



# Frequency Response of Thin Film Chip Resistors

## ABSTRACT

High frequency measurements from 0.1 GHz to 40 GHz were performed on industry standard flip chip thin film resistors from Vishay Thin Film. The results of these measurements are reported in this paper. A lumped circuit model is presented that accurately predicts the response of various part values and case sizes. The results of the measurements and model are combined to demonstrate basic design guidelines for microwave thin film resistors.

## INTRODUCTION

As the industry extends products into the GHz range, an understanding and improvement of resistive products' performance needs to be extended into this range. Historically, thin film resistors have been used in areas requiring high-precision, long-term stability, and low temperature coefficient of resistance. Frequency performance of thin film resistors, in excess of 100 MHz, typically involves a roll-off of the impedance to either inductive or capacitive-dominated values, commonly referred to as parasitic impedance. <sup>(1)(2)(3)(4)</sup>

Microwave frequency measurements were made on various thin film part values and case sizes. Correlation of the experimental data to a mathematical lumped circuit model demonstrated a relation of parasitic impedance to case size, DC resistance, and trim style. Extrapolation of the model to different part values and higher frequencies was used to predict roll-off performance and demonstrate design guidelines for high-frequency (0.1 GHz to 100 GHz) thin film resistors.

TABLE 1 - PARAMETERS FOR DIFFERENT CASE SIZES UTILIZED					
CASE SIZE	LENGTH (inch/mm)	WIDTH (inch/mm)	RESISTOR AREA (inch <sup>2</sup> /mm <sup>2</sup> )	MODEL INTERNAL COEFFICIENTS	
				C (pF)	L (nH)
0201	0.02/ 0.51	0.01/ 0.25	0.00004/ 0.02581	0.0206	1.73 x 10 <sup>-5</sup>
0402	0.04/ 1.02	0.02/ 0.51	0.000352/ 0.22710	0.0262	1.89 x 10 <sup>-3</sup>
0402 (wrap)	0.04/ 1.02	0.02/ 0.51	0.000352/ 0.22710	0.0392	0.1209
0603	0.064/ 1.626	0.032/ 0.813	0.000816/ 0.52645	0.0403	0.0267

## EXPERIMENTAL

Precision thin film resistors from 50  $\Omega$  to 1000  $\Omega$  were constructed on high performance 99.5 % alumina substrates with case sizes of 0201, 0402, and 0603, (see table 1) and two termination methods (i) flip chip and (ii) wrap around, see figure 1. The resistive material was physical vapor deposited (PVD) nickel-chrome (NiCr) with a  $\pm 50$  ppm thermal coefficient of resistance (TCR). An optimized laser trim was used to provide a balanced resistor with low internal parasitic effects. The resistor element was protected with overcoats designed for electrical, mechanical, and environmental protection.

High frequency testing was performed on parts mounted to quartz test boards. Quartz test boards were chosen to minimize the contribution of the board effects at high frequencies. The quartz test boards were fabricated using microstrip technology; the RF ground plane is located on the reverse side. All parts were mounted on identical boards and tested independently, see figure 2. Wrap around parts were mounted with the resistor up and flip chip parts were mounted with the resistor down, see figures 1 and 2.

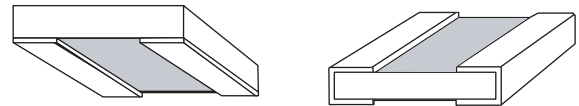


Fig. 1 - Termination styles:  
Left - flip chip, resistor down  
Right - wrap around, resistor up

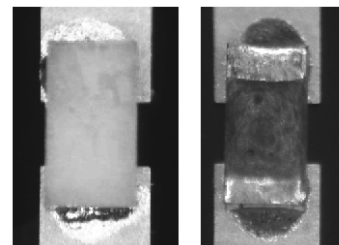
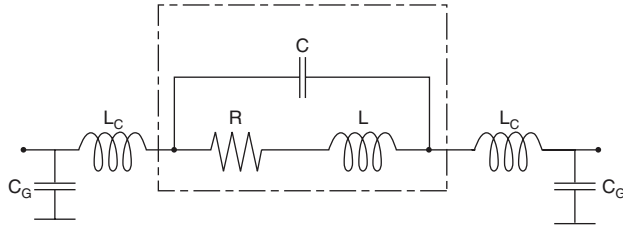


Fig. 2 - Mounting on resistors on RF grounded quartz substrates for testing  
Left - flip chip, resistor down  
Right - wrap around, resistor up

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- C:** internal shunt capacitance
- L:** internal inductance
- R:** resistance
- L<sub>c</sub>:** external connection inductance
- C<sub>G</sub>:** external capacitance to ground

Fig. 3 - Lumped equivalent circuit used for modeling, a transmission line model was added for the resistor's landing pad and the test substrate's mounting pad effects

Modelithics, Inc. was contracted to perform S-parameter measurements. The S-parameter data was then used to extract the lumped circuit topology shown in figure 3, where the chip's contact pads are included in the transmission line model of the test substrate's mounting pads. The topology from figure 3 has been used by other experimentalist, the terms are described as (i) internal capacitance as a coupling of the pads, (ii) external capacitance as a coupling to the boards ground plane, (iii) internal and external inductance as the finite length of the resistor and pads, and (iv) internal inductance is also affected by the skin effect, or the decreasing of the effective thickness resistor as the frequency increases and is frequency dependent. (2)(4)(6)(7)

### RESULTS

Figures 4 through 6 show the impedance response normalized to the device value for 0201, 0402 and 0603 case sizes. These graphs show that the resistors tend to have either a dominant shunt capacitance, or series inductance, depending on the resistor value. These results are in agreement with other publications. (1)(8) Papers where only values lower than 100 Ω were measured tend to correlate the observed series inductance to the skin effect or surface impedance used in waveguide and resonant cavity applications. (2)(4)(5)(9)(10) These papers note that the increasing impedance is proportional to the square root of the frequency. (2)(4) The skin effect however does not support the decreasing impedance for higher resistor values. We have chosen instead to model the results with a lumped circuit mathematical representation, figure 3. To model the observed decreasing impedance a fixed internal impedance was included in the topology (see figure 3) to describe the finite length of the resistor and provide a mechanism for the observed increasing impedance of lower ohm resistor values. (2)(4)(6)(7)

The fitted results for the lumped circuit model are plotted with the data in figures 4 to 6. The fitted model coefficient values are listed in table 1 and figure 7. The fitted results of part values above 100 Ω are typically very good. Fitted results of the part values less than 100 Ω do not completely describe all the parts, i.e. the 0201 case has a small peak at about 30 GHz that is not described by the model, see inset in figure 4.

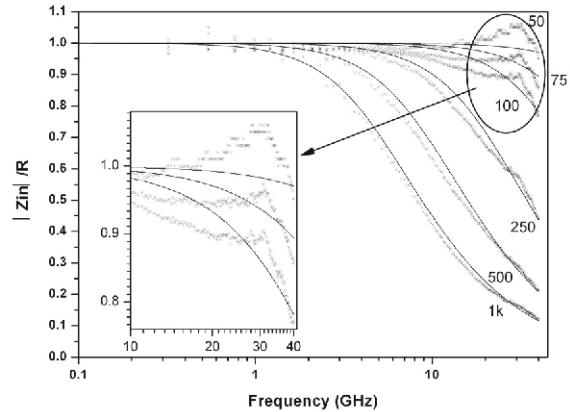


Fig. 4 - 0201 flip chip  
The minor peak for the smaller parts at 30 GHz is not accurately modeled by the circuit of figure 3 (see inset). This is the smallest case size tested and had the best impedance performance.

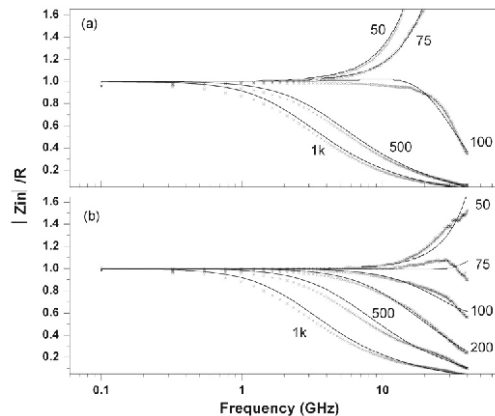


Fig. 5 - 0402 case size  
Both the (a) wrap and (b) flip chip terminations are plotted. The flip chip outperforms the wrap termination. The 75 Ω flip chip demonstrates the 0201 difficulty with modeling small peaks.

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Peaks are seen in all the case sizes, particularly for 100  $\Omega$  and less. The external and internal inductive, resistive, and capacitive (LRC) equivalent circuits, shown in figure 3, can describe this peak mathematically. Large peaks; such as with the 0402 wrap; are modeled very well by this circuit and small peaks; such as exhibited with the 0201 case size; are more difficult to model without modifications to this circuit.

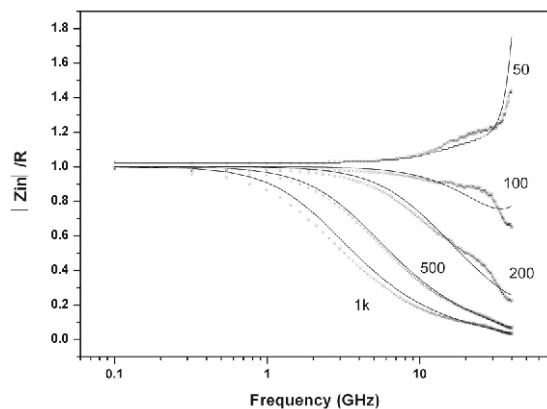


Fig. 6 - 0603 flip chip

The 100  $\Omega$ , and to some extent the 200  $\Omega$  part, demonstrate the 0201 difficulty with modeling small peaks above 25 GHz.

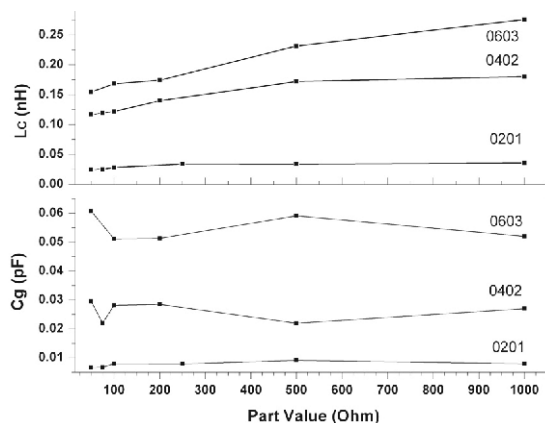


Fig. 7 - Modeling coefficients from figure 1. The large difference in impedances for case sizes clearly demonstrates the importance to minimize the footprint of the device.

As the case size is increased the performance and therefore the model coefficients are affected. Figure 8 plots the impedance performance for different part values and case sizes. The smallest case size, 0201, performs better than both the 0402 and 0603 case sizes for all part values. The differences in the 0402 and 0603 case sizes are moderate and occasionally reversed and may be related to the device dimensions. The maximum area the resistor can cover for each case size is given in table 1. The ratios of the resistor area by case size (0603 : 0402 : 0201) are 1 : 2.32 : 20.4. The dimension change to 0201 from 0603 or 0402 is significant and can explain the large difference in device performance.

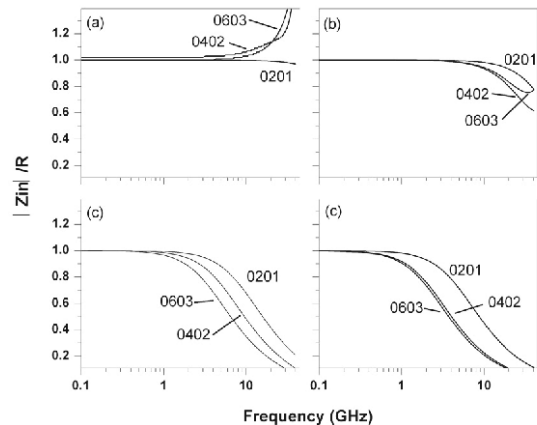


Fig. 8 - Case size comparison of 0201, 0402, and 0603 Plot (a) is 50  $\Omega$ , (b) 100  $\Omega$ , (c) 500  $\Omega$ , and (d) 1000  $\Omega$ .

The 0201 case size clearly out performs 0402 and 0603 case size.

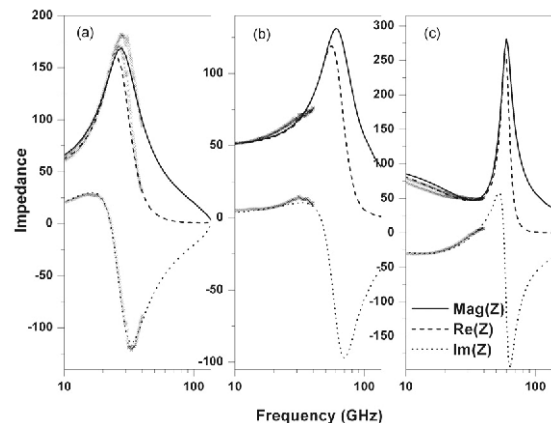


Fig. 9 - Prediction of devices from the model for (a) 0402 wrap, (b) 0402 flip chip, and (c) 0402 flip chip with L-cut trim. By extending the range of the model results indicates the presence and approximate location of the peak observed with some of the tested devices.

The external modeling coefficients, figure 7, show similar results to the case size impedance performance, figure 8. The external coefficients are clearly dependant on case size and part values. The smaller case size gives smaller coefficients and the inductance coefficients increase for increasing part value while the capacitance coefficients remain relatively constant. The internal coefficients do not have a large dependency on size or part value; rather their average values are included in table 1.

Modeling results extending beyond the measurement range can be used to predict the LRC peak location and magnitude. Figure 9 extends the model to 150 GHz for the 0402 case size; (a) 50  $\Omega$  wrap, (b) 50  $\Omega$  flip, and the (c) 100  $\Omega$  L-cut. The wrap termination data displays an almost complete peak; the flip and L-cut chips show different regions of the peak and its predicted location and magnitude. The flip chip data has the real part displaying a positive slope with an inflection point in the imaginary data the model continues beyond these points and predicts a 60 GHz peak. An L-cut on a 100  $\Omega$  flip chip has

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the imaginary part displaying a positive slope with a inflection point in the real data; the model continuing beyond 40 GHz predicts the same 60 GHz peak with a larger magnitude.

Terminations were tested for the 0402 case size, figure 3. The impedance frequency response for the flip style was less dependant on part value from 50 Ω to 200 Ω. The use of microstrip test boards caused the wrap around termination ground plane to be located further away from the resistor than the flip chip. The additional distance from the ground plane and increase in lead length will affect the resultant performance of the device. <sup>(5)</sup>

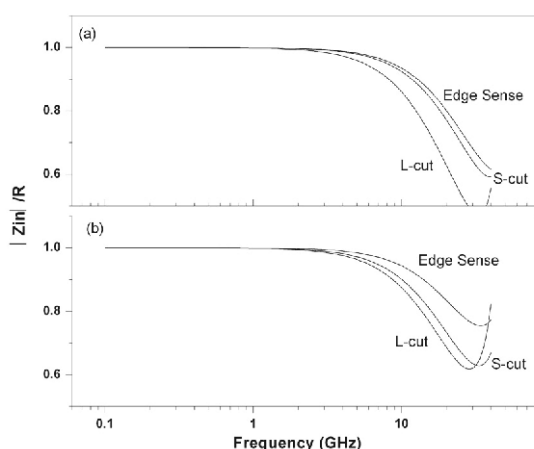


Fig. 10 - Comparison of trim methods for the (a) 0402 and (b) 0603 case sizes. The edge sense trim has the best impedance performance.

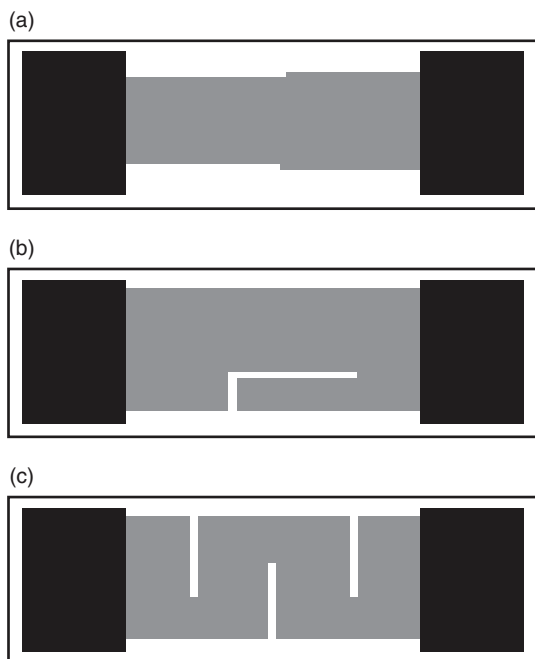


Fig. 11 - Trim methods: (a) balanced edge sense, (b) L-cut, and (c) S-cut

Trim methods were tested on the 100 Ω, 0402 and 0603 products, figure 10. A plunge cut with a bend at the end for fine trim (L-cut) and a block pattern with a two or more straight plunge cuts to form a serpentine pattern (S-cut) were tested and compared to the standard edge sense trimming, figure 11. The balanced edge sense trim outperformed the S-cut, which outperformed the L-cut. In the case of the 0402 the edge and S-cut were similar, while for the 0603 the S-cut was more similar to the L-cut.

### CONCLUSIONS

Performance at high frequency is dependent on the case size, trim method, part value and termination style. The reduction in parasitic impedance for smaller cases sizes is consistent with the smaller landing pads and device dimension. The large change between 0201 and the 0402 and 0603 can be related to significant reduction in maximum resistor area. The ratios of the maximum areas for the resistors by case size (0603 : 0402 : 0201) are 1 : 2.32 : 20.4. The small change in device area for the 0402 and 0603 case sizes is most likely related to the small differences and occasional reversal in the device performance.

Previous papers have described resistors with a skin effect type model. We have found the various impedance responses for different part values are not completely supported by a skin effect only model. We have utilized a lumped circuit model with capacitor and inductors to model and predict the frequency response of standard flip chip resistors manufactured by Vishay Thin Film (FC series).

Trim style does affect the impedance performance. The difference between an S- and L-cut is not quantifiable or consistent, but their impedance performance is reduced from that of balanced edge sense trimmed method used for the standard resistors. The difference in S- and L-performance may be related to the depth o location of the trim in the resistor structure for two different trim styles, this was not monitored or recorded. Vishay Thin Film has made standardized the balanced edge sense trim method for its FC series high frequency thin film chip resistors.

Termination style differences, wrap and flip, can be enhanced by the type of test boards used. The microstrip style used has the RF-ground plane located on the backside of the board. The flip chips were mounted with the resistors down and the wrap terminations with the resistors up. Thus the amount of material and its effective dielectric constant between the resistor and ground was different in these two cases, and can affect the RF performance of the device. Vishay Thin Film provides both wrap and flip terminations in its FC series high frequency thin film chip resistors.

*We would like to thank Modelithics, Inc., Tampa, FL, for all the high frequency measurements and analytic modeling.*