TANTALUM AND NIOBIUM OXIDE CAPACITORS EQUIVALENT CIRCUIT MODEL APPLICABILITY TO SIMULATION SOFTWARE

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ABSTRACT

Real world passive components have not been used in creating models for circuit simulation software. Ideal passive components (resistors, capacitors, inductors) are routinely used in simulation software. Unfortunately, ideal and real passive components have significant differences in their electrical parameters. These differences lead to inaccuracies between actual hardware performance and expected results based upon software simulation programs.

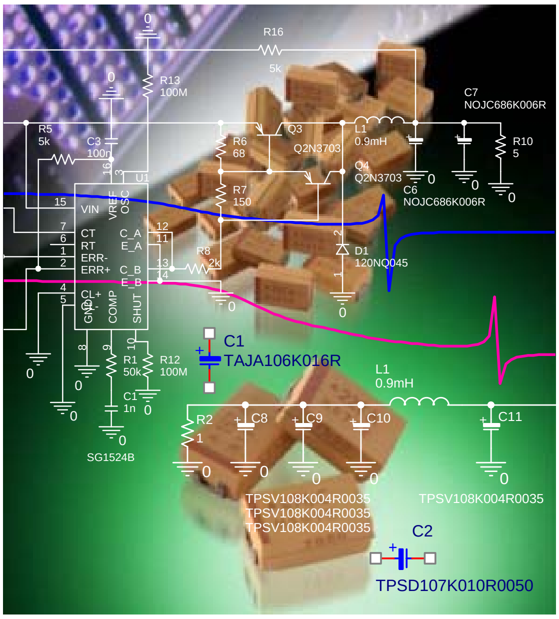
This paper will describe the development of equivalent circuit diagram for real capacitor behavior. Use of this real world model in simulation software will guarantee an accurate simulation response in developed circuit diagram.

The model, which is presented, includes real component behavior for Tantalum and Niobium Oxide capacitors. Tantalum and Niobium Oxide components are slightly dependent with temperature and thus the article will describe model structure with temperature dependences.

INTRODUCTION

All real capacitors have parasitic features not taken into account in ideal capacitor models. These differences can have a major impact on electrical functionality within a circuit. Better understanding of real capacitor behavior can help to create more accurate solutions for equipment development. The use of an Equivalent circuit diagram (capacitor model) will yield a better understand electrical reaction in electrical circuit.

COMPARISON OF IDEAL AND REAL CAPACITORS



An Ideal capacitor has only one element – its capacitance value. Parasitic ESR (equivalent serial resistance), ESL (equivalent serial inductance) and LI (leakage current) through the component are assumed to be zero. The VA characteristic of ideal capacitor is a linear dependence in both directions with zero characteristic slope. Likewise, ideal capacitors are not dependent with temperature.

Real capacitors have defined capacitance level, and also have significant ESR, ESL and LI parasitic electrical parameters. The magnitude of those parasitic parameters depends on manufacturing technology, methods and material systems. These non-ideal parameters have significant influence on filtering, smoothing and further functionality in electronic applications.

Ideal capacitors have constant capacitance through whole frequency range, but real capacitor cannot have flat capacitance through whole frequency range. This is due to the frequency effects of parasitic ESR and ESL.

The real world capacitor has leakage current in the component. Its dielectric layer is not an ideal insulator and with reverse voltages the level of leakage current will increase rapidly due to MIS structure [1].
Tantalum and Niobium Oxide capacitors are both polar components and the leakage behavior in reverse voltage conditions looks like a diode's VA characteristic - with a typical bend.
These parameters vary with temperature, which has a measurable influence in whole circuit design. These are some of the reasons that real capacitors demonstrate significantly different performance in assembled electronic circuits vs ideal capacitor simulations.

DESCRIPTION OF REAL CAPACITOR EQUIVALENT CIRCUIT DIAGRAM

Equivalent circuit diagrams have been developed to demonstrate the real world functionality of Tantalum and Niobium Oxide capacitors. This circuit diagram has been created from ideal passive and semiconductor components (C, R, L, and D), which describe the real world capacitor's in-circuit behavior.

The equivalent circuit diagram of Figure 1

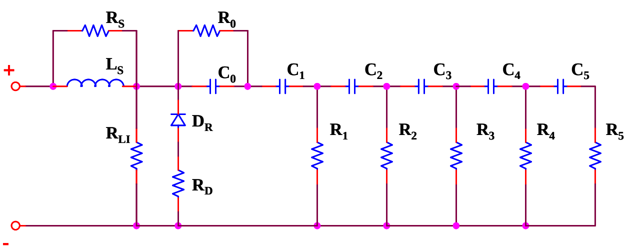


Figure 1: The structure of equivalent circuit diagram (independent on temperature)

shows structure, which simulates real capacitor behavior. The electrical response is represented by ladder of ideal resistors R_1, R_2, R_3, R_4, R_5 and capacitors C_1, C_2, C_3, C_4, C_5. The various components describe decreasing of capacitance with frequency increasing (Figure 2.).
The increase in ESR level at low frequencies is described by the resistor R_0 and capacitor C_0 in parallel combination. The capacitor C_0 has high capacitance value, because the real capacitors value is represented by this capacitor.
Self-inductance of the capacitor is modeled by the parallel combination of inductance L_S and resistance R_S to create a self-resonance behavior with the rest of circuit capacitance.
Tantalum and Niobium Oxide capacitors are polar components with MIS (Metal

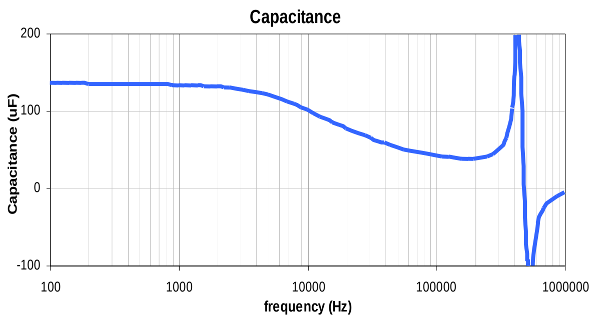


Figure 2: Capacitance behavior through the frequency range

Insulator Semiconductor) structure [1] thus the electrical behavior in reverse voltage is different compared to regular polarization [2]. In the reverse mode, tantalum and niobium oxide dielectrics are modeled by a diode D_R and resistor R_D integrated in the equivalent circuit diagram. The diode D_R has band at 10% of capacitor's rated voltage to describe the real change of VA curve of the capacitor. Serial resistance R_D describes the slope of VA characteristic after the bend. The diode D_R and serial resistance R_D do not describe leakage current of the capacitor since the diode D_R has negligible influence on whole leakage current (reverse leakage current of the diode is many times lower than existing leakage current through the resistor R_{LI}).

Resister R_{LI} describes leakage current LI through the component, because value of resistor R_{LI} represents value of leakage current of modeled capacitor.

The equivalent circuit diagram includes temperature dependence, even though this is less significant for tantalum and niobium dielectrics than for other high CV ceramic components.
There are no voltage dependences included in the model, since Tantalum and Niobium Oxide capacitor characteristics are independent of DC bias voltage. Real capacitors are temperature dependent and thus the components from the equivalent circuit

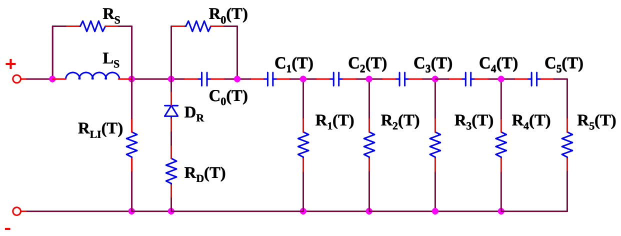


Figure 3: The structure of equivalent circuit diagram with temperature dependent components

diagram have temperature dependences. Real world temperature dependences are demonstrated in figure 3. Temperature dependence is represented in the equivalent circuit diagram by temperature function of resistors (R_0(T), R_1(T), R_2(T), R_3(T), R_4(T) and R_5(T)) and capacitors (C_0(T), C_1(T), C_2(T), C_3(T), C_4(T) and C_5(T)). Basically, they describe capacitance and ESR performance of the capacitor across the frequency spectrum. Leakage current of the capacitor are likewise logarithmically temperature dependent and this influence is included into R_{LI}(T). Figure 4 shows the capacitance and ESR response with

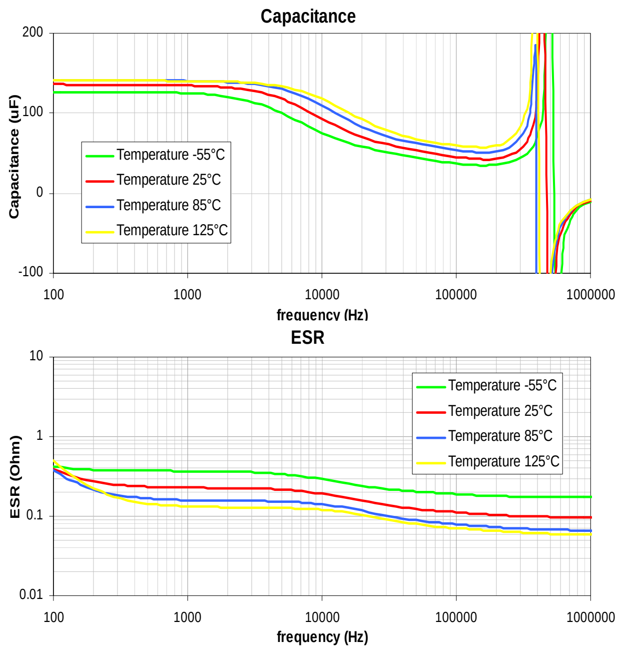


Figure 4: Capacitance and ESR behavior through the frequency range with temperature dependence

temperature and frequency. Additionally, ESR is shown across frequency.

TANTALUM AND NIOBIUM OXIDE MODEL CREATION FOR SIMULATION SOFTWARE IMPLEMENTATION

Simulation software is a popular and common tool for electronic equipment development. It is used as a modern method for quick and flexible circuit design. The model of equivalent circuit diagram has been developed for both Tantalum and Niobium Oxide capacitors. Those Tantalum and Niobium Oxide capacitors use similar technology and thus the model could be employed for both

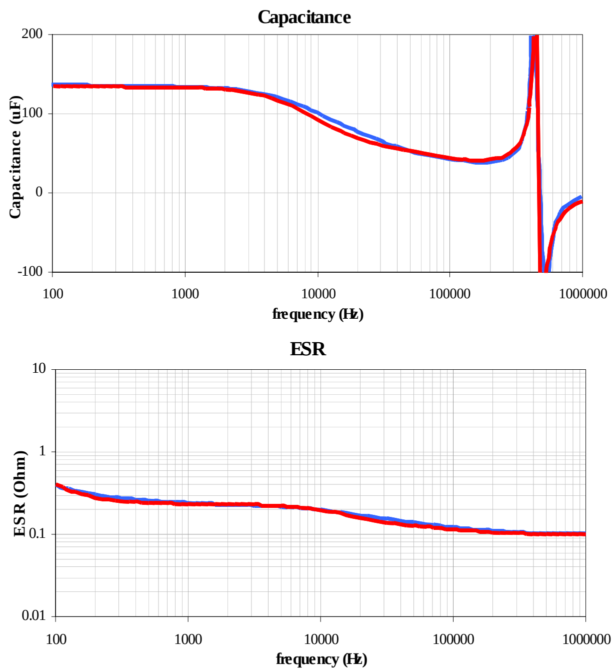


Figure 5: Comparison real measurement and simulation response of equivalent circuit diagram

kinds of components. The model was matched with real measurement and the result of this matching has given equivalent performance characteristics to real measurement.

Modeled characteristic (red curves) closely match actual measurement (blue curve) of device as shown in Figure 5.

This equivalent circuit diagrams of capacitors can be used for implementation into simulation software, for example PSpice and others simulation software [3]. The equivalent circuit diagrams of capacitors are unified into a library, which is compatible with required simulation software. The library is then integrated/implemented into simulation software and subsequently used for total circuit diagram creation, consequential simulation and evaluation. A complete designed circuit diagram could be built from many types of components (transistors, resistors, capacitors, diodes, inductors, integrated circuits, etc.). Example of one such circuit diagram suitable for simulation is shown in Figure 6. The circuit can be fully simulated and each electrical parameter of components can be evaluated. This simulation result of circuit diagram can be considered to be like the real physical measurement. Simulation of designed circuit is quicker and more flexible compare to physical

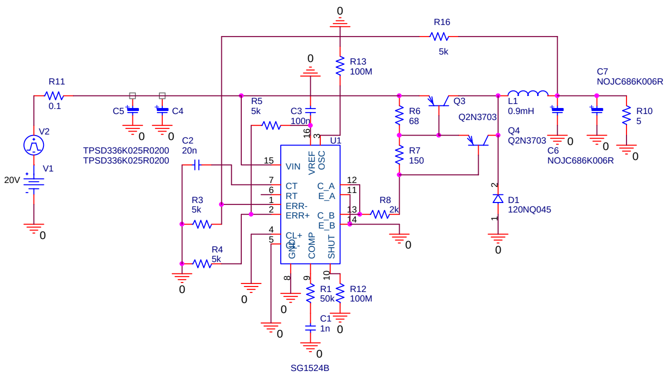


Figure 6: Example of circuit diagram suitable for simulation

assembly and manual measurement of evaluated PCB. The final result of both should be the same, because simulation includes real behavior of all used components and it could be proven by result from the measurement.

DESCRIPTION OF LIBRARY STRUCTURE AND SIMULATION SOFTWARE

Tantalum and Niobium Oxide chip capacitor equivalent circuit models were developed in a library format for simulation software. These libraries are suitable for direct importing/implementing into simulation software (PSpice and others). The libraries include all electrical parameters for Tantalum and Niobium Oxide series capacitors and allow fast, flexible creation and simulation of practical circuit designs. These libraries are intended for use in both frequency and transient simulations over the full operating temperature range for each component. The library can be a powerful tool that enables the realisation of flexible design solutions with minimum physical bread boarding, resulting in reduced overall time-to-market.

Each library consists of two files applicable to software simulation packages.

The library incorporates a netlist file, which includes network connection of ideal components with the same structure that describes equivalent circuit diagram (Figure 3).

The netlist included into the library will be used for mathematical model calculation after implementation into simulation software.

Simulation software usually needs two kinds of files. One file consists of netlist and the second file is symbol package for correct viewing on software board. Mathematical models contain electrical parameters equivalent circuit diagrams for Tantalum and Niobium Oxide components. The components' part numbers with circuit symbol are included into second package file. These libraries of mathematical (equivalent circuit diagram) and symbol package can be implemented into simulation software and used for schematic circuit design and subsequent simulation of all electrical parameters as will be described at the next section.

EXAMPLE OF CIRCUIT DIAGRAM CREATION WITH SIMULATED AND MEASURED RESULTS

This section gives examples of simulation software to create circuit diagrams and their results.

Components are basically dragged and dropped to create whole circuit diagram (Figure 7). The circuit diagram demonstrates

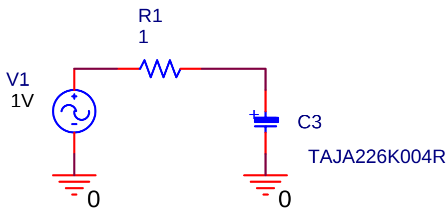


Figure 7: Real capacitor simulation

how behavior of real capacitors could be measured and simulated by the software. The capacitor is then connected with a sweeping source to demonstrate output response of electrical parameters and evaluate real capacitance, ESR and impedance manners. All electrical parameters of the real capacitor are simulated and shown in Figure 8, which can show behavior of those parameters like the real measurement.

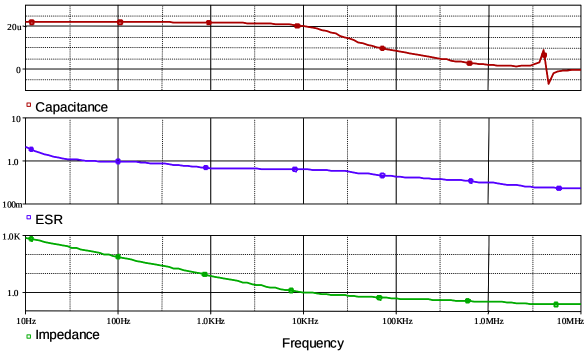


Figure 8: Capacitance, ESR and Impedance behavior of simulated real capacitor

Figure 9 represents a circuit diagram of output passive filters for comparing tantalum and ceramic capacitors on smoothing output voltage level in the circuit diagram. The

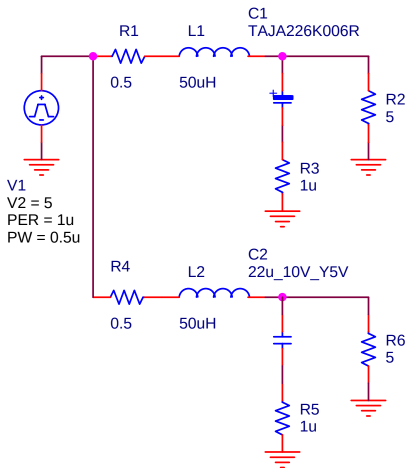


Figure 9: Circuit diagram of output passive filters comparison

output voltage ripple is also shown in Figure 10 for comparison between tantalum and

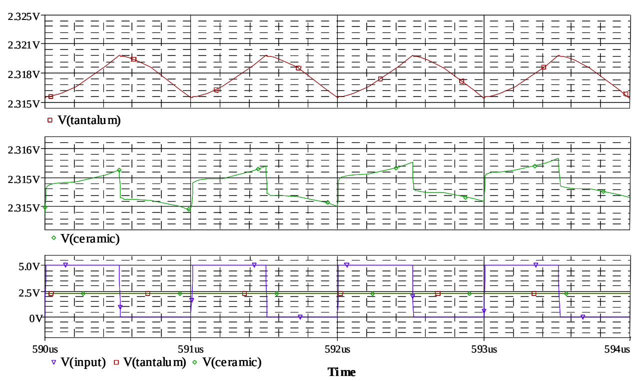


Figure 10: Simulation result of ripple voltage

ceramic components. In this case, tantalum capacitor has a smoother voltage ripple characteristic V(tantalum) than the ceramic V(ceramic), where voltage spikes are presented, although overall output filtering is similar. The same example was evaluated with actual measurement (Figure 11) using real world physical components.

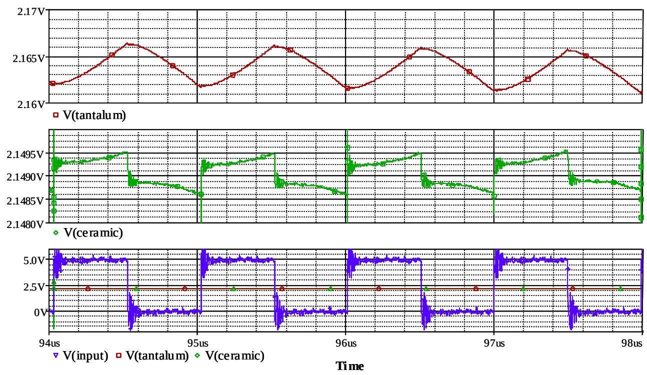


Figure 11: The result of measured ripple voltage level

The simulation and measurement were compared and no significant differences were found there. This proves that simulation works just like real measurement. Therefore measurement can be replaced by simulation to yield create quick development cycles.

The last example demonstrates the flexibility of simulating a real DC/DC converter application (Figure 12). An actual DC/DC

Figure 12: Physical DC/DC converter

converter was measured and overloaded to create higher output voltage ripple to demonstrate that overloaded DC/DC converter can be successfully simulated as well.

The input and output voltage levels are represented by graphs in Figure 13. The DC/DC converter was then created and consequently simulated with the simulation software as well as with real equivalent circuit components (Figure 14). Figure 15 shows the result of the simulation. The simulation is again the same like real measurement, which proves further correct functionality of equivalent circuit diagrams. The simulation displays an identical response. This demonstrates how quickly the designer, using real equivalent circuit diagrams for all components in developmental circuit, can evaluate a circuit design change. There is no need to use real samples of components, because real models can offer fully substitute physical components.

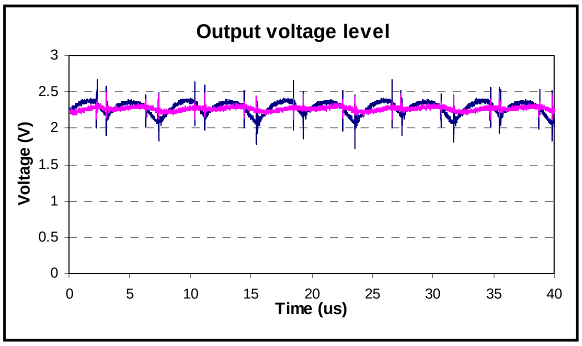


Figure 13: Measured result of voltage transient real DC/DC converter before and after output passive filter

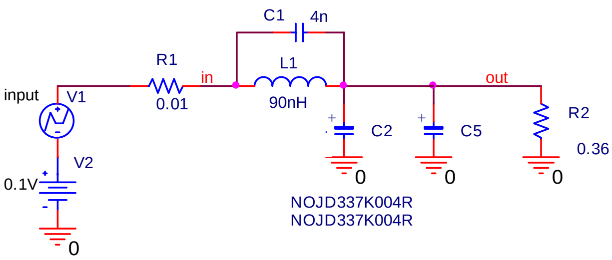


Figure 14: Circuit diagram for simulation of DC/DC converter output filter

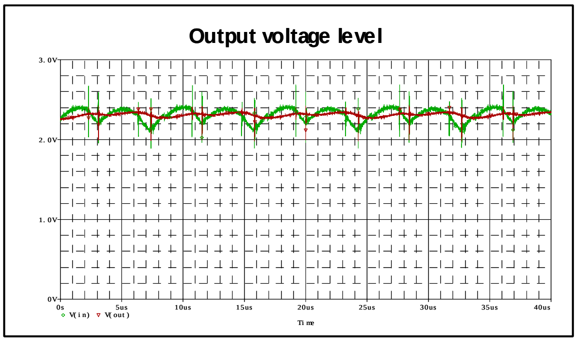


Figure 15: Simulation result voltage transient of DC/DC converter before and after output passive filter

SUMMARY

Equivalent circuit diagram has been developed because of the need to create a realistic view of real capacitors.

Those models could now be used for creation of a library. The library is able to be implemented into some simulation software and thus simulate and evaluate real behavior of whole electronic circuit design.

The library of electronic components for simulation software is a useful tool for fast, flexible electronic circuit design and development.

Component files from the library can be used for frequency and temperature analysis in wide range of applications, also including transient investigation.

Examples were used to demonstrate the flexibility of these libraries; circuit designs can be evaluated using variety of components together with Tantalum and Niobium Oxide capacitors.

Libraries are an integral part of any simulation software, which can incorporate equivalent circuit models for all real passive and active components.

REFERENCES

[1] J.Sikula et al., Tantalum Capacitor as a MIS Structure; CARTS USA 2000, 102-106

[2] A.Teverovsky, Reverse Bias Behaviour of Surface Mount Solid Tantalum Capacitors; CARTS USA 2002, 105-123

[3] Penzar’s TopSPICE (www.penzar.com) includes real world Tantalum and Niobium Oxide capacitors libraries into simulation software