Mittuniversitetet

MID SWEDEN UNIVERSITY

Assignment-Module-III

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Introduction

LTspice is an easy to used but yet very powerful spice simulator mainly used for simulation or electronic circuits. The underlying equations used in electrical circuits have the same form as many other physical system such as magnetic, thermal, mechanical. This gives an opportunity to utilize the simulator to perform more complicated tasks such as coupled physical simulations in a very efficient way that cannot be achieved with full FEM simulations. In this assignment three different systems should be modeled. First electrical coupling from a switched DC regulator to a sensitive analog signal will be investigated and then two electron thermal systems.

TASK-I. Transient heating of a MOSFET under over current conditions.

Task guidance

The task is to simulate the self heating of a transistor that is used in an invert circuit turned on at the nominal grid frequency 50Hz. Set up a simulation using the transistor GS66516B (GaN systems) to switch at 50% duty cycle at 50Hz. The transistor should drive a load of 3 Ohm from 100V source. The transistor is connected to a heat sink with the characteristic as in the figure. The heat sink model is based in the a thin isolation material and a following heat sink.
For accurate modeling of the heating of semiconductor devices both temperature dependent transistor model should be used but also a realistic thermal model off the transistor and thermal design.

1. Experimental circuit

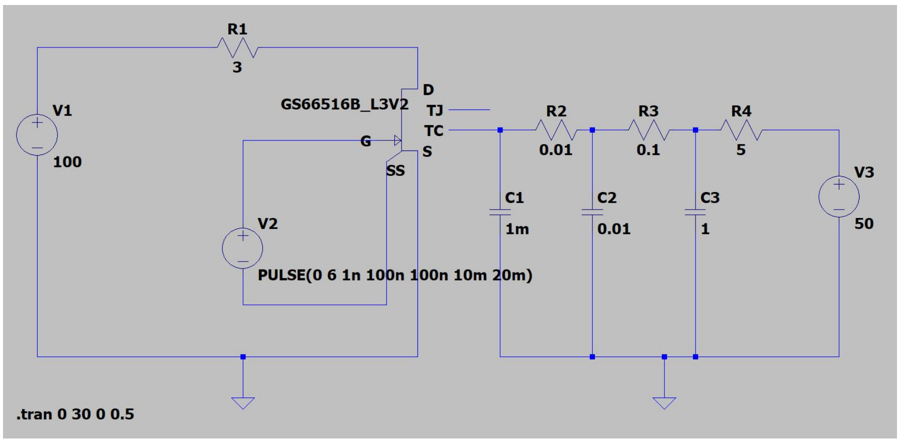


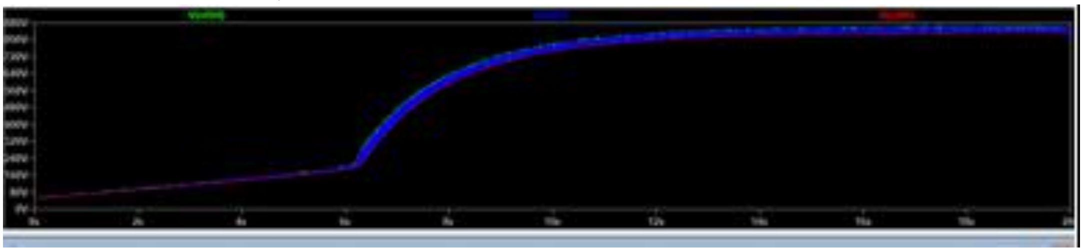
Figure1 circuit overview

2. Conclusion

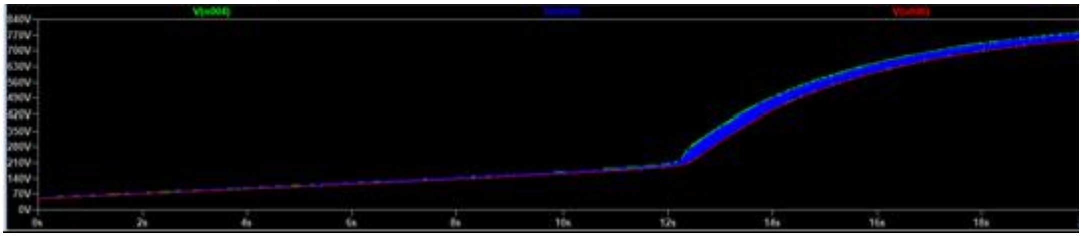
✓ **Determine how fast the circuit will take before over heating.**

After many simulations, over heating time are effected by **Resistor4** and **Capacitor3** changing.

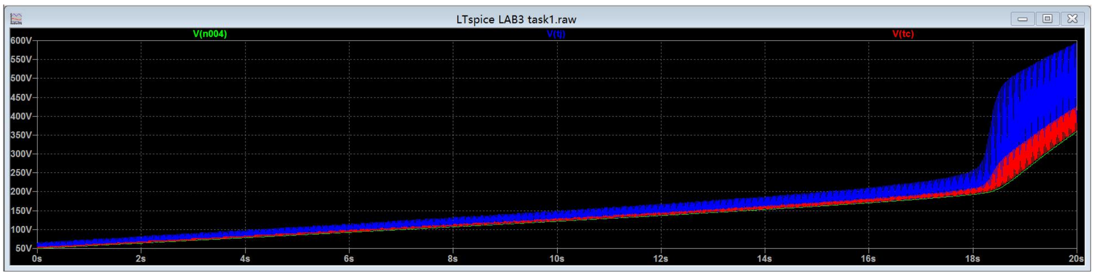
- When C3 = 1F ,OHtime is around 6s



- When C3 = 2 F, OHTime is around 12s



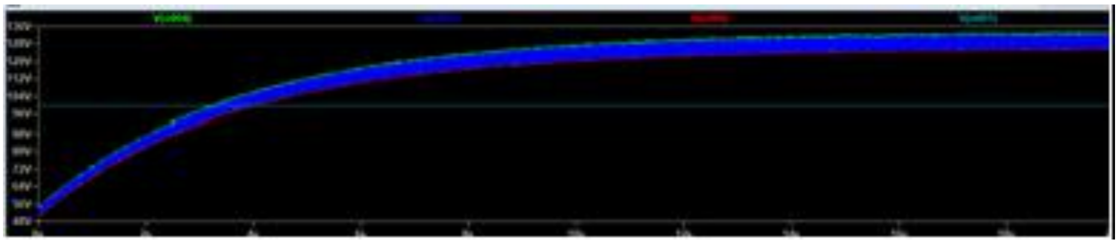
- When C3 = 3F, OHTime is around 18 s



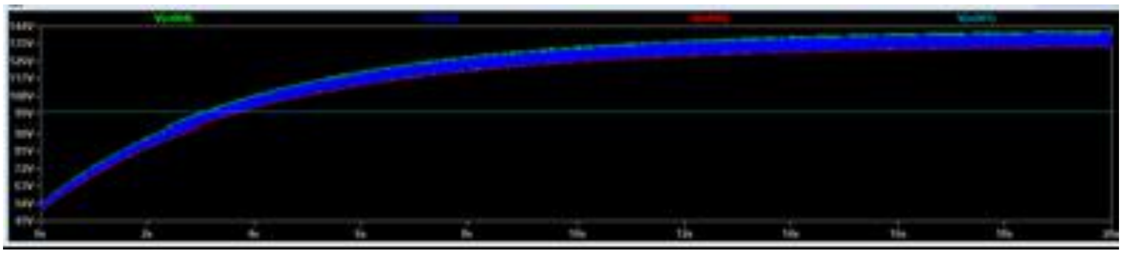
According to the simulation, we can sum up that the capacitance rising can delay the over heating time, striving for a longer time for the circuit to operate effectively.

Then I set C3 = 1F and change the value of R4

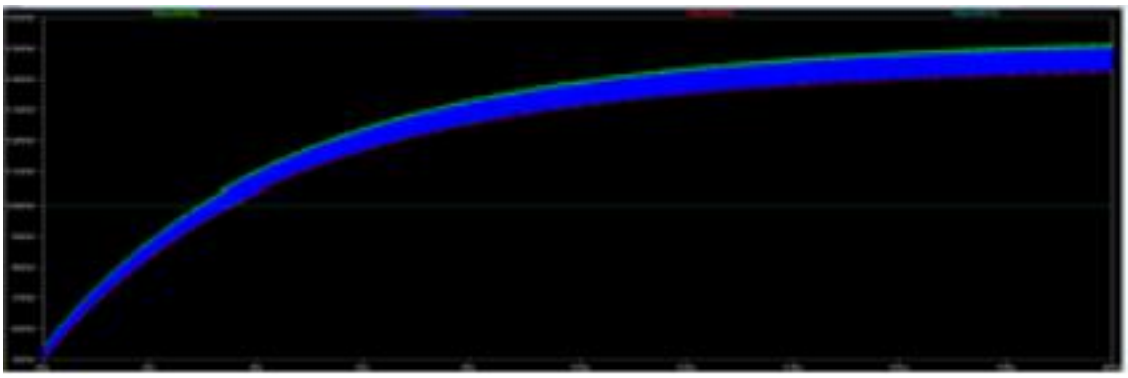
- When R4 = 2Ω



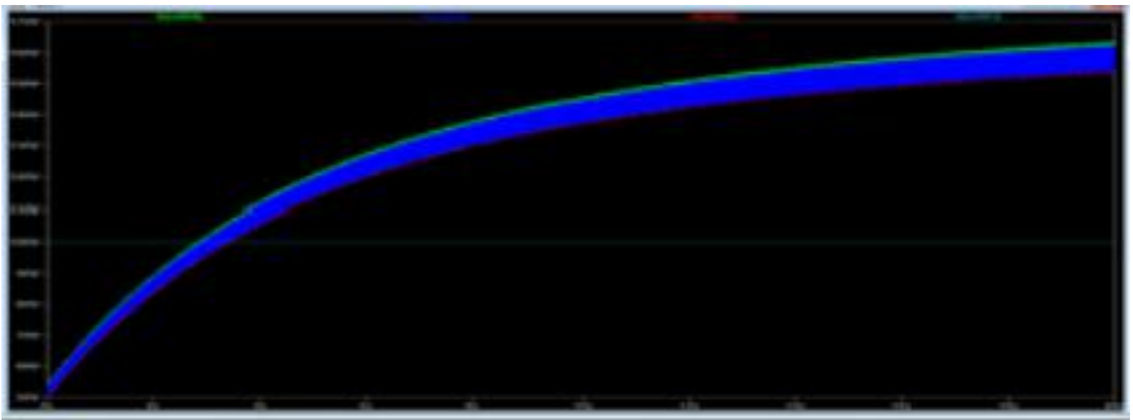
- When R4 = 2.1Ω



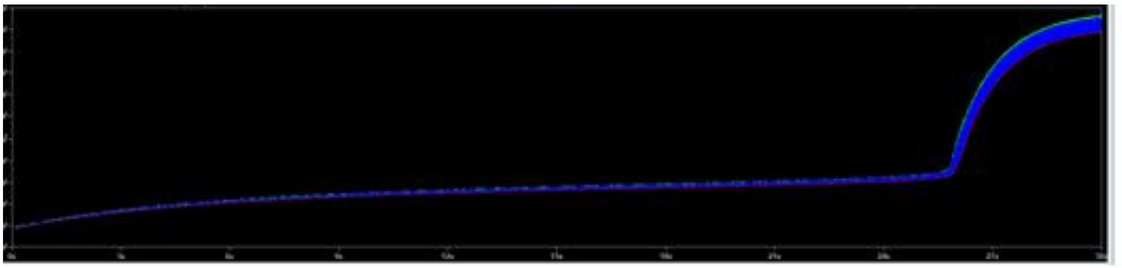
- When R4 = 2.2Ω



- When R4 = 2.3Ω



● When R4 = 2.4Ω



At first, we found the resistance critical value. When we set the resistance more than 2.3Ω, the circuit will fail with a dramatic rise in simulation windows and not affected by capacitance. And then we focus on effective parts which resistance lower than critical value. It shows that the higher resistor4 value we put, the more working time we get.

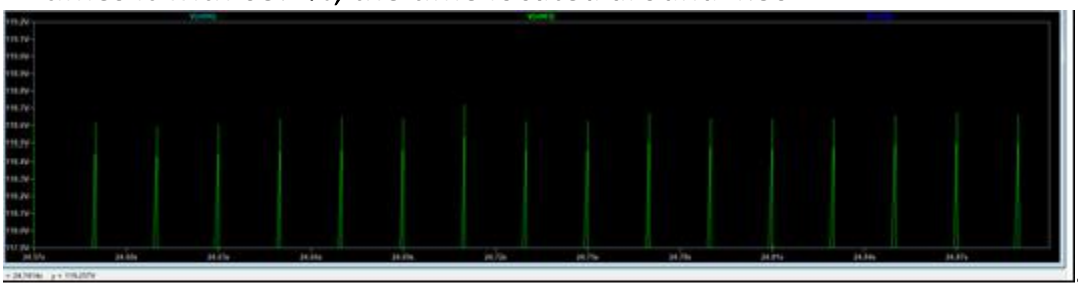
✓ **What are the important factors in the thermal design.**

Voltage input, resistance and capacitance are the important factors in the thermal design. The effect of R and C were covered before. The voltage input also not hard to understand, because it is the energy that the circuit needs to withstand when it is running. More energy supply naturally causes the circuit to be more prone to heat.

✓ **Calculate the dominant thermal time constant of the design.**

The thermal time constant is the time which the time taken to reach 63.2% of the maximum temperature. So we compare several groups data and get the result is R4×C3

● C3 = 3F , R4 = 1.5Ω, The maximum temperature is around 118.6℃, we times it with 63.2%, the time located around 4.5s



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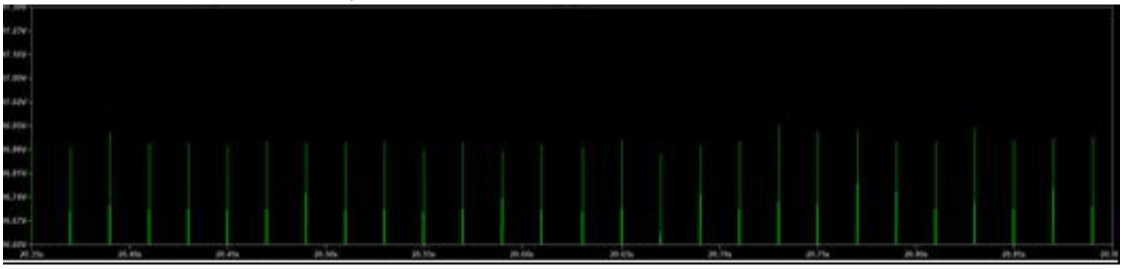
- C3 = 3F , R4 = 1Ω , The maximum temperature is around 96.9℃, we times it with 63.2%, the time located around 3s



- C3 = 1F , R4 = 1Ω , The maximum temperature is around 96.1℃, we times it with 63.2%, the time located around 1s

✓ **Discuss overall methods to ensure fail safe operation of an inverter like this.**

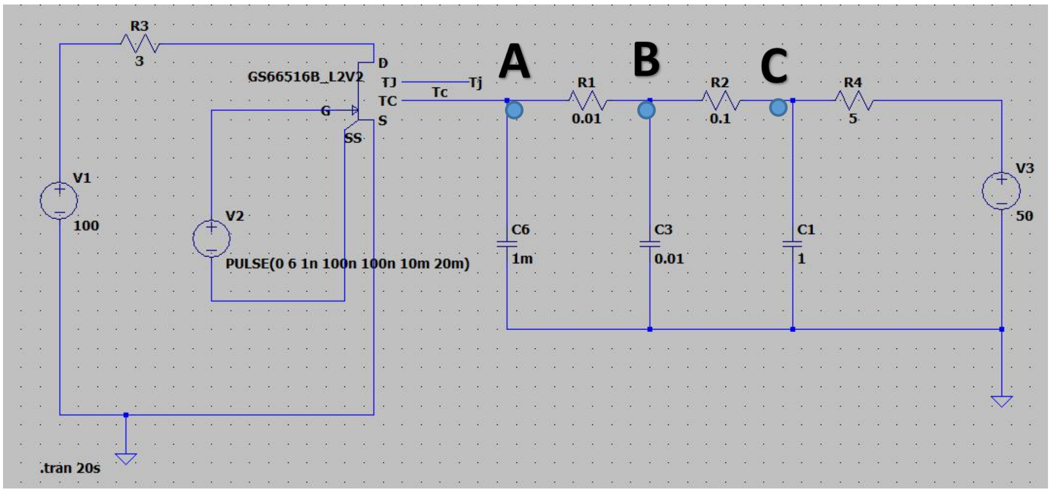


Figure 2 Temperature sensor setting point

We can put temperature sensors in point A, B or C.
In point A we measure the Case temperature. According to the data sheet file, the junction temperature is 150 degrees. At that time, case temperature at around 129 degrees. So we can put a temperature sensor in that point and make sure working temperature lower than 125 degrees, although the Tc is a fluctuating value.

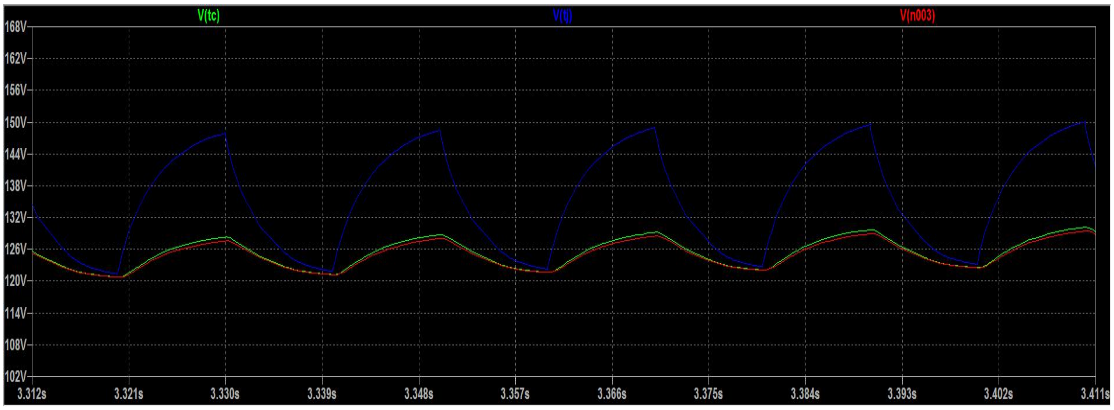


Figure3 point A and B

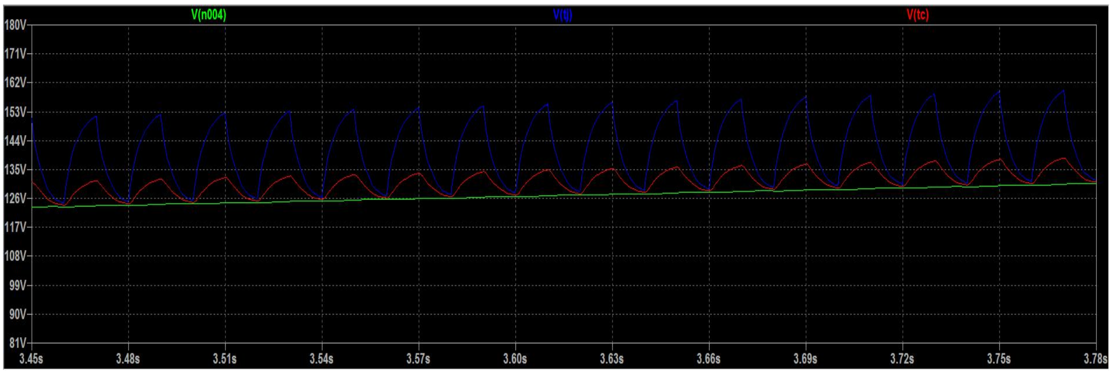


Figure4 point C

For the point B, it all most overlapping with A point value, so i think probably it can place the same temperature sensor at point B.

In point C we measure the temperature is 30 degrees below the maximum temperature. So if temperature lower than 120 degrees, it can safety working.

Task-II. Resistive heating application

Task guidance

In heating applications one challenge is that the resistance of an electrical wire is not constant but change with temperature during the heating. Additionally the thermal properties of the surrounding media will influence the behavior. The heating system is constructed by etched aluminum on a foil. The foil windings is arranged in three 1m sections connected in parallel. The sections is 10um thick and 1mm wide and separation between two tracks is 10mm. The two glass plates are each 5mm thick and the heater is driven by a 12V source.

✓ **Preform all calculations in Excel**

Δr (um)	Δ r (m)	r (um)	r (m)	KL(2w+2r π)	Thermal resistance Rth (Ω)	(Δr+r)^2-r^2	Thermal capacitance Cth (F)
10	0.00001	10	0.00001	0.001980288	0.005049771	3E-10	0.036480964
90	0.00009	100	0.0001	0.00252288	0.035673516	2.61E-08	0.456323868
200	0.0002	300	0.0003	0.00372864	0.05363886	0.00000016	1.5719808
700	0.0007	1000	0.001	0.0079488	0.088063607	0.00000189	12.7768732
1000	0.001	2000	0.002	0.0139776	0.07154304	0.000005	30.8334

I used following formulas to calculate the thermal resistance and capacitance:

$$Thermal\ resistance\ R_{Th} = \frac{L}{kA} = \frac{\Delta R}{Thermal\ conductivity \times Area}$$

$$Area = \big((Width \times 2) + (2 \times Radius \times \pi)\big) \times Length$$

$$Radius\ r = 10\mu m, 100\mu m, 300\mu m, 1mm, 2mm$$

$$Material\ thermal\ conductivity\ k = 0.96\,\frac{W}{mK}$$

$$Length\ L = 1m$$

$$Width\ W = 1mm$$

$$Thermal\ capacitance\ C_{Th} = \frac{C}{V\rho} = \frac{Thermal\ capacity}{Volume \times density}$$

$$Volume\ V = L\Big((2 \times \Delta r \times W) + \big(\pi((r + \Delta r)^2 - r^2)\big)\Big)$$

✓ **Calculate the thermal resistance of the heating wire**

$$\boldsymbol{R_{Th}} = \frac{\boldsymbol{L}}{\boldsymbol{kA}}$$

✓ **Design the system in LTspice with a voltage source andresistor.**

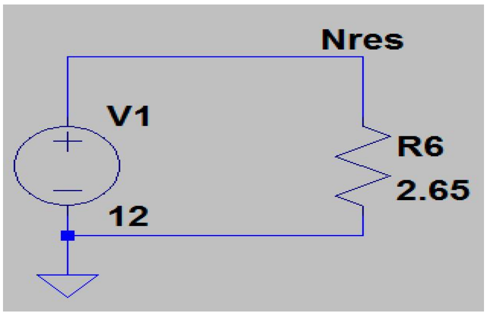
The voltage source was set up as 12V. We used following formula to calculate the resistance for the aluminium section:

(Conductivity of Aluminum 2,65e-8 Ohm m)

$$R = \frac{\rho L}{A} = \frac{Resistivity \times Length}{Cross\ sectional\ area} = \frac{Resistivity \times Length}{Radius \times Width} = \frac{2.65\times(10^{-8})(\Omega\mathrm{m})\times 1m}{10\mu m\times 1\mathrm{mm}}$$

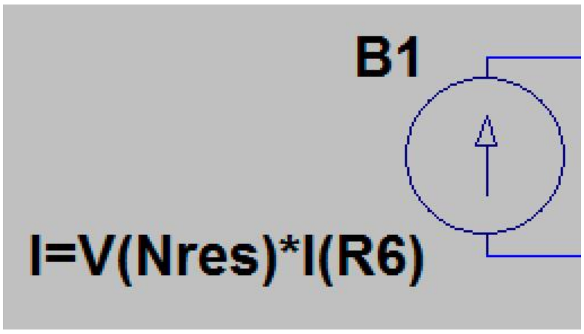
$$= 2.65\Omega$$

The circuit was shown in following figure. The net connecting the voltage source and the resistor.



✓ **Set up a behavioral current sourcce to emulate the power dissipation in the aluminum wire**

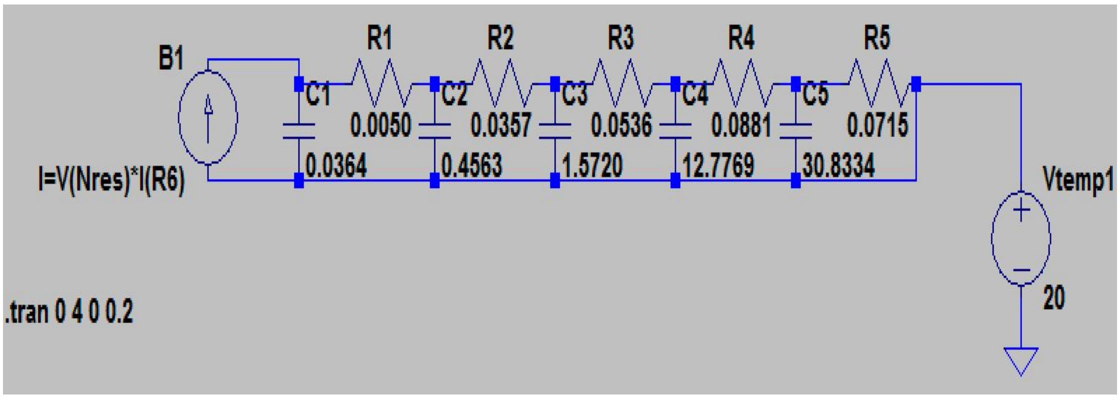
The behavioural current source was set up. We can get output power which made by 12 V source and current of resistance.



✓ **Design a lumped thermal model**

- Calculate thermal resistance and Capacitances connected as a C-R-C-R- C... network for different distance from the aluminum wire.

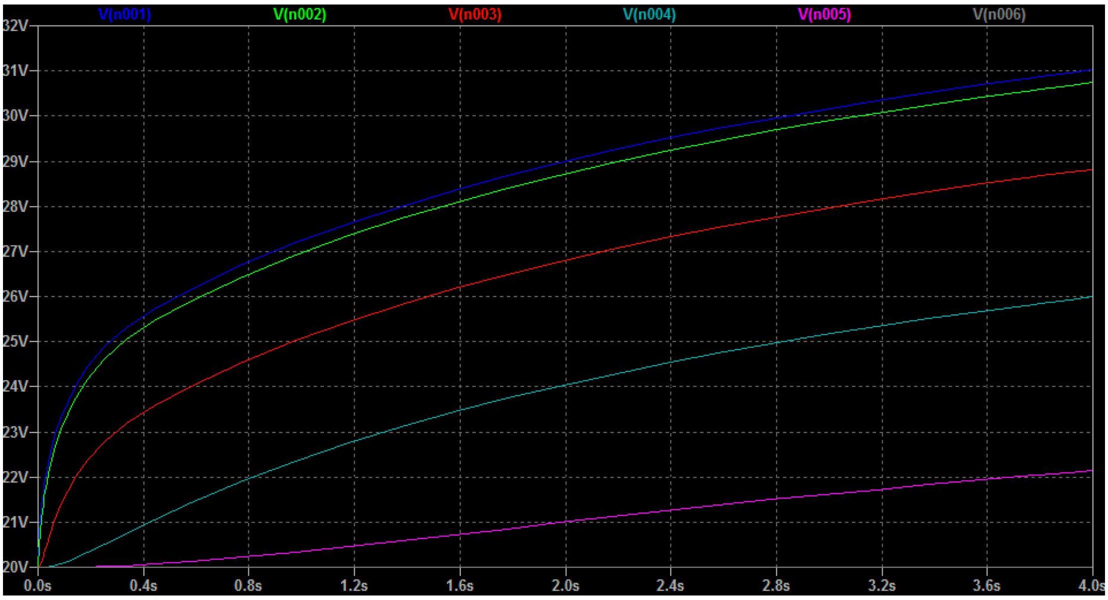
- The different segments with the following distance from the wire; 10um, 100um, 300um, 1mm, 2mm (segment thickness 10, 90, 200, 700, 1000um).



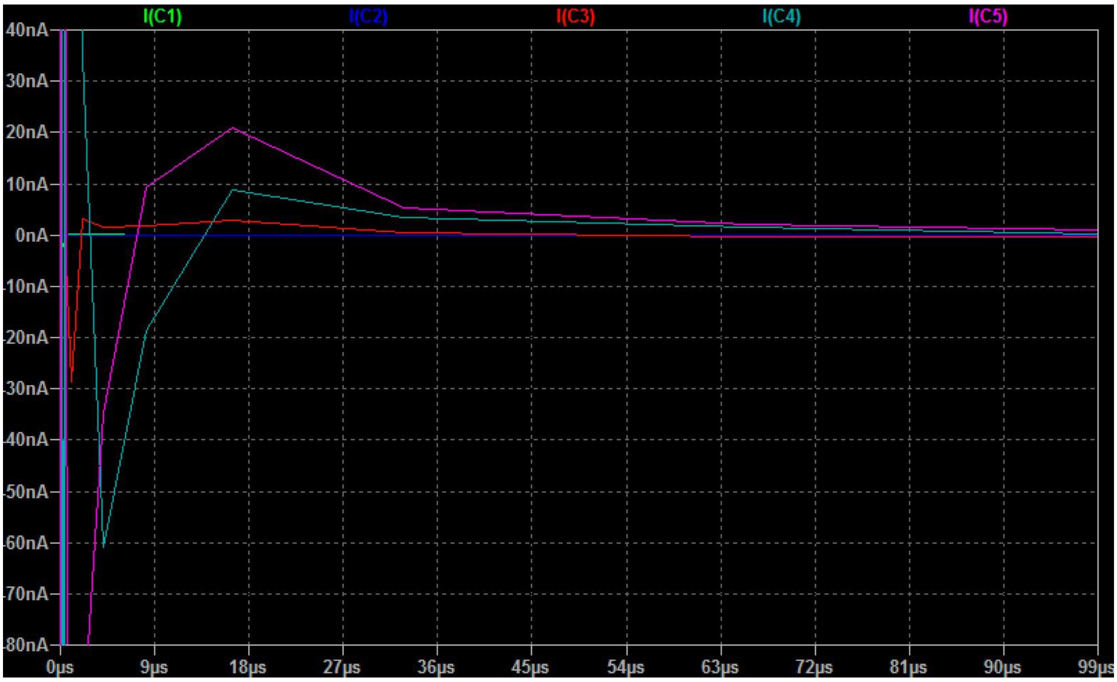
The results of the thermal resistance and capacitance with the following distance (10um, 100um, 300um, 1mm, 2mm) were taken from the Excel sheet.

✓ **Perform a thermal simulation assuming a constant resistance.**

From this figure below we can see, The lines from top to bottom are the nearest to the longest distance. The results show that a shorter distance from the aluminium results in a higher voltage which represents temperature.

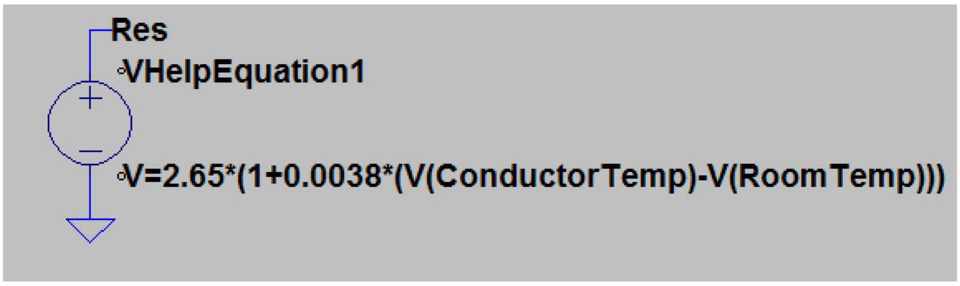


Over time, the currents in the capacitors are all stabilized at the same level (0nA) and have different startup behaviors. The nearest one have the best performance. The results show that the larger distances increase the capacitive effect.



✓ **Implement the temperature dependent resistance for the heating wire.**

For Implement the temperature dependent resistance, we replaced the constant resistance with a behavioural current source. The current source was configured to output a current equivalent to the products of the 12V source divided by the voltage of the temperature circuit.



Resistance values for conductors at any temperature other than the standard temperature (20 Celsius) on the specific resistance table must be determined through yet another formula.

The temperature dependent voltage circuit was implemented according to this formula:

$R = R_{ref} [1 + \alpha(T - T_{ref})]$

Where,

$R =$ Conductor resistance at temperature "T"

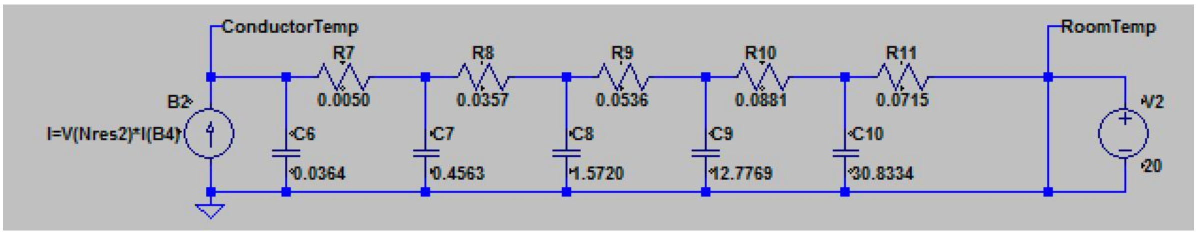
$R_{ref} =$ Conductor resistance at reference temperature T_{ref}, usually 20^{o} C, but sometimes 0^{o} C.

$\alpha =$ Temperature coefficient of resistance for the conductor material.

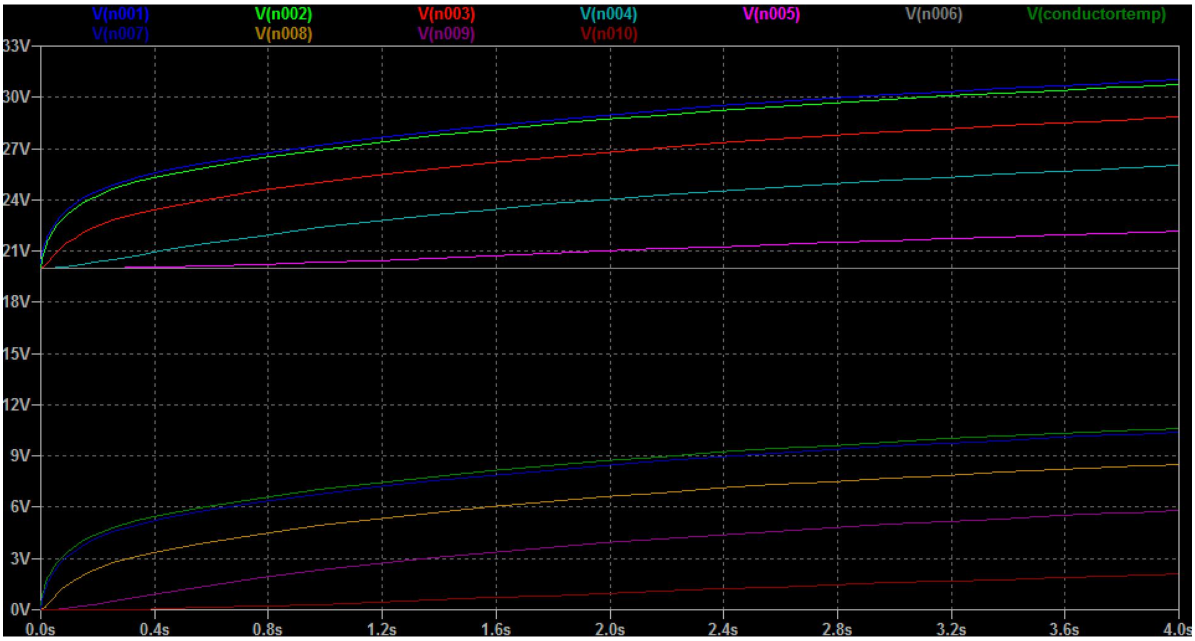
$T =$ Conductor temperature in degrees Celcius.

$T_{ref} =$ Reference temperature that α is specified at for the conductor material.

Then, we created two label nets ‘Conducto Temp’ and ‘RoomTemp’ to simulate temperature.



- ✓ **Hand in a report showing voltages, currents, power and temperatures as function of time both with constant resistor and the temperature dependent resistor.**



As shown in the following table, the temperature decreased by an average of 20.26

Distance (m)	Constant resistance (V)	Temperature dependent (V)	Change
10um	31.02	10.64	20.38
100um	30.74	10.37	20.37
300um	28.82	8.52	20.3
1mm	25.98	5.79	20.19
2mm	22.13	2.07	20.06
		Average change	20.26