MPD MICROWAVE PRODUCT DIGEST

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Ultra-Miniature High Linearity SPDT Switch for WLAN Applications

By Jay Yang and Rick Cory, Skyworks Solutions, Inc.

In the past few years, wireless local area networks (WLANs) have been blooming around the world as the infrastructure of office and home communication. The increasing demand has motivated the introduction of advanced WLAN standards such as IEEE802.11n to meet various application requirements, such as laptop computers and access points. As fixed mobile convergence (FMC) becomes more widespread, WLAN is increasingly desirable for integration into mobile devices, such as cellular smart telephones and personal entertainment devices (music or video handheld appliances), along with global positioning systems (GPS), digital cameras, gaming and RFID, among other applications. In order to integrate these applications into the ever-shrinking physical volume of the mobile devices, each functional block has to be scaled down in size. In today's digital communication systems, switches are playing an important role in a variety of functions, such as transmit/receive (T/R) switching and power control, which significantly affect the overall terminal performance. As a key element of the WLAN, the design engineer has no choice but to hunt for single pole double throw (SPDT) switches with compact size, low cost, and high performance.

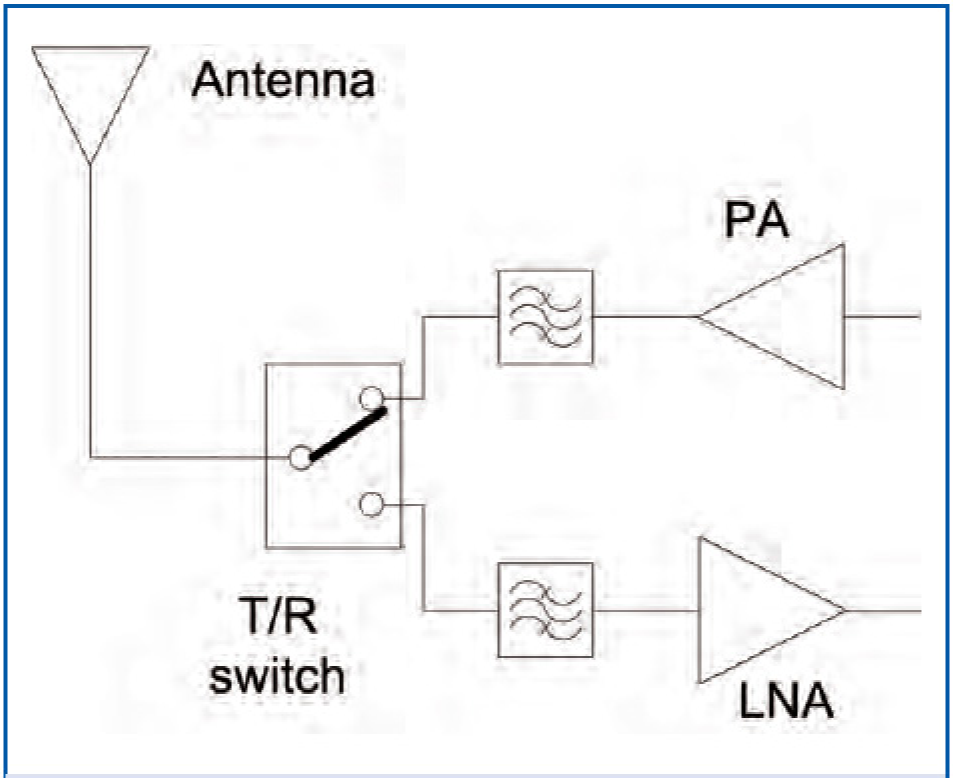

Figure 1: Typical T/R Switch in a typical IEEE802.11 application

In the typical RF front end of a WLAN application shown in **Figure 1**, the SPDT T/R switch is located at the input of the receiver low noise amplifier (LNA) and the output of the transmitter power amplifier (PA) to enable sharing of the antenna between transmitter and receiver. The switch is required to have low insertion loss and high isolation at frequencies ranging from 2 GHz to 6 GHz to cover the bandwidth of the various WLAN standards as specified in IEEE802.11a/b/g.

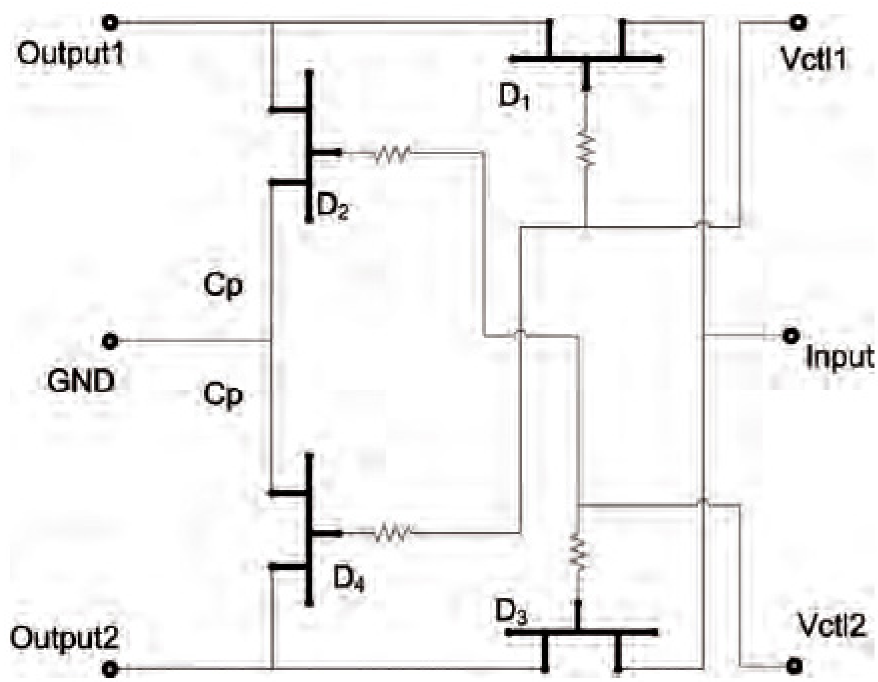

Figure 2: Typical SPDT switch circuit

In WLAN devices, amplitude and phase distortion directly affect the quality of the communication. The most significant parameter for analyzing such signal distortion in the latest communication system protocols is error vector magnitude (EVM). This is a measurement of modulation accuracy, or how well the signal is conveyed by modulation of the phase and amplitude of an RF signal. EVM measurements provide more insight into the performance of the SPDT switch as a key element in the communication link. The factors which can impact EVM include the transmission frequencies, level of input power to the switch, and the magnitude of the control bias applied to the switch. In addition, EVM performance becomes more critical with multicarrier modulation techniques such as orthogonal frequency division multiplexing (OFDM), which is used in WLAN standards IEEE802.11a, g and n. A complete characterization of switches should include analysis of EVM over the range of transmission frequencies, over the expected input power range, and over an allowable range of DC control bias levels.

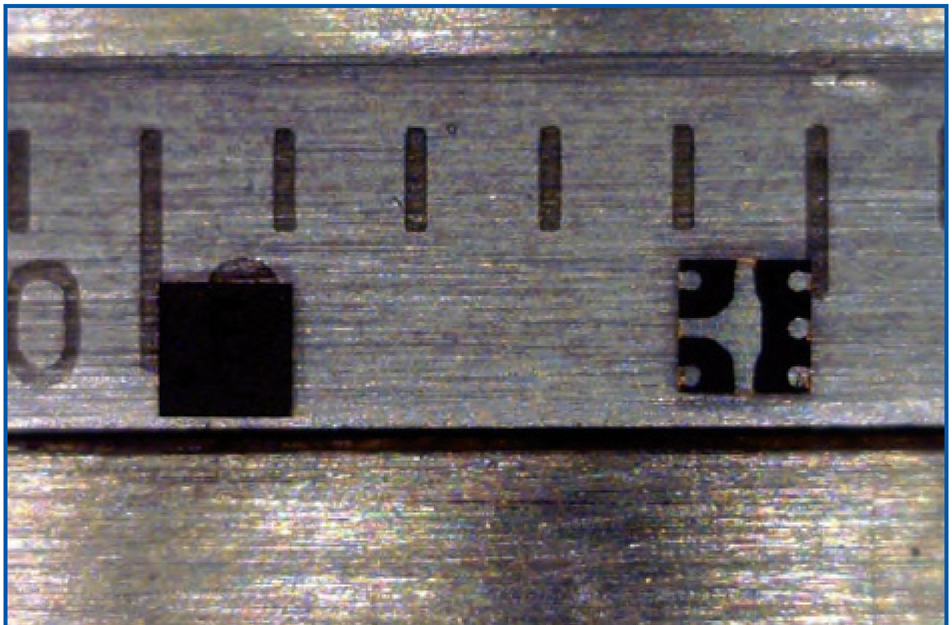

Figure 3: The SKY13351-378LF in 1 mm x 1 mm package, top view (left) and bottom view (right)

The peak power of the transmitter can have a significant effect on the performance of the SPDT switch. In theory, the peak-to-average ratio is 17 dB for an OFDM signal with 52 sub-carriers. This large peak-to-average power ratio (PAPR) exhibited in WLAN systems requires that systems should be designed to be operated “backed off”; the average power level of operation must be several dB lower than the power compression level of all the components in the signal path in order to ensure that clipping and other types of signal distortion do not occur. In reality, some signal clipping can be tolerated without significantly degrading the transmitter performance, and therefore, a smaller back-off is tolerable to meet the EVM and packet error rate (PER) requirements of these systems. For example, 4 dB back-off from saturated power is required at low data rate, while around 10 dB back-off is required at 54 Mb/s rate. That is, if we assume the transmit average power level is 20 dBm, then a T/R switch with a 0.1 dB compression level of 24 dBm is acceptable to meet the PER requirements for the low data rate, but a T/R switch with a 0.1 dB compression level of at least 30 dBm is necessary to meet PER requirements for the high data rate. When a high PAPR occurs, in order to avoid amplitude and phase distortions, the SPDT switch for the transmitter would need much larger power handling capabilities than the average power level; in this high PAPR case, a 1W switch is required to handle a 100 mW average power signal. For the emerging 27 dBm average power access point market, a 5W switch is needed to ensure minimal distortion is produced.

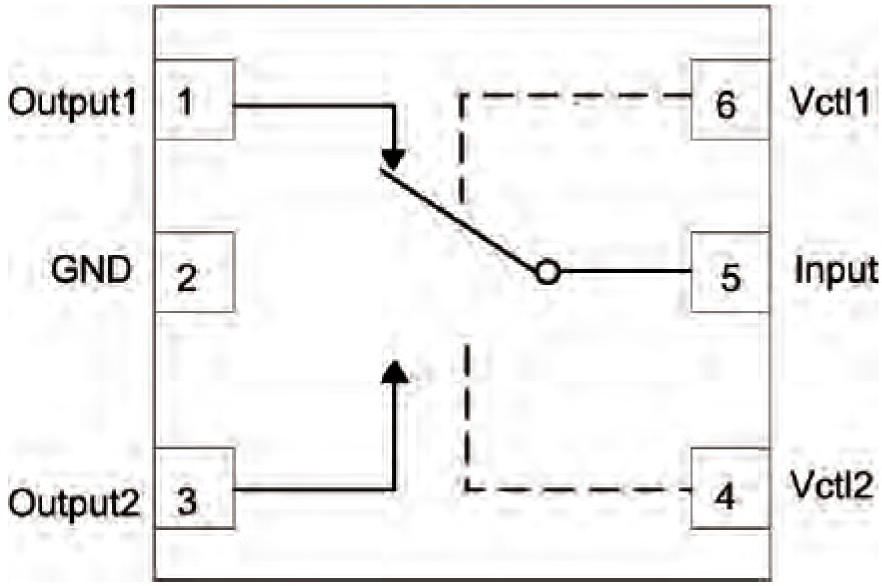

Figure 4: The SKY13351-378LF block diagram

Design and Fabrication Challenges

Currently, monolithic microwave integrated circuit (MMIC) switches fabricated with the technologies of field-effect transistors are widely used in low power applications because of the great flexibility they enable in the design of integrated subsystems or systems into a chip, their fast switching speed, negligible power consumption, and small chip size. More complex switching functions, such as those single pole multi throw switches being used in multi-mode mobile devices, are much easier to implement in GaAs MMIC technology than those fabricated by traditional switching component technology.

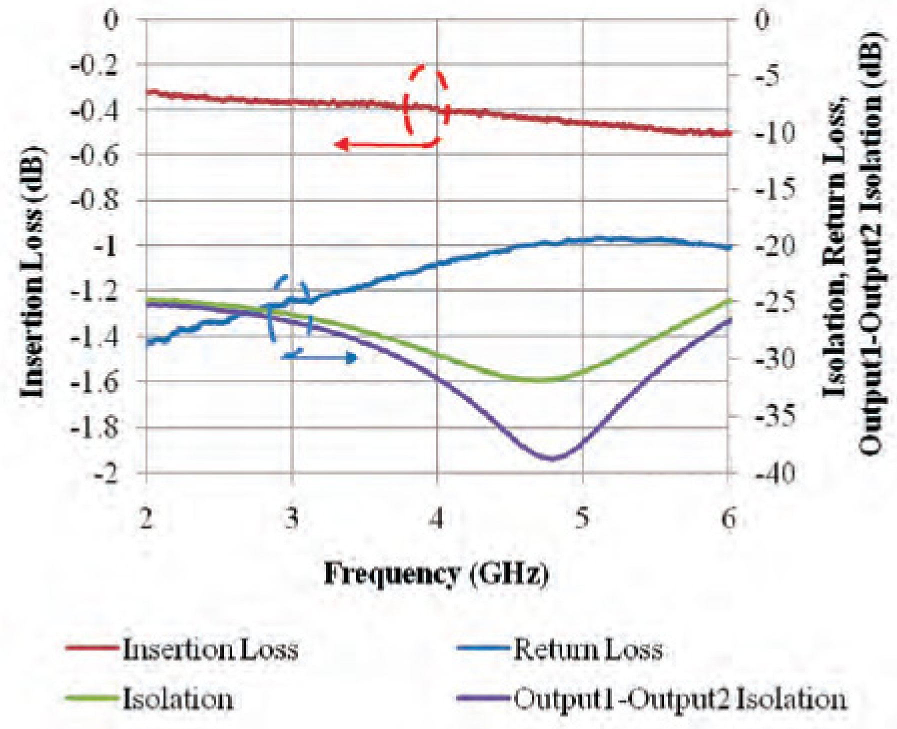

Figure 5: Insertion loss, isolation, return loss, and output1 - output2 isolation of the SKY13351-378LF

Of the FET technologies, there are several reasons why the pseudomorphic high electron mobility transistor (pHEMT) technology is ideal for switching applications. Compared to the traditional metal semiconductor field effect transistor (MESFET) technology, pHEMT devices have a lower channel resistance (Ron) at the similar threshold voltage (Vth) and hence yield a lower insertion loss when utilized as a series switching element. Due to the very low output capacitance of the submicron pHEMT device, good isolation can be achieved in the switch. The very low knee voltage and low gate current make these pHEMTs ideal for low-voltage operation, which is crucial for battery lifetime in portable systems such as cellular telephone handsets. Furthermore, switches based on pHEMT technologies have higher linearity compared with MESFETs at low-voltage operation. Still, the requirements for low insertion loss, high isolation, wideband operation, and high linearity in WLAN pose several challenges to the design and production of switches.

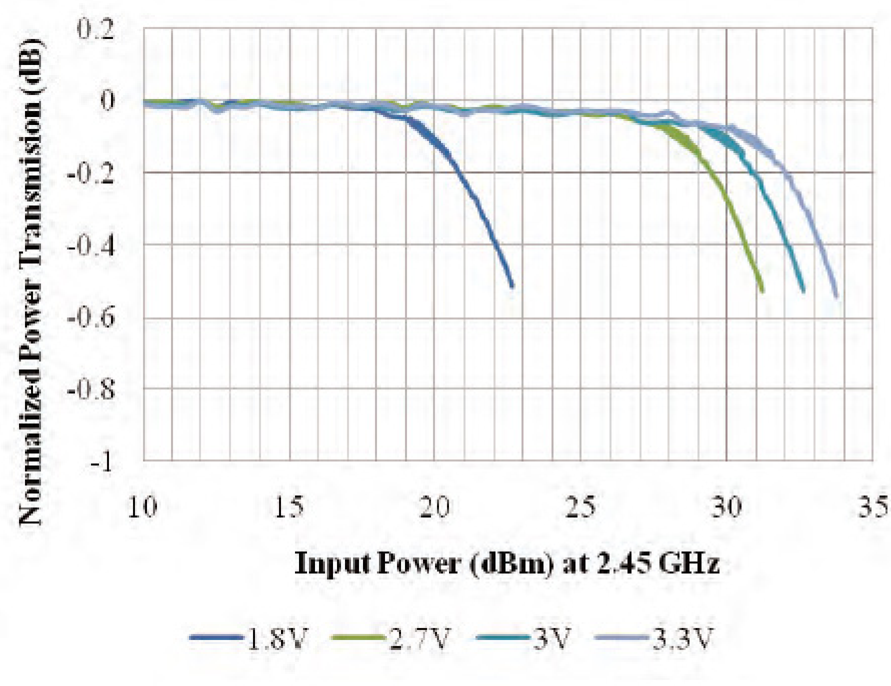

Figure 6: Power handling vs. input power at 2.45 GHz

The first challenge is to achieve low insertion loss and a high isolation with relatively small size, as measured by the "periphery" of the pHEMTs, over a wide operational bandwidth. **Figure 2** shows a typical circuit for a SPDT switch using pHEMTs. In this circuit, one of the most important characteristics of pHEMTs for T/R switch applications is on-state resistance Ron. The Ron is indirectly proportional to the periphery of the pHEMT. As the periphery is reduced, the Ron is increased, so the insertion loss increases when the pHEMTs are used as series devices, as D1 and D3 in **Figure 2**. When the pHEMT is utilized as a shunt element, as D2 and D4 in the circuit of **Figure 2**, the on resistance is desired to be as small as possible to achieve a high isolation.

A SPDT must have high power handling capability to ensure the SPDT will operate at high transmit power levels with low amplitude and phase distortion, especially for the high PAPR which occurs in WLAN systems. The switch's power handling ability is determined by power handling capabilities of the series and shunt FETs which comprise the switch. For series FETs, the power handling capabilities can be predicted by

$$P = I_{ds} Z_0^{\,2} \quad \text{(Yang et al)}$$

where is the FET saturation current. The current is proportional to the FET's periphery, the smaller the FET, the lower saturation current, and the lower power handling capability for series FETs. For shunt FETs, the power handling capabilities can be estimated by the equation

$$P = n^2 \cdot (V_{bias} - V_{th})^2 / (2 \cdot Z_0)$$

(Katzin et al),

where Vth is the threshold voltage of the FETs, Vbias is the control bias applied to the gate, and n is the number of stacking FETs. The stacking FET configuration is the traditional way to achieve high power in MMIC switch. However, within a limited area of a 1 mm x 1 mm package, the room to employ the stacking FET topology is extremely restricted.

Packaging the MMIC SPDT die into a small package requires an efficient MMIC layout design. The MMIC layout efficiency can be reached by scaling down the transistors' (pHEMT) size, such as gate length, source to drain distance, ohmic contacts' area, and so on, without much trade-off in performance. This requires innovations in the design and fabrication of FETs and components, such as pHEMTs, MMIC resistors, and MMIC capacitors. In the confined space of a miniature package, the bonding pads and circuits are very close to each other, which increases electromagnetic and electrostatic coupling. If these electromagnetic and electrostatic effects are not well taken care of, the performance of the SPDT may degrade.

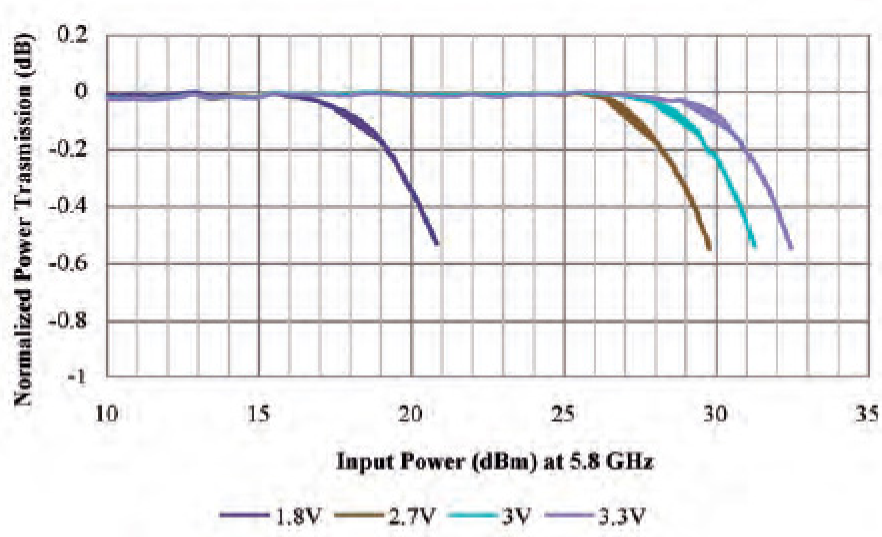

Figure 7: Power handling vs. input power at 5.8 GHz

Because of these challenges, there are very few SPDTs with low insertion loss, high isolation, and good linearity in a 1 mm x 1 mm package in the market.

Product Introduction and Performance

The SKY13351-378LF GaAs MMIC SPDT switch delivers industry-leading low insertion loss, high isolation, and high linearity performance in an ultra-miniature, low profile 6-pin package which measures 1 mm x 1 mm x 0.45 mm high, as shown in **Figure 3**. The ultra-miniature footprint and low profile make the SKY13351-378LF a potential candidate for use in module designs, and an ideal choice for mobile devices with integrated multi-application capability.

The block diagram of the SKY13351-378LF is shown in **Figure 4**. The control bias can be as low as 1.8 V. With operation capability from 2 GHz to 6 GHz, the SKY13351-378LF is well suited for various WLAN standards, including IEEE802.11a, IEEE802.11b, IEEE802.11g, and IEEE802.11n. Key specifications include 0.3 dB typical insertion loss at 2.5 GHz and 0.5 dB at 6 GHz; 25 dB typical input to output isolation at 2.4 GHz; and at 6 GHz, 25 dB typical output to output isolation is achieved at 2.5 GHz and 27 dB obtained at 6 GHz.

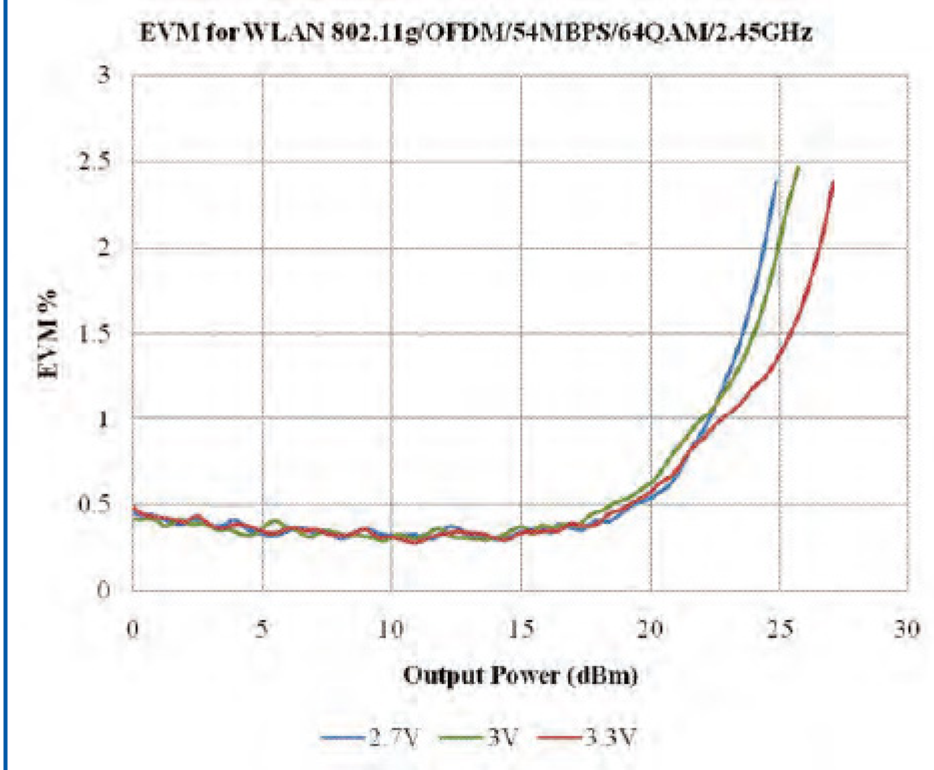

Figure 8: Measured EVM for IEEE802.11g at 2.4 GHz

The large signal characterization of insertion loss versus incident input power was measured at 2.45 GHz and 5.8 GHz using a CW input signal. At 2.45 GHz, the on-state power handling – defined as the input power which produces 0.5 dB compression – is 22.5 dBm, 31 dBm, 32.5 dBm, and 33.5 dBm under the control voltage of 1.8 V, 2.7 V, 3 V, and 3.3 V respectively, as shown in Figure 6. At 5.8 GHz, the 0.5 dB compression points 21 dBm, 30 dBm, 31.5 dBm, and 32.5 dBm for control voltage of 1.8 V, 2.7 V, 3 V, and 3.3 V respectively, are plotted in **Figure 7**. These power handling values are by far the best performance reported for SPDT products in 1 mm x 1 mm packages in the market. Because of the SKY13351-378LF's high power handling capability, sufficient back-off is possible in WLAN applications.

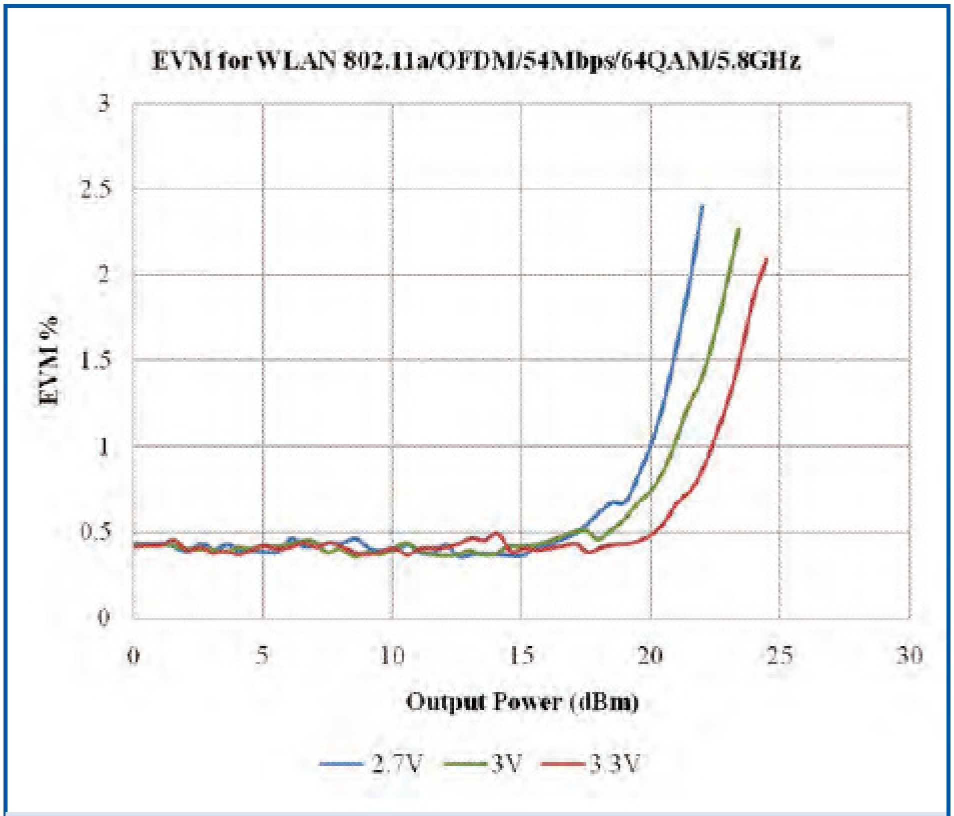

Figure 9: Measured EVM for IEEE802.11a at 5.8 GHz

The superior linearity of the SKY13351-378LF is evaluated versus incident input power modulated by different WLAN standards and is shown in **Figure 8** and **Figure 9**. These figures show the EVM results as a function of the input power and control bias. **Figure 8** shows the EVM measured by sweeping the incident power of an IEEE802.11g/OFDM/54 Mbps/64 QAM modulated signal; and **Figure 9** shows the EVM measured using an IEEE802.11a/OFDM/54 Mbps/64 QAM input signal.

Conclusion

Skyworks Solutions continues to lead the way with state-of-the-art innovations in high performance switches. The SKY13351-378LF raises the performance bar for SPDT T/R switches by providing low insertion loss, high isolation, and high linearity. Packed in an ultra-miniature 1 mm x 1 mm package, the SKY13351-378LF is well-suited for mobile WLAN devices and other multi-function integrated devices.

In addition to this SPDT switch, Skyworks Solutions provides other high performance SPDT solutions for WLAN applications. They include the AS179-92LF, SKY13323-378LF, and SKY13344-378LF. These products offer flexibilities for the designer to select SPDT switches for WLAN applications by package, power level, bandwidth, and bias pins location. Datasheets and supporting information for all of Skyworks Solution's products are available online at www.skyworksinc.com.

References

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