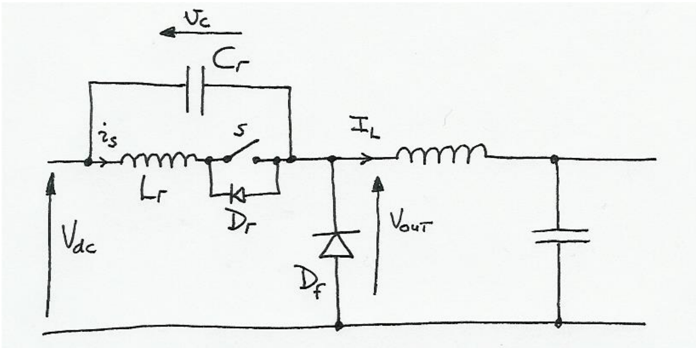
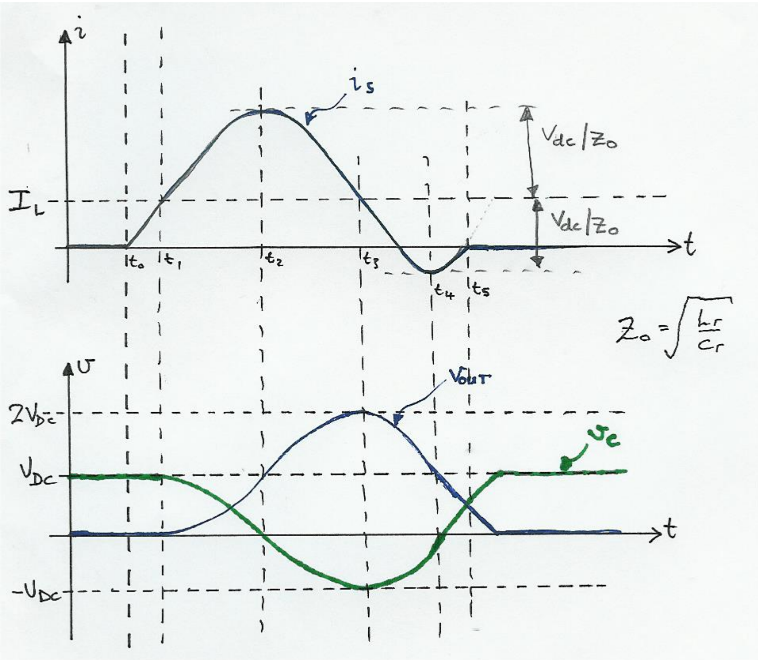
EEE307 2012 / 2013 answers - DAS

Qu. 1

a. – Zero Current Switched Buck Converter



The resonant components C_r and L_r shape the switch current and allow the device to switch under lossless conditions.



- Initially, switch s is off and the load current freewheels through diode D_f. At time t_0, S is switched on under zero current conditions (the resonant inductor L_r prevents an instantaneous change in the current through S).
- The switch current i_s now rises linearly to the value of the output inductor current I_L.
- When the switch current equals the output inductor current, there is no current flowing in the diode D_f and this switched off, the voltage V_{out} can now rise as it is no-longer clamped at 0V by D_f.
- As V_{out} rises, v_c falls.
- i_s peaks at $I_L + V_{dc}/Z_o$ (where Z_o is the characteristic impedance of the resonant circuit C_r, L_r). This occurs as v_c passes through 0V.
- i_s reaches I_L again when $v_c = -V_{dc}$

- The current i_s continues to fall and reverses, returning the excess stored energy in the resonant inductor to the supply through D_r. As the current is now flowing in the diode and not the switch, the switch may be turned off without switching loss. The switch therefore has zero current turn on and turn off.

b. To ensure loss-less switching, the load current I_L should not exceed V_{dc}/Z_o, as this would prevent the inductor current returning to zero at the end of the resonant cycle, leading to switching loss in the circuit.
Therefore $Z_o = 5/1 = 5\Omega$

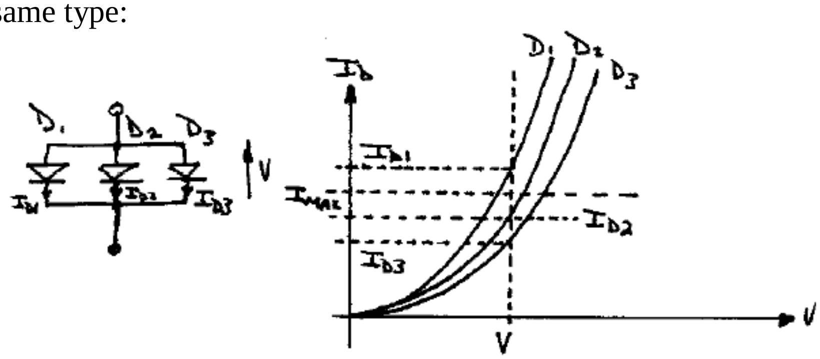
Given $\sqrt{\frac{L_r}{C_r}} = 5\,\Omega$ and $\frac{1}{2\pi\sqrt{L_r C_r}} = 500kHz$, we can solve for the resonant tank component values.

***C_r* = 64nF,** and ***L_r* = 1.6µH.**

c. A MOSFET would be a suitable choice for the switching technology, as it is capable of switching in ~10ns and would be able to change state in an insignificant time with respect to the resonant cycle. Other devices such as the BJT would not be able to switch at a high enough frequency due to minority carrier storage effects within the device.

Qu 2

a) If three diodes are hard wired in parallel, Kirchoff's law says they must have the same voltage drop across each of them. However, as diode characteristics are never identical, even if they are of the same type:

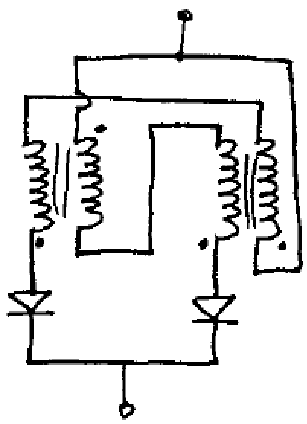


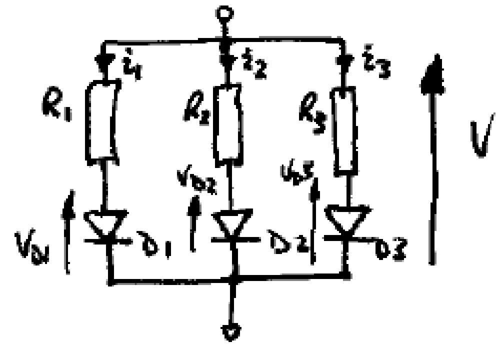
Parallel operation of devices may lead to different currents in each of the devices. This may lead to failure of diode D1 in this case. The simplest way to overcome this is to de-rate the diode by the use of a paralleling factor, where:

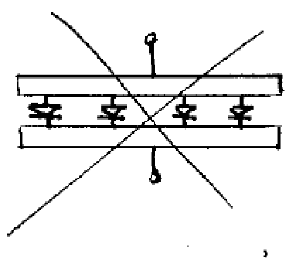
$$\frac{current\ in\ average\ diode}{current\ in\ heavily\ loaded\ diode} = paralleling\ \ factor$$

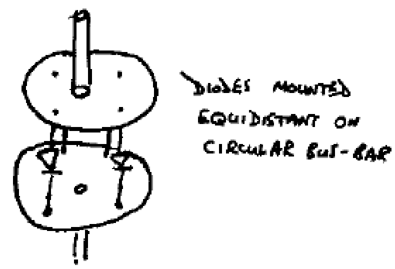
b) All forward characteristics of a diode are dependant on temperature, all diodes should be mounted on a common heatsink to ensure a uniform temperature between the devices. Also, the path lengths in each parallel leg should be the same, to equalize bus-bar inductance. This helps prevent un-equal current sharing due to unequal inductive impedance in series with each diode.

The use of coupled reactances or series resistors will ensure both dynamic and static current sharing.

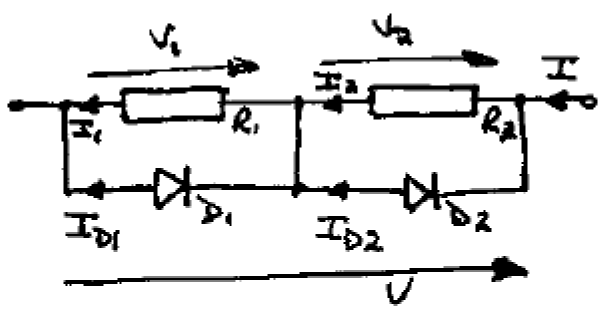








c) Diodes connected in series will carry the same reverse leakage current (Kirchoff). However, differences in device characteristics will then lead to uneven voltage sharing of the reverse voltage, to a point where one of the diodes may fail (possibly to a short circuit causing a chain failure!).



Max leakage current = 400μA, given maximum of 10% difference in shared voltage, ΔV=50V, therefore:

$$R = \frac{\Delta V}{\Delta I_L} \quad = \quad \frac{50}{400 \times 10^{-6}} \quad = \quad 125k\Omega$$

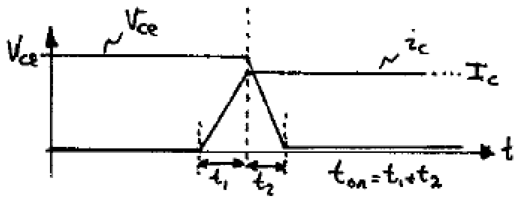
Given a maximum voltage across the resistors of 550V, the power in the resistor is given by V^2/R = 2.42W, nominally 2.5W.

d) Given a current of 50A and a duty cycle of 0.5, the rms current is 35.36A, and the loss in the incremental resistance is $35.56^2 \times 50m\Omega$ = 63.22W per diode, the junction loss is 0.5×50×0.7 = 175W per diode, and given there are 2 devices on a common heatsink, the total losses are:

476.44W, which for a 20^{o}C rise above ambient requires a thermal resistance of 0.042^{o}C/W.

Qu3

a) ***Inductive load:***



An inductive load is more typical of power electronic circuits.

Here, the inductive load keeps the current flowing, via the freewheel diode. The diode cannot start conducting when the BJT switches off until the voltage across the BJT has risen above V_d and forward biased the diode. Until the diode conducts, it cannot provide an alternate path for the load current, so the BJT must carry the full load current whilst the voltage across the BJT rises to forward bias the diode at switch off of the BJT. Similarly, at turn-on of the BJT, the diode cannot switch off until the current flowing through it falls to zero, therefore the voltage across the BJT is clamped at the power supply rail until the current through the BJT rises to the load current level.

Here then, the energy per turn on switching event can be calculated from the following, assuming a linear characteristic:

$$E_{on} = V_{CE} \cdot \int_0^{t_1} \frac{I_C . t}{t_1} dt + I_C \cdot \int_0^{t_2} \left(V_{CE} - \frac{V_{CE} . t}{t_2} \right) dt$$

$$E_{on} = \frac{V_{CE} . I_C}{2} . (t_1 + t_2)$$

$$E_{on} = \frac{V_{CE} . I_C}{2} . t_{on}$$

Now when operating at switching frequency f:-

$$P_{AVE(on)} = \frac{V_{CE} . I_C . t_{on} \cdot f}{2}$$

similarly, $$P_{AVE(off)} = \frac{V_{CE} . I_C . t_{off} \cdot f}{2}$$

Average switching loss becomes $$P_{AVE(switching)} = \frac{V_{CE} . I_C . (t_{on} + t_{off}) . f}{2}$$

b.) Top Left – 25% - Switch conducting.

Bottom Left – 75% - Diode conducting.
Top Right – 75% - Diode conducting.
Bottom right – 25% - Switch conducting.

Losses in a switch at 25% are:
Switching loss = 0.5*40*5*(200ns+300ns)*30kHz = 1.5W
On-state loss = 5 * 5 * 0.5 * 25% = 3.125W

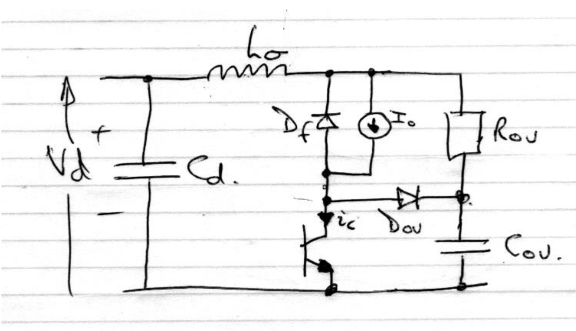
Diode on-state loss at 75% = 5 * 0.5 * 75% = 1.875W

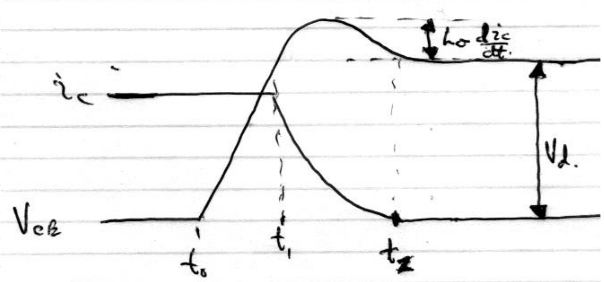
Total losses in devices = 2 * 1.5 + 2 * 3.125 + 2 * 1.875 = 13W

Given a 30^{o}C rise in temperature for 13W, the thermal resistance of the heatsink required is < 30/13 = **2.3^{o}C/W**.

c) Given that 200Hz is within the switching speed of a thyristor, the first answer will be yes, HOWEVER, as a thyristors cannot be turned off without a commutation circuit to force the current through the thyristor to zero, then the answer must be NO.

4 (a).





The energy stored in the stray inductance L_σ when the switching device is on has to be dissipated safely on device switch-off otherwise the energy will result in a large voltage spike on the collector of the device, possibly resulting in device breakdown. The diode provides a path for the energy to flow at switch-off, and be transferred to the capacitor C. The voltage on this then rises above the supply voltage, and the excess charge is dissipated within the snubber resistance R. This safely dissipates the stores energy in the leakage inductance, without causing a problem to the switching device. This is an over-voltage snubber circuit.

(b). Given that the stray inductance in the circuit is 10μH, and the load current is 5A, the energy stored in the inductance is $0.5LI^2$ = 125μJ

Given the voltage on the snubber capacitor is initially 100V, and the final voltage should be <120V, then the change in energy on the capacitor is that stored in the inductance, and
$E=0.5\times120^2\times C - 0.5\times100^2\times C$

We have **C=56.8nF**.
Also, given the switching frequency of 10kHz, a half period would be 50μs, therefore the voltage should return to the input supply voltage in 1/10th of this time = 5μs. Therefore R=5μs/(2.2×C) = **40Ω.,** and should be rated at **>1.25W** as it has 125μJ dissipated in it per cycle, at 10kHz.

(c). If the switching was performed by 2 parallel BJT's in a higher power system, there may be a problem with the static and dynamic current sharing within the devices. The BJT suffers from a positive temperature co-efficient with regard to it's conductivity, therefore as the temperature increases in the device, the conductivity device also increases, leading to more current flow. Therefore if one of the two parallel devices becomes hotter than the other, it will have a lower conductivity, and therefore carry more current. This will, in-turn, lead to it becoming even hotter and possible thermal run-away occurring. This may also occur during dynamic switching of the device, and lead to uneven current sharing during transient operation.