A Simple Model for the Prediction of AC-DC Difference of Multi-Junction Thermal Converters

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***Abstract* — This paper describes a simple model for planar multi-junction thermal converters based on physical dimensions and properties of the converter chip and all wire bonds. The model was used to explain extremely low (< 700 µV/V) AC-DC differences at 100 MHz. Two designs of multi-junction thermal converters (MJTC) were tested against the model and the results are presented.**

***Index Terms* — AC-DC Difference, Planar Multi-junction Thermal Voltage Converters, MJTC, SPICE model.**

I. INTRODUCTION

AC voltage is a unique measurement that requires a standard to compare the energy from an AC voltage to that of a DC voltage. Several notable designs of voltage converters have been used with ever decreasing AC-DC differences and uncertainties. Today, it is possible to know AC voltage to within 16 µV/V at 1 MHz; however, as the frequency increases to 100 MHz, the expanded uncertainty ($k=2$) in the measurements increases to 0.18 %. There are many causes for the increasing uncertainty with increasing frequency that were previously accounted for through various physical models [1-4]. While all of these models focused on explaining the results, available literature does little to link physical design parameters to electrical models in a fashion that can readily be used to revise designs.

LTSPICE[1] is a common electrical engineering tool that permits quick simulations of electrical circuits. The advantages of using this tool are quick computations and ease of adding additional components such as capacitance for a bifilar resistor versus a straight geometry.

II. MULTI-JUNCTION THERMAL CONVERTER DESIGNS

The premise for this work was based on knowing the physical dimensions and general layout of the multi-junction thermal voltage converter (MJTC) chip. Based on these, estimates for the resistance, capacitance and inductance were created using simple models and approximations.

The first design, referred to as coaxial, consists of a resistive element that is a straight line on the substrate. The signal and ground connections for the device are on opposite ends of the device. The second design, referred to as bifilar, consists of a U-shaped resistive heating element, with signal and ground connections at the same reference plane. Both general designs have been in use at the National Institute of Standards and Technology (NIST) for a number of years and detailed descriptions of the designs and AC-DC differences from 10 Hz to 100 MHz are readily available in the literature [5, 6].

III. COMPONENT CONTRIBUTIONS

The model was based on an impedance for each of the various sections as shown in Fig. 1. For the practical purposes of this work, the typical coaxial connector was not included in the model, as the dimensions and materials are not readily changed; however, the authors acknowledge the connector does contribute to the AC-DC difference as described by Huang, et al. [2]. We identified the following seven conductors as contributors to the AC-DC difference: Wire from connector to carrier, Carrier, Wire bond from carrier to MJTC chip, MJTC

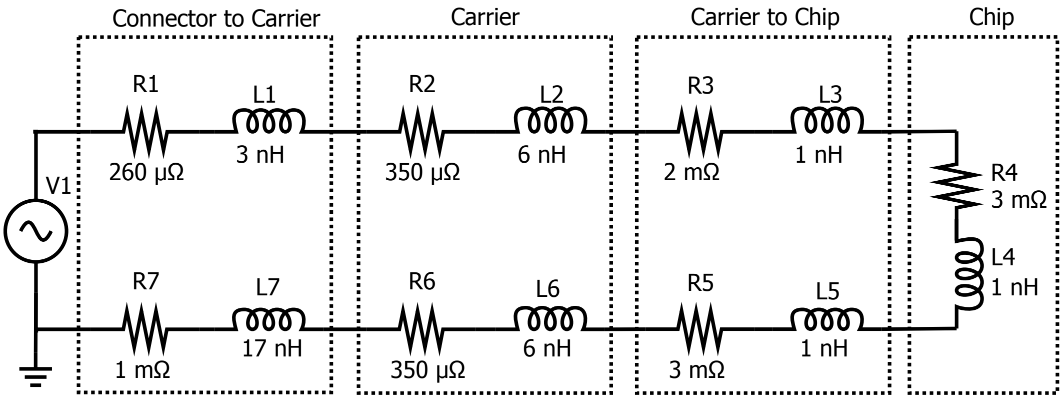

Fig. 1. Schematic of LTSPICE model for coaxial MJTC device without typical coaxial connector.

chip, Wire bond from MJTC chip to carrier, Carrier, and Wire from carrier to connector. For each of the conductors, an inductance and a resistance were calculated using common material properties and measured dimensions. These values were then entered into the LTSPICE model as shown in Fig. 1.

IV. RESULTS

The model was run from DC to 100 MHz, and the resulting AC-DC difference values were calculated and compared with two actual devices that were built for each of the designs. Analysis of the data shown in Fig. 2 yields agreement within the expected measurement uncertainties highlighted in Table 1.

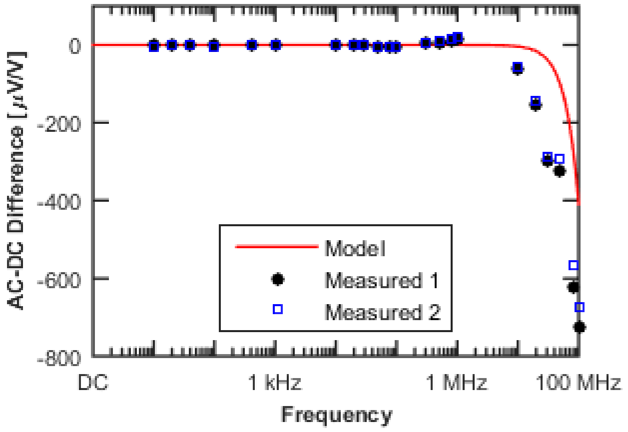

Fig. 2. AC-DC difference of coaxial MJTC as measured on two devices of the same configuration with comparison to LTSPICE model. Error bars are omitted from this plot for clarity.

Further testing of the model was conducted through implementation of a second design referred to as bifilar. In this design the resistive element of the MJTC forms a U-shape, that adds capacitance to all elements as the signal and ground paths are parallel. The results for the second design and comparison to two actual devices are shown in Fig. 3.

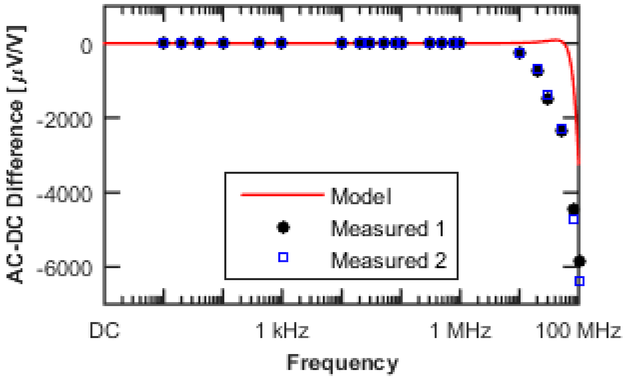

Fig. 3. AC-DC difference of bifilar MJTC as measured on two devices of the same configuration with comparison to LTSPICE model. Error bars are omitted from this plot for clarity.

Table 1. AC-DC difference measurement uncertainties for key frequencies.

Frequency	1 kHz	1 MHz	10 MHz	100 MHz
Expanded Uncertainty (k =2) [µV/V]	1.7	18	150	1800

VI. CONCLUSION

A simple model for estimating the AC-DC difference of MJTC's from physical design parameters was created and compared to actual devices. The results indicate overall general agreement with experimental data for both coaxial and bifilar designed devices. The gained insight from the model can be used to further develop MJTC AC-DC difference standards.

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[1] Certain commercial software is identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the software identified is necessarily the best available for the purpose.