



SKYWORKS®

PIN Limiter Diode 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.

Receiver Protection

Skyworks' silicon product offerings include PIN limiter diodes 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, LTE base stations and other radio and radar receivers.

These receivers must be capable of processing very small signals, necessitating the use of extremely sensitive circuit blocks that can contain fragile semiconductors. Many of these systems must also be capable of surviving very large incident signals without damage to their sensitive components. The receiver protection limiter, or simply referred to as limiter, can protect the receiver from large input signals allowing the receiver to function normally when these large signals are not present. Limiters are most often employed in radar transceivers, whose transmitters and receivers are tuned to the same frequency. The transmitter produces a peak signal in the kilowatts or megawatts range, which is applied to an antenna and is also typically utilized by the receiver. The receiver must be capable of reliably detecting and processing very weak reflected signals. It is achieved with the use of a sensitive, low noise amplifier (LNA) at its input, or in some cases receivers apply the received signal directly to the input of a downconverter mixer. Receivers use sensitive semiconductor components that can be damaged by even a small portion of the transmitter signal possibly coupled to the receiver input, by either a reflection from the antenna or by other means. A limiter can protect these components.

PIN Limiter Diodes for Radio Transceiver Protection

The radio transceiver is a device that can send and receive information over the same medium. The block diagram shown in Figure 1, represents a design approach for many end uses, including cellular telephone base stations, land mobile radios, electronic countermeasure systems, portable two-way communications systems, avionics systems and more. A transceiver combines the transmitter and receiver into one unit. The transmitter processes and converts analog baseband signals to a higher frequency analog signal, which is radiated from the system antenna. The receiver's function is the converse of the transmitter's function: a high-frequency signal is transduced by the antenna from electromagnetic energy propagated through free space to a voltage/current waveform. This signal is optionally applied to a receiver protector circuit, the output of which is filtered and applied to a low noise amplifier stage. Skyworks offers PIN limiter diodes to perform this function.

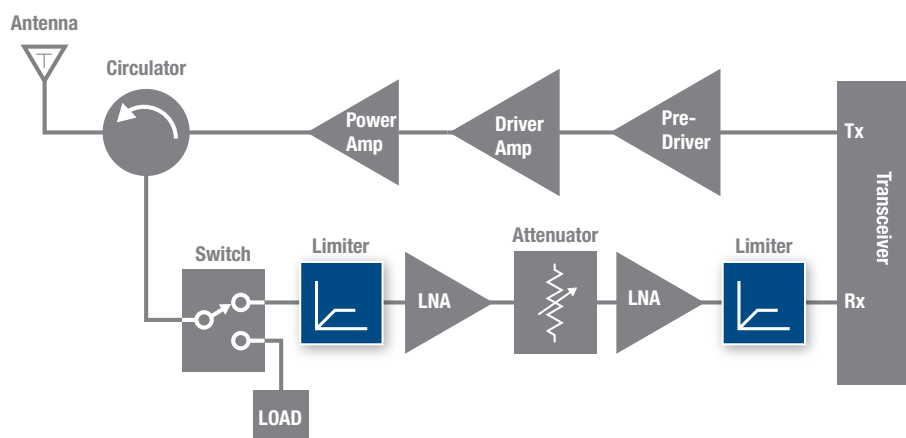


Figure 1. Radio Transceiver Block Diagram

PIN Limiter Diodes

The receiver protector function is performed by a specially processed PIN diode, known as a limiter diode. The PIN limiter diode is an incident-power-controlled, variable resistor. In the case when no large input signal is present, the impedance of the limiter diode is at its maximum, thereby producing minimum insertion loss, typically less than 0.5 dB. The presence of a large input signal temporarily forces the impedance of the diode to a much lower value, producing an impedance mismatch which reflects the majority of the input signal power back towards its source.

The input power level at which the limiter diode's impedance starts to decrease in response to a large input signal amplitude is primarily determined by the diode's I-layer thickness. The diodes which "turn on" at the lowest signal levels have the thinnest I-region layer. For example, the output power vs. input power characteristic for a very thin diode is shown in Figure 2. In this example, the diode's impedance begins to decrease with only 10 mW incident power. Its impedance is sufficiently decreased to produce 1 dB of excess insertion loss at approximately 12 dBm, known as the threshold level.

The function of limiter diodes in receiver protection circuits is shown in Figure 3.

The circuit design for a single-stage limiter is shown in Figure 4. With a small input signal present, the diode presents a very large shunt impedance to the transmission line, so it produces very little insertion loss. The inductance of the RF choke is selected to also produce a very large shunt impedance. As the input signal gets larger, it forces charge carriers into the I-layer of the diode, which reduces the diode's impedance. This reduction in impedance produces an impedance mismatch at the diode which reflects some portion of the input signal power.

The RF choke serves as the DC return in the diode's RF detector role. In the absence of a signal, the choke also discharges the charge stored in the diode and the DC blocking capacitors. Under small signal conditions, below the limiting threshold, the rectified current is insufficient to lower the diode junction resistance. As a result, the diode appears as a capacitance shunted by a large resistance.

Under large signal conditions the incident signal exceeds the threshold power level, the diode's I-layer is flooded with carriers during the positive half-cycle of the incoming RF signal. Most of these carriers persist through the negative half-cycle, DC current begins to flow in the loop formed by the diode and the bias return choke, and the diode biases itself to a low value of resistance in a matter of nanoseconds. Under the influence of this self-generated bias current, the diode's junction resistance falls to a very low value, shorting out the transmission line. With a small incident signal, the diode appears to be a capacitive reactance in parallel with a large resistance. The values of these two components are determined by the physical design of the die. The major effect of the presence of these components in shunt with the transmission line is to increase small signal insertion loss.

When a large signal, larger in magnitude than the threshold level, is present the resistance of the equivalent circuit is significantly reduced and is forced to approach the minimum value. This

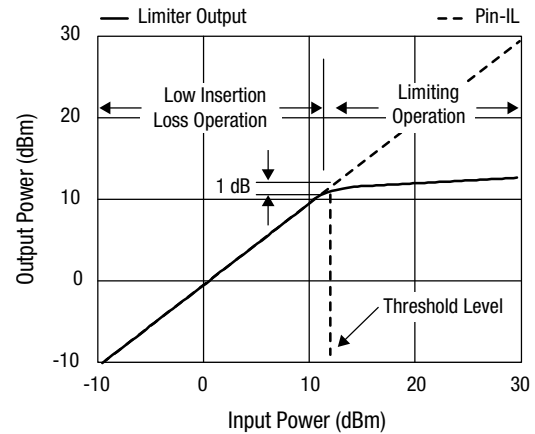


Figure 2. Output Power vs. Input Power for a Single-stage Limiter

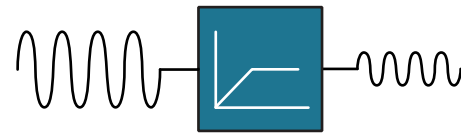


Figure 3. Limiter Diodes in Receiver Protectors Prevent Damage from Large Signals to Sensitive Receiver Components

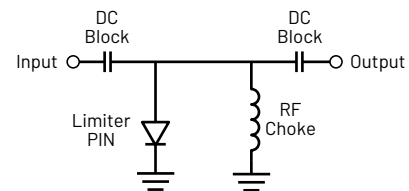


Figure 4. A Single-stage Limiter

PIN Limiter Diodes

minimum value of resistance is also determined by the physical design of the diode. The minimum value of resistance determines the maximum insertion loss, or isolation, that the diode can produce. Depending on signal frequency and the specific characteristics of the diode, isolation of 15 to 30 dB can be expected from a single stage.

Limiter diodes of different I-layer thicknesses may be cascaded to produce a receiver protector that can withstand very large input power while allowing low flat leakage output power. These are known as multi-stage limiters. An example of this is a two-stage limiter circuit as shown in Figure 5. The PIN limiter diode at the input is commonly referred to as the “coarse limiter”. This diode has the thicker I-region layer and sets the max power handling and isolation. The PIN limiter diode at the output, commonly referred to as the “clean-up stage,” is the diode with thinner I-region layer, selected so the threshold level of the circuit is low enough to protect any connected receiver components like an LNA. The coarse limiter is normally placed one quarter wavelength ($\lambda/4$), or an odd multiple of one-quarter wavelength, from the clean-up stage towards the signal source. For extremely large input signals, 3 or more stage limiter circuit can be constructed with each stage spaced a $\lambda/4$ apart as shown in Figure 6.

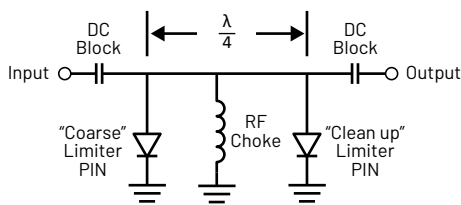


Figure 5. Multi-stage, 2-stage Limiter Circuit

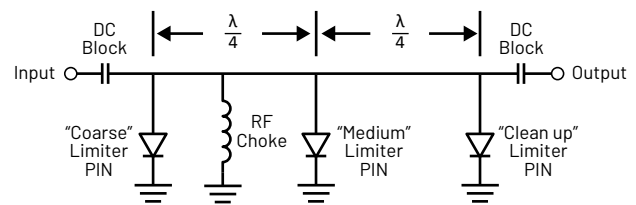


Figure 6. Multi-stage, 3-stage Limiter Circuit

Skyworks limiter diodes are available as unpackaged die and in several types of packages. In most cases the requirements of the end application will determine the optimal physical diode configuration.

Selecting PIN Limiter Diode Packaging

Die (Packageless)



Diode die, sometimes known as chips, do not have the parasitic reactances and thermal resistance associated with a package part. This configuration produces the widest bandwidth and highest frequency of operation as well as maximum power dissipation capabilities. Diode die are used in integrated and multi-chip modules to provide passive receiver protection over a wide range of frequencies from 100 MHz to over 30 GHz.

Thermocompression bonding with gold wire or ribbon leads should be used to attach the chip anode to the circuit. Either ball bonding or wedge bonding may be used. The latter is generally preferred since smaller bond areas are possible with less parasitic capacitance.

Ceramic-Metal Packages



Ceramic-metal packages offer several advantages over plastic packages. Their parasitic inductances and capacitances are generally lower, sometimes by as much as 75%, than plastic surface mount technology (SMT) packages previously described. Their thermal resistances are also usually much lower than the large majority of plastic SMT packages. Most ceramic packages used for limiter diodes are capable of being hermetically sealed, thereby offering maximum protection to the die against environmental contaminants such as sodium (Na), water vapor, etc.

PIN Limiter Diodes

Plastic Surface Mount Technology Packages



Plastic surface mount technology (SMT) packages are inexpensive and are compatible with modern pick-and-place assembly techniques, so they are optimal choices for high-volume, low-cost final product assemblies. While careful attention has been paid to minimizing package parasitic reactances, they are always present in these type of diode configurations. The parasitic package capacitance and package inductance inherently reduces the bandwidth over which a diode may be used and can affect insertion loss and isolation. Plastic SMT packages also add thermal resistance to the die, thereby reducing the amount of power a diode can dissipate without exceeding its maximum rated operating junction temperature.

Integrated Modules



Integrated modules are fully integrated limiter circuits in a small plastic surface-mount package. The modules are designed for use as a passive receiver protector in wireless or other RF systems. Modules include the PIN limiter or Schottky diodes, DC blocking caps and RF choke if applicable. The module simplifies the application for designers and the small package design reduces printed circuit board area.

PIN Limiter Diode Die

Skyworks' broad product portfolio includes PIN limiter diode die. The dice are very small and bondable with wire or ribbon bonding. They are very useful for RF module designers in a variety of receiver protector applications.

Part Number	P_{1dB} Threshold Level (dBm)	I-Layer Thickness (μm)	Insertion Loss @ -10 dBm and 1 GHz (dB)	Max. Series Resistance @ 10 mA and 1 GHz (W)	Max. Junction Capacitance @ 0V (pF)	Max. CW Input Power (dBm)	Multi-stage Limiter Application
CLA4601-000	+12	1.0	0.1	2.5	0.12	+36	Clean-up
CLA4602-000	+12	1.0	0.1	2.0	0.20	+36	Clean-up
CLA4603-000	+10	1.5	0.1	2.0	0.20	+3	Mid-range
CLA4604-000	+12	2.0	0.1	2.5	0.12	+40	Clean-up
CLA4605-000	+11	2.0	0.1	2.0	0.20	+40	Clean-up
CLA4606-000	+11	2.5	0.1	2.0	0.20	+41	Mid-range
CLA4607-000	+26	7.0	0.1	2.0	0.20	+43	Coarse
CLA4608-000	+23	7.0	0.2	1.2	0.60	+43	Coarse
CLA4609-000	+37	20	0.3	1.5	0.26	+44	Coarse
CLA4610-000	+22	4.5	0.1	2.2	0.13	+40	Mid-range
CLA4611-000	+25	12	0.3	1.2	0.20	+40	Mid-range

1. RF Frequency=2.6 GHz, T=25°C

PIN Limiter Diodes

Packaged PIN Limiter Diodes

In addition to bondable die, Skyworks offers packaged PIN limiter diodes. The packages include pill, leaded and unleaded square ceramic hermetic packages and lower cost plastic surface mount technology (SMT) packages for receiver protection applications. For more information, please visit www.skyworksinc.com.

Part Number	P_{1dB} Threshold Level (dBm)	I-Layer Thickness (μm)	Insertion Loss @ -10 dBm and 1 GHz (dB)	Typ. Series Resistance @ 10 mA and 1 GHz (W)	Max. Junction Capacitance @ 0V (pF)	Max. CW Input Power (dBm)	Max. Peak Input Power ² (dBm)
CLA4601-XXX	+12	1.0	0.1	2.0	0.37	+36	+62
CLA4602-XXX	+12	1.0	0.1	1.5	0.45	+36	+64
CLA4603-XXX	+10	1.5	0.1	1.5	0.45	+38	+65
CLA4604-XXX	+12	2.0	0.1	2.0	0.37	+40	+64
CLA4605-XXX	+11	2.0	0.1	1.5	0.45	+40	+63
CLA4606-XXX	+11	2.5	0.1	1.5	0.4	+41	+64
CLA4607-XXX	+26	7.0	0.1	1.5	0.45	+43	+66
CLA4608-XXX	+23	7.0	0.2	0.5	0.85	+43	+69
CLA4609-XXX	+37	20	0.3	1.0	0.51	+44	+62
CLA4610-XXX	+22	4.5	0.1	1.7	0.38	+40	+65
CLA4611-XXX	+25	12	0.3	0.8	0.35	+40	+64
SMP1330-XXX	+9	2.0	0.3	1.6	1.0	+35	+48

1. RF Frequency=2.6 GHz, T=25°C

2. Pulsed power measurements taken at 1 μs pulse width, pulse frequency = 10 kHz, and 0.01% duty cycle.

Package Type Key (-XXX)

Ceramic-Metal Package Types Available (CLA Parts Only)

- -203: Pill 1
- -210: Pill 2
- -219: 2-pin Square (Leadless)
- -240: 2-pin Square (Leaded)

Plastic Package Types Available

- -005: SOT-23 (SMP1330 Only)
- -040: SOD-882 (SMP1330 Only)
- -085: Center pin GND DFN (All Parts)

PIN Limiter Diodes

PIN Limiter Diode Modules

While discrete limiter diodes can be combined to create a variety of receiver protector circuits, integrated limiter modules are designed to simplify their application. A single-stage limiter circuit requires, a PIN limiter diode, a bias choke and DC blocking capacitors. All these components can be entirely integrated into a small flat lead package for ease of application, economy of space and cost such as the one shown in Figure 7.

Part Number	Type	RF Test Frequency (GHz)	Typ. P_{1dB} Threshold Level (dBm)	Typ. Insertion Loss @ 0 dBm (dB)	Max. Saturated Power (dBm)	Flat Leakage Power (dBm)	Package (mm)
SKY16601-555LF	Single-stage	2.5	+11	0.1	+29	13 @ Pin = +20 dBm	2-Pin MLP 2.5 x 2.5 x 0.75
SKY16602-632LF	Anti-parallel	0.9	+6	0.3	+30	6 @ Pin = +10 dBm	2-Pin DFN 2.3 x 2.3 x 0.55
SKY16603-632LF	Anti-parallel	2.6	+8	0.3	+35	9 @ Pin = +15 dBm	2-Pin DFN 2.3 x 2.3 x 0.55

In addition to a single-stage limiter module, another type of limiter module is the anti-parallel limiter. Like the single-stage limiter module, it includes the DC blocking caps, but the limiting circuit is accomplished by connecting diodes in parallel with the polarities in opposite directions as shown in Figure 8.

During the positive or negative cycle of the incoming RF signal, one diode rectifies the incoming RF and produces a current proportionate to the incident RF power. One PIN diode, which is connected in an anti-parallel configuration to the other diode, provides a return path for the current and behaves like a current controlled resistor.

At power levels below the diode detection threshold, the unbiased PIN diode's equivalent junction resistance is considerably higher than the transmission line characteristic impedance. Therefore, most of the incident power will pass through one limiter with almost no attenuation. Depending on the polarity, if the incoming RF signal is above the diode's threshold, the rectification of RF produces a current that lowers the PIN diode equivalent resistance. At very low resistance values, most of the incident power is reflected back to the source and only a small fraction is dissipated in the PIN diode.

To lower the module limiting threshold, a Schottky diode can be used in place of one of the PIN limiter diodes to generate the bias current for the other PIN diode limiter (SKY16602-632LF). Since a Schottky diode has a lower turn-on threshold voltage than a PIN limiter diode the P_{1dB} threshold is also lower. The Schottky diode is turned on first since the forward voltage is less than the PIN limiter diode. Similar to the discrete diode limiter operation, the input power level at which the limiter diode's impedance starts to decrease in response to a large input signal amplitude is primarily determined by the diode's I-layer thickness. For a low threshold limiter, at least one of the diodes is selected with a small I-region while the other is selected for the required max power operation. By incorporating thicker I-region PIN diodes in an anti-parallel configuration (SKY16603), this provides for low distortion without the need for a choke for a DC return. The low distortion resulting from the even-order distortion generated by each diode will have opposite polarities and self-cancellation occurs to the extent that the diodes are matched.

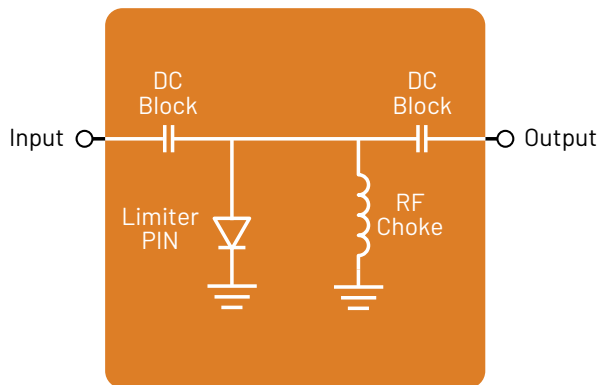


Figure 7. Single-stage Limiter Module (SKY16601-632LF)

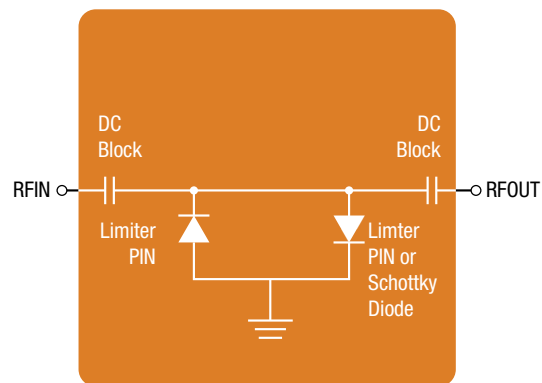


Figure 8. Anti-parallel Limiter Module (SKY16602-632LF and SKY16603-632LF)



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