A T/R Diversity RF Switch Design Using PIN Diodes

This design combines low-cost implementation with good RF performance

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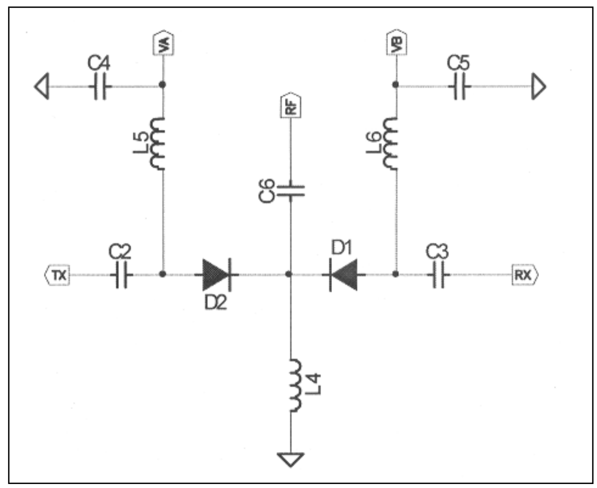
TDMA is a very popular standard for today's wireless communication equipment. It is widely adopted in TDMA based cellular phones, GSM handsets and wireless LANs. One of the most important building blocks for TDMA is a high performance RF switch. The RF switch's main function is to switch between the transmitter (Tx) and the receiver (Rx). Typical design requires low insertion loss (IL), low intermodulation distortion (IMD), high isolation between Tx and Rx, fast switching time, and low current consumption. In mobile phone and outdoor wireless LAN applications, the environment also presents the fading problem to the system designer. One low-cost and effective way to combat fading is diversity. This article discusses a T/R switch with inherent space diversity at 2.45 GHz.



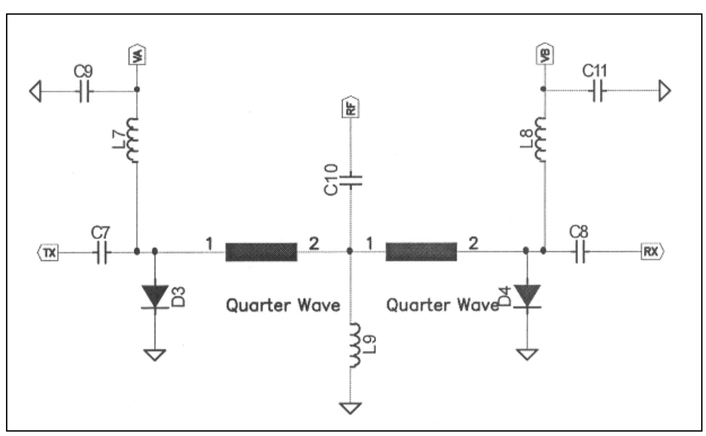
▲ **Figure 1. A typical SPDT switch topology with series diodes.**

PIN diode switch design

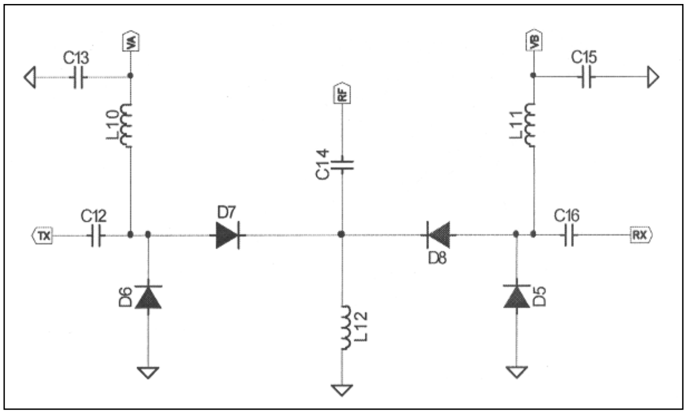
An RF switch can be implemented with either a MESFET or PIN diode. The MESFET-based RF switch is good for MMIC design, while PIN diodes are good for low-cost discrete design. This paper focuses on the design using a PIN diode. Typical single pole double throw (SPDT) topologies are shown in Figures 1, 2 and 3.

In Figure 1, a pair of series PIN diodes is used. The incoming RF signal can be switched to either Tx or Rx by turning on one of the PIN diodes while the other is off. For example, if V_a is a 5 V and V_b is –5 V, then D2 is on. The RF port is connected to Tx. If V_a and V_b are reversed, then D1 is on. The RF port is connected to Rx.

In Figure 2, a pair of shunt-configured PIN diodes is used. The shunt-configured PIN diodes are combined with quarter-wave transmission



▲ **Figure 2. Switch with λ/4 wave sections to permit the use of shunt diodes.**



▲ **Figure 3. Series-shunt switch with high isolation.**

line. The incoming RF signal is switched to either Tx or Rx, depending on which diode is on. If D4 is on and D3 is off, the RF port sees open circuits on the side of D4, so the RF signal is connected to Tx. If the bias voltage is reversed, the RF signal is connected to Rx.

Figure 3 features a design using a combination of series and shunt-configured PIN diodes. This design will have a very high isolation between Tx and Rx. When D7 and D5 are on, the RF signal is connected to Tx. When D6 and D8 are on, the RF signal is connected to Rx.

All the above topologies are widely used in RF and microwave design, and all give good performance. All are also are symmetric. They are good for a general purpose application, but that could also be to their disadvantage. First, a pair of digital control signals is needed. Typically, a cascade logic inverter is needed to control the general purpose SPDT switch. Second, bias current is always needed for either the Tx or Rx mode, even when the system is in stand-by or sleep mode. No current consumption is desired when the system is in stand-by mode. Finally, the general purpose SPDT switch is symmetric. The Rx and Tx can be reversed without seeing any performance difference, so it does not have any diversity capability.

An even better RF switch topology is a T/R switch. It offers performance similar to the above general purpose SPDT RF switch, but without the disadvantages associated with the SPDT switch.

T/R switch design

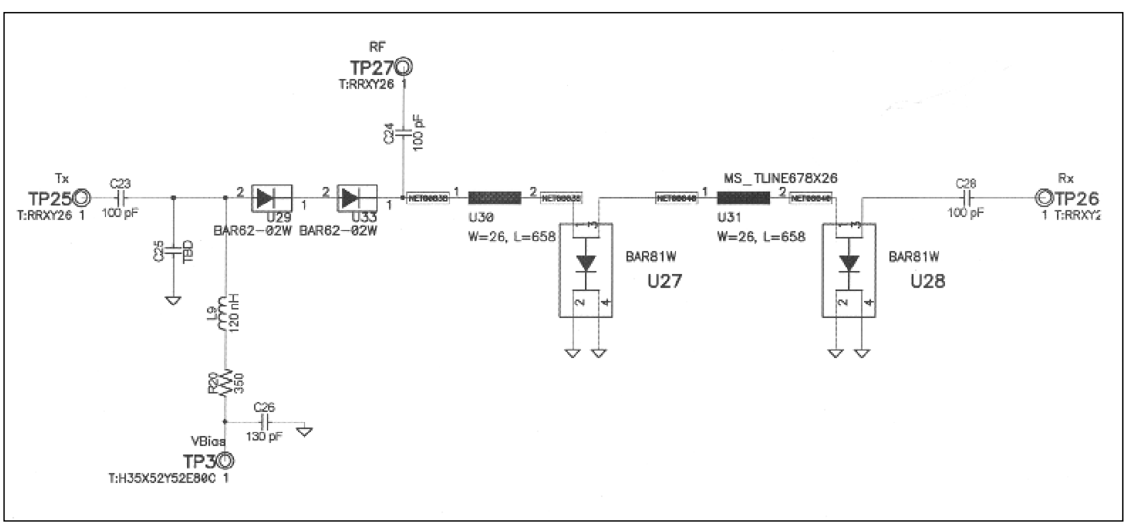
The schematic and layout of a T/R switch design at 2.45 GHz are shown in Figures 4 and 5. The basic circuit consists of a pair of series PIN diodes on one side and a pair of shunt PIN diodes combined on the other side. The extra diode is added on each side to provide more isolation and diversity.

The left half of the T/R switch is similar to half of the circuit in Figure 1, while the right half of the T/R switch is similar to half of the circuit in Figure 2. The Tx port is placed on the left and the Rx port is placed on the right. Notice that only one control signal is needed for this design. When V_{bias} goes to 5 V, all four diodes will be on at the same time. The two series diodes provide the low insertion loss path from the Tx to RF port. The two shunt diodes are placed after the quarter wave TL.

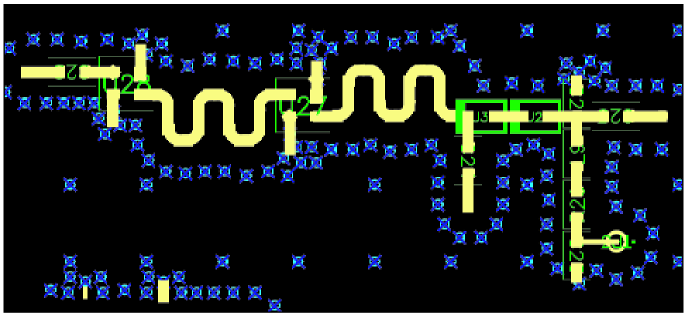
When the two shunt diodes are on, it presents a very high impedance state from either RF or Tx to Rx. Thus, all the RF signals coming in from Tx will arrive to the RF port with minimum leakage to Rx. During the Rx mode, the control voltage is 0 V. All four diodes are in off states. The RF comes into the RF port, and sees a transmission line (TL) one half a wavelength long on the Rx side. On the Tx side, the RF signal will see an open circuit since the two series PIN diodes are in the off state. Thus, the majority of the RF signal arrives at the Rx port with minimum leakage to Tx.

The above description gives a brief introduction to how a T/R switch works. The careful reader might observe that no bias current is needed during the Rx mode. The Rx mode is typically stand-by mode for a receiver. Minimum current consumption will conserve the battery power and increase the stand-by time.

The basic T/R switch circuit shown in Figure 4 was built and tested. The major design parameter was tested, and the result is shown in

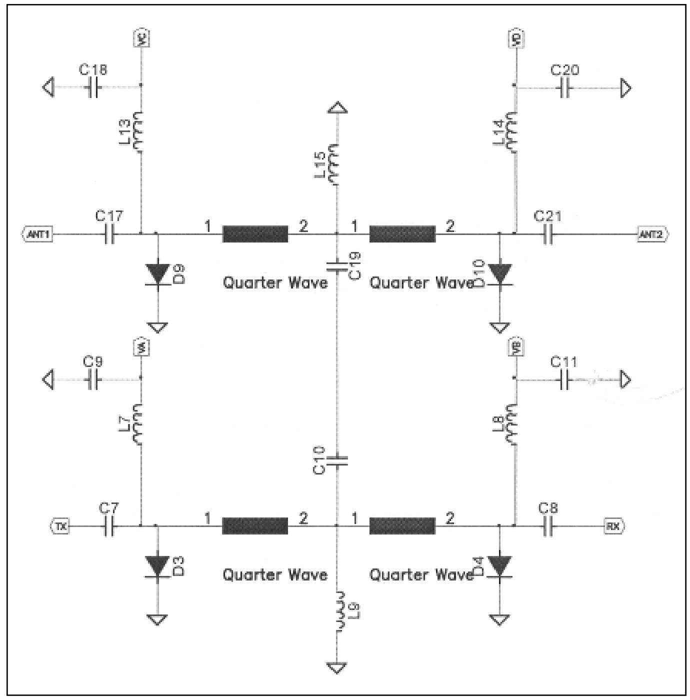


▲ **Figure 4. Schematic of a 2.45 GHz T/R switch with series diodes on the Tx port and shunt diodes on the Rx port.**



▲ **Figure 5. Circuit board layout for the switch circuit shown in Figure 4.**

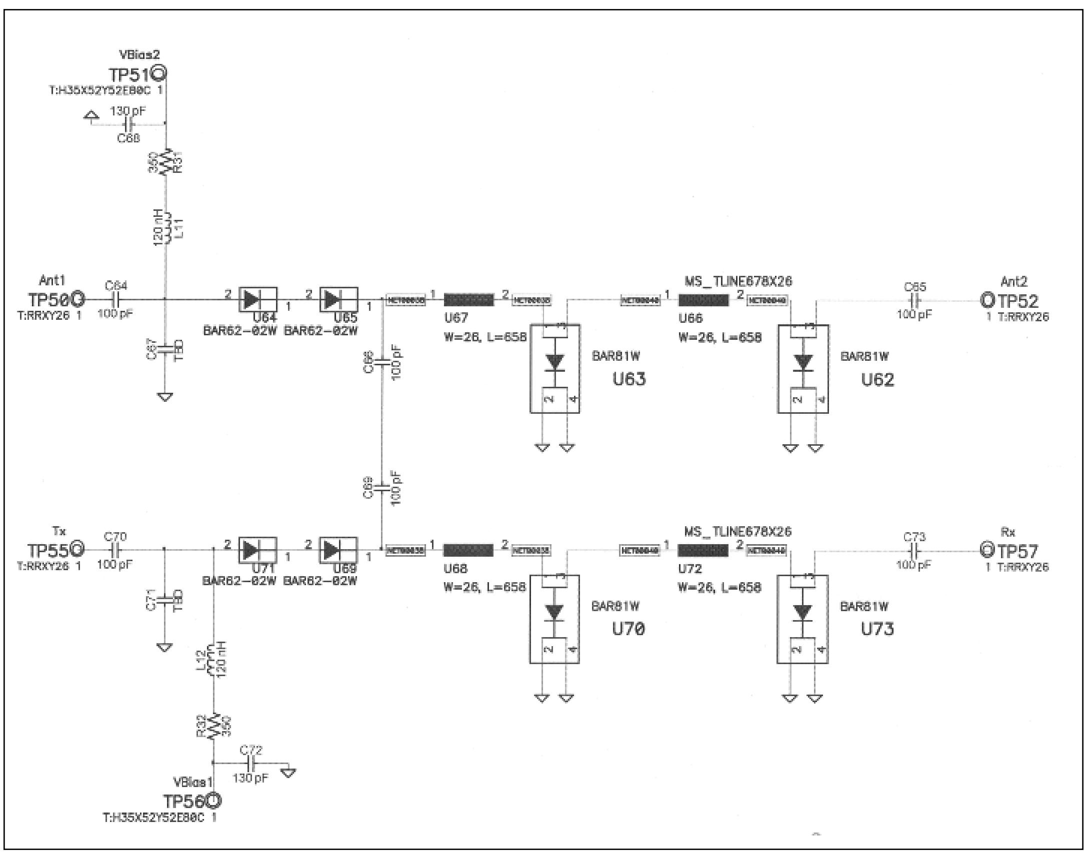
Figure 8. The IL from Tx to the RF port is –1.2 dB, with about 0.3 dB cable and connector IL loss. The IL from the RF port to Rx is 1.3 dB. Again, the IL includes cable and connector loss. The isolation from Tx to Rx is 44 dB during the Tx mode. During the Rx mode, the isolation is 24 dB from Rx to Tx, but isolation is not critical in the Rx mode because the Rx signal typically is very small, and the Tx chain does not have any significant reverse gain. The return loss (RL) is better than –14 dB under all conditions.



▲ **Figure 6. Two shunt switches provide both T/R and diversity antenna switching.**

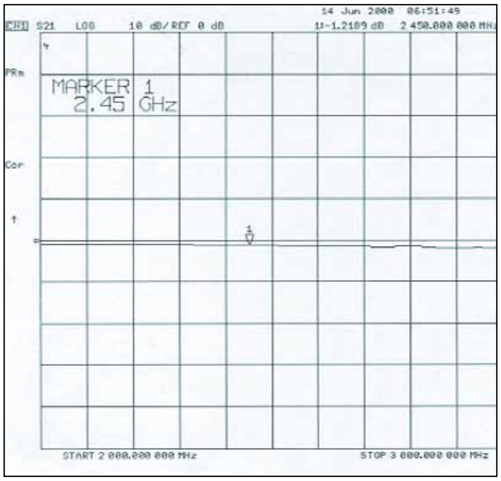
Diversity

As mentioned before, diversity is a low-cost and effective way to combat fading. In mobile and outdoor urban environments, multiple paths are available for the signal to reach its destination. The signal might arrive in-phase or out-of-phase. It is typically modeled as Rayleigh fading. In the case that the signal arrives out-of-phase, the RF signal will experience high signal loss. The purpose of the diversity is to provide several different paths to receive the signal. The strongest signal will be picked as an incoming RF signal. Commonly used diversity schemes are space, angle, polarization, field, frequency and time. In this design, space diversity is used because of the simplicity. The two antennas are spaced at a minimum of a half wavelength apart, which will work well for space diversity.

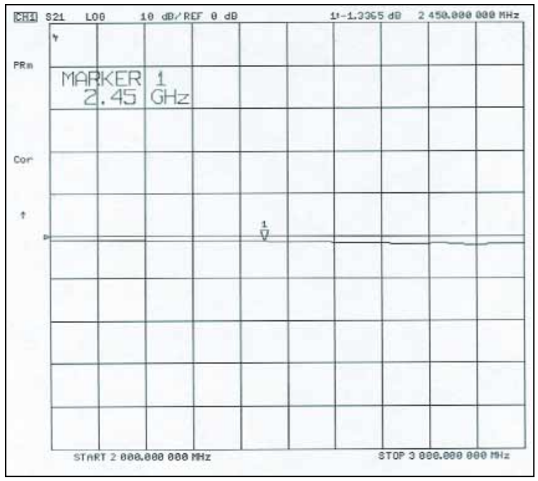


▲ **Figure 7 . Circuit diagram of a diversity switch using two shunt switch sections.**

The T/R switch cir-



▲ **Figure 8. Tx mode IL including cable loss.**



▲ **Figure 9. Rx mode IL including cable loss.**

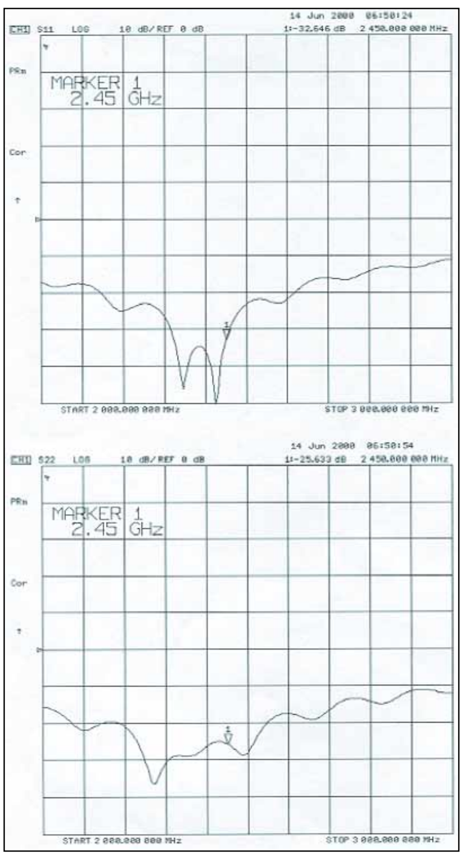
cuit presented in Figure 4 is a three-port building block containing Rx, Tx and the RF port. The standard SPDT has three ports with one antenna port. To accommodate two antenna ports, two basic RF switches are connected at the antenna port, as shown in Figure 6.

The circuit shown in Figure 6 uses two shunts configured as a SPDT switch. All the other SPDT switches can be used to build the diversity switch. Because the basic SPDT is symmetric, the two antenna paths are exactly the same.

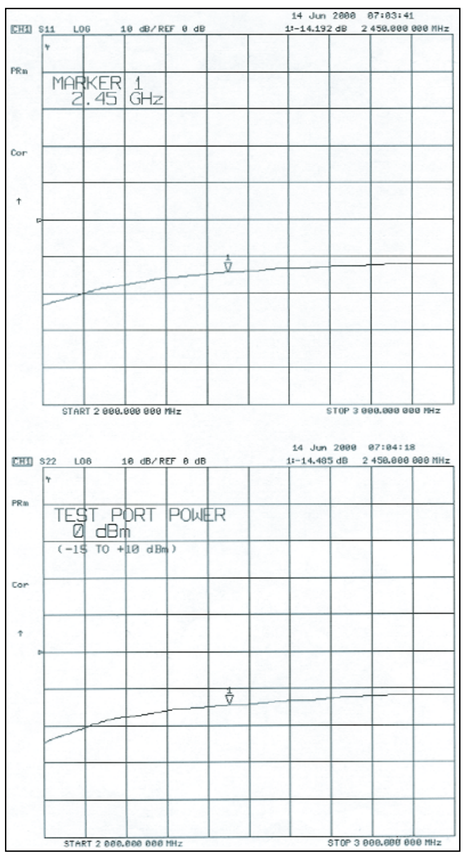
To achieve space diversity, a minimum of a half wavelength TL has to be added intentionally in one of the antenna paths. The half wavelength TL will require more space and increase IL.

A diversity switch based on a T/R switch (see Figure 4) does not have that problem. Because in the Rx branch of the T/R switch, there are already two quarter wavelength TLines, there is already about a half-wave phase difference between Rx and Tx. No additional half wavelength TL is needed as in the standard SPDT based diversity switch.

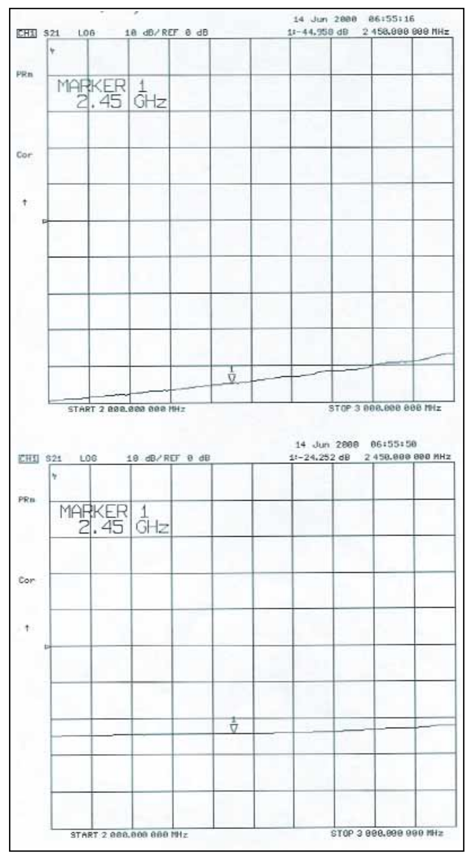
The T/R diversity switch shown in Figure 7 will require another board spin. It has not been built, but the performance of the T/R diversity switch can be easily deduced from the single stage T/R switch. The IL will be about 2 dB in both the Tx and Rx modes, while isolation between Tx and Rx remains the same at 44 dB.



▲ **Figure 10. Tx mode matching performance.**



▲ **Figure 11. Rx mode matching performance.**



▲ **Figure 12. Isolation between Tx and Rx ports.**

Conclusion

A low cost diversity RF switch at 2.45 GHz has been presented. It features low insertion loss, low bias current, high isolation and good matching, as shown in Figures 8 through 12. Compared to the standard SPDT switch, it only needs two control signal lines and no bias current consumption during Rx mode. The low-cost RF switch has built-in diversity. ■

Acknowledgments

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