SKYWORKS®

High Power Switch Design Guide

Proven Performance and Leadership

As a world-class supplier of RF microwave components for today's wireless communication systems, Skyworks delivers the highest performance silicon and GaAs discrete products. These solutions are manufactured using cutting-edge processes driven by decades of industry experience and leadership. Our portfolio meets a wide range of wireless communications applications and microwave functions—all backed by best-in-class customer service, advanced manufacturing capabilities and technology leadership.

PIN Diode Switches for High Power Transceivers

Skyworks' silicon product offerings include high power PIN diode switches for use in a wide variety of microwave applications including WLAN, handset, Satcom (LNB/DBS-CATV), automotive, military, aerospace, defense, test and measurement, metering, medical, RFID, TD-SCDMA, 5G NR systems, transmit/receive switching and failsafe switching for LTE base stations and other radio and radar receivers.

Designers of high power transceivers or radios for commercial and military applications are typically restricted to design with proven technologies and 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. A robust switch is required 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, radio designers were limited to the use of 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. Mechanical switches are large in size, slow switching and expensive. Radio designers needed a highly reliable, integrated, low cost switch solution. The solution is PIN diode technology. While Skyworks offers a line of discrete PIN diodes for radio designers to develop their own switch circuits (see Table 1), it recommends its low cost, highly integrated high power PIN diodes single-pole double-throw (SPDT) switch modules in a QFN package for simplicity of use and system integration (see Table 2).

Skyworks' line of SPDT transmit and receive (T/R) switch modules are ideal for use in up to 120 W RF input power applications. They provide excellent performance and value, and leverages Skyworks' extensive design knowledge, technical leadership, manufacturing expertise and superior quality. The switch modules feature high power handling, high isolation in the deselected transmission path, low loss connection between the antenna and the receiver, high linearity, fast switching speed, simple bias control, all within a compact package.

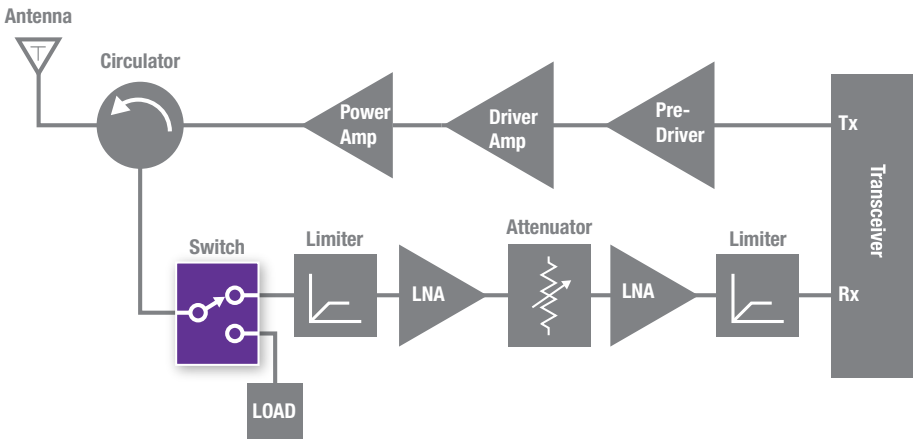


Figure 1. Radio Transceiver Block Diagram

High Power PIN Diode Switching

Signal routing in many radio architectures must be dynamic. A common antenna may be alternately connected to the transmitter and to the receiver signal chains; frequency agility or frequency hopping may be accomplished by selecting the output of one of two or more local oscillators, or it may be advantageous to bypass a receiver low noise amplifier to prevent distortion and extend dynamic range when a large receive signal is present. The PIN diode's wide range of RF impedance as shown in Figure 2, coupled with the ability to produce very low distortion, make them excellent switching elements. With proper circuit and driver design, PIN diodes can handle large power levels in the order of hundreds of Watts. Switches designed to handle high power levels can switch in less than 100 ns with the right choice of diode and switch topology.

PIN Diode Switch Topologies

Multi-throw PIN diode switches have been designed with up to 10 throws or more and with as few as a single throw. Insertion loss and isolation are both functions of the chosen switch topology as well as the properties of the PIN diodes which comprise the switch. Most PIN diode switch topologies are reflective; that is, when they are in their isolation state they present either an RF open circuit or an RF short circuit to the transmission lines to which they are connected. Absorptive PIN diode switch topologies, which always present a very small return loss to their systems, are possible but are slightly more complex than reflective circuits. PIN switch topologies consist of PIN diodes in series with their transmission path, in shunt with their transmission path, or both. Typically, multiple diode topologies are necessary to produce high RF isolation in the isolated path.

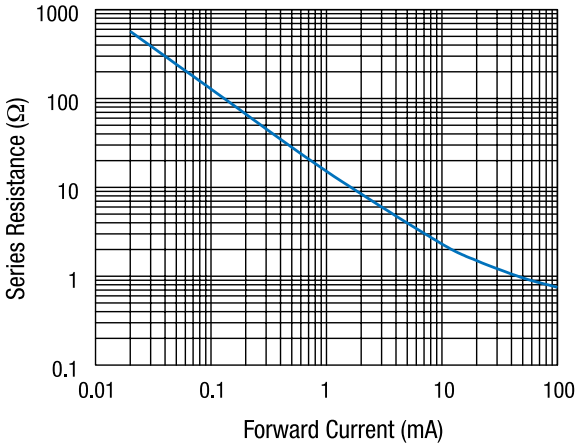


Figure 2. Series Resistance vs. Forward Bias Current—SMP1302

Single-Pole Single-Throw (SPST) PIN Switches

For the SPST With series PIN diode (Figure 3), the insertion loss of the switch is determined by the series resistance of the PIN diode when it is forward-biased. The isolation is determined by the diode's capacitive reactance when it is reverse-biased.

For the SPST With shunt PIN diode (Figure 4), the insertion loss of the switch is determined by the diode's capacitive reactance when it is reverse-biased. The isolation is determined by the series resistance of the PIN diode when it is forward-biased.

For the SPST With series and shunt PIN diodes (Figure 5), the insertion loss of the switch is determined by the series resistance of the series PIN diode when it is forward-biased and the capacitive reactance of the shunt diode when it is reverse-biased. The isolation of this switch is determined by the series diode's capacitive reactance when it is reverse-biased and the resistance of the shunt PIN diode when it is forward-biased. This SPST topology can produce greater isolation than either of the single-diode topologies can produce.

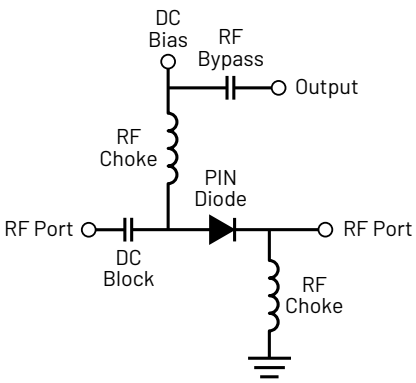


Figure 3. SPST With Series PIN Diode

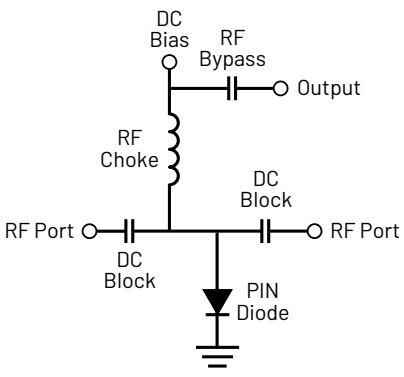


Figure 4. SPST With Shunt PIN Diode

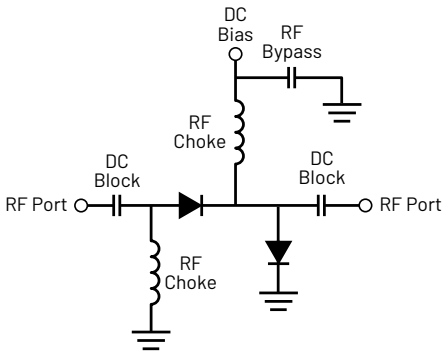


Figure 5. SPST With Series and Shunt PIN Diodes

High Power PIN Diode Switching

Single-Pole Double-Throw (SPDT) PIN Switches

As is the case for the series PIN diode SPST, the isolation of either of the arms of the SPDT (Figure 6) is determined by the capacitive reactance of its series diode. Insertion loss is determined by the forward-biased series resistance of its PIN diode.

The isolation of either arm of the SPDT comprising shunt PIN diodes (Figure 7), is determined by the forward-biased series resistance of its PIN diode. The insertion loss of either arm is determined by the capacitive reactance of its PIN diode.

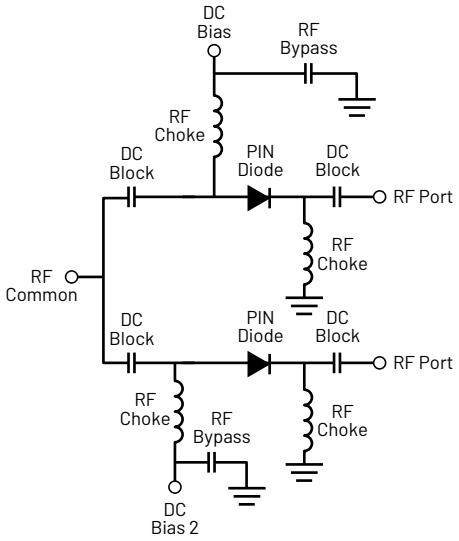


Figure 6. SPDT With Series PIN Diodes

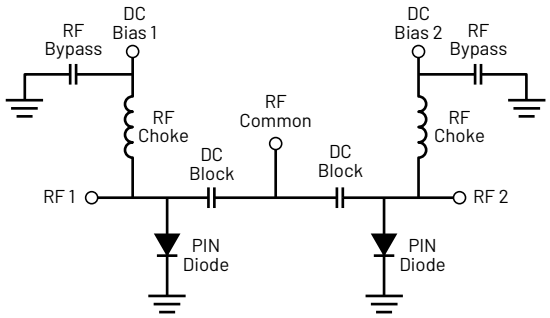


Figure 7. SPDT With Shunt PIN Diodes

The series-shunt diode SPDT topology shown in Figure 8 is widely utilized for applications in which higher isolation is required. In this topology, the series diode on the side of the switch which is intended to pass the signal is forward-biased to produce low resistance, while the shunt diode on the same side of the switch is biased out of conduction so that it produces the lowest capacitance in parallel with a very large resistance. The insertion loss of this side of the switch is determined by the combination of the series resistance of the series diode and primarily by the capacitance of the shunt diode. The diodes on the side of the switch which is intended to be in isolation are biased conversely to those in the insertion loss side of the switch. The series diodes are biased out of conduction and the shunt diode is forward-biased. The isolation of this side of the switch is mainly determined by the capacitance of the series diode and the resistance of the shunt diode. Refer to "Design with PIN Diodes" application note on Skyworks' Web site for more information about the performance of each of these topologies.

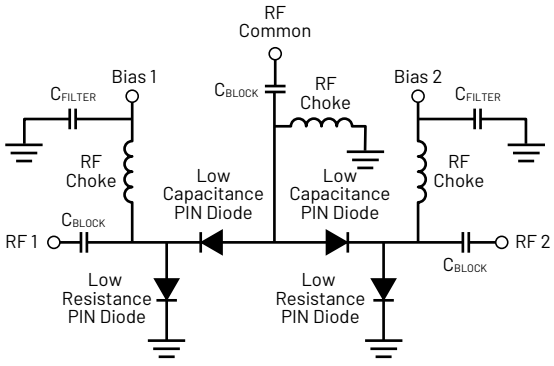


Figure 8. High Isolation Generic PIN SPDT

PIN Diode Power Handling

High Power PIN Diode Switching

With proper design, PIN diode switches can handle very large power signals. Important diode parameters for switches designed to handle power levels higher than 1 W include the diode's voltage rating and thermal resistance. Other diode parameters, such as series resistance, capacitance and I-layer thickness, are also factors to the determination of maximum power handling.

Thermal Resistance

A PIN diode is utilized as a variable impedance in switches. When the diode is forward-biased, it presents a resistance to the circuit. This resistance will dissipate power. The dissipated electrical power is converted to heat as described by Joule's Law ($P = I^2R$). For good reliability, the junction temperature of the PIN diode must be kept as low as possible and not exceed 175 °C, so the temperature of the diode's surroundings as well as its thermal resistance are critically important. The diode's junction temperature, T_J, is

$$T_J = T_C + P_D\Theta_{JC}$$

where

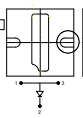
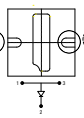
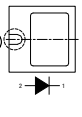
T_C = Case temperature, typically expressed in °C
P_D = Power dissipated in the diode, in W
Θ_{JC} = Thermal resistance of the media between the diode junction and the case temperature, in °C/W

Thermal resistance is a very important consideration in power handling determination. The total thermal resistance is the sum of the thermal resistance of the die/package combination, typically denoted Θ_{JC}. This is the thermal resistance from junction to "case" otherwise referred to as the terminals of the diode package, and the thermal resistance from the surface on or to which the diode is mounted.

Voltage Rating

The voltage rating of the PIN diode describes the absolute maximum voltage which can be impressed across the diode without driving it into avalanche breakdown. The sum of the peak RF voltage and the DC bias voltage must not exceed the voltage rating of the PIN diode.

Table 1. PIN Diode Selection

Part Number	Package Type Extension & Part Marking						Nom. I-Layer Thickness	Junction Capacitance (CJ)	Series Resistance (RS)	Voltage Rating (Vr)	Thermal Resistance (Θ_{JC})	Forward Voltage (VF)	Application
	-011LF SOD-323	-040LF SOD-882	-079LF SC-79	-084LF QFN 2x2	-085LF QFN 2x2	-087LF QFN 2x2							
Package Configuration							(um)	VR = 30 / 50 V 1 MHz (pF)	1 = 10 mA 100 MHz 500 MHz (Ω)	(V)	Series (°C/W)	IF = 10 mA (V)	
Description	Single	Single	Single	Shunt	Shunt	Series							
SMP1302	RF	W	C3	-	RF1	RF	50	0.12	3	200	21.7 (087LF)	0.8	Switch / Attenuator
SMP1304	-	-	C4	-	RG	PG	100	0.07	7	200	19.2 (087LF)	0.8	Switch / Attenuator
SMP1307	RJ	-	-				175	0.08	15	200	44	0.85	Attenuator
SMP1320	RL	N	C5				7	0.12	0.9	50	87	0.825	Switch
SMP1321	RM	C	C6		RM		12	0.07	2	100	115	0.86	Switch
SMP1322		T	CC				7	0.66	0.45	50	87	0.825	Switch
SMP1324	-	-	-	-	-	PW	100	0.9	0.45 @ 50 mA	200	98	0.9	Switch/ Attenuator

High Power PIN Diode Switching

Table 1. PIN Diode Selection

Part Number	Package Type Extension & Part Marking						Nom. I-Layer Thickness	Junction Capacitance (CJ)	Series Resistance (RS)	Voltage Rating (Vr)	Thermal Resistance (Θ_{JC})	Forward Voltage (VF)	Application
	-011LF SOD-323	-040LF SOD-882	-079LF SC-79	-084LF QFN 2x2	-085LF QFN 2x2	-087LF QFN 2x2							
SMP1325	–	–	–	–	RH	PH	100	0.48 @ 20 V (087LF) 0.56 @ 20 V (085LF)	1.3	200	108 (087LF) 13 (085LF)	0.65	Switch / Attenuator
SMP1331	–	KE1	KE	–	RJ	RK	30	0.13	1.7	200	26	0.8	Switch / Attenuator
SMP1334	–	–	–	MG	–	–	50	0.4	2	200	10	0.75	Switch / Attenuator
SMP1340	–	D	CE	–	–	–	5	0.10 Typ. @ 10 V	1.2	50	120	0.88	Switch
SMP1345	–	U	CF	–	–	RU	10	0.18 @ 5V	1.5	50	122	0.89	Switch
SMP1352	RR	S	CG	–	–	–	50	0.35 Max. @ 20 V		200	81	0.8	Switch
SMP1371	–	–	–	–	–	RY	12	1.2 Max @ 20 V	0.5	35	116	1 @ 50 mA	Switch / Attenuator

Selecting PIN Diode Packaging

Plastic Surface Mount Technology Packages

Plastic surface mount technology (SMT) packages are inexpensive and are compatible with modern pick-and-place assembly techniques. They are optimal choices for high-volume, low-cost final product assemblies. Packages include the internal PIN diode wire bond connections for customers without bonding capability. Several packages are available for specific series or shunt configuration. Table 1 shows Skyworks' high power PIN diode offering. In addition to small leaded packages like SOD-882, Skyworks offers high power PIN diodes in a QFN package which produces lower thermal resistance and reduces the effects of the parasitic inductance of the anode bond wires. The cathode of the die is soldered directly to the top of the exposed paddle. This paddle is composed of copper, so its thermal resistance is very low. The copper ground paddle minimizes the total thermal resistance between the I-layer, which is the location where most heat is generated under normal operation, and the surface to which the package is mounted. Minimal thermal resistance between the diode I-layer and the external environment minimizes junction temperature.

Integrated Modules

Integrated modules are fully integrated high power switch circuits in a small plastic surface-mount package. The module simplifies the application for designers and the small package design reduces printed circuit board area. The large center copper ground paddle minimizes the total thermal resistance between the I-layer of the diode and the surface on which the package is mounted. Modules include multiple PIN diodes and integrated driver circuits, if applicable. Table 2 shows Skyworks' PIN diode switch module offering.

High Power PIN Diode Switching

Integrated High Power Pin Diode Modules

Skyworks offers a family of highly integrated broadband, high power handling, high linearity single-pole double-throw (SPDT) transmit and receive (T/R) switches. The SKY12207-478LF, SKY12208-478LF, and SKY12210-478LF SPDT T/R switch designs consist of a series-connected PIN diode placed between the transmitter power amplifier and antenna, and a series and shunt-connected PIN diode connected at the receiver port (Figure 9).

As shown in Figures 10a and 10b, when the transmitter is on, forward current is applied to the transmit series diode (low impedance state), allowing low insertion loss between the transmitter and antenna. The high impedance of the receiver series diode protects it from the transmitter power, and the forward-biased shunt diode on the receiver side improves the antenna to receive isolation by shunting the RF signal to ground that is not blocked by the receiver series diode.

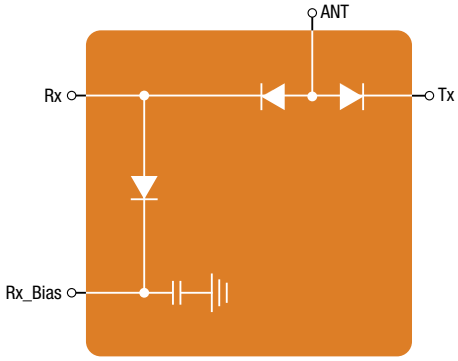


Figure 9. Typical SPDT With Series-Shunt Configuration

When the receiver is on, forward current is applied to the receive series diode (low impedance state), allowing low insertion loss between receiver and antenna. The series transmit, and shunt receive PIN diodes are at zero bias (high impedance state). This results in low loss between the antenna and the receiver and isolates the off transmitter.

The SKY12212-478LF, SKY12245-492LF and SKY12248-492LF switches operate similarly to the designs described above but incorporate an additional shunt diode on the transmit side (Figure 11) to improve ANT-Rx isolation. This symmetrical configuration provides high off isolation in either Tx or Rx mode.

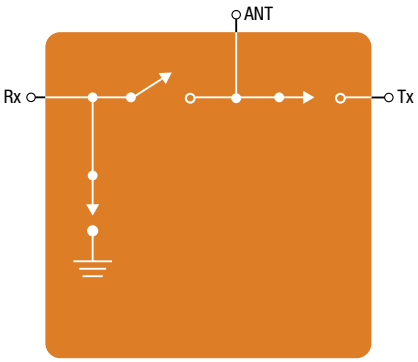


Figure 10a. w
Typical SPDT in Transmit State

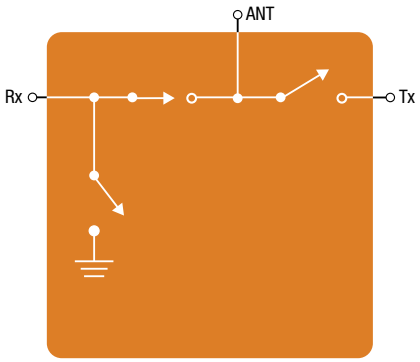


Figure 10b.
Typical SPDT in Receive State

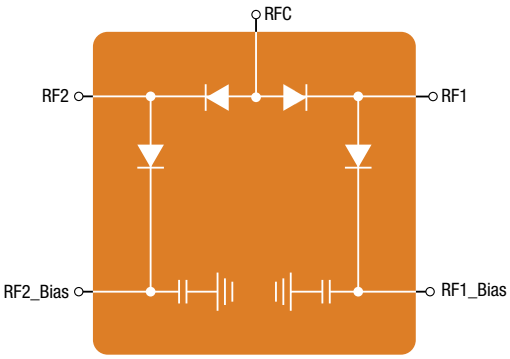


Figure 11. High Isolation Symmetrical Series Shunt Configuration SPDT

Table 2. High Power PIN Diode Switch Modules

Part Number	Description (Reflective)	Frequency (GHz)	Typ. Ant-Rx Insertion Loss (dB)	Typ. Ant-Rx Isolation Loss (dB)	Max. Power (W)	Package (mm)
SKY12207-478LF	SPDT	0.9–4.0	0.3–0.6	30–42	50	QFN 16L 4 x 4 x 1.5
SKY12208-478LF	SPDT	0.02–2.7	0.2–0.5	35–50	50	QFN 16L 4 x 4 x 1.5
SKY12210-478LF	SPDT	0.9–4.0	0.3–0.6	33–44	100	QFN 16L 4 x 4 x 1.5
SKY12212-478LF	SPDT	0.05–2.7	0.3–0.4	24–47	100	QFN 16L 4 x 4 x 1.5
SKY12245-492LF*	SPDT	0.1–5.0	0.2–0.7	35–45	100	QFN 20L 5 x 5 x 1.5

*Includes integrated driver

High Power PIN Diode Switching

Table 2. High Power PIN Diode Switch Modules (continued)

Part Number	Description (Reflective)	Frequency (GHz)	Typ. Ant-Rx Insertion Loss (dB)	Typ. Ant-Rx Isolation Loss (dB)	Max. Power (W)	Package (mm)
SKY12248-429LF	SPDT	0.1–42	0.2–0.7	36–45	120	QFN 20L 5 x 5 x 1.5

*Includes integrated driver

Pin Diode SPDT Isolated Arm Reverse Bias

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 required for the PIN diode to hold the "off" or isolated arm of a SPDT in its high-impedance state in the presence of RF signals large enough to instantaneously apply a forward voltage to the diode and into conduction. The magnitude of the reverse voltage required for a high power switch depends on frequency, RF voltage and PIN diode I-region width.

For traditional high power PIN diode switch topologies, this reverse bias (>5V) is supplied from a system voltage rail. Some systems do not have this option available and require the switch to generate its own reverse bias from the lower voltage supply. This can be done by the use of a boost converter similar to the one shown in Figure 12. A boost converter is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input to its output. It is a class of switched-mode power supply containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or a combination of the two. To reduce voltage ripple, filters made of capacitors are normally added to a converter's output and input.

The SKY12245-492LF (Figure 13) is an innovative high power SPDT pin diode switch which simplifies the switch operation with the incorporation of an integrated digital control driver and a DC-to-DC boost converter. The digital control driver switches the RF states with a simple transistor-transistor logic (TTL) logic signal of 0 to 3V and includes the switching transistor needed for the DC-to-DC converter. The external circuitry required for the boost converter is detailed in the data sheet.

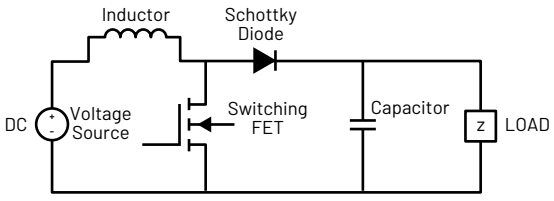


Figure 12. DC-to-DC Boost Converter Circuit

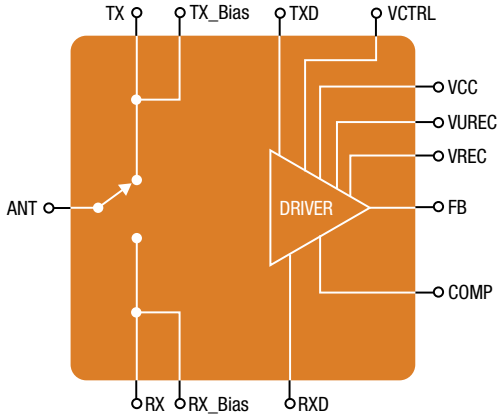


Figure 13. High Power SPDT Switch With Integrated Controller

For more information, please visit our website at www.skyworksinc.com.