

APPLICATION NOTE

APN1001: Circuit Models for Plastic Packaged Microwave Diodes

Abstract

This paper reports on the measurement and establishment of circuit models for SOT-23 and SOD-323 packaged diodes. Results indicate that the 1.5 nH estimate for the SOT-23 is a useful result, as is 1.2 nH for SOD-323 single packaged diodes. It was also determined that the effective inductance of the SOT-23 may be reduced to approximately 0.4 nH by adding a second bond wire and modifying the microstrip line. Other lead configurations, including parallel bond wires and common cathode configurations, were also studied.

Introduction

Discrete, low-cost, surface mount semiconductor diodes are attractive choices for UHF and microwave applications where package parasitic may have a significant impact on performance. The most common package styles are the SOT-23 and the SOD-323 (Figure 1) which were neither designed nor intended for RF service. A primary limitation to their high-frequency performance, particularly in PIN diode shunt connected switches, is parasitic package inductance, which limits high-frequency isolation. The model information available from vendors of these devices has been generally limited to estimates of inductance, typically 1.5 nH, for single junction SOT-23 diodes. Establishing a better model will enable circuit designers to better predict performance and possibly give the manufacturer alternative designs to reduce package parasitic effects.

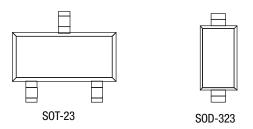


Figure 1. Diode Package Styles

Package Modeling

Network Analysis

To create a high-frequency device model S-parameter, measurements were taken over a wide frequency band so that resonance and other high order effects would be included in the measurements. This procedure utilizes an HP 8510C vector network analyzer. The package under test was inserted into an Inter-Continental Microwave test fixture as a series connected element. This fixture uses a Thru-Reflect-Line calibration procedure to produce accurate calibration and assures a reference plane at the device under test.

Using this methodology, a circuit model was generated for each of the devices as shown in Figures 2 and 3. These models produce very good correlation between the measured and simulated performance as shown in Figure 4.

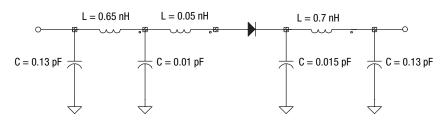


Figure 2. SOT-23 Circuit Model

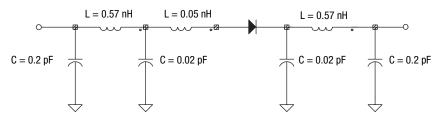


Figure 3. SOD-323 Circuit Model

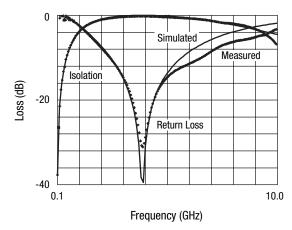


Figure 4. Measurement vs. Model Simulation of a SOT-23 Package

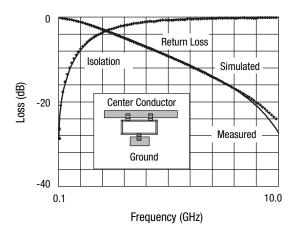


Figure 5. SOT-23 Validation: Simulation vs. Measurement

Impedance Measurements

The HP 4291A Impedance Analyzer, an instrument based on measuring the vector V/I with coverage from 1 MHz–1.8 GHz, was also utilized to characterize inductance of the packages under consideration. Measurements were taken on a group of PIN diodes that were forward biased to low values of forward resistance. The inductance values derived from these measurements are shown in Table 1 and compare well with the values derived from network analysis. The advantage of the direct impedance measurement is the capability of a quick measurement without the necessity of hard bonding the device to a substrate.

Validation of Simulated Model

Validation of the model was performed by placing the diode into a test circuit that simulates a shunt connected switch. The test circuit was constructed using a Duriod microstrip board and the device was placed as shown in Figure 5. This provided a different operating environment because not only was the diode connected differently, but the microstrip insulator had a different dielectric constant.

The measured performance of this circuit was imported into the circuit simulator and compared to a simulation using the circuit model. Figure 6 shows good validation of the network analyzer generated model.

Alternative SOT-23 Designs for Lower Inductance

To reduce the total inductance of the SOT-23 package, alternative wire bonding schemes were studied. Figure 6 shows four bonding wire designs considered in this study. The measured inductance of these bonding schemes are shown on Table 1.

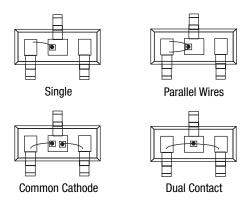
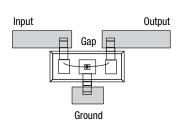


Figure 6. SOT-23 Configurations

The single wire SOT-23 diode with 1.5 nH inductance will perform with 10.1 dB isolation at 900 MHz as a shunt connected switch. The inductance is reduced to 1.2 nH if a parallel bond wire is attached to the diode contact. This will increase the isolation to 11.6 dB. A further reduction of inductance may be obtained by adding a second diode chip in a common cathode configuration. This reduces the inductance to 0.84 nH resulting in an increase in isolation to 14.6 dB.

Since two junctions are employed, in the common cathode alternative, the capacitance is doubled under reverse bias. The consequence may be an adverse effect on insertion loss. The inductance of the dual bond wire design is similar to the common cathode design resulting in similar performance. But, if the package is inserted in the microstrip circuit with a gap in the



transmission line as shown in Figure 7, then the effective inductance is reduced to below 0.4 nH and the isolation is increased to 20 dB at 900 MHz. Figure 7 shows a plot of the measured isolation of the dual bond wire package versus frequency to 4 GHz. A plot of an inductance of 1.5 nH is shown as a reference.

Table 1 shows a summary of the effective package inductance values for the SOD-323 and SOT-23 packaged diodes with alternative wiring configurations using the measurement techniques described.

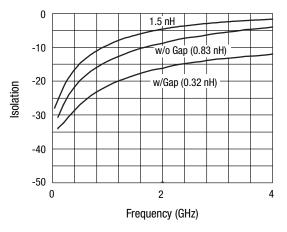


Figure 7. SOT-23 Dual Bond Wire With and Without a Gap

Package	Configuration	S-Parameter Model (nH @ 1 GHz)	S-Parameter Validation (nH @ 1 GHz)	HP 4291A Inductance (nH)
S0T-23	Single junction	1.45	1.5	1.5/1.7
S0T-23	Dual no gap	1.2	0.9	
S0T-23	Dual gap	0.5	0.4	
S0T-23	Parallel bonds			1.2
S0T-23	Common cathode			0.84
S0T-323	Single junction	1.1	1.19	1.2

Table 1. Summary of Package Inductance Values

Conclusion

As a result of this effort, accurate and concise microwave models are now available for commonly used, low-cost, surface mount, SOT-23 and SOD-323 packaged diodes. The measurement methodology utilized de-imbedding techniques valid at frequencies through 10 GHz. This material will assist design engineers to design and predict circuit performance using these popular devices.

In addition, it was demonstrated that the inductance of the SOT-23 may be significantly reduced by modifying both the internal package wiring and the microstrip transmission line. This further improves the frequency response of the package.

Reference

R.W. Waugh and D. Gustedt, "Low Cost Surface Mount Power Limiters," Proceedings RF EXPO WEST, March 1992, pp. 19-40.

© Skyworks Solutions, Inc., 1999. All rights reserved.

Copyright © 2002, 2003, 2004, 2005, Skyworks Solutions, Inc. All Rights Reserved.

Information in this document is provided in connection with Skyworks Solutions, Inc. ("Skyworks") products or services. These materials, including the information contained herein, are provided by Skyworks as a service to its customers and may be used for informational purposes only by the customer. Skyworks assumes no responsibility for errors or omissions in these materials or the information contained herein. Skyworks may change its documentation, products, services, specifications or product descriptions at any time, without notice. Skyworks makes no commitment to update the materials or information and shall have no responsibility whatsoever for conflicts, incompatibilities, or other difficulties arising from any future changes.

No license, whether express, implied, by estoppel or otherwise, is granted to any intellectual property rights by this document. Skyworks assumes no liability for any materials, products or information provided hereunder, including the sale, distribution, reproduction or use of Skyworks products, information or materials, except as may be provided in Skyworks Terms and Conditions of Sale.

THE MATERIALS, PRODUCTS AND INFORMATION ARE PROVIDED "AS IS" WITHOUT WARRANTY OF ANY KIND, WHETHER EXPRESS, IMPLIED, STATUTORY, OR OTHERWISE, INCLUDING FITNESS FOR A PARTICULAR PURPOSE OR USE, MERCHANTABILITY, PERFORMANCE, QUALITY OR NON-INFRINGEMENT OF ANY INTELLECTUAL PROPERTY RIGHT; ALL SUCH WARRANTIES ARE HEREBY EXPRESSLY DISCLAIMED. SKYWORKS DOES NOT WARRANT THE ACCURACY OR COMPLETENESS OF THE INFORMATION, TEXT, GRAPHICS OR OTHER ITEMS CONTAINED WITHIN THESE MATERIALS. SKYWORKS SHALL NOT BE LIABLE FOR ANY DAMAGES, INCLUDING BUT NOT LIMITED TO ANY SPECIAL, INDIRECT, INCIDENTAL, STATUTORY, OR CONSEQUENTIAL DAMAGES, INCLUDING WITHOUT LIMITATION, LOST REVENUES OR LOST PROFITS THAT MAY RESULT FROM THE USE OF THE MATERIALS OR INFORMATION, WHETHER OR NOT THE RECIPIENT OF MATERIALS HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

Skyworks products are not intended for use in medical, lifesaving or life-sustaining applications, or other equipment in which the failure of the Skyworks products could lead to personal injury, death, physical or environmental damage. Skyworks customers using or selling Skyworks products for use in such applications do so at their own risk and agree to fully indemnify Skyworks for any damages resulting from such improper use or sale.

Customers are responsible for their products and applications using Skyworks products, which may deviate from published specifications as a result of design defects, errors, or operation of products outside of published parameters or design specifications. Customers should include design and operating safeguards to minimize these and other risks. Skyworks assumes no liability for applications assistance, customer product design, or damage to any equipment resulting from the use of Skyworks products outside of stated published specifications or parameters.

Skyworks, the Skyworks symbol, and "Breakthrough Simplicity" are trademarks or registered trademarks of Skyworks Solutions, Inc., in the United States and other countries. Third-party brands and names are for identification purposes only, and are the property of their respective owners. Additional information, including relevant terms and conditions, posted at www.skyworksinc.com, are incorporated by reference.