WHITE PAPER

Low Cost Antenna Tuning Using Skyworks PIN Diodes

Introduction

Antenna tuning is becoming a required technology in high end wireless mobile devices due to the proliferation of frequency bands and the desire to serve a global customer base. Many wireless devices are integrating more than 5 distinct frequency bands including multiple technologies. Designing a broadband antenna to service these bands is very challenging and often not feasible. This is especially true in devices employing a very broad low band or high band, often needed in LTE devices today. A low cost and high volume production avenue for creating a tunable antenna is a PIN diode. Through use of a PIN diode a reconfigurable antenna can provide a design advantage by reducing antenna volume while achieving high radiated efficiency for all frequency bands and modes of operation. The following pages describe several methods through which an antenna tuner can be created via a Skyworks PIN diode.

PIN Diode Theory and Applications

PIN diodes have long been used as fast switching current controlled resistors in applications such as RF switches and attenuators. They exhibit excellent linearity and very broad band performance and are supplied in a variety of packages and configurations ranging from bare die to multiple diodes arranged in a common package.

A less known but very useful application for the PIN diode is the switching of circuit elements. Those elements can range from Inductors and capacitors used in filter structures to switching of transmission lines used in phase shifters, distributed filters and fast switching agile antenna structures.

Refer to the basic PIN diode switch and its associated circuitry shown in Figure 1 and as described in Skyworks' application note, "Design with PIN Diodes," document number 200312. As detailed in Table 1 when VC1 is biased to 5 V and VC2 is biased to 0 V, diode D1 is forward biased and appears as a low impedance. As current is increased in the forward direction the value of Rs (series resistance) becomes lower and the overall insertion loss of the switch is reduced. When the polarities of VC1 and VC2 are reversed as shown in Table 1, the diode appears as an open circuit or large resistance with some associated reverse bias capacitance (Cj). The insertion loss of the structure becomes high and most of the energy is reflected back towards the RF source. So by its nature this type of switch would be defined as a reflective switch when in the zero or reverse biased state.

The biasing circuitry has been highlighted and offers the ability for the diode to be either forward or reversed biased. This has the advantage of improved linearity vs. the biasing structure shown in Figure 4. That bias circuitry is simpler in its implementation and component count, only requiring a positive current to switch the diode to the "Low" impedance or "ON" state. The issue may come in the reverse bias condition where this example corresponds to 0 V. This may be sufficient for applications that may not require very high levels of linearity. But for improved linearity as an example in the presence of interfering or blocking tones the bias circuitry utilized in Figure 1 is preferred.

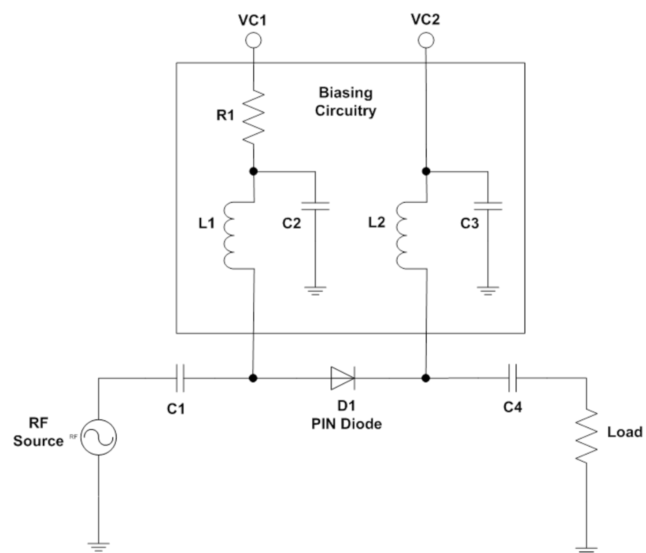

Figure 1. PIN Diode Switch and Associated Circuitry

Table 1. Diode Bias and Impedance

Bias State			
VC1 Volts	VC2 Volts	Diode Impedance	Switch State
5	0	Low	On
0	5	High	Off

Lumped Element Tuning Example

Refer to the schematic shown in Figure 2. Inductor L1, capacitor C1 and the parasitic off condition of diode D1 and inductor L2 are resonant at approximately 1.65 GHz. Upon the application of a small bias current to diode D1, in this instance approximately 5 mA, inductor L2 will now appear to be in parallel with inductor L1 decreasing it equivalent value and in turn raising the resonant frequency to approximately 2.05 GHz. There is a change of Quality factor (Q), of the structure and this is mostly attributed to the "ON" resistance of the forward biased PIN diode. As the diode current is increased its resistance will be lowered and in turn the Q of the resonant structure will increase as noted in Figure 3. This example clearly shows that the resonant frequency of this particular lumped element antenna matching structure can be altered. This has the advantage of increasing the useable bandwidth of the antenna, improving performance with a minor increase in circuit complexity and associated cost.

The Skyworks SMP1322-040LF PIN diode is an excellent choice for applications of this type. The SMP1322-040LF exhibits very low series resistance (R_S) at a given value of forward current (I_F). It is packaged in a small profile 0402 low capacitance package.

Another excellent choice if low total capacitance (C_T) is required is the Skyworks SMP1345-040LF PIN diode. Total capacitance at 5 V is 0.2 pF typical. The SMP1345-040LF is also packaged in the same small profile 0402 low capacitance package as the SMP1322-040LF.

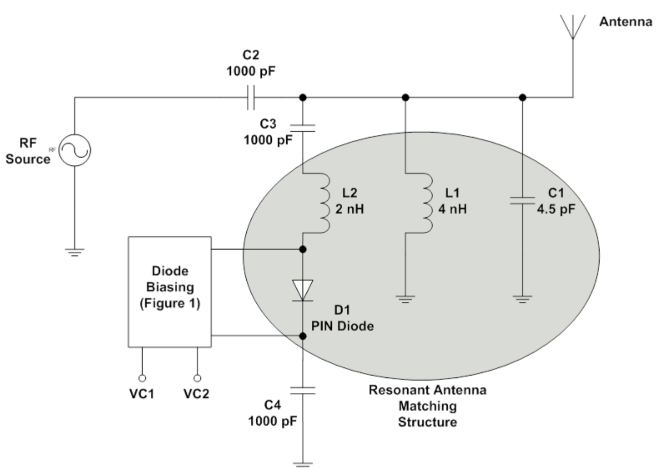

Figure 2. Lumped Element Tuning Schematic

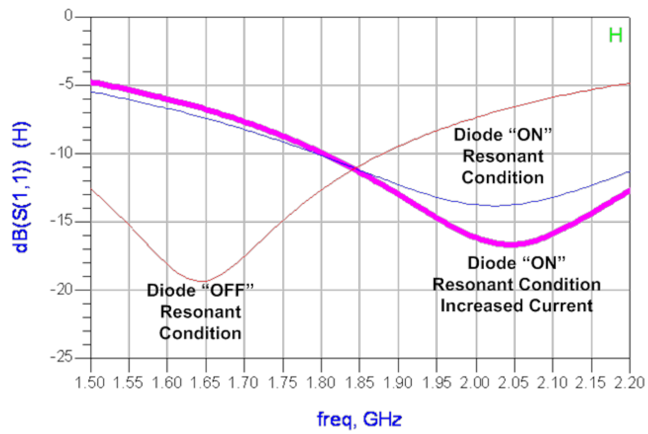

Figure 3. Resonant Frequency, Current vs. Resistance

Distributed Transmission Line Tuning Example

Refer to the schematic shown in Figure 4. In this particular example the PIN diode is being used to alter the resonant frequency of a distributed transmission line structure. Transmission lines TL1 and TL2 are configured as an open circuit stub with PIN diode D1 configured to either increase or decrease the overall electrical length of the stub depending upon its bias condition. Inductor L2 is a large RF choke and provides a DC path to ground as a return for the diode while presenting an open circuit to the RF signal at approximately 1900 MHz. The remaining circuit components are for providing a DC bias to the diode D1, and DC blocking to the RF input and output ports.

When diode D1 is in its 0 V or reverse bias state, its overall impedance is high, and electrical length of the open stub appears at the end of transmission line TL1, including the small "OFF" capacitance of the PIN diode. Refer to Figure 5 for the response of the structure in the 0 V bias condition. As diode D1 is forward biased at approximately 5 mA, its resistance decreases and effectively appears as a low impedance path between transmission lines TL1 and TL2.

The increase in the effective electrical length of the resonant stub results in lowering the resonant frequency of the structure. By varying the length of transmission lines TL1 and TL2 both the resonant frequency as well as the frequency differential between the "ON" and "OFF" diode states can be set.

Again, it can be seen that even using distributed transmissions lines as resonant elements, the PIN diode has the ability to alter the resonant frequency of the structure without adding a great deal of complexity or cost.

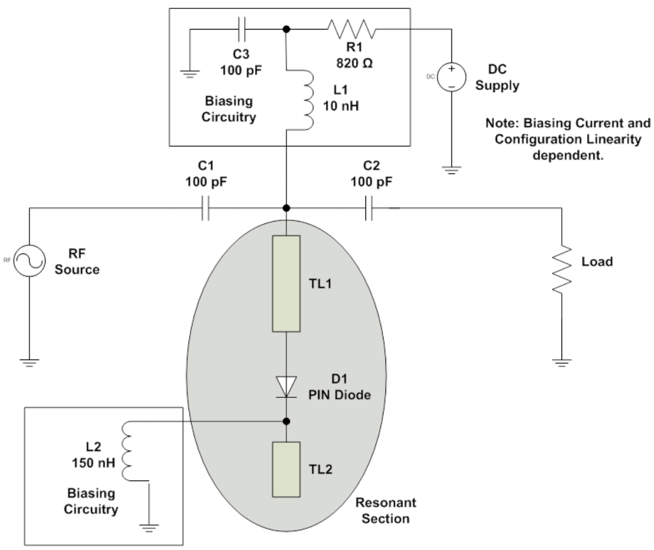

Figure 4. Use of PIN Diode to Alter the Resonant Frequency of a Distributed Transmission Line Structure

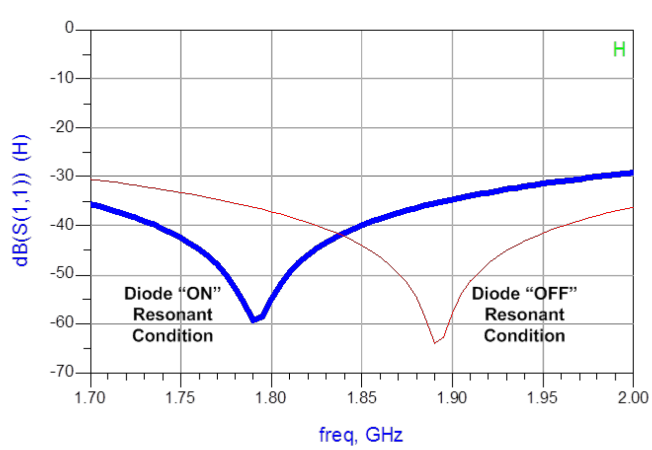

Figure 5. Distributed Transmission Line Structure Resonant Frequency Response, Current vs. Resistance

Planar Inverted-F Antenna (PIFA) Tuning Example

Consider the simplified Planar Inverted–F Antenna (PIFA) structure shown in Figure 6. Assuming this particular array is tuned to have an approximate center frequency centered at PCS1900 (1850–1990 MHz) band of interest. Ideally the bandwidth of the antenna would also cover the GSM1800 (1710–1880 MHz) band of interest without any appreciable performance degradation. The nature of these antenna structures is to be inherently narrow band. One method of increasing the usable bandwidth of such an antenna structure is to switch in an additional radiator section(s) using a low "ON" resistance PIN diode. As described in the previous transmission line example, additional segments of transmission line were switched in to increase the electrical length of the open circuit resonator. The idea is much the same in the PIFA antenna example. The frequency shift in the overall response profile would look quite similar to that in Figure 5. The exception being that the return loss (S11) on the band edges of each null would be degraded from those shown in the ideal circuit response of Figure 5. The absolute delta between the shifts would be determined by both the secondary resonator length as well as the characteristics of the PIN diode at those particular bias conditions. This ultimately results in antennas structures that can operate over wider bandwidths without sacrificing performance and potentially reducing the volume required by the antenna to support the increased bandwidth.

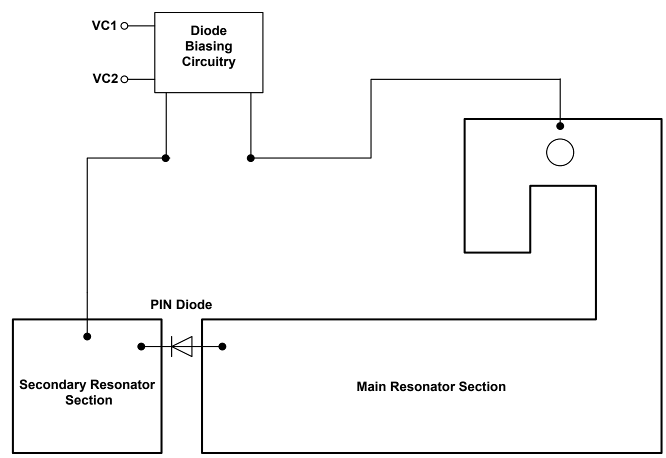

Figure 6. Planar Inverted–F Antenna (PIFA) Structure

The very low "ON" resistance and low "OFF" capacitance of the PIN diode makes it the ideal device for switching these types of structures.

The PIN diode is also quite linear as compared to other switching devices such as pHEMT FETs or bipolar switching transistors. Switching times in general are also extremely fast, facilitating rapid hopping between antenna states.

Skyworks offers a large assortment of PIN diodes varying in package and performance variations. Please refer to Table 2, PIN Diode Selection Guide, for specific information on these particular PIN diodes. The 0402 package and dimensions are shown in Figure 7.

Table 2. PIN Diode Selection Guide

Lowest Series Resistance Switching PIN Diodes

Part Number	Min. V_B I_R = 10 µA (V)	Max. C_T V_R = 30 V F = 1 MHz (pF)	Typ. V_F @ I_F = 10 mA (V)	Max. R_S I_F = 1 mA F = 100 MHz (Ω)	Typ. R_S I_F = 10 mA F = 100 MHz (Ω)	Typ. T_L I_F = 10 mA (ns)	Nominal I-Region Thickness (µm)
SMP1322-040LF	50	1	0.825	1.5	0.5	400	8

Lowest Capacitance Switching PIN Diodes for High Isolation

Part Number	Min. V_B I_R = 10 µA (V)	Max. C_T V_R = 20 V F = 1 MHz (pF)	Typ. V_F @ I_F = 10 mA (V)	Typ. R_S I_F = 1 mA F = 100 MHz (Ω)	Max. R_S I_F = 10 mA F = 100 MHz (Ω)	Typ. T_L I_F = 10 mA (ns)	Nominal I-Region Thickness (µm)
SMP1345-040LF	50	0.2	0.89	3.5	2	100	10

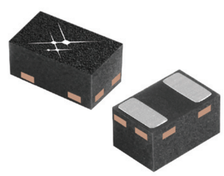

Figure 7. SOD-882 2L (0402) 1.00 x 0.60 x 0.46 mm

References

[1] M. Komulainen, M. Berg, H. Jantunen, E. T. Salonen, C. Free, "A Frequency Tuning Method for a Planar Inverted-F Antenna" IEEE Transactions on Antenna and Propogation, Vol. 56, No. 4, April 2008.

[2] J. H. Lim, G. T. Black, Y. I. Ko, C. W. Song, T. Y. Yun, "A Reconfigurable PIFA Using a Switchable PIN-Diode and Fine-Tuning Varactor for USPCS/ WCDMS/ m-WiMAX/ WLAN" IEEE Transactions on Antenna and Propagation, Vol. 58, No. 7, April 2010.

[3] "Design with PIN Diodes" Application Note, Skyworks Solutions, Inc. Available at: http://www.skyworksinc.com

[4] SMP1322-040LF Data Sheet, Skyworks Solutions, Inc. Available at: http://www.skyworksinc.com

[5] SMP1345-040LF Data Sheet, Skyworks Solutions, Inc. Available at: http://www.skyworksinc.com