Effect of DC Bias on Effective Capacitance of MLCCs

M. Fraser

Rough Draft

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Appendix

1. Introduction

Opening up any modern computer will reveal hundreds of electrical components, ranging from the miniscule resistors to large chips with hundreds of electrical contacts. Among these one shows up on nearly every circuit board. A multi-layer ceramic capacitor or MLCC is used in just about every circuit produced today. Both in precise high speed applications, such as on a CPU, and high power designs, like a DC-DC converter, they have a wide range of uses. Through their combination of ease of use in assembly, low cost, and small size, MLCCs have become an indispensable tool in circuit design.

Figure 1: MLCCs come in many shapes and sizes, with some as small as a grain of sand

Despite being mainly used in mass production of consumer products, MLCCs are simultaneously used in hobbyist designs. While nearly always coming in Surface Mount packages, though hole packages exist as shown in Figure 1, making them easy to solder by hand. And while other types of capacitors exist, they do not offer the same characteristics.

These simple electronic components can be modelled mathematically, but the real-world impacts how they function.

1.1. Voltage, Current, and Resistance

To understand their function and why they are universally used, it is important to first understand the basic theory of how electricity flows. Voltage, a potential difference, causes current, the flow of electrons, through a conductor.

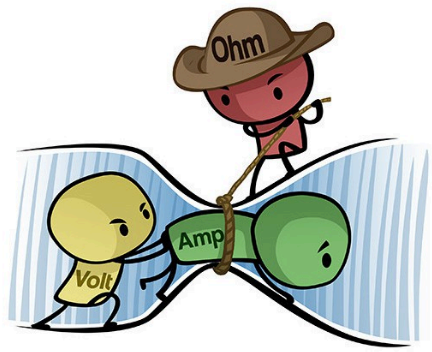

Figure 2: A popular cartoon representing voltage and amperage

When a voltage difference, such as from a battery, is applied across a conductor, current is allowed to flow unrestricted through that conductor. This is known as a short circuit. The amount of current flowing can be limited by using a resistor. A resistor is a component where the current flowing is directly proportional to the amount of voltage across the resistor. This relationship is shown in the following equation where $V =$ voltage (measured in volts), $I =$ current (measured in Amps), and $R =$ Resistance (measured in ohms).

$$V = I \cdot R$$

This relationship is known as Ohm's Law. As an example, if a 5V battery is connected to a 100Ω resistor, the current can be found.

$$V = I \cdot R$$

$$5V = I \cdot 100\Omega$$

$$\frac{5V}{100\Omega} = I$$

$$0.02A = I$$

As seen above knowing any two variables of this equation allows solving for the third. The equation can be manipulated to solve for Resistance, $R = \frac{I}{V}$, or current, $I = \frac{V}{R}$.

1.2. Model of Capacitor

A capacitor is a device where the current flowing through is proportional to the rate of change of voltage. That is, $I = C\frac{dv}{dt}$ where C is the capacitance in Farads. When a capacitor is connected to a current source the voltage across the capacitor will increase at a constant rate.

This models an ideal capacitor, but real capacitors and especially MLCCs face non-idealities which change this model. One of the most important, yet often overlooked, ones in MLCCs is DC-bias. DC-bias causes the capacitance, C, of a capacitor to be reduced as a voltage is applied across the capacitor. This introduces a new curve, which is the capacitance versus voltage curve. Manufacturers of capacitors will provide this graph. An example of the DC Bias graph of standard capacitor is shown in Figure 3.

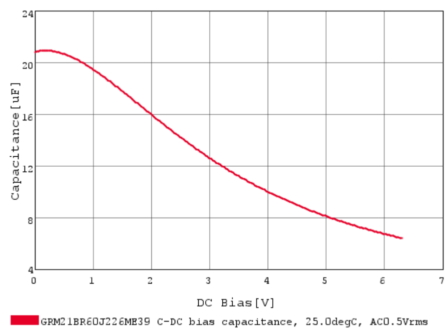

Figure 3: Capacitance versus Voltage on a Murata 22 μF capacitor

These curves have a domain of $0 < V < v_{\max}$ due to maximum ratings and capacitors not having directionality.

1.3. Research Question

The effect of DC Bias is mainly used in AC analysis applications, such as for a bypass capacitor, but is important when a device is first turned on, and a MLCC goes from 0V to V_{on}. Often components will have an enable pin that will only allow the device to turn on when the voltage reachess a certain threshold. Meeting rigid timing requirements neccesitates knowing how quickly the voltage across a capacitor will rise. This this paper will attempt to find **the effect DC Bias has on the effective capacitance of a MLCC during device turn on.**

2. RC Formula

2.1. Applications

Creating the constant current source in Section 1.2 for a capacitor can be difficult, so instead a resistor, as mentioned in Section 1.1, can be used to limit voltage increasing across a capacitor. Resistors, similar to capacitors, are relatively cheap and come in small package sizes. Combining these two components creates a circuit often referred to as an RC Circuit.

Figure 4: Schematic of RC Circuit

This circuit is often used to limit noise in a system in order to prevent unexpected behvavior. Additionally it can be used to slow down the rise time of voltage across a capacitor. This is the application that will be exmained here.

By mathmatically modelling this circuit the below equations are generated.

$$V_R + V_C = V_{\text{on}} \quad \rightarrow \quad V_C = V_{\text{on}} - V_R$$

$$V_{\text{out}} = V_C = V_{\text{on}} - V_R$$

Substituting in the formula from Section 1.1 for V_R we get:

$$V_{\text{out}} = V_{\text{on}} - IR$$

And finally using the equation for a capacitor from Section 1.2 to replace I:

$$V_{\text{out}} = V_{\text{on}} - RC\frac{dV}{dt}$$

This formula currently isn't very helpful because we are not able to input a time to get the output voltage, but it can be turned into the popular RC Formula as shown below.

$$V_{\text{out}}(t) = V_{\text{on}} \cdot \left(1 - e^{\frac{-t}{RC}}\right)$$

This allows us to get the output voltage with a specific time.

2.2. Derivation

The formula in Section 2.1 can be derived using the following process.

Math Math

3. LTspice

3.1. Advantages

Modern software allows us to simulate these environments. Compared to assembling the actual circuit this can reduce cost and increase speed in developing prototypes. The software used for simulation of circuits is Simulation Program with Integrated Circuit Emphasis. Many options exist for SPICE, but LTspice® from Analog Devices will be used here.

3.2. Schematic

3.3. Modeling DC Bias

3.4. Results

4. Experiment

4.1. Advantages

An experiment allows the greatest degree of accuracy in determing the behavior of a capacitor in the real-world but is also the costliest

4.2. Set Up

4.3. Results

Addtional information on setup can be found in Appendix A

5. Deriving Formula

5.1. Derivation

5.2. Results

Plot of graph using above derived formula Figuring out a formula for capacitance vs voltage (probably linear)

Substitute this formula into the Starting formula

6. Comparison of Methods

Graphs

Short paragraph and analysis

7. Generalization

Compare capacitance vs. voltage of different types of capacitors (x5r, x7r, 0805, 0603)

Try to find a general formula that can fit this curve

Do five again but with a generalized formula

Compare to LTSPice and Experimental results

8. Conclusion

How this could be useful in my life and elsewhere

Why it might not be accurate (This focused on bulk capacitors which might not be as common for enable pins due to size, Model might not be accurate because capacitance might not immediately change with dc applied across the capacitor (maybe experiment with this with different resistor values and see if C from RC stays the same))

Something else?

A Experimental setup

B Photos