

A High Power Solid State T-R Switch

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Introduction

Radio transceiver designers are always faced with a dilemma: how to direct the high power transmit signal to the antenna, prevent that signal from entering the sensitive front end of the local receiver, while also allowing a low-loss connection between the antenna and the receiver.

The manner in which this problem is solved depends somewhat on the architecture of the system. If the radio and receiver operate on different frequencies, then a filter network known as a diplexer can be placed between the antenna, transmitter output and receiver input. The filters in the diplexer separate and direct the transmit and receive signals to their desired destinations while preventing them from arriving where they do not belong.

Systems that utilize the same frequency for transmit and receive signals obviously cannot use the diplexer approach. For these transceivers, solid state switches are configured as transmit-receive (T-R) switches to perform this important function.

Antenna Switch Designs

A T-R switch may be configured using a series connected PIN diode between the antenna and transmitter and an additional one between the antenna and receiver. This configuration is shown in figure 1.

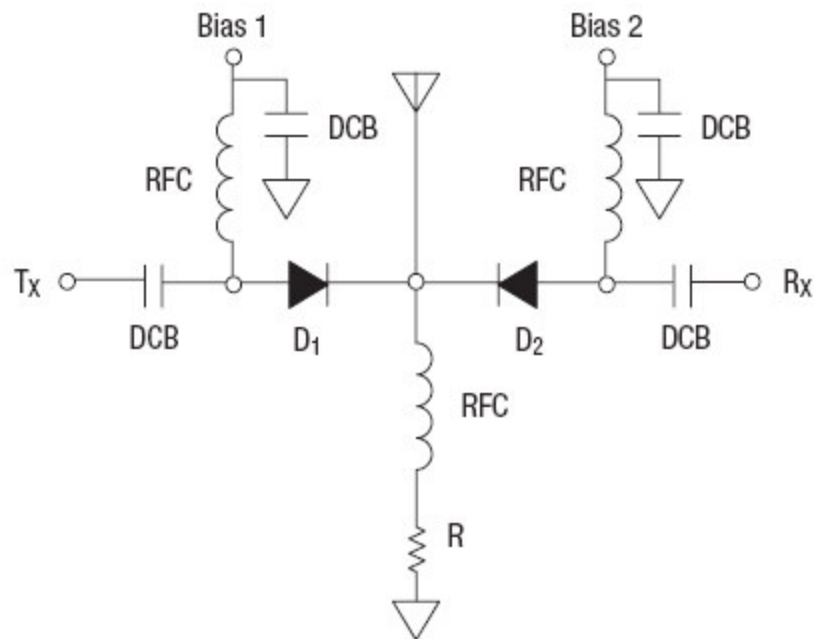


Figure 1. Broadband Transmit-Receive Switch Design

This SPDT switch is operated by supplying forward current to the arm where low insertion loss is desired and reverse or zero bias to the isolating arm. This is a relatively simple approach and has the benefit of being broadband, resulting from the absence of any frequency selective elements. A consequence of this design

is that power handling of a series connected PIN diode is generally poor, limiting the maximum power transmitted. Also, there is a requirement for forward current in receive or standby state.

A more common approach utilizes series and shunt connected PIN diodes as shown in figure 2.

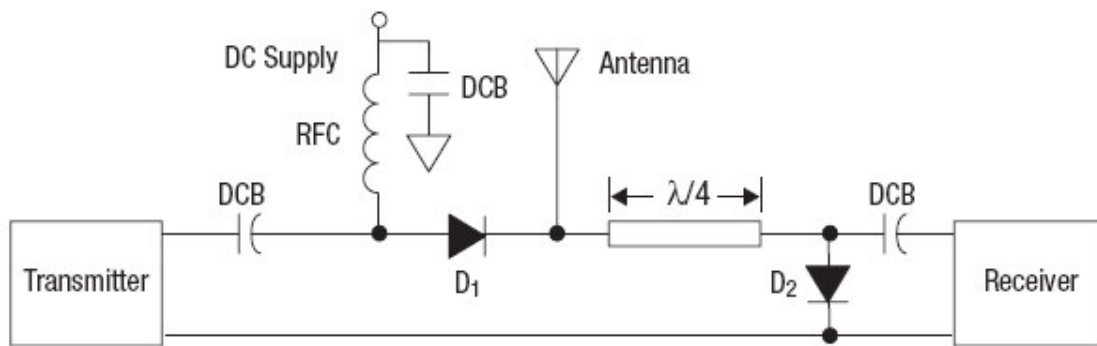


Figure 2. Quarter Wave T-R Switch Design

In this design, both PIN diodes are forward biased in the transmit state with the series connected diode, D1, allowing a low insertion loss path between transmitter and antenna and the receiver protected by the low impedance of the shunt diode, D2. This low impedance is transformed by a quarter wave transformer which projects high impedance to the antenna terminal. In the receive state both PIN diodes may be at zero bias; thus in this configuration the switch requires no energy. This design is also limited in its power handling by

utilizing a series connected diode in the transmit arm. It should also be noted that, during transmit, the shunt diode in the receiver arm is carrying the same RF current as the antenna and must have adequate power dissipation capability.

A High Power Handling Solid State T-R Switch

A design comprising two shunt PIN diodes and a pair of quarter wave transformers can handle significantly higher RF power than the circuits shown in figures 1 and 2.

The SKY12204 SPDT Switch utilizes two shunt connected PIN diodes to achieve high power handling, 25 watts CW and 100 watts peak, and low loss, 0.6 dB typical, as a T-R switch in the frequency range from 1.90 to 2.10 GHz for TD-SCDMA base station and other applications.

The internal circuit of the SKY12204 is shown in figure 3. The circuit comprises a single pole double throw switch, which has two identical sections, connected to each other at the RF port called "Antenna."

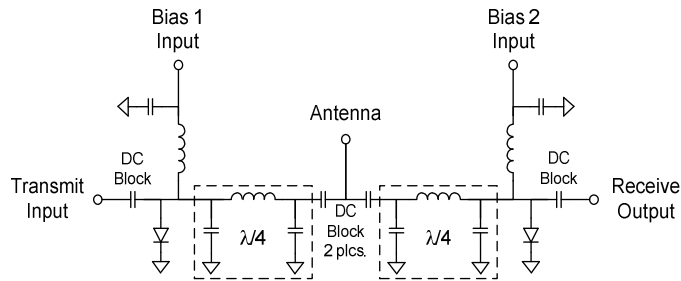


Figure 3. The SKY12204 Circuit

This switch is operated in one of two discrete states. The diode in one side of the switch is forward-biased, resulting in low impedance providing isolation between the antenna port and the RF port on this side of the switch, while the diode on the other side of the switch is in the reverse-bias state, providing high impedance resulting in low insertion loss between its RF port and the antenna port. The other state is the converse of the first state: that is, the diode that is forward-biased in the first state is non-conducting in the second state, and the diode that was non-conducting in the first state is forward-biased in the second state.

There are internal DC blocking capacitors in series with the two switched RF ports, as well as between each switch section and the antenna port.

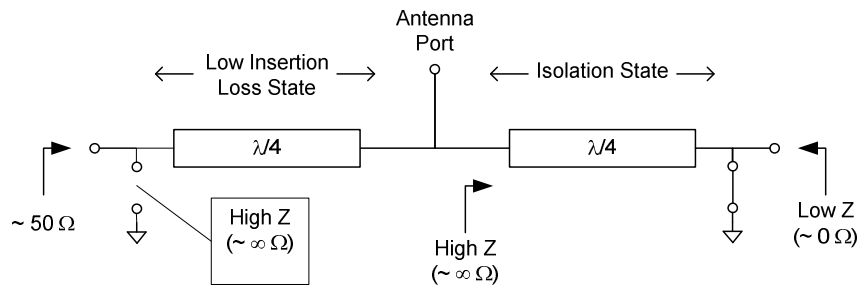


Figure 4. The SKY12204 Equivalent Circuit

The isolation state is produced by applying 50 mA forward bias the diode. This produces a low RF impedance in shunt with the RF transmission line, thereby reflecting RF energy back to its source and provides low loss to reliably handle the RF power dissipated in the diode. This low impedance is transformed to a high impedance at the antenna port by the lumped equivalent circuit of a quarter wavelength transmission line, labeled “ $\lambda/4$ ” in figures 3 and 4.

The insertion loss state is produced by biasing the diode to high impedance. The PIN diode produces high impedance when it is in its non-conducting state. 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 SKY12204 switch at 25 watts

incident power 7 volts reverse voltage is specified. This was determined experimentally and it conforms to theoretical analysis. The presence of reverse bias voltage also reduces harmonic and intermodulation distortion produced by the non-conducting PIN diode.

The SKY12204 Performance

The following graph indicates typical performance of the SKY12204. The data were taken at: $T_A = 25\text{ }^\circ\text{C}$, $Z_0 = 50\text{ Ohms}$.

TX, Transmit Mode: $V_{\text{BIAS } 1} = -7\text{V}$, $I_{\text{BIAS } 2} = 50\text{ mA}$

RX, Receive Mode: $I_{\text{BIAS } 1} = 50\text{ mA}$, $V_{\text{BIAS } 2} = -7\text{V}$

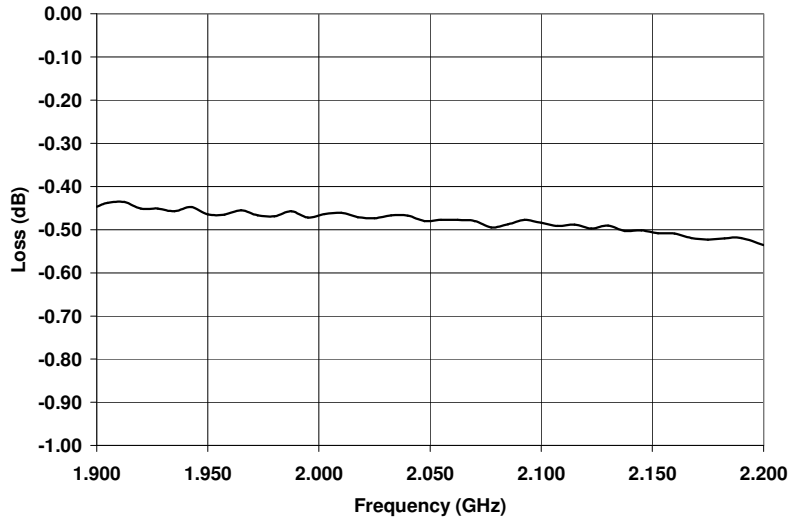


Figure 5. The SKY12204 Transmit Mode Insertion Loss

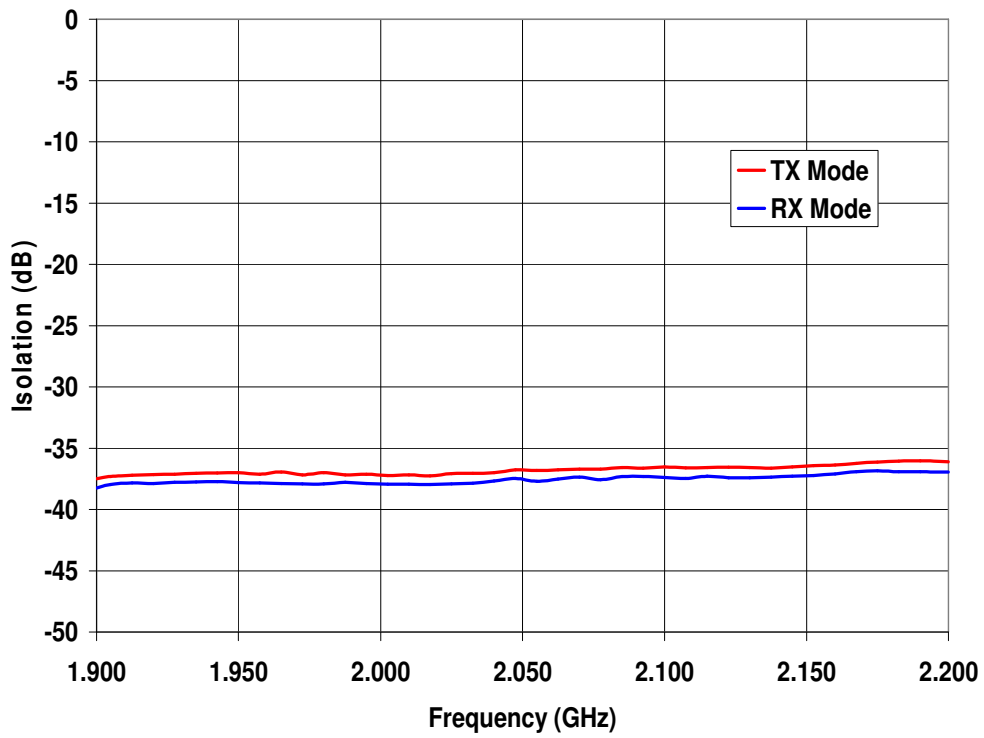


Figure 6. The SKY12204 Receive Mode Insertion Loss

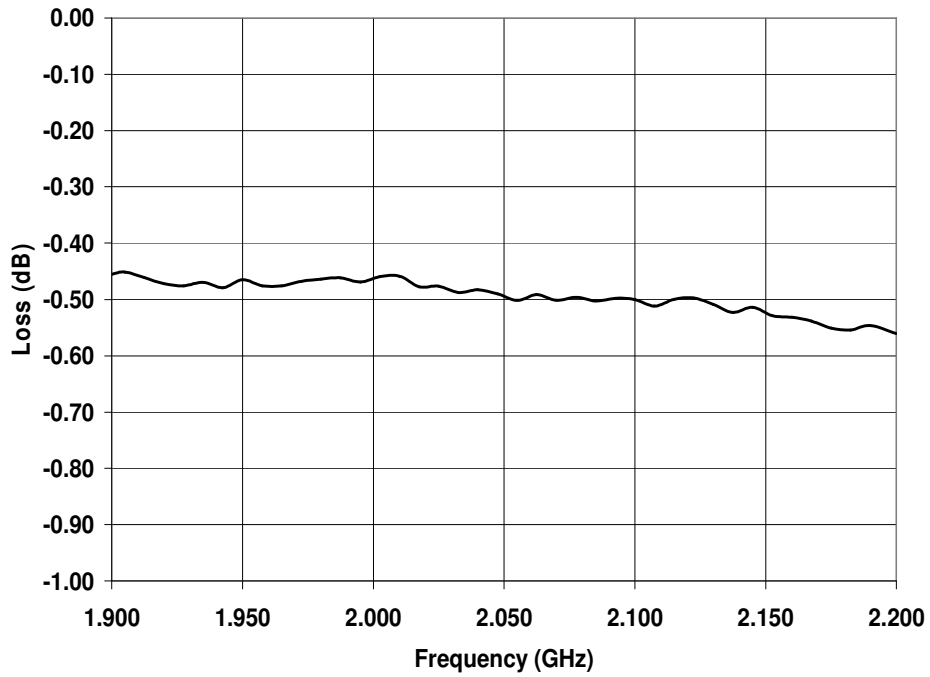


Figure 7. The SKY12204 Isolation vs. Frequency

Power Handling

The power handling capability of the SKY12204 relates to the power dissipation rating of the PIN diode in shunt with the receiver. It may be shown that in the transmit mode the RF current in this diode is the same magnitude as the RF current in the antenna. For a matched load, the expression for power dissipated in the diode is as follows:

$$P_{diss} = \frac{R_{sx} P_{trans}}{Z_0}$$

The PIN diode chip used is the APD2220-000. This device has typical series resistance (R_s) at 50 mA of 1 Ω . At 25 watts transmitter power, the power dissipation calculates to 0.5 watts. The thermal resistance rating of this diode is 80 $^{\circ}\text{C}/\text{W}$, resulting in a 40 $^{\circ}\text{C}$ rise in junction temperature. For reliable operation the maximum junction temperature should be no higher than 175 $^{\circ}\text{C}$.

For a mismatched load the dissipated power increases dramatically. It can be shown that for a load standing wave ratio (SWR) of 2.0 the dissipated power increases to 0.88 W and for a totally mismatched load, $\text{SWR}=\infty$, the power dissipation will theoretically rise to 2.0 W. These are worst case scenarios that assume: the phase of the mismatch causes maximum current in the PIN diode;

and, the power amplifier generates full voltage and current into the mismatched antenna.

Distortion

In a forward biased PIN diode distortion is generated because of the instantaneous change of diode resistance within the period of the RF signal resulting in a time varying resistor. This effect has been analyzed and shown that for a switching PIN diode, distortion improves with increasing frequency and a thin I-region PIN diode has better distortion properties than a thicker one. Distortion is also proportional to the ratio of stored charge (forward current multiplied by carrier lifetime) and inversely proportional to PIN diode resistance.

The distortion generated by a reverse biased PIN diode is caused by the instantaneous change in capacitance and conductance during the period of the RF signal. The distortion is poorest at zero bias and improves with increasing reverse bias voltage. Reverse bias distortion increases as frequency is increased and a thick I-region PIN diode has better reverse bias distortion than a thinner one.

Distortion measurements were performed on the SKY12204 switch by applying two +15 dBm signals at 5 MHz spacing in band and measuring the amplitude of the third order intermodulation signals relative to the carriers. The input third order intermodulation intercept point (IIP3) is calculated from this measurement.

Calculation of IIP3 showed values greater than +90 dBm; measurements were limited by baseline measurement system noise which showed IIP3 greater than +80 dBm. Skyworks conservatively specifies IIP3 at >+70 dBm, typical, for the SKY12204.

Conclusion

Several solid state T-R switch topologies exist for radio transceivers. Skyworks Solutions has introduced a high power T-R switch, the SKY12204, which can handle 25 W CW, 100 W peak transmitter power operating from 1.90 to 2.10 GHz.

References

1. *Design with PIN Diodes*, Skyworks' Application Note APN1002.
2. R. Caverly and G. Hiller, "Distortion in PIN Diode Control Circuits", *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-35, p. 492, May 1987.
3. R. Caverly and G. Hiller, Establishing the Minimum Reverse Bias for a PIN Diode in a High Power Switch, *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-38, p. 1938, Dec. 1990.