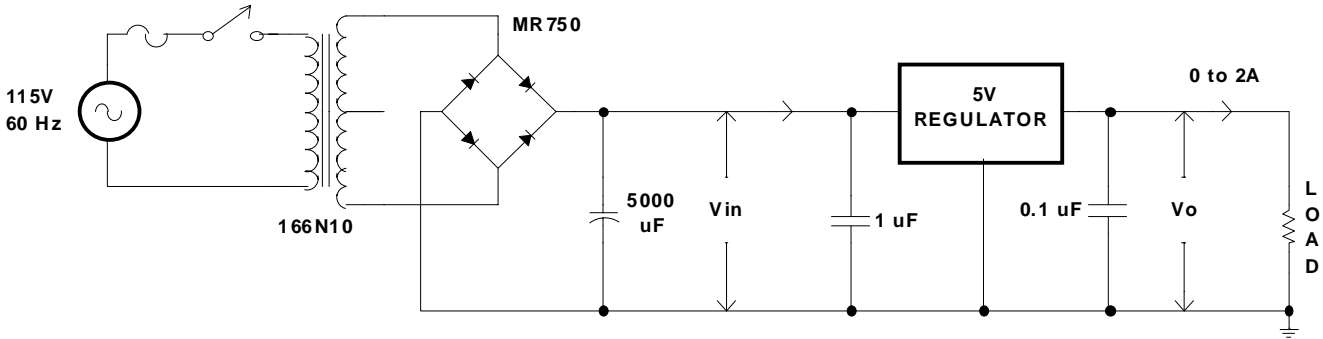


No.1 Power Supply Analysis



- A) Using Schade curves, determine the following: $V_{in(NL)}$, $V_{in(FL)}$, $V_{sec(NL)}$, $V_{sec(FL)}$, $I_{sec(FL)}$, $I_{pri(FL)}$, $I_F(\text{peak})$, $I_F(\text{rms})$, $I_F(\text{ave})$, $I_F(\text{surge})$, $\Delta V_{in(\text{rms})}$ max and $\Delta V_{in(\text{pp})}$ max.
- B) Is the transformer correct for the job? Explain. Note that the transformer can run at its maximum rated current without any problems - there is safety margin built in.
- C) Verify all of step A results using mcap. The transformer parameters you have to specify for Microcap are: L_{pri} , L_{sec} , coupling coef. Assume L_{pri} is such that the transformer magnetising current is 10% of its full load current.

$$\frac{N_{pri}}{N_{sec}} = \frac{V_{pri}}{V_{sec(NL)}} = \sqrt{\frac{L_{pri}}{L_{sec}}} = \frac{115}{10,7} = 10,75 \quad I_{pri(mag)} = 0,1 \times I_{sec(FL)} \times \frac{N_{sec}}{N_{pri}} = 0,1 \times 4 \times \frac{1}{10,75} = 37,22 \text{ mA}$$

$$L_{pri} = \frac{V_{pri}}{\omega I_{pri(mag)}} = \frac{115}{120 \pi \times 37,22m} = 8,2H \quad L_{sec} = L_{pri} \left(\frac{N_{pri}}{N_{sec}} \right)^{-2} = 8,2 \times (10,75)^{-2} = 71 \text{ mH}$$

Assuming a coupling coefficient of 99.5%, the transformer μCap parameter values should read: 8.2, 71m, 0.995 in the value field. Don't forget to add a series resistor in the secondary winding to simulate the transformer losses.

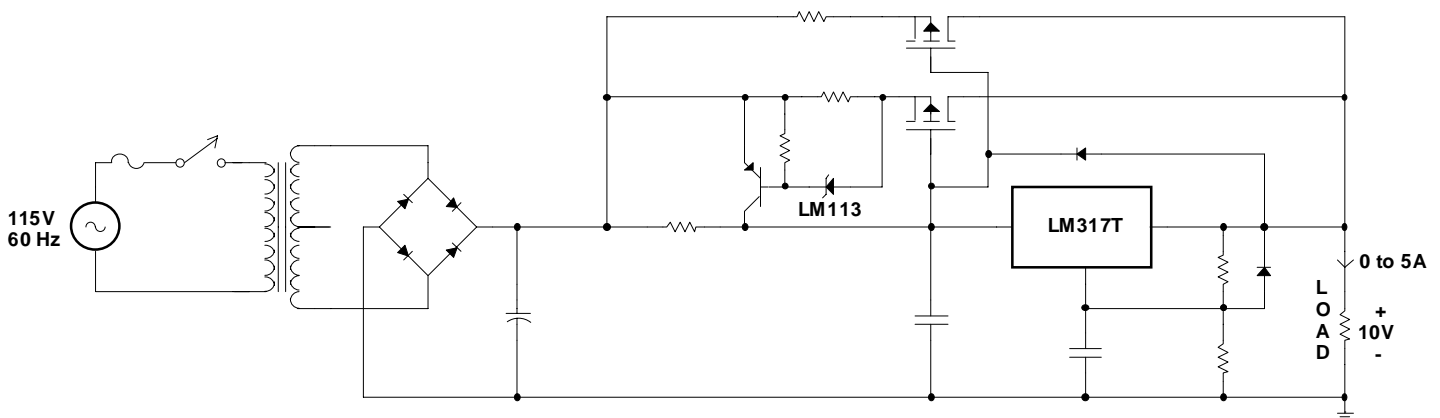
- D) Determine the maximum heat sink thermal resistance allowed if the voltage regulator has $T_J(\text{max}) = 150^\circ\text{C}$, $\theta_{JC} = 1,5^\circ\text{C/W}$ and $\theta_{CS} = 0,2^\circ\text{C/W}$ - assume $T_A = 25^\circ\text{C}$.

No.2 Power Supply Design

Design a DC power supply of +10V for a 0 to 5A load. Specify all of the components to be used. Don't forget to specify the heat sinks required by the voltage regulator, the PNP transistor and the power MOSFETs. The LM113 is a precision reference used to provide a more accurate current limit because V_{BE} of the PNP is not known accurately. Set the current limit above 5A, say around 6.5A, to guarantee voltage regulation right up to 5A. Do this problem without Schade curves using

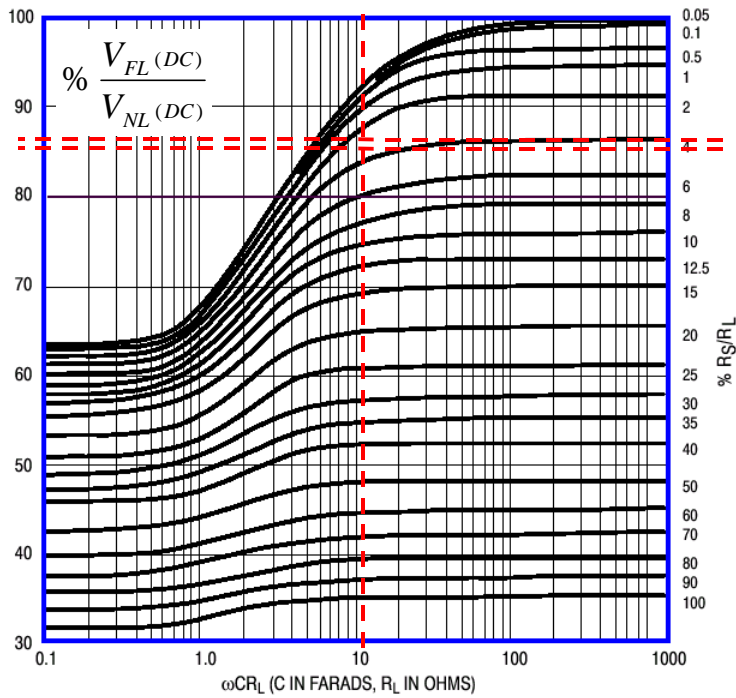
$$R_S = (V_{sec(NL)} - V_{sec(FL)}) / I_{sec(FL)} \quad I_F(\text{rms}) = I_{sec(\text{rms})} \times \sqrt{2} \quad \text{for diodes}$$

$$\Delta V_{RIP(PP)} \approx \frac{I_{FL(DC)} \times \Delta t}{C_{FIL}} \quad V_{SEC(pk)} = V_{FL(DC)} + \frac{\Delta V_{RIP(PP)}}{2} + 2 V_{DF} \quad I_{FL(DC)} \approx 0.62 \times I_{SEC(\text{rms})}$$



No.1 A) Transformer : $V_{sec(NL)} = 10,7V$

$V_{sec(FL)} = 10V$ at $I_{sec(FL)} = 4A$ $R_s = (10,7-10)/4 = 0,175\Omega$



First iteration

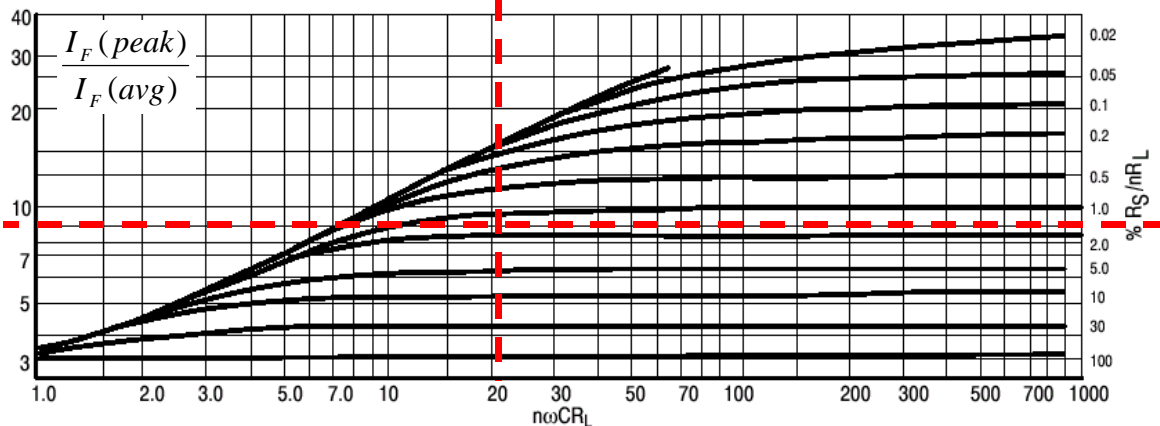
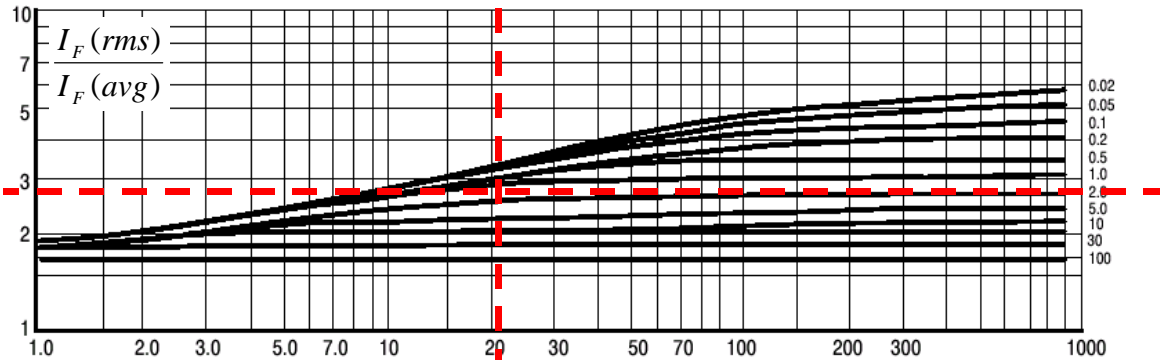
Assume an initial value for $V_{in(FL)}$

$V_{in(NL)} = 10.7 * 1,41 - 2 = 13.13V$
 Let $V_{in(FL)} = 10 * 1,41 - 2 = 12,14V$
 $R_L = 12,14V / 2A = 6,07\Omega$
 $R_s/R_L = 0.175 / 6.07 * 100 = 2.88\%$
 $\omega CR_L = 120\pi * 5000\mu * 6.07 = 11.44$
 We read $V_{in(FL)}/V_{in(NL)} = 0.86$
 $V_{in(FL)} = 0.86 * 13.13 = 11.29V$

Second iteration

Assume $V_{in(FL)} = 11.29V$ and re-do

$R_L = 11.29V / 2A = 5.64\Omega$
 $R_s/R_L = 0.175 / 5.64 * 100 = 3.1\%$
 $\omega CR_L = 120\pi * 5000\mu * 5.58 = 10.5$
 We read $V_{in(FL)}/V_{in(NL)} = 0.85$
 therefore
 $V_{in(FL)} = 0.85 * 13.13 = \mathbf{11.16V}$ final



From the diode current curves, we read at $n\omega CR_L = 2 * 120\pi * 5000\mu * (11.16 / 2) = 21$ and $R_s/nR_L = 1.57\%$

$I_F(rms) = 2.75 * I_F(avg) = 2.75 * 1A = 2.75A$

$I_F(peak) = 9 * I_F'(avg) = 9 * 1A = 9 A_p$

$I_F(surge) = V_{NL}/R_s = 13.13 / 0.175 = 75 A_p$

Ripple Voltage

Without Shade curves, we have:

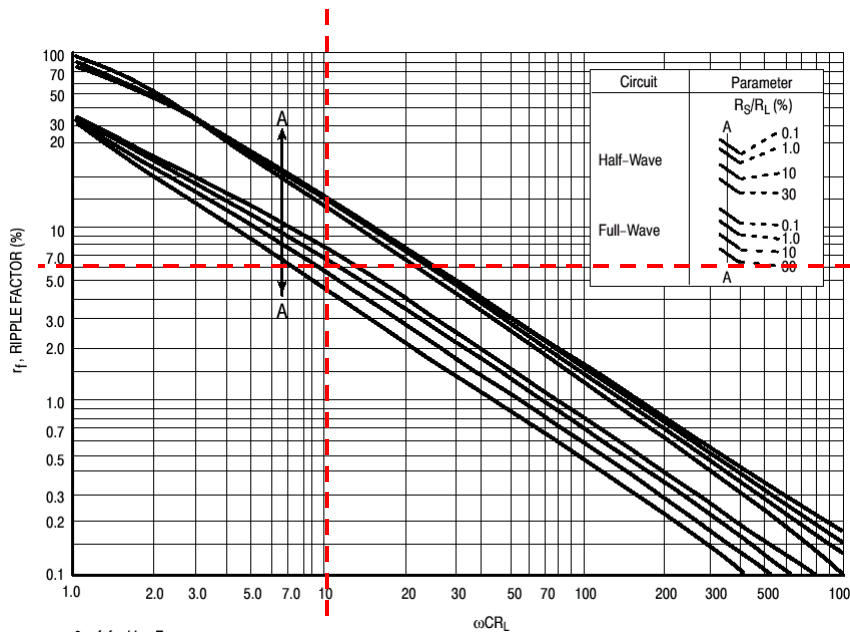
$$\Delta V_{in}(PP) = \frac{\Delta Q}{C_{FIL}} = \frac{I \times \Delta t}{C_{FIL}} \approx \frac{2 \times (1/120)}{5000\mu} = 3.33 V_{PP}$$

which always yields a larger value than the actual ripple voltage because we assumed that the capacitor discharges during an entire half cycle of the 60 Hz sine wave.

From Schade curves, we read at $R_S/R_L = 3.1\%$ and $\omega CR_L = 10.5$

$$\Delta V_{in}(rms) = 6\% \text{ of } V_{in}(FL) = 0.06 * 11.16 = 0.67V$$

$$\Delta V_{in}(pp) = 2 * 1.73 * 0.67 = 2.32 V_{PP}$$



Transformer: For a bridge rectifier, we have $I_{sec}(rms) = 1.414 * I_F(rms) = 1.414 * 2.75 = 3.89A$ max

$$I_{pri}(rms) = I_{sec}(rms) \times \frac{N_{sec}}{N_{pri}} = I_{sec}(rms) \times \frac{V_{sec}(no\ load)}{V_{pri}} = 3.89 \times \frac{10.7}{115} = 0.362A$$

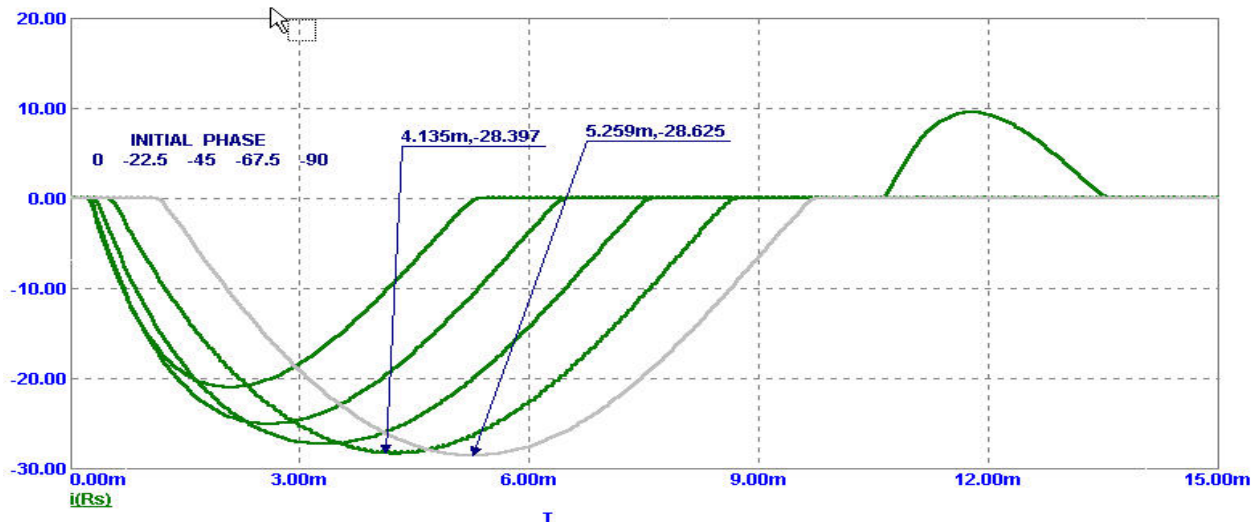
$$V_{sec}(pk) = V_{FL}(DC) + \Delta V_{RIP}(pk) + 2V_{DF} = 11.16 + 0.5 \times 2.32 + 2 = 14.32 V_p \quad V_{sec}(rms) = 14.32 / \sqrt{2} = 10.13V$$

No.1 B) $I_{sec}(rms) = 3,89A$ max from Schade curve calculations which is less than the maximum rated value of 4A, therefore the 166N10 transformer is fine for the job.

No.1 C)

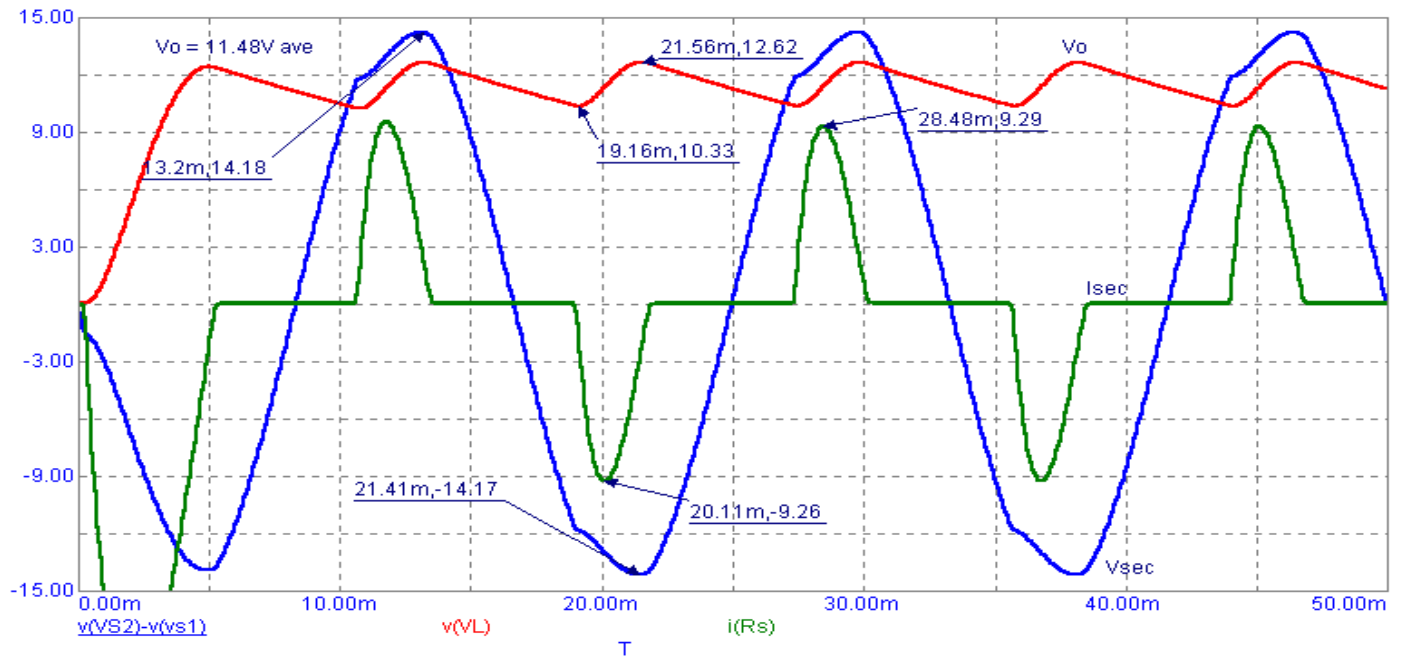
Initial surge current in transformer secondary winding at 2A DC Full Load

$$L_{pri} = 8.2H, L_{sec} = 71\text{ mH}, k = 1.0$$

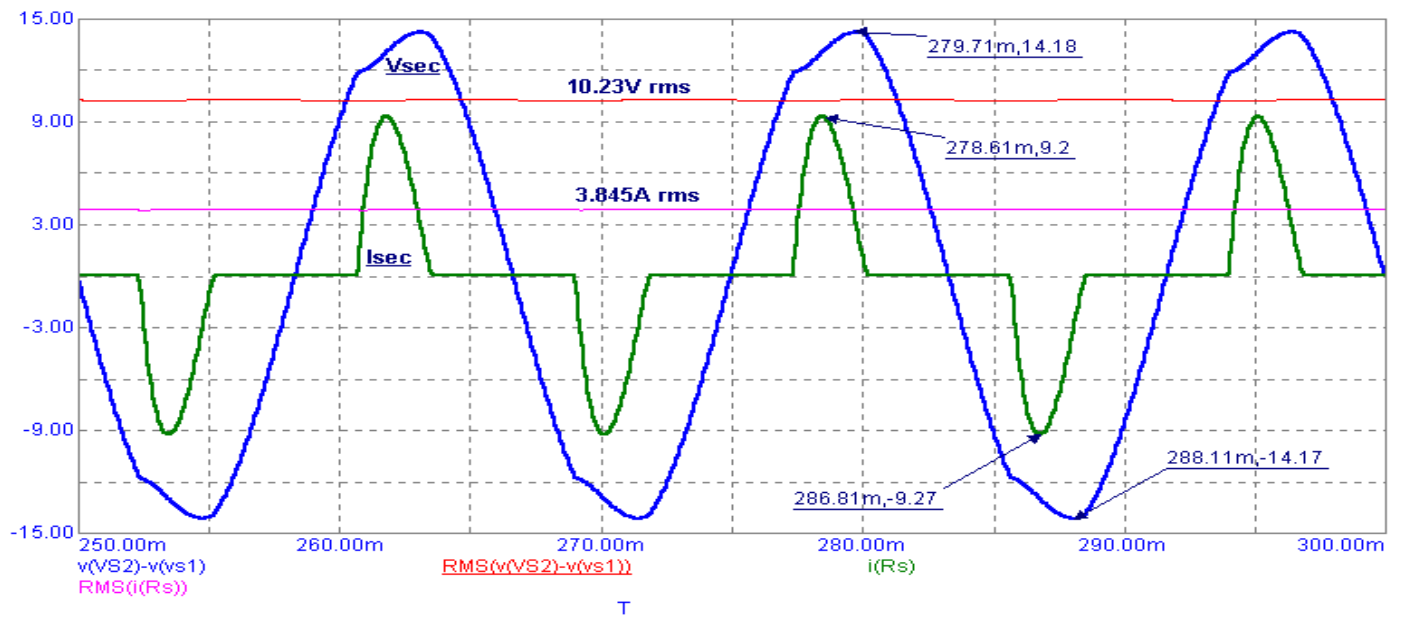


NOTE: The maximum surge current is a function of the initial phase angle of V_{pri} and also depends on the primary and secondary inductance values – for the same voltage ratio the inductance ratio will be the same and if we use inductances 10 times smaller, the initial surge current will go up. Because the inductance slows down the rate of increase of the current, it will never reach the maximum value calculated, that is $I_{surge\ max} = V_{NL}/R_S$.

Settled Waveforms at 2A DC Full Load – Lpri =8.2H, Lsec = 71 mH, k = 1.0



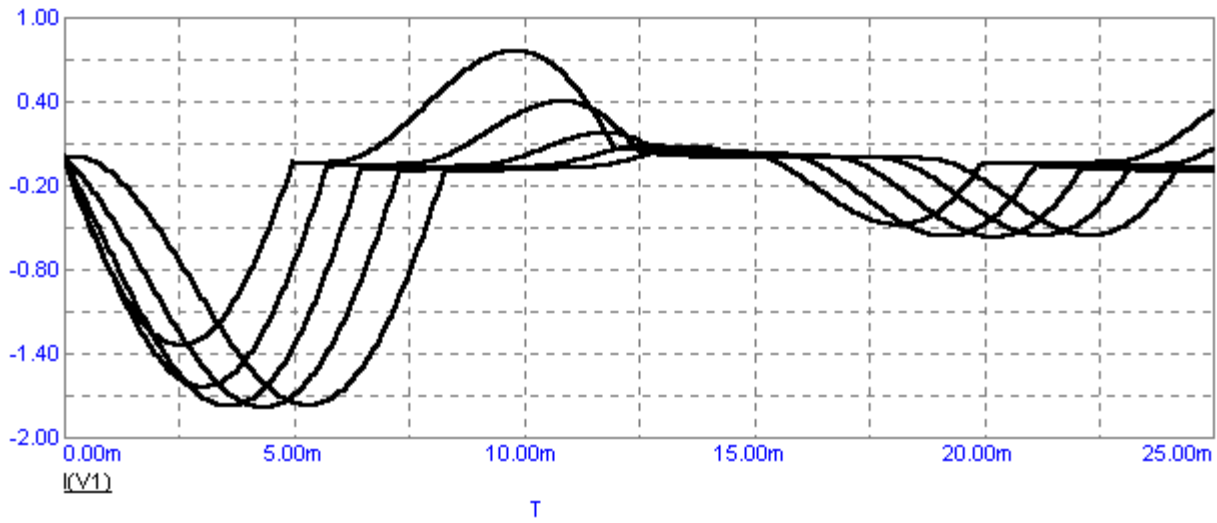
Settled Waveforms and their RMS Values at 2A DC Full Load



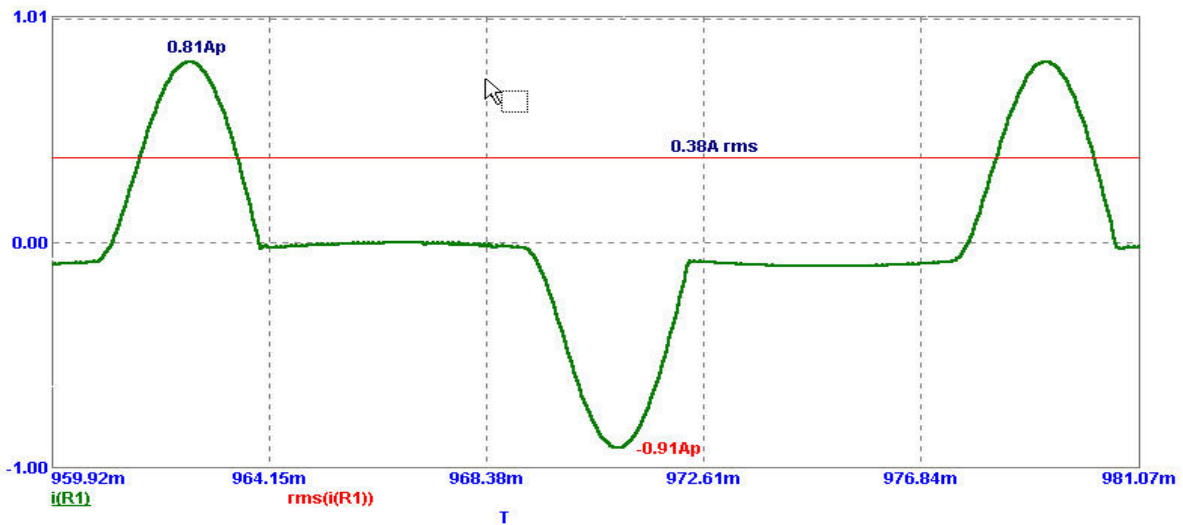
Comparison of theoretical values and microcap values

	V _{FL} (DC)	Ripple	V _{sec} (pk)	V _{sec} (rms)	I _{sec} (pk)	I _{sec} (rms)	I _{pri} (pk)	I _{pri} (rms)
Theo	11.16V	2.32V _{pp}	14.32V _p	10.13V	9 A _p	3.89 A	0.837A _p	0.362A
μCap	11.48V	2.3V _{pp}	14.18V _p	10.23V	9.27A _p	3.845 A _p	0.81A _p -0.91A _p	0.38A

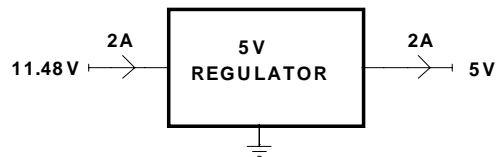
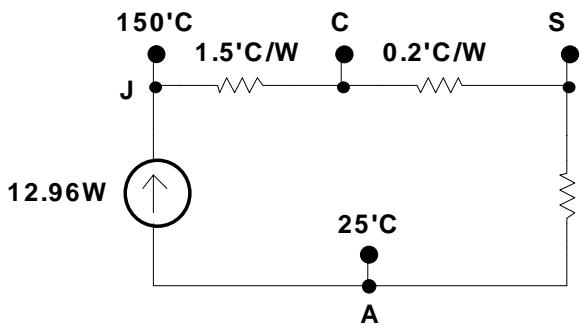
Initial Surge of Primary Winding Current at 2A DC Full Load



Settled Primary Winding Current at 2A DC Full Load



No.1 D) From the μ Cap simulation, we have $V_{in} = 11,48V$ DC and $\Delta V_{in} = 2.3$ Vpp



$$P_{reg} = (11.48 - 5) \cdot 2A = 12.96W \text{ max at full load}$$

$$\theta_{SA} < \frac{150 - 25}{12.96} - 1.5 - 0.2 = 7.95 \text{ } ^\circ C/W$$

Filter Capacitor: We assumed $\Delta V_{rip} = 4 V_{PP}$ at a maximum I_{DC} of 6.5A at the unregulated supply O/P.

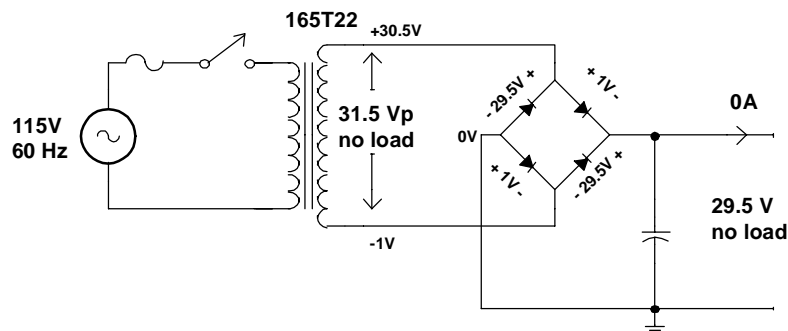
$$C_{FIL} > \frac{\Delta Q}{\Delta V_{rip(PP)}} = \frac{I_{DC} \times \Delta t}{\Delta V_{rip(PP)}} = \frac{6.5 \times (1/120 \text{ Hz})}{4} = 13\,542 \mu\text{F}$$

Let's use three 5000 μF capacitors in parallel.

This will produce 3.6 V_{PP} maximum ripple at 6.5A and

$$V_{NL(DC)} = \sqrt{2} \times 22.3 - 2V_{DF} = 29.54\text{V} \quad V_{FL(DC)} = \sqrt{2} \times 22 - 2V_{DF} - 0.5\Delta V_{RIP} = 27.3\text{V}$$

Diode Bridge: Assuming $I_{DC} = 6.5\text{A max}$, we have $I_F(\text{avg}) = 0.5 \times 6.5 = 3.25\text{A}$
 $I_{sec}(\text{rms}) = 6.5 / 0.62 = 10.48\text{A}$ and $I_F(\text{rms}) = 0.707 \times I_{sec}(\text{rms}) = 7.4\text{A}$
 Maximum surge $I_{FSM} = (31.5 - 2) / 25 \text{ m}\Omega = 1180\text{A}$
 $PIV = 29.5\text{V max}$ from circuit shown beside



One should select diodes that can handle the above maximum currents and PIV. The maximum surge will never reach 1180A because of transformer inductance. Select diodes that can handle $I_F(\text{avg}) > 10\text{A}$ and $PIV > 50\text{V}$ and simulate circuit to obtain actual surge current – you must obtain winding inductance values from manufacturer or measure it to be able to simulate accurately.

Fuse and switch: $I_{pri} = I_{sec} \times \frac{V_{sec(NL)}}{V_{pri}} = 12 \times \frac{22.3}{115} = 2.33 \text{ A}_{rms}$ The “Little Fuse” application data says to use $I_{nom} = I_{max} / 0.75 = 2.33 / 0.75 = 3.1\text{A}$ for a slo-blo

fuse operating at 25 °C ambient temperature – if it operates at higher ambient temperatures, then the fusing current decreases and one must select a higher fuse rating. Let's use a 3A fuse assuming at 25°C. The switch must be able to handle 2.33A and the 115V.

LM113: This is a 1.22V precision reference IC with a maximum rated current of 50 mA.. It requires 0.5 mA typical to operate, therefore let's use a bleeder resistor across the EB junction of Q3 to provide say 1.5 mA to the LM113 when Q3 turns ON and $V_{BE3} = 0.7\text{V}$. $R_{BE} = 0.7/1.5\text{m} = 467 \text{ }\Omega$ and use 470 Ω std

The maximum current will be $I_z = \frac{0.7}{R_{BE}} + \frac{I_{C3 \text{ max}}}{h_{FE \text{ min}}} = \frac{0.7}{470} + \frac{0.5}{85} = 7.37 \text{ mA}$ which is well below the maximum of 50 mA.

NOTE: the BD438 (PNP transistor Q3) data sheets specify $h_{FE} = 85$ to 375 at $I_C = 0.5\text{A}$ and $V_{CE} = -1\text{V}$

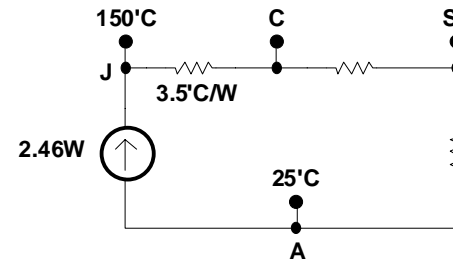
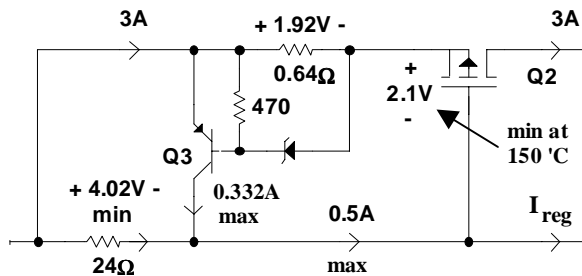
PNP transistor BD438

$I_{C3 \text{ max}} = 0.332\text{A}$, assume 0.5A for safety. The worst case power dissipation for Q3 is then

$$P_{Q3} = V_{CE3 \text{ max}} I_{C3 \text{ max}} = 5.92\text{V} \times 0.5\text{A} = 2.46\text{W}$$

$$\theta_{CS} + \theta_{SA} < \frac{150 - 25}{2.46} - 3.5 = 47.3 \text{ }^\circ\text{C/W}$$

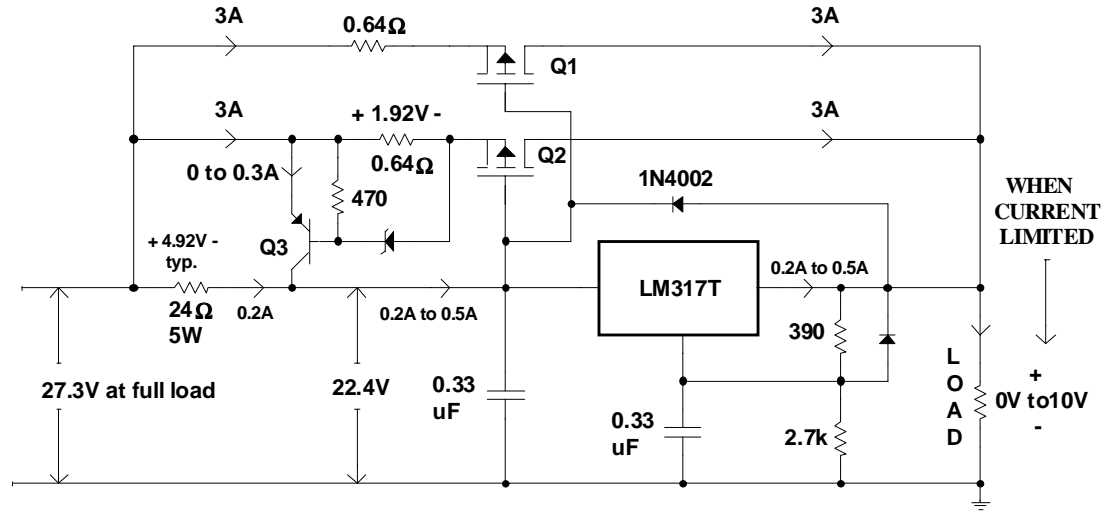
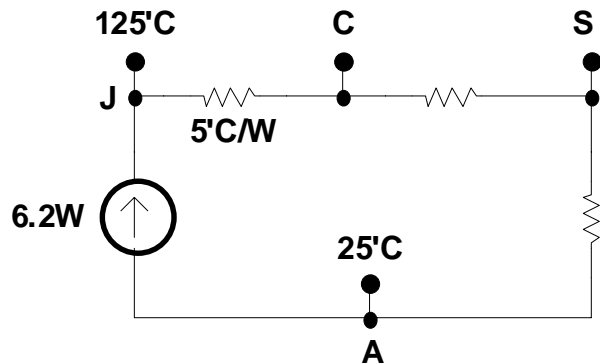
Use heat sink + insulator with less than 23.5°C/W for safety.



LM317T:

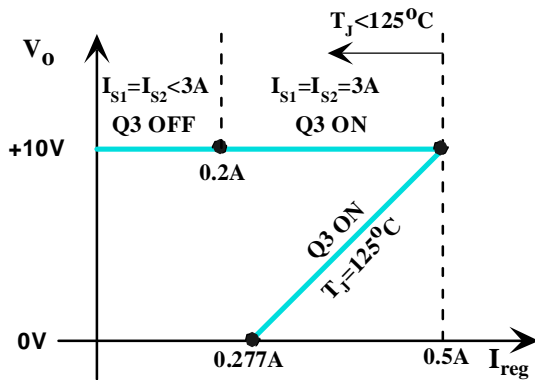
$$P_{reg} = (22.4 - 10) \times 0.5A = 6.2W$$

$$\theta_{CS} + \theta_{SA} = \frac{125 - 25}{6.2} - 5 = 11.13 \text{ } ^\circ C/W$$

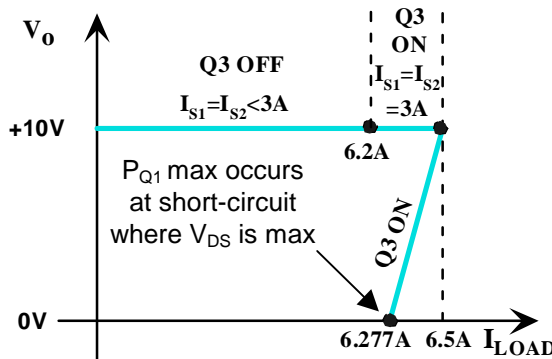


We have to select a heat sink-insulator combination that has a thermal resistance of 11.1°C/W in order to current limit the LM317T at 0.5A. Note that the MOSFET's go into current limiting before the LM317T does because that occurs when $I_{reg} = 0.2A$ typical which corresponds to $V_{SG} = 3V$ typical at 3A. The short-circuit current of the

LM317T will be $I_{reg} = \frac{6.2W}{22.4V - 0V} = 0.277A$ which means a short-circuit current of 6.277A in the load.



Regulator load regulation characteristics

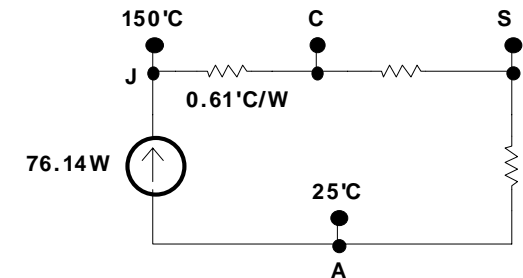


Power supply load regulation characteristics

MOSFET's SFH9250L

$$P_{Q1 \max} = P_{Q2 \max} = V_{DS \max} \times I_{S \max} = (27.3 - 1.92 - 0) \times 3A = 76.14W$$

$$\theta_{CS} + \theta_{SA} < \frac{150 - 25}{76.14} - 0.61 = 1.03 \text{ } ^\circ C/W$$



Pick individual heat sinks with $\theta_{CA} < 0.5^\circ C/W$ for safety – this includes insulator thermal resistance.