunt diode on the RX side of the switch are in the reverse-bias state which provides high impedance, resulting in high isolation between the TX port and the antenna port.

<table>
<thead>
<tr>
<th>Switch State</th>
<th>Path</th>
<th>Control Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Antenna-to-Receiver Port (Pin 2 to Pin 7)</td>
<td>Transmitter-to-Antenna Port (Pin 14 to Pin 2)</td>
</tr>
<tr>
<td>Receive</td>
<td>Low insertion loss</td>
<td>High isolation</td>
</tr>
<tr>
<td>Transmit</td>
<td>High isolation</td>
<td>Low insertion loss</td>
</tr>
</tbody>
</table>

Table 1. SKY12208-478LF Switch Control Logic

Most new radio designs can only support positive value bias control. The SKY12208-478LF and SKY12212-478LF operate with both +5 V and +28 V positive supplies to provide the voltage differentials needed for reverse bias. Positive forward currents are achieved by applying a positive voltage across external resistors R1 and R2. Figure 6 shows the external-bias circuitry, which includes RF chokes, RF bypass and DC blocking capacitors for use in most applications. This circuitry defines the DC and RF performance of the switches. Component values and sizes can be found in the product data sheets. For improved RF performance below 200 MHz and power levels above 42 dBm, a slightly modified external bias circuit is recommended. Reference Skyworks applications note, “SKY12212-478LF Low Frequency Tuning,” found on the Skyworks website.
In the ANT-TX mode, the low insertion loss state is produced by applying 50 mA (SKY12208-478LF) or 100 mA (SKY12212-478LF) of forward bias to the TX series diode and RX side shunt diode, while the RX series diode is reverse biased with 28 V. In the ANT-RX mode, the low insertion loss state is produced by applying 100 mA of forward bias to the RX series diode while the TX series diode and the shunt diode on the RX side are reversed biased with 28 V. Tables 1 and 2 indicate the switching logic of the SKY12208-478LF and the SKY12212-478LF, respectively, measured at the package pins. For typical applications, 5 V is supplied at the ANT port resistor to set up the voltage differential needed to produce the current through the series diodes when in forward conduction mode, or a reverse bias state when the TX or RX pins are 28 V. Table 3 indicates switching logic of the SKY12208-478LF and SKY12212-478LF schematic circuit.

When large signals are applied to a PIN diode, the RF electric field forces charge carriers into the i-layer, thereby reducing the diode’s impedance. In other words, the resistance decreases as input power increases. A substantial reverse bias is applied to the PIN diode to hold the diode in its high-impedance state in the presence of RF voltages large enough to instantaneously apply forward voltage to the diode and possibly into conduction. The magnitude of reverse voltage required in a high-power switch depends on frequency, RF voltage and PIN diode i-region width. For the SKY12208-478LF at 50 Watts or the SKY12212-478LF at 100 Watts incident power, 28 volts reverse voltage is specified. This value was determined experimentally and conforms to theoretical analysis. The large reverse bias voltage also reduces harmonic and intermodulation distortion produced by the reverse biased, “off state” PIN diode.

Figures 7 illustrates the typical performance characteristics of the SKY12208-478LF and SKY12212-478LF. The data was taken at TA = 25°C, Zo = 50 Ohms.
High Power Handling Solid State for RF Path and Band Switching

Skyworks also offers the lower power, PIN diode based, SKY12211-478LF (40 W) symmetrical SPDT switch. This switch has symmetrical switching paths from a single common port. It is the ideal part to meet the >20W power handling requirement and fast switching speed not attainable by FET based switches.

<table>
<thead>
<tr>
<th>Path</th>
<th>Control Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFC-to-RF2 Port</td>
<td>RFC Port Bias (V)</td>
</tr>
<tr>
<td>RFC-to-RF1 Port</td>
<td>RF2 Port Bias (V)</td>
</tr>
<tr>
<td></td>
<td>RFI Port Bias (V)</td>
</tr>
<tr>
<td>Low insertion loss</td>
<td>5</td>
</tr>
<tr>
<td>High isolation</td>
<td>0 (ground)</td>
</tr>
<tr>
<td>High isolation</td>
<td>28</td>
</tr>
<tr>
<td>Low insertion loss</td>
<td>0 (ground)</td>
</tr>
<tr>
<td></td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>0 (ground)</td>
</tr>
</tbody>
</table>

Table 5: Schematic Circuit Switch Control

The SKY12211-478LF SPDT switch operates in the frequency range of 0.02 to 2.7 GHz. It utilizes series, shunt diodes on both sides to achieve high-power handling of 40 watts CW, low insertion loss of 0.3 dB typical and high isolation of >45 dB. The switch can be used in many applications, but its primary application is as a frequency band or RF path switch. It useful in military and aerospace communication system applications, JTRS, SDRs, VHF, UHF, land mobile radios, cable TV systems and public safety radios. The device is provided in a 4 x 4 x 1.5 mm, 16-pin quad flat no-lead (QFN) package.

The internal circuitry of the SKY12211-478LF is shown in Figure 8. The circuit is a reflective, single pole double throw switch with symmetrical sections. The common antenna port is labeled “RFC”. Both output ports incorporate low resistance, thin i-region series and shunt diodes capable of handling high RF power levels while providing low “on-state” insertion loss, high “off-state” isolation and fast switching speed in the order of 40 nS. Small MIS chip capacitors connected to the shunt diodes provide an AC-ground return, as well as RF tuning, while the switch operates in the isolation state. The SKY12211-478LF is constructed with maximum isolation below 2.0 GHz.
The switch is operated in one of two discrete switch states as shown in Figure 9. In RFC-RF1 mode, the series diode on the RF1 side of the switch and the RF2_BIAS shunt diode on the RF2 side of the switch are forward-biased, resulting in low impedance and low insertion loss between the RFC port and the RF1 port. At the same time, the series RF2 diode and the RF1_BIAS shunt diode on the RF1 side of the switch are in the reverse-bias state, which provides high impedance, resulting in high isolation between the RF2 port and the RFC port.

In RFC-RF2 mode, the series diode on the RF2 side of the switch and the RF1_BIAS shunt diode on the RF1 side of the switch are forward-biased, resulting in low impedance and low insertion loss between the RFC port and the RF2 port. At the same time, the series RF1 diode and the RF2_BIAS shunt diode on the RF2 side of the switch are in the reverse-bias state, which provides high impedance resulting in high isolation between the RF2 port and the RFC port.
Most new radio designs can only support positive value bias control. The SKY12211-478LF operates with both a +5 V and +28 V positive supplies to provide the voltage differentials needed for reverse bias. Positive forward currents are achieved by applying a positive voltage across external resistors R1, R2 and R3. Figure 10 shows the external-bias circuitry, which includes RF chokes, RF bypass and DC blocking capacitors for use in most applications. This circuitry defines the DC and RF performance of the switch. Component values and sizes can be found in the product data sheets.

In the RFC-RF1 mode, the low insertion loss state is produced by applying 50mA of forward bias to the RF1 series diode and RF2 side shunt diode, while the RF2 series diode and the RF1 side shunt diode is reverse biased with 28 V. The reverse is true for RFC-RF2 insertion loss state. Table 4 indicates the switching logic of the SKY12211-478LF, measured at the package pins. For typical applications, 5 V is supplied at the RFC port resistor to set up the voltage differential needed to produce the current through the series diodes when in forward conduction mode, or a reverse bias state when the RF1 or RF2 are 28 V. Table 5 indicates the switching logic of the SKY12211-478LF schematic circuit.

When large signals are applied to a PIN diode, the RF electric field forces charge carriers into the i-layer, thereby reducing the diode’s impedance. In other words, the resistance decreases as input power increases. A substantial reverse bias is applied to the PIN diode to hold it in its high-impedance state in the presence of
RF voltages large enough to instantaneously apply forward voltage to the diode and possibly into conduction. The magnitude of reverse voltage required in a high-power switch depends on frequency, RF voltage and PIN diode l-region width. For the SKY12211-478LF at 40 Watts, 28 volts reverse voltage is specified. This value was determined experimentally and conforms to theoretical analysis. The large reverse bias voltage also reduces harmonic and intermodulation distortion produced by the reverse biased, “off state” PIN diode.

Figure 11 illustrates the typical performance characteristics of the SKY12211-478LF. The data was taken at TA = 25°C, Zo = 50 Ohms

**Conclusion**

Aerospace and defense radio transceiver designers now have a low cost solution to replace expensive mechanical switches and relays. Skyworks has introduced the SKY12208-478LF, SKY12211-478LF and SKY12212-478LF solid state, high power, SPDT, T-R switches which can handle 40, 50 and 100 W CW operating from 0.02 to 2.7 GHz. Data sheets and application notes for these products may be found on the Skyworks website.

Also available from Skyworks are the SKY12207-478LF (50 W), SKY12209-478LF (40 W), SKY12210-478LF (100 W) and SKY12215-478LF (125 W) high power SPDT switches, operating from 0.9 to 4.0 GHz. These switches are particularly useful in WiMAX, TD-SCDMA or LTE base stations applications or other infrastructure equipment. Please visit our website.

**References**