Supplemental Problems

Part II: Chapters 19 - 30

to accompany the 3rd Edition of

Power Electronics: Converters, Applications and Design

by

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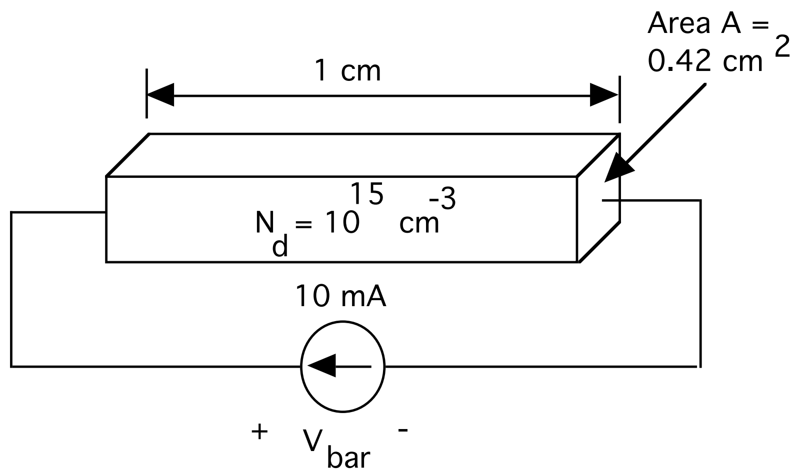
Chapter 19 - Semiconductor Physics

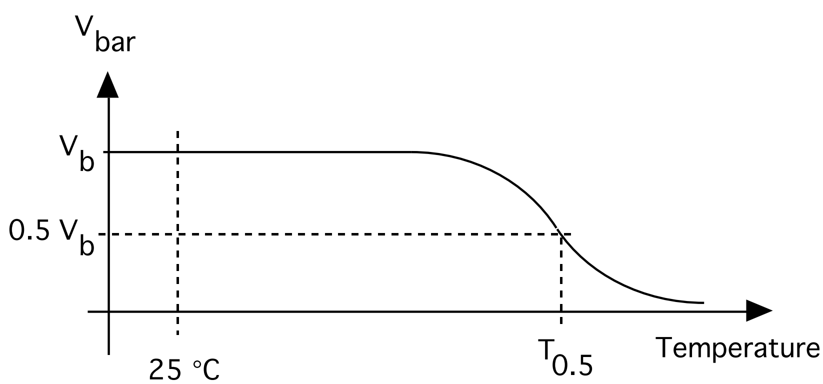
S19.1 An abrupt pn junction has 10^{14} cm^{-3} donors on the n-type side and 10^{14} cm^{-3} acceptors on the p-type side. At what temperature will the properties of junction disappear?

S19.2. Consider the bar of n-type silicon shown below with a current of 10 ma flowing through it.



a. What is voltage drop, V_{bar}, at room temperature?

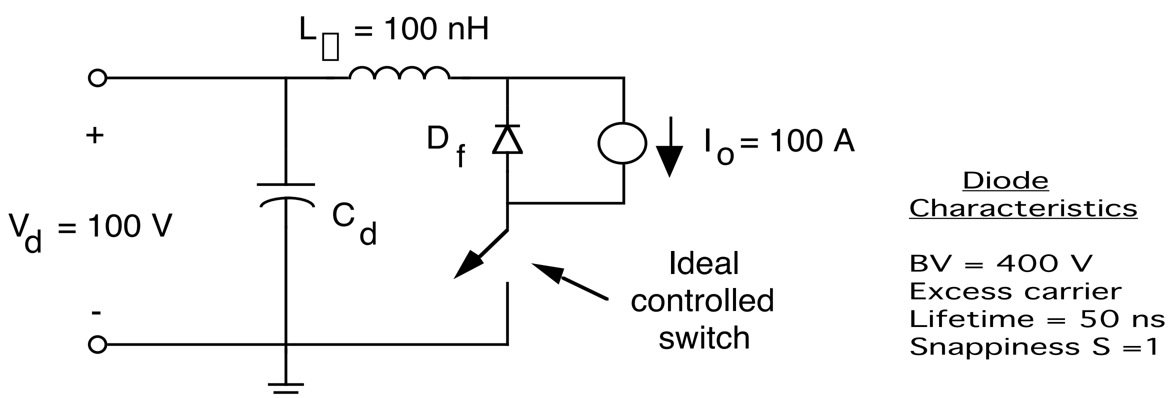
b. The voltage V_{bar} changes with temperature as illustrated below. Explain qualitatively the observed behavior.



c. Estimate the temperature $T_{0.5}$ where the voltage drop across the bar is 50% of the room temperature value. You may assume temperature independent mobilities.

Chapter 20 - Power Diodes

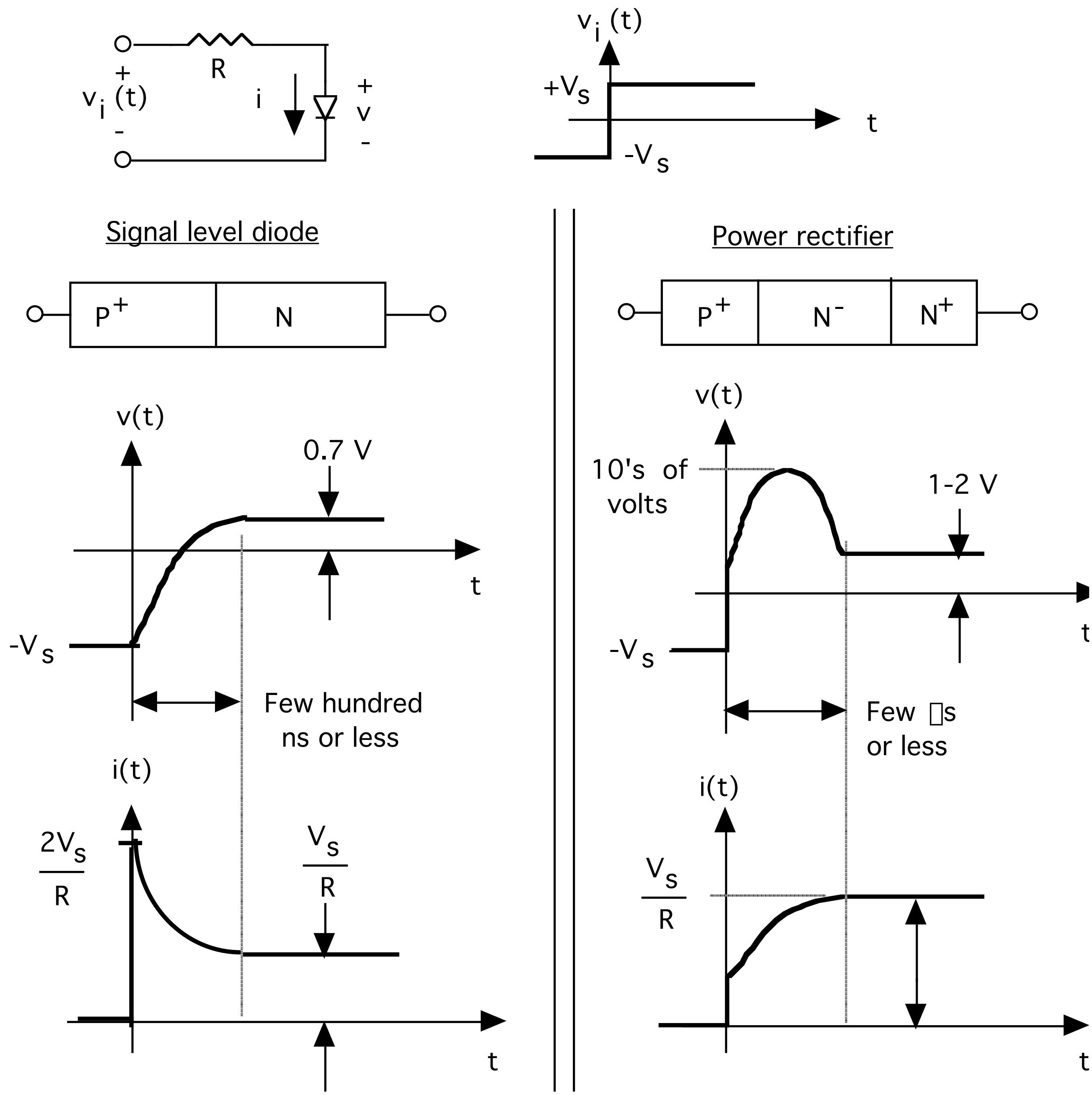
S20.1 Consider the circuit shown below. All components in the circuit are ideal except for the diode. The characteristics of the diode are listedbelow. For simplicity, assume that the reverse-recovery current waveform of the diode is triangular, i.e. that the current grows towards I_{rr} at a constant rate given by $\frac{di_R}{dt}$ and then falls towards zero from I_{rr} at a rate controlled by the snappiness factor S.



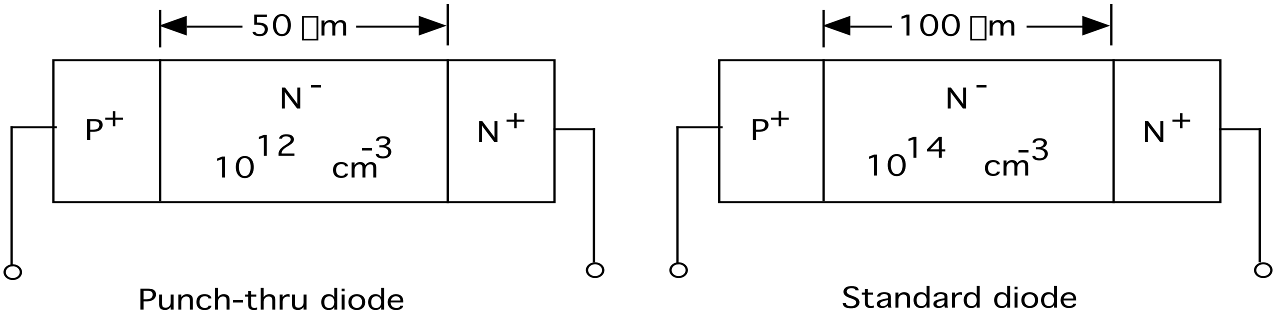
a. Estimate the reverse-recovery current I_{rr} and reverse-recovery time t_{rr}.

b. Is a snubber circuit required to protect the diode? Justify your answer.

S20.2. A signal level diode and a fast power rectifier are tested in the circuit shown below. The voltage and current responses of the two diodes are also shown below. Qualitatively, but briefly explain the causes or reasons for the differences in the behavior of the two types of diodes.



S20.3. Consider the two diode structures shown below. The punch-thru structure has the same breakdown voltage as the standard diode geometry. However the punch-thru diode is expected to have a significantly smaller reverse recovery time t_{rr} compared to the standard diode geometry.

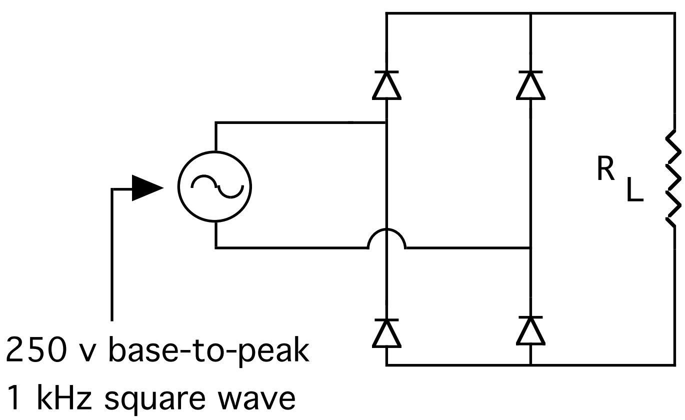


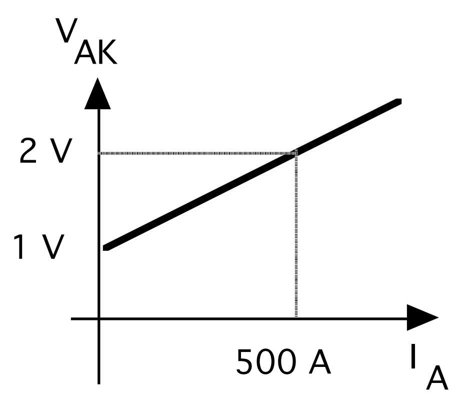
a. Qualitatively explain why the punch thru diode geometry is expected to have a significantly shorter reverse recovery time t_{rr}.

b. Will any aspects of the behavior of the punch-thru diode be inferior to the standard diode? Briefly and qualitatively explain.

c. Approximately estimate how much shorter t_{rr} in the punch-thru diode will be compared to the standard diode.

S20.4. The diode rectifier circuit shown below must deliver 100 kW of power to the load R_L. The diodes are all identical. $T_{j,max}$ = 150 °C ; $R_{\theta j\text{-}c}$ = .1 °C/W



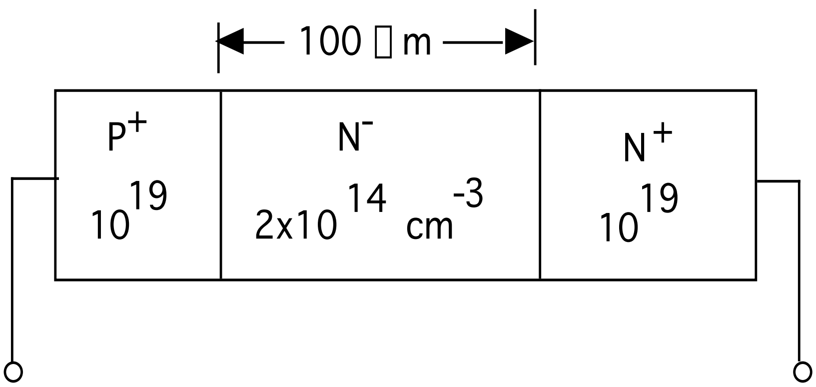


a. Specify what the blocking voltage rating and maximum average forward current rating of the diodes should be. Include a factor of safety of 25% in the ratings.

b. Specify the required value of thermal resistance $R_{\theta,c\text{-}a}$ of a heat sink for the diodes.

S20.5. A one-sided step junction with a p-side doping density N_A much greater than the n-side doping density of N_D conducts a current I when forward biased by a voltage V_F. The current is to be increased by a factor of two (to 2I) by adjusting the carrier lifetime τ. What adjustment is required in the carrier lifetime to realize this change in current?

S20.6. Consider the diode shown below**.**

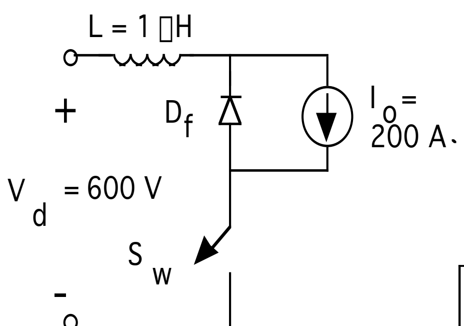


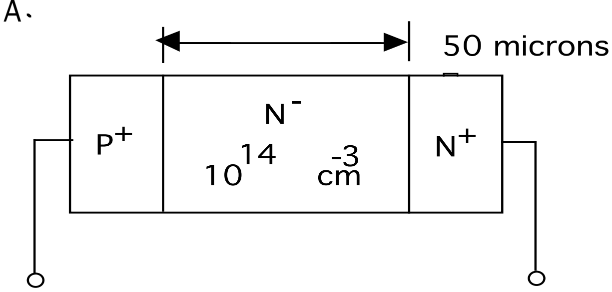
a. Estimate the breakdown voltage BV_{BD} of the diode.

b. Estimate the leakage current of the diode assuming that the area of the diode is 1 cm^2.

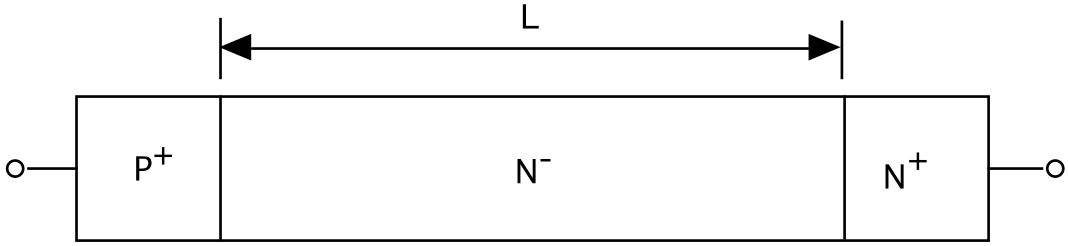
c. Estimate the on-state voltage for a forward current of 500 amps.

S20.7 Consider the silicon diode structure shown below. This diode is used as a free-wheeling diode in the step-down converter shown below. Estimate the reverse-recovery current I_{rr} and reverse recovery time t_{rr} of the diode when it is used in the circuit. The switch S_w is ideal. Assume that the snappiness factor S of the diode is equal to one.





S20.8 The silicon p-i-n diode shown below is to be designed to have a breakdown voltage of 1500 V.

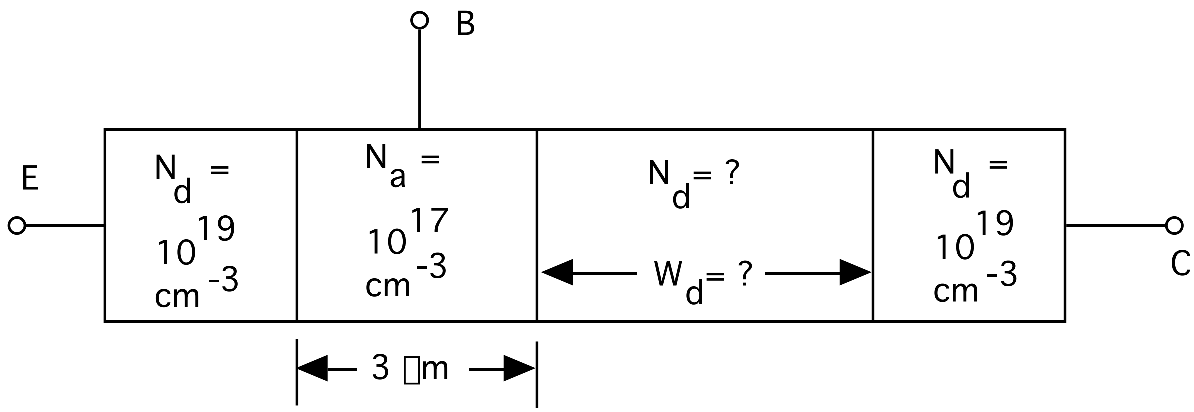


a. What should be the length, L, of the drift region and what should be the doping density?

b. The diode will be used as the free-wheeling diode D_f in the step-down converter shown below. The switch S_w has a current rise and fall time of 100 nsec. Approximately estimate the expected magnitudes of the reverse recovery current, I_{rr}, and reverse-recovery time, t_{rr}.

Chapter 21 - BJTs

S21.1. Consider the one dimensional model of a BJT shown below. Assume that the transistor has a beta of 20.

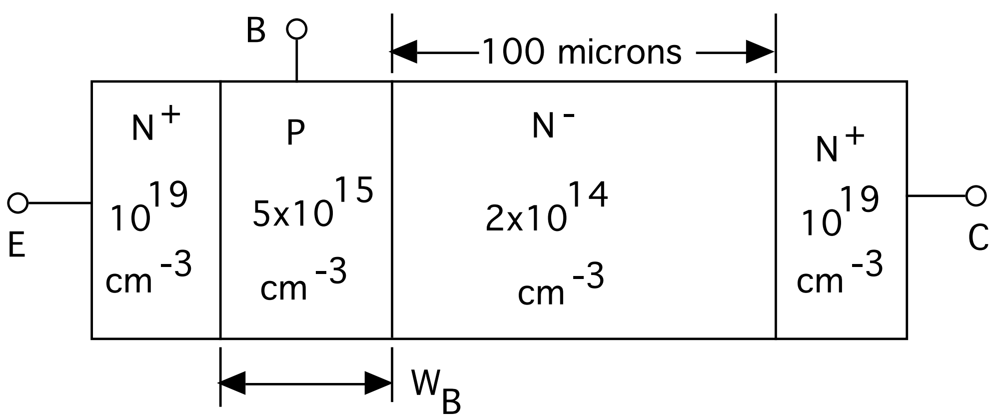


a. (Approximately estimate what the drift region doping level can be if BV_{CEO} = 100V.

b. Approximately estimate the required length W_d of the drift region.

c. What should be the excess carrier lifetime in the drift region?

S21.2. Consider the transistor geometry shown below. The beta (β) of the transistor is equal to 10.

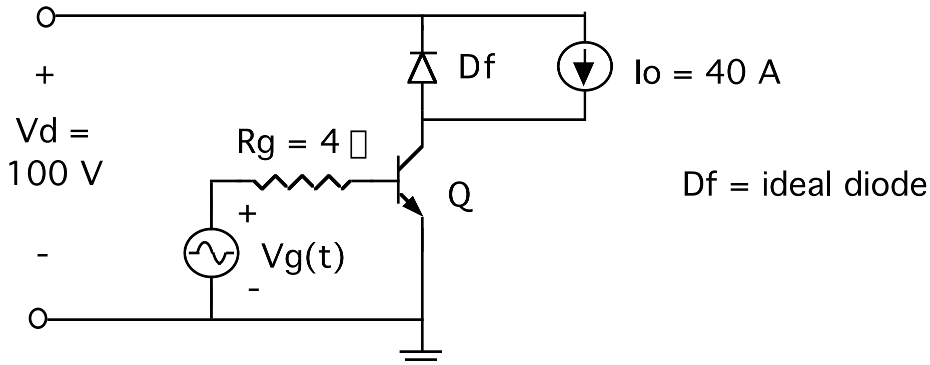


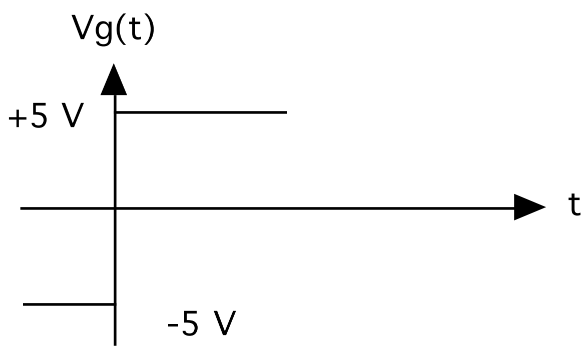
a. What is the breakdown voltage BV_{CEO} of the transistor?

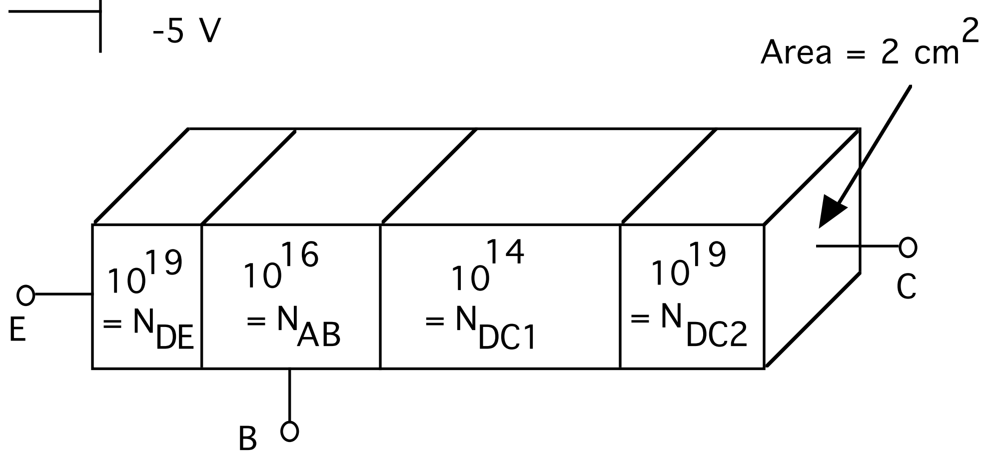
b. How large must the base width W_B in order to avoid reach-thru?

S21.3. Why are NPN transistors used much more than PNP transistors as switches in power electronics applications?

S21.4. An NPN transistor is used in the step-down converter circuit shown below. A simple diagram of the transistor's internal structure is also given below. Estimate the turn-on delay time of the transistor in this circuit. Use average values of space-charge capacitance. Clearly explain your averaging proceedure.





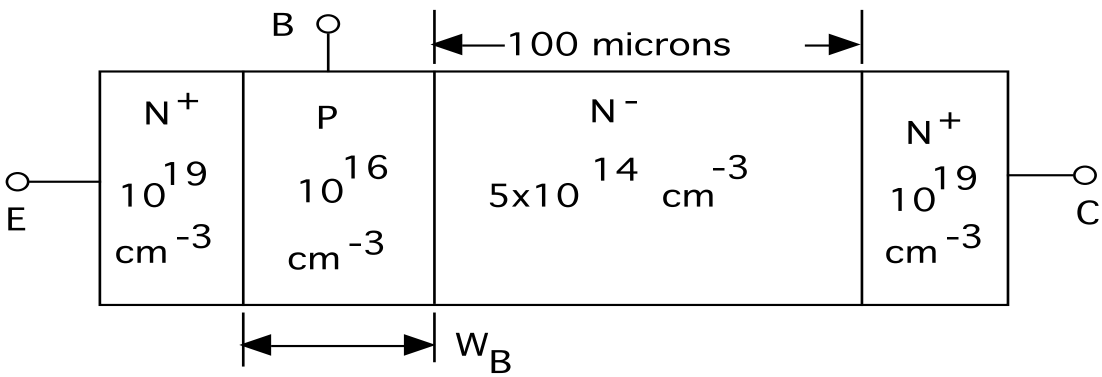


All pn junctions = step junctions

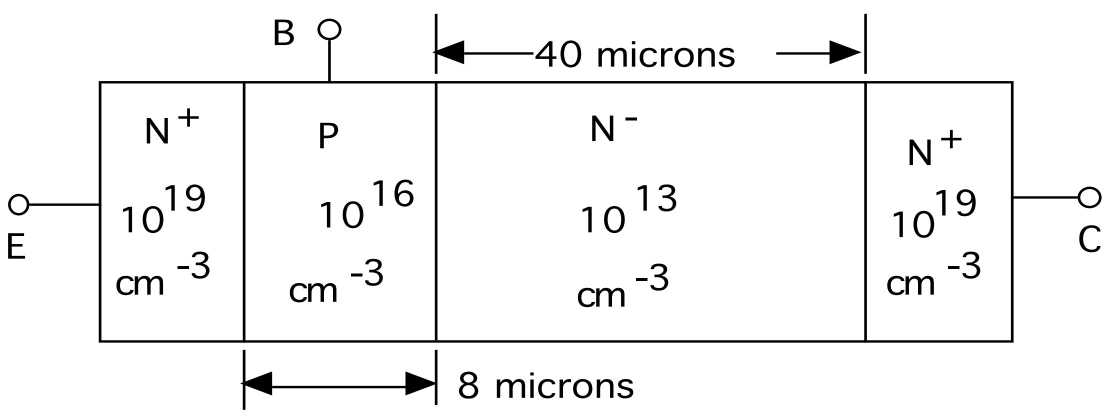
S21.5. In designing a transistor for a specific value of BV_{CEO}, the base width must be large enough to avoid reach-through. This requires that the base width $W_B >$ $x_{pC}(BV_{CBO}) + x_{pE}(BV_{EBO})$. $x_{pC}(BV_{CBO})$ is the protusion of the CB depletion layer on to the base side of the CB junction at $V_{CB} = BV_{CBO}$ and $x_{pE}(BV_{EBO})$ is the protusion of the BE depletion layer on to the base side of the BE junction at $V_{BE} = - BV_{EBO}$. However device manufacturers make W_B several times larger than this minimum value.

a. Explain why they do this. (The answer is not to provide a margin of safety against reach-through.)

b. For the BJT shown below, find the required value of W_B assuming that the manufacturer uses the design criteria of $W_B = 5\,[x_{pC}(BV_{CBO}) + x_{pE}(BV_{EBO})]$.

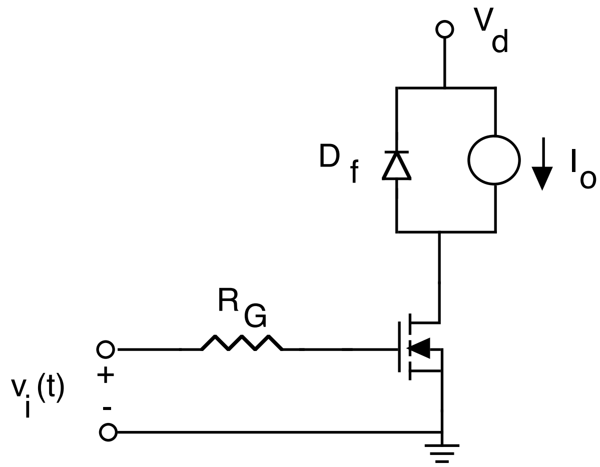


S21.6 Consider the transistor geometry shown below. The beta (β) of the transistor is equal to 10. Specify a blocking voltage rating for this transistor. Include a 50% factor of safety.



Chapter 22 - MOSFETs

S22.1 Consider the MOSFET step-down converter circuit shown below. The voltage rise and fall times, t_{rv} and t_{fv}, are much larger than current rise and fall times, t_{ri} and t_{fi}. Briefly explain why this is so. You may assume that the value of C_{gd} is a constant independent of V_{DS} and the free wheeling diode D_f is ideal.



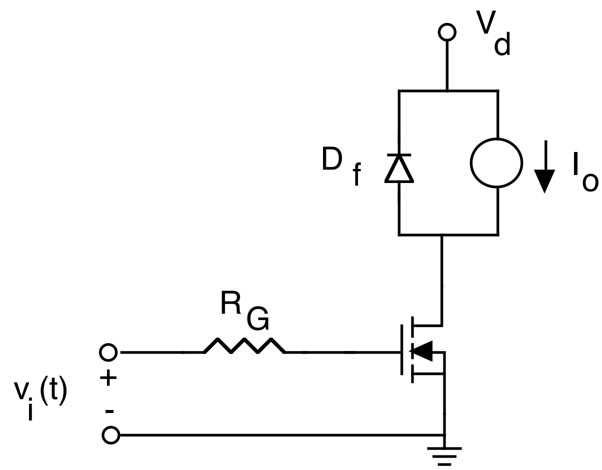
S22.2. In the step-down converter circuit of Problem #1, V_d = 250 V and I_o = 50 A.
The MOSFET parameters are listed below:
BV_{DSS} = 400 V , $I_{D,max}$ = 80 A, $V_{GS,th}$ = 5 V, $r_{DS}(on)$ = .05 Ω,
$T_{j,max}$ = 175 °C, $R_{\theta j\text{-}a}$ = .5 °C/W, $t_{d(on)}$ = $t_{d(on)}$ = 10 ns, t_{ri} = t_{fi} = 25 ns,
t_{rv} = t_{fv} = 175 ns

a. What is the power dissipation in the MOSFET assuming a switching frequency f_s = 10 kHz and a duty cycle D = 50%?

b. What is the maximum average power that can be dissipated in the MOSFET? Assume an ambient temperature of 25 °C.

c. The duty cycle D will vary from 20% to 90%. What is the maximum permissible switching frequency f_s? Assume that the period $1/f_s$ is large compared to the switching times of the MOSFET.

S22.3. In the step-down converter circuit shown below, V_d = 300 V and I_o = 30 A.

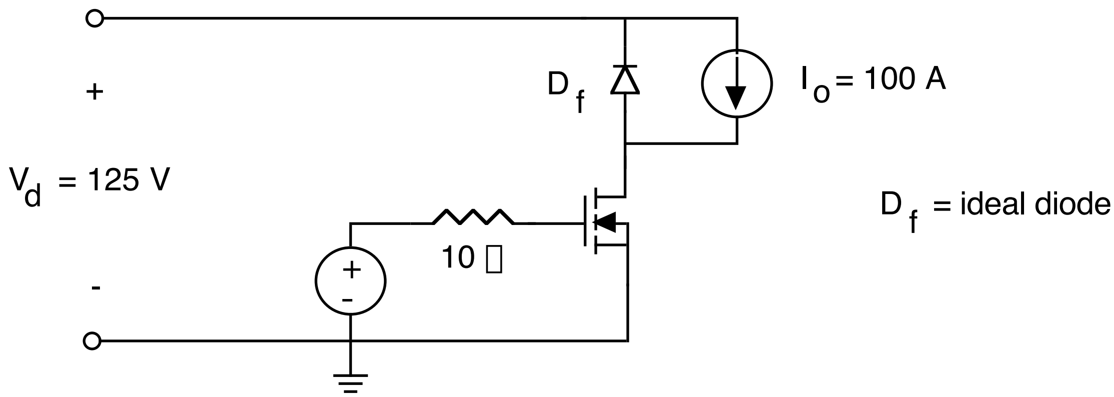


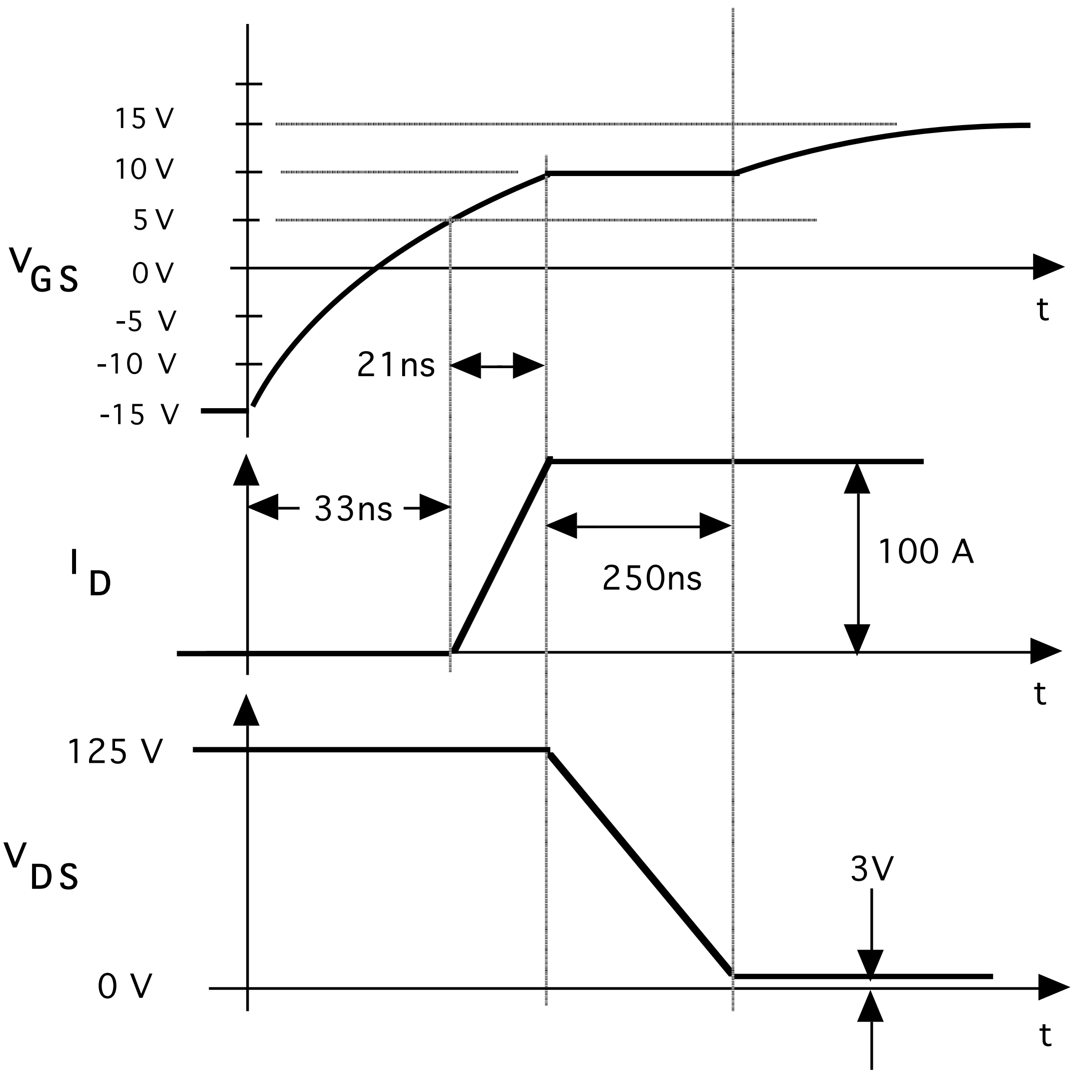
The MOSFET parameters are listed below:
BV_{DSS} = 400 V , $I_{D,max}$ = 80 A, $V_{GS,th}$ = 5 V, $r_{DS}(on)$ = .1 Ω,
$T_{j,max}$ = 175 °C, $R_{\theta j\text{-}c}$ = .25 °C/W = junction-to-case thermal resistance,
The switching times are adjustable over a wide range by the magnitude of the gate-source voltage provided by the drive circuit.

a. The power dissipation in the MOSFET at a switching frequency f_s = 10 kHz and a duty cycle D = 50% is to be limited to 100 W. What should be the the switching times t_{ri}, t_{fv}. t_{fi}, and t_{rv}. Assume that $t_{rv} = t_{fv} = 6t_{ri} = 6t_{fi}$ and further assume that $t_{d(off)} = t_{d(on)} = 0$.

b. The maximum average power dissipated in the MOSFET will be limited to 200 W. Assuming an ambient temperature of 25 °C, what is the maximum allowable case-to-ambient thermal resistance, $R_{\theta c\text{-}a}$, of the heat sink on which the MOSFET is to be mounted?

S22.4. The MOSFET-driven step-down converter circuit shown below produces the turn-on waveforms which are shown with the circuit diagram.





a. What is the threshold voltage V_{GSth} of the MOSFET?

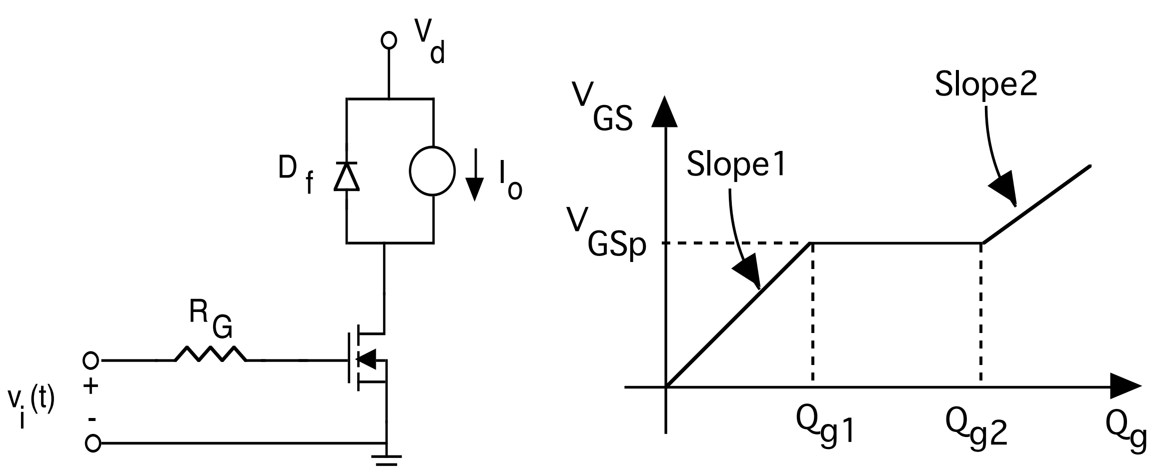
b. What is the MOSFET transconductance g_m?

c. What is the on-state resistance $r_{DS(on)}$?

d. What is the gate-drain capacitance C_{gd}?

e. What is the gate-source capacitance C_{gs}?

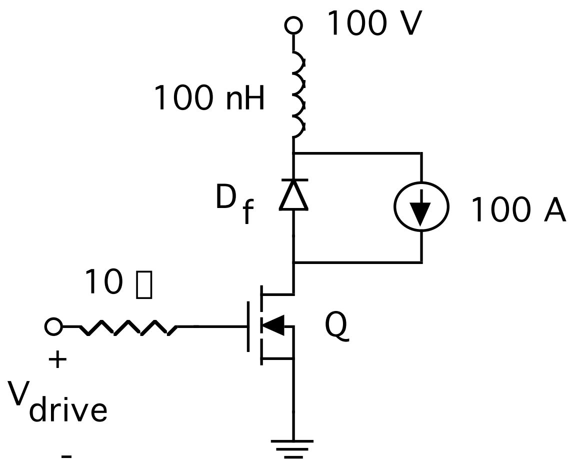
S22.5. Shown below is a graph of the gate-source voltage V_{GS} as a function of the gate charge Q_g with a specified drain current I_D and drain-source voltage V_{DS}. Such graphs are often included on specification sheets of MOSFETs and IGBTs and are aconvenient way of summarizing the influence of gate-source, gate-drain, and drain-source capacitances. These graphs are most useful in the design of circuits with clamped inductive loads such as is shown below. Express the slopes (Slope1 and Slope2) and breakpoints (V_{GSp},Q_{g1} and V_{GSp},Q_{g2}) indicated on the V_{GS} versus Q_g graph in terms of the parameters of the step- down converter circuit and the parameters of the MOSFET. Assume that all of the MOSFET parameters listed below are constant independent of MOSFET voltages or currents.



MOSFET parameters

threshold voltage $V_{gs(th)}$; transconductance g_m
gate-source capacitance C_{gs} ; gate-drain capacitance C_{gd}

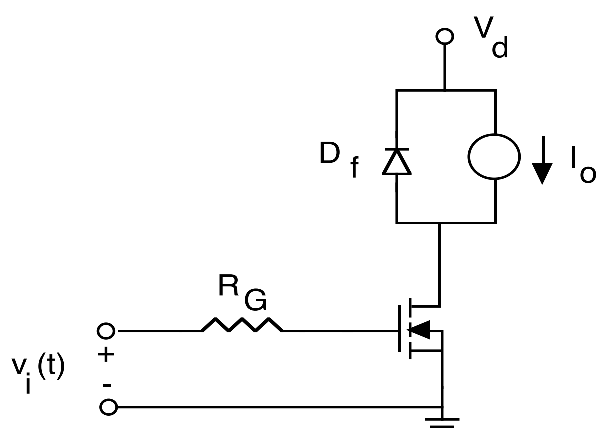
S22.6. Consider the MOSFET step-down converter shown below. It is operating in an ambient temperature of 50 °C at a switching frequency of 30 kHz (duty cycle of 50%). The free-wheeling diode D_f is ideal. Is the transistor being overstressed and if so, how? Be specific and quantitative in answering the question.

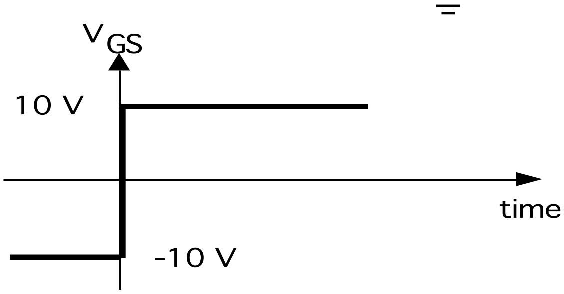


MOSFET Characteristics

BV_{DSS} = 150 V
$I_{D,max}$ = 125 A
$T_{j,max}$ = 150 °C
$R_{\theta,j-a}$ = 1 °C/W
$t_{ri} = t_{fi}$ = 50 ns
$t_{rv} = t_{fv}$ = 200 ns
$r_{DS(on)}$ = 0.01 ohms

S22.7. Consider the MOSFET step-down converter circuit shown below. Assume I_o = 100 A, V_d = 100 V, R_G = 25 ohms, and $V_i(t)$ is shown below. The parameters of the MOSFET are also listed below. Estimate the turn-on delay time $t_{d,on}$.



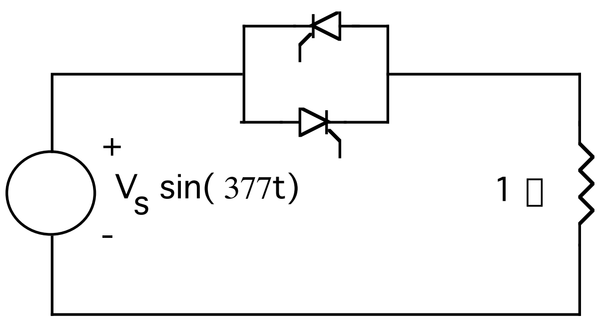


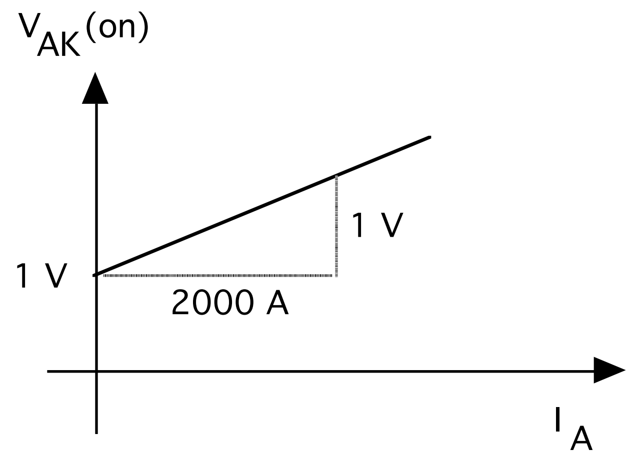
MOSFET Parameters

V_{th} = 5 V
g_m = 20 A/V
C_{gs} = 500 pF
C_{gd} = 1000 pF
$r_{DS,(on)}$ = 0.02 ohms
$R_{\theta ja}$ = 0.5 °C/W
$T_{j,max}$ = 150 °C

Chapter 23 and 24 - SCRs and GTOs

S23.1. Consider the SCR circuit shown below. The SCR has the following characteristics:
$T_{j,max}$ = 125 °C ; V_{BO} = 3000 V ; $I_{A,max}$ = 2000 A ; $R_{\theta j\text{-}c}$ = .05 °C/W

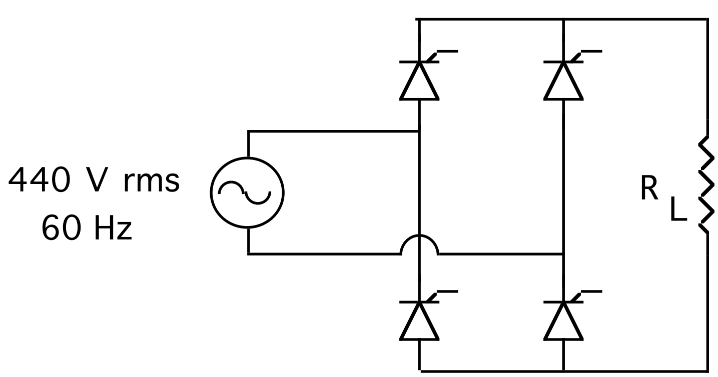


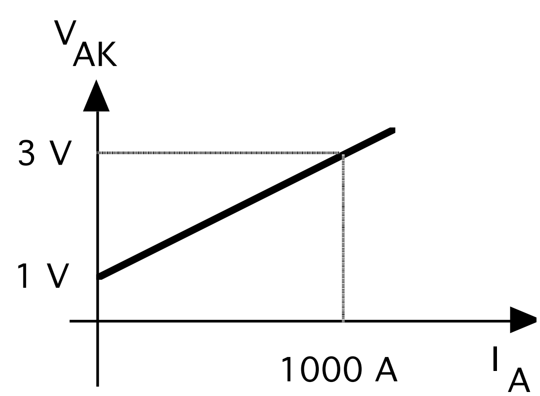


a. Assume that the case temperature is 50 °C. What is the maximum average power $P_{SCR,max}$, that can be dissipated in the thyristors?

b. Estimate the maximum power that can be delivered to the load.

S23.2. The SCR inverter circuit shown below must deliver 1 megawatt of power to the load R_L under maximum power conditions (trigger angle equal to zero). The thyristors are all identical.
$T_{j,max}$ = 125 °C ; V_{BO} = 3000 V ; $I_{A,max}$ = 2000 A ; $R_{\theta j\text{-}c}$ = .05 °C/W

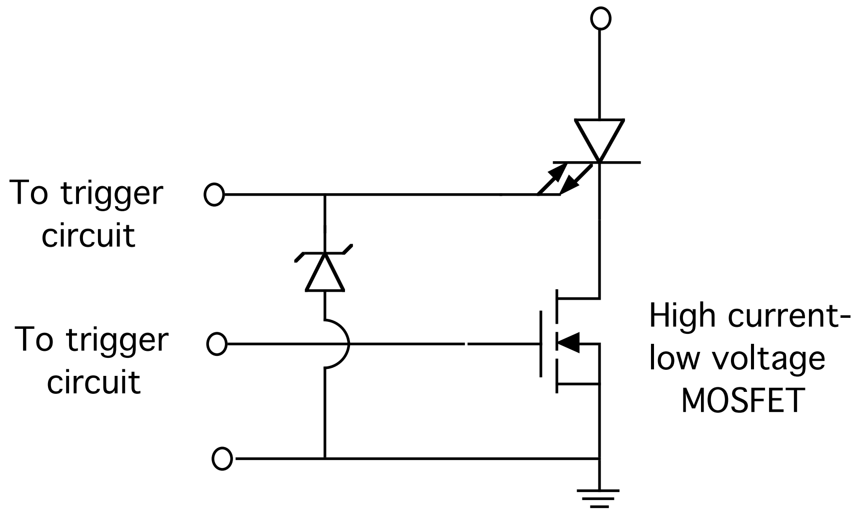




a. Specify what the blocking voltage rating and maximum average forward current rating of the SCRs should be. Include a factor of safety of 25% in the ratings.

b. Estimate what the power dissipation rating of the thyristor should be including a factor of safety of 25%.

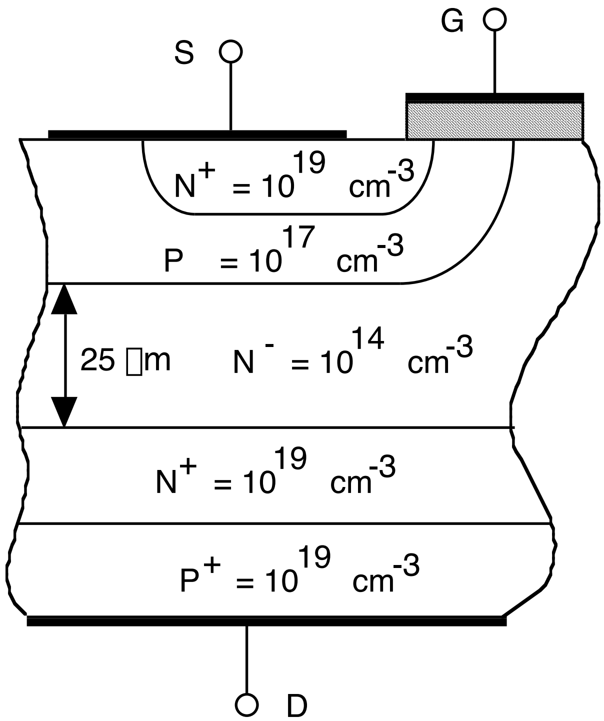
S23.3. A cascode circuit arrangement shown below has been proposed for the control of a GTO. Briefly discuss the advantages and disadvantages of this arrangement.



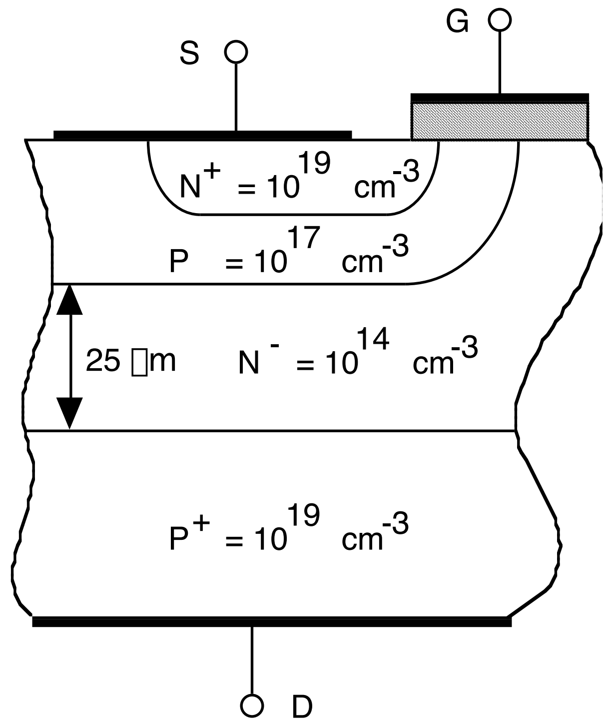
S23.4. The stray inductance $L_{\square}$ in the turn-off snubber of Fig. 24-3, pp. 617 of <u>Power Electronics: Converters, Applications, and Design, 2nd Edition</u>, by Mohan, Undeland, and Robbins will cause an overvoltage across the GTO. Estimate the maximum stray inductance that can be tolerated in the circuit if the overvoltage is not to exceed 1.5 V_d. Express the estimate in terms of the circuit parameters. Assume that the turn-on snubber acts like a constant current source of value I_o during the GTO current fall time t_{fi} = 1 μsec.

Chapter 25 - IGBTs

S25.1. Consider the symmetric and antisymmetric IGBTs shown below.



Antisymmetric IGBT



Symmetric IGBT

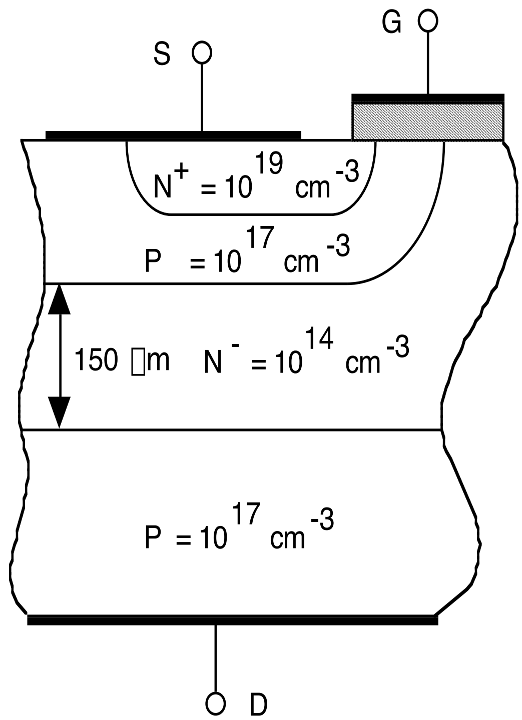
a. Estimate the forward blocking voltage BV_{DSS} of each IGBT.

b. Estimate the reverse blocking voltage V_{RM} of each IGBT.

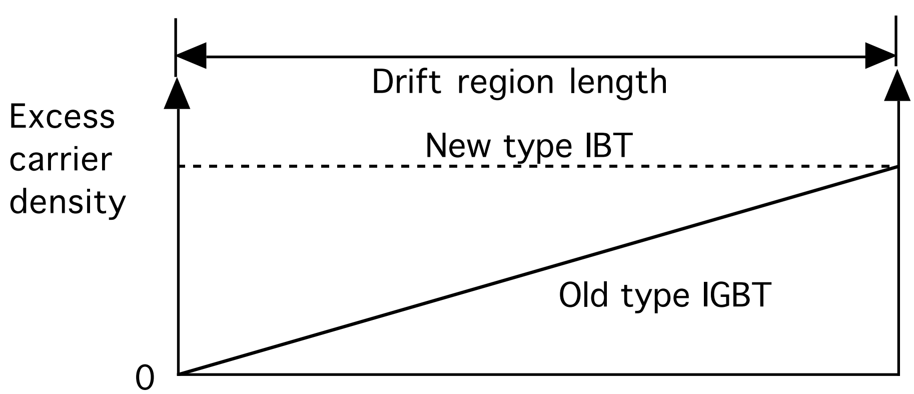
S25.2 Consider the IGBT shown below.

a. Estimate the forward blocking voltage BV_{DSS} that will be printed on the specification sheet for the IGBT shown above. The device manufacturer uses a 50% factor of safety in specifying the breakdown voltage.

b. The IGBT is rated for a maximum drain current of 20 A and at this current level, the drift region voltage drop is one volt. Assuming that the IGBT chip is square in shape, specify the length and width of the chip on which the IGBT is fabricated. Only 25% of the total chip area is effective in carrying current, the rest is used for connecting the many source and gate regions together. Use a value $n_b = 10^{16}$ cm^{-3} as the excess carrier density value at which the mobilities and carrier lifetime begin to decrease with further increases in excess carrier density.

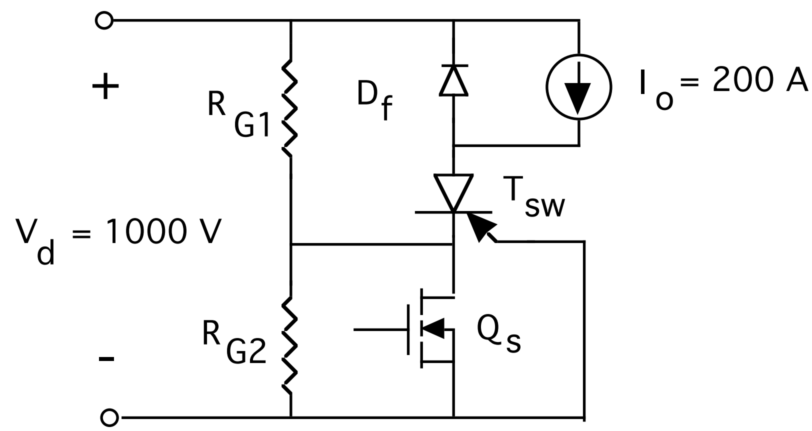


S25.3. Older types of IGBTs have an excess carrier distribution in the drift region that is triangular as shown below. Newer IGBT structures manage to get a flat distribution as is also shown in the figure. Compare the on-state resistance of the older IGBT against that of the newer IGBT assuming that both have the same drift region length, same excess carrier lifetime, same cross-sectional area, and the same breakdown voltage rating. Further assume that the maximum excess carrier density at the collector end of the drift region is the same for both devices.



Chapter 26 - Emerging Devices

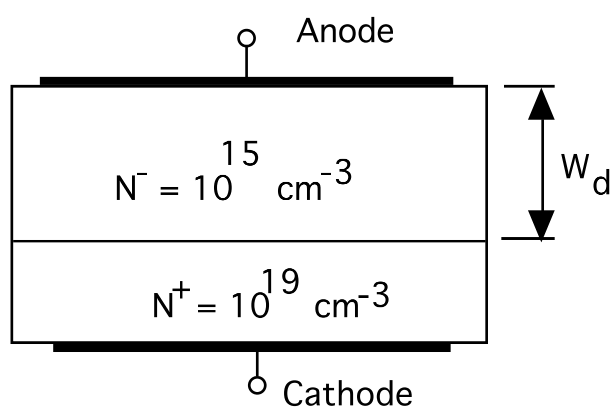
S26.1. Consider the step-down converter shown below which employs an FCT and a MOSFET. The blocking gain, β, of the FCT is equal to 40.



a. What should be the values of R_{G1} and R_{G2} in order to insure proper operation of the FCT? Assume $R_{G1} + R_{G2} = 1\ M\Omega$ and include a 25% factor of safety in the blocking voltage capability of the circuit.

b. Describe the characteristics the MOSFET in this circuit should have including breakdown voltage and maximum average current capability.

S26.2. Consider the Schottky diode geometry shown below. For simplicity no guard rings or field plates are shown. The performance of this diode geometry implemented in silicon is to be compared against the same geometry implemented in gallium arsenide. The breakdown voltage of the diode is to be 125 volts. The properties of silicon and gallium arsenide are listed below.

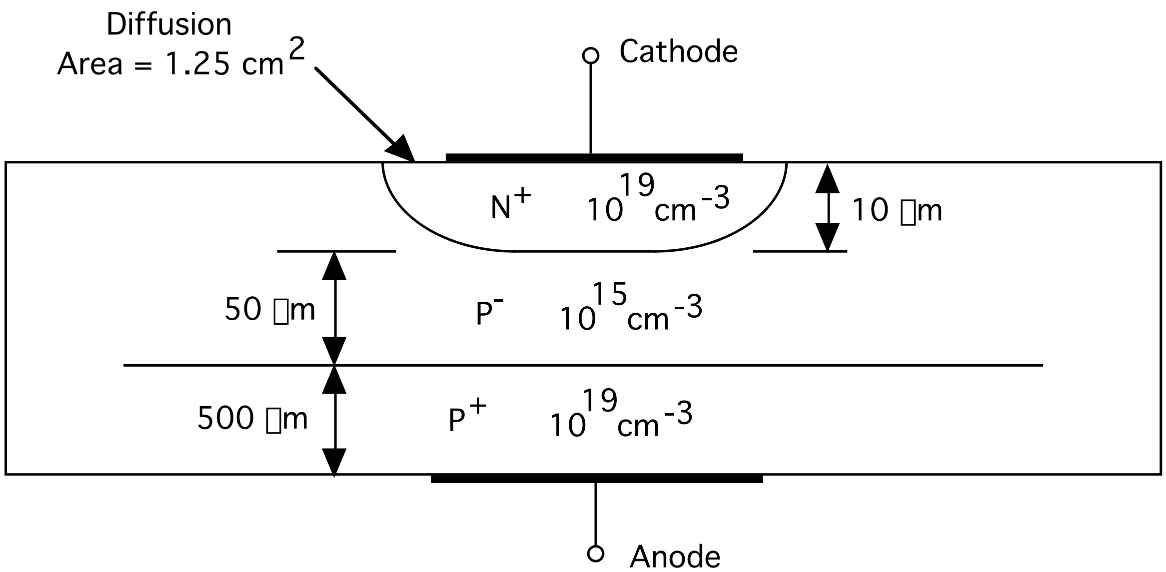


Property	Si	GaAs
Bandgap @ 300 K [ev]	1.12	1.43
Relative dielectric constant	11.8	12.8
Saturated drift velocity [cm/sec]	$1x10^7$	$2x10^7$
Thermal conductivity [Watts/cm- °C]	1.5	0.5
Maximum operating temperature [°K]	300	460
Melting temperature [°C]	1415	1238
Electron mobility @ 300 °K [cm^2/V-sec]	1400	8500
Breakdown electric field [V/cm]	$3x10^5$	$4x10^5$

a. Find the appropriate length, W_d, of the drift region for both the silicon and gallium arsenide versions of the diode. The length is to be minimized so that the resistance of the drift region is minimized.

b. How does the drift region resistance of the silicon diode compare with that of the gallium arsenide diode. Each diode has the same cross-sectional area and the length W_d found in part a.

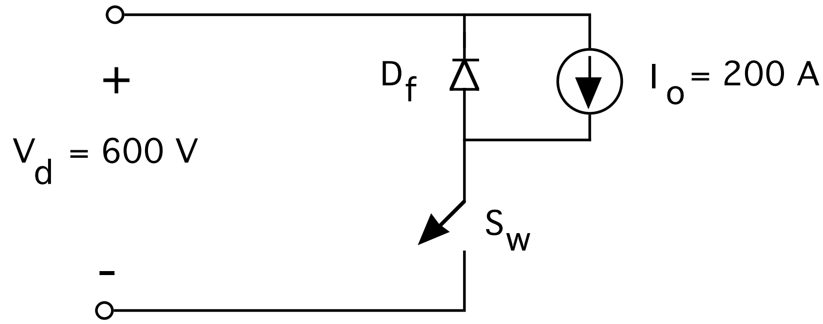
S26.3 A novice device engineer has designed the gallium arsenide rectifier diode shown below.It is supposed to have a breakdown voltage of 2000 V and a maximum average forward current rating of 2000 A. The maximum current density in the diode should not exceed 250 A/cm^2. The diode is a non-punch-through geometry. Test results reveal that the diode does not work properly. List what is wrong with the design and briefly describe how to correct each design fault. Treat each design error you find independent of all the others. A list of useful physical properties of GaAs are listed below.



Parameter	Value
Bandgap @ 300 °K [eV]	1.43
Relative dielectric constant	12.8
Electron mobility @ 300 °K [cm^2/V-sec]	8500
Hole mobility @ 300 °K [cm^2/V-sec]	1500
Breakdown electric field [V/cm]	$4x10^5$
Thermal conductivity [W/cm-°C]	0.5

S26.4. Consider the step-down converter circuit shown below. The switching frequency is 15 kHz. The breakdown voltage of the free-wheeling diode is specified with a 50% factor of safety. The characteristics of the switch S_w are given below.

Maximum instantaneous current = 300 A
Blocking voltage = 1000 V
$t_{ri} = t_{fi} = 0.5\ \mu s = t_{fv} = t_{rv}$



Estimate the reverse-recovery time t_{rr} and reverse recovery current I_{rr} of the free-wheeling diode assuming that it is a gallium arsenide diode.

S26.5. A Schottky diode is to be fabricated using silicon carbide. The diode is to have a breakdown voltage rating of 1500 V and is to conduct a maximum average forward current of 500 A. The physical parameters of silicon carbide are given below.

$\varepsilon_R = 9.7$; $E_G = 2.2$ eV ; $\mu_n = 1000\ cm^2$/V-sec ; $E_{BD} = 4x10^6$ V/cm

a. Specify the doping density and length of the drift region.

b. At the maximum forward current, the drift region drop is not to exceed 2 V. Specify the cross-sectional area of the drift region.

S26.6. Shown below are the vertical cross-sections of several power devices. Indentify each of them and answer the following questions regarding their basic properties. Enter your answers on the table provided.

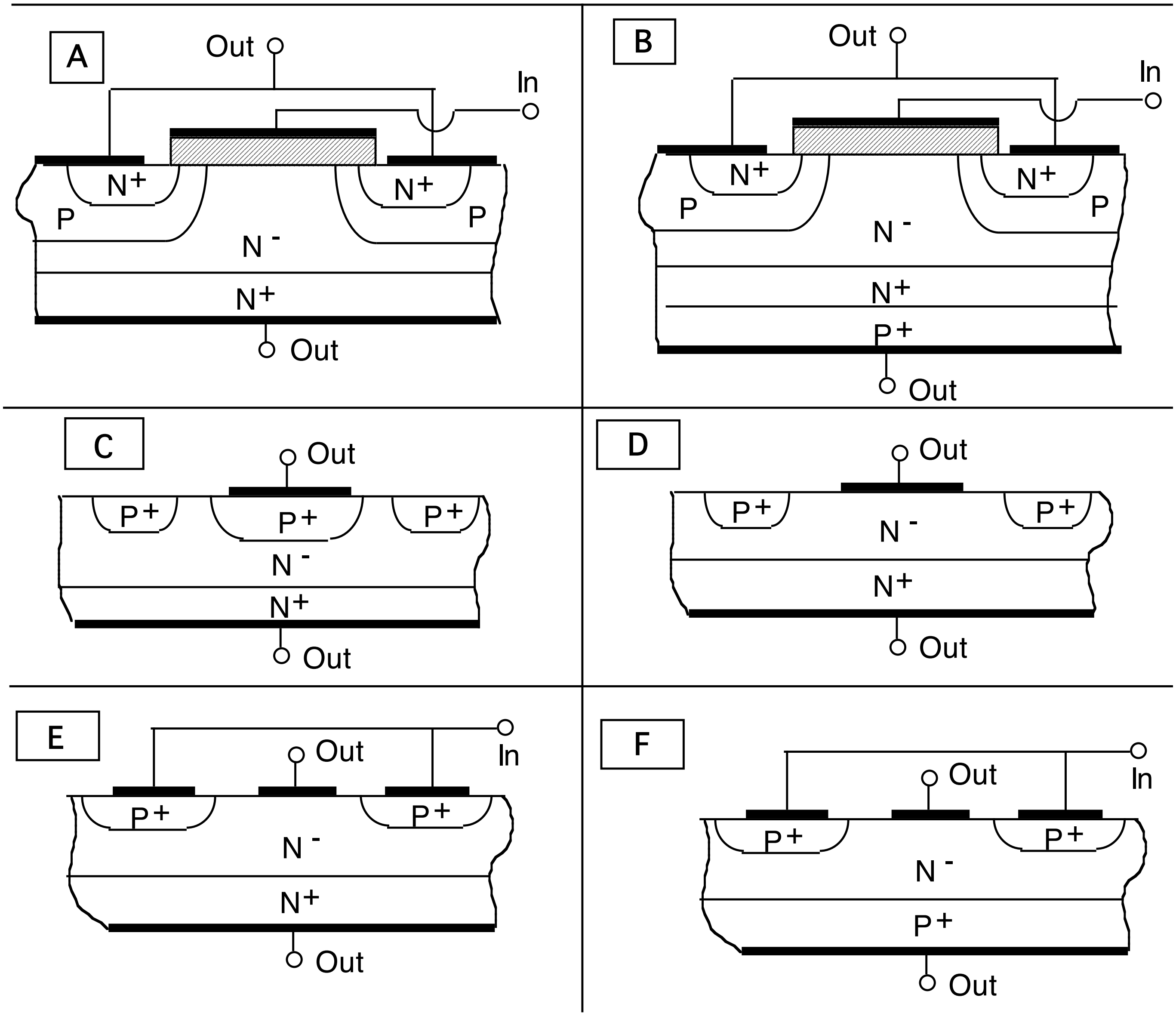
Type of device - BJT, IGBT, GTO, etc.

High power ($V_{off} \cdot I_{on} > 1$ Megawatt)? yes or no

Fast (t_{on}, $t_{off} < 0.5\ \mu s$)? yes or no

$\frac{dv}{dt}$ &/or $\frac{di}{dt}$ limits? specify which - no numerical values required

Figure	A	B	C	D	E	F
Type of Device						
High Power?						
Fast?						
$\frac{dv}{dt}$, $\frac{di}{dt}$ limits?						

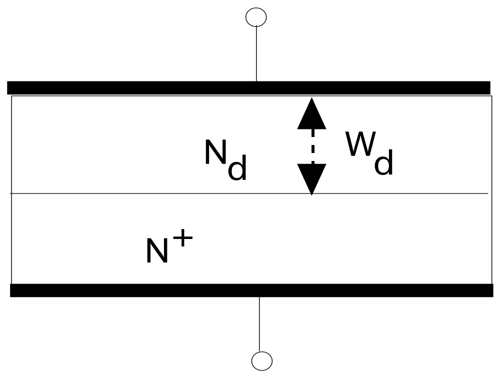


S26.7. A Schottky diode is to be made from diamond and is to have a blocking voltage rating of 2000V and an on-state current rating of 1000 A. The current density must be limited to 800 A/cm^2.

a. Specify the doping density N_d and the length W_d of the drift region.

b. Estimate the on-state voltage drop across the drift region when the maximum current is flowing in the diode.

S26.8. A silicon carbide schottky diode is to be designed to hold off 3000 V when reverse biased and conduct 1000 A when forward biased. The basic structure is shown below. Assume that the depletion regions are plane and parallel with the surface of the wafer so that there are no field crowding problems.



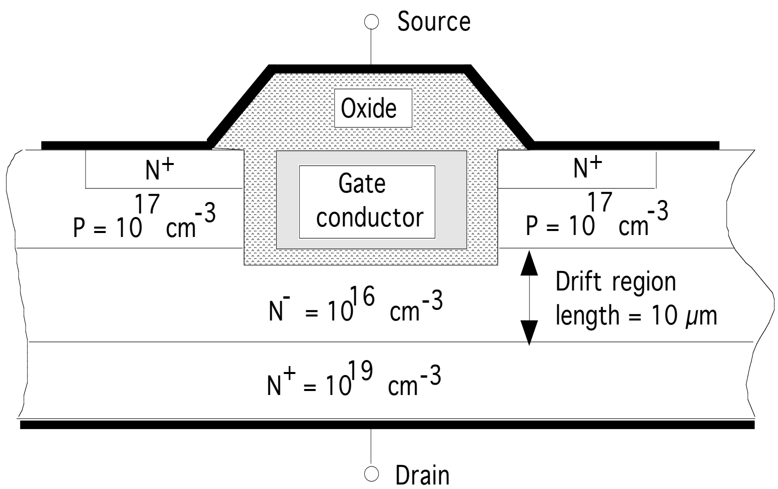
SiC Material Data

Bandgap @ 300 °K [ev]	2.9
Relative dielectric constant	10
Saturated drift velocity [cm/sec]	2.5×10^7
Thermal conductivity [Watts/cm□°C]	5.0
Maximum operating temperature [°K]	1240
Intrinsic carrier density [cm^{-3}] @ 25 °C	
Melting temperature [°C]	sublimes >1800
Electron mobility @ 300 °K [cm^2/V-sec]	600
Breakdown electric field [V/cm]	2×10^6

a. Specify the required doping density in the drift region and the length of the drift region.

b. Thermal considerations dictate that the power dissipation in the diode be limited to 500 watts when it is forward biased. Assume that the forward bias voltage V_{fwd} is only the drift region drop, V_{drift}. Specify the cross-sectional area of the diode.

S26.9. The so-called UMOSFET (or trench-gate MOSFET) shown below is to be fabricated in diamond. Some of the physical properties of diamond are listed in the table below.



Property	Diamond
Bandgap @ 300 °K [ev]	5.5
Relative dielectric constant	5.5
Saturated drift velocity [cm/sec]	$2.7\text{x}10^7$
Thermal conductivity [Watts/cm-°C]	20
Electron mobility @ 300 °K [cm^2/V-sec]	2200
Breakdown electric field [V/cm]	$1\text{x}10^7$

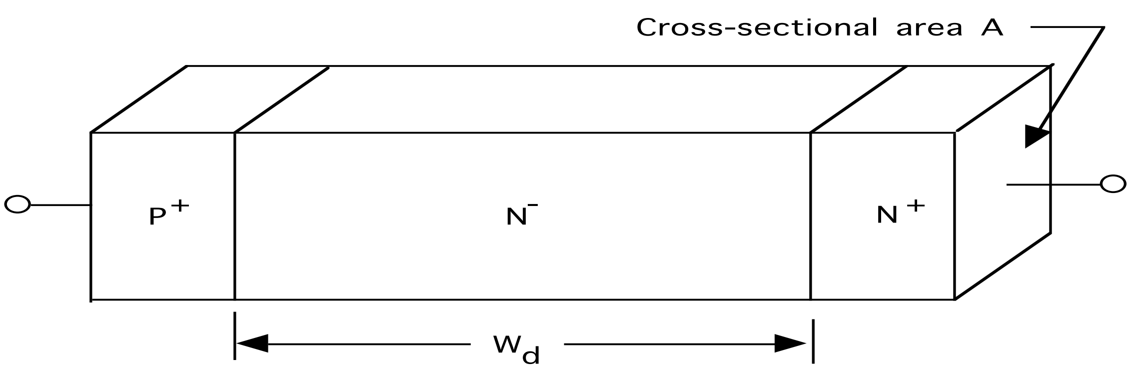
a. Estimate the breakdown voltage V_{DSS}.

b. Estimate the cross-sectional area required if the MOSFET is to conduct 500 A in the on-state and the on-state voltage is not to exceed 1 V. You may assume that only the drift region contributes to the on-state losses.

S26.10. Conduct a brief survey of commercially available high voltage Schottky diodes, both silicon, gallium arsenide. And silicon carbide. Include the first page of the specification sheets for the highest voltage Schottky you are able to find in each material.

S26.11. A pn junction diode is to be fabricated in silicon carbide. A diagram of the diode is shown below. The diode is to have the following characteristics:
BV_{BD} = 2000 V ; $I_{on,max}$ = 2000 A ; V_{on} = 2 V when I_{on} = 1000 A
A table listing the important characteristics of silicon carbide is shown below.

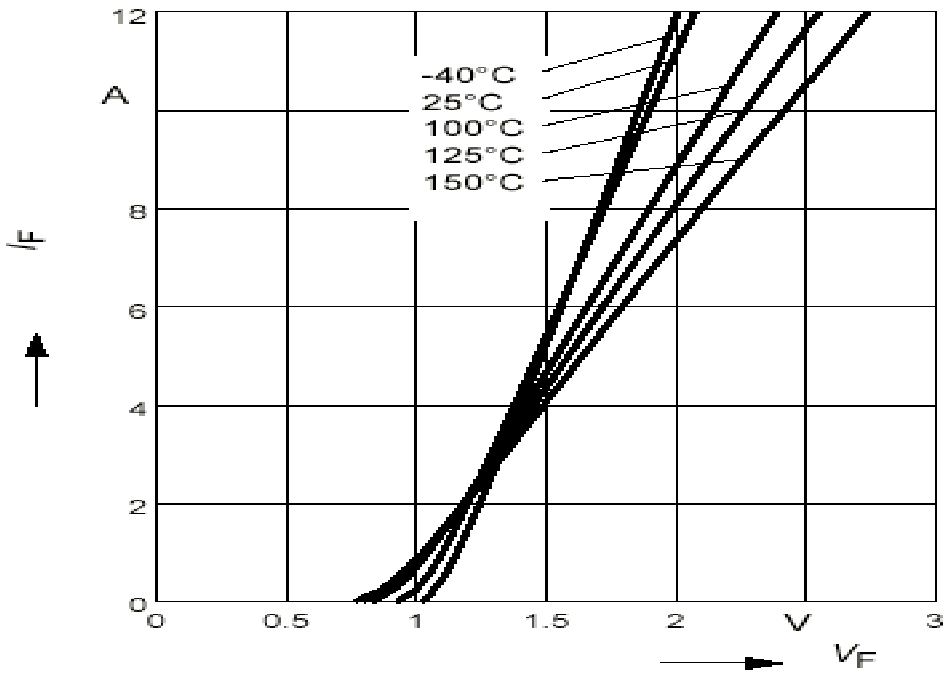
Property	SiC
Bandgap @ 300 °K [ev]	2.2
Relative dielectric constant	9.7
Saturated drift velocity [cm/sec]	2.5×10^7
Thermal conductivity [Watts/cm-°C]	5.0
Intrinsic carrier density [cm^{-3}] @ 25 °C	10^5
Electron/hole mobility @ 300 °K [cm^2/V-sec]	1000
Breakdown electric field [V/cm]	2×10^6



a. Specify the length W_d of the drift region and the doping level of the drift region.

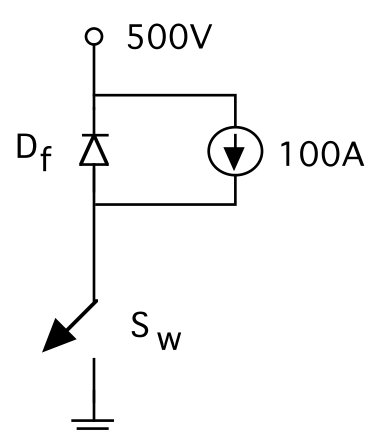
b. Specify the cross-sectional area A. You may assume that both the excess carrier lifetime and the carrier mobilities begin to decrease at carrier densities above $n_b = 10^{17}$ cm^{-3}.

S26.12. Shown below is the forward bias I-V curve of the new 600V-6A model SDP06S60 silicon carbide Schottky diode made by Infineon Technologies of Germany. Use the room temperature I-V curve for this problem.



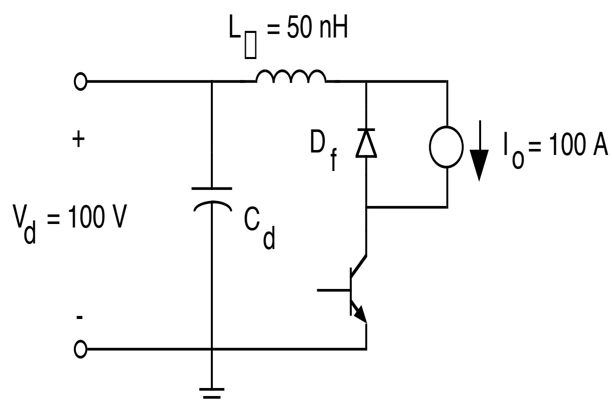
a. Estimate the drift region length, W_d, and its doping level N_d of this diode.

b. What is the approximate conducting area of the diode?



Chapter 27 - Snubbers

S27.1. The step-down converter circuit shown below is switched at a 25 kHz rate. 100 watts of power are dissipated in the BJT including switching losses. The ambient temperature is 25 °C. The BJT parameters are listed below. The collector current and collector-emitter voltage vary linearly in time during the switching transient. The rest of the circuit components are ideal.



BJT Characteristics

BV_{CBO} = 300V
β = 16
$T_{j,max}$ = 150 °C
$R_{\theta,j-a}$ = 2 °C/W
$I_{C,max}$ = 125 A
$t_{ri} = t_{fv}$ = 0.1 μs
$t_{rv} = t_{fi}$ = 0.2 μs
$t_{d,on}$ = 0.1μs
$t_{d,off}$ = 0.3μs

a. In what way or ways is the transistor being overstressed in this application. Justify your answer quantitatively.

b. Specify the type or types of snubber circuits needed in this circuit for reducing the stresses on the transistor to a safe level. The number of snubber circuits used should be minimized. Justify your choices.

S27.2. Assume that the circuit of problem #S27.1 requires a turn-off snubber.

a. Determine the values of R_s and C_s used in the snubber circuit.

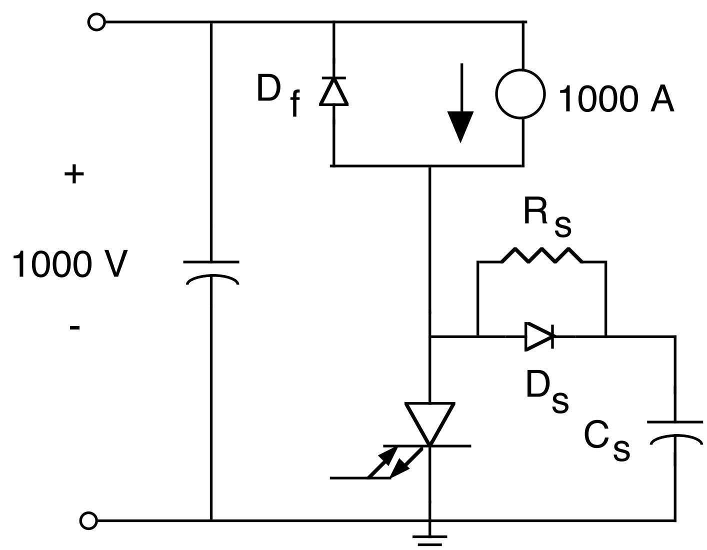
b. How much power is dissipated in the snubber resistance R_s?

c. Estimate the reduction in the transistor turn-off losses afforded by the turn-off snubber.

S27.3. A turn-off snubber circuit is to be designed for the GTO step-down converter circuit shown below. The specifications for the GTO are listed below. The other circuit components are ideal. The switching frequency is 5 kHz.

$$I_{A,max} = 1500\text{ A},\ BV_{BO} = 1500\text{ V},\ \square_{off} = 5,\ \left.\frac{dI_A}{dt}\right|_{max} = 500\text{ A/}\square\text{s},$$

$$\left.\frac{dV_{AK}}{dt}\right|_{max} = 750\text{ V/}\square\text{s},\ t_{fi} = 1\ \square\text{s}$$

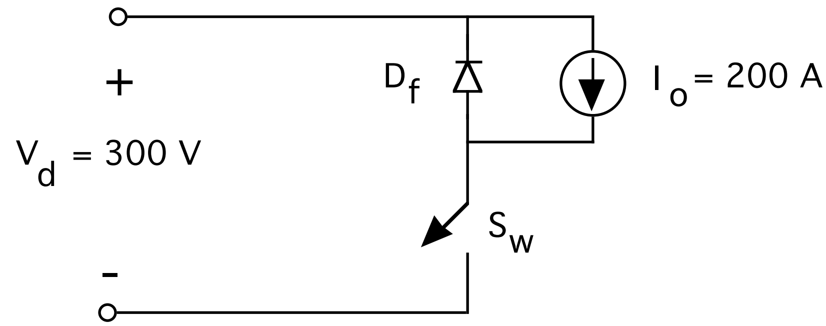


a. The design proceedure used for turn-off snubbers for BJTs will not produce satisfactory results if used for GTOs. Explain why.

b. Estimate values for C_s and R_s for the GTO turn-off snubber.

S27.4. Consider the step-down converter circuit shown below. The switching frequency is 10 kHz. The characteristics of the free-wheeling diode and the switch S_w are given below.

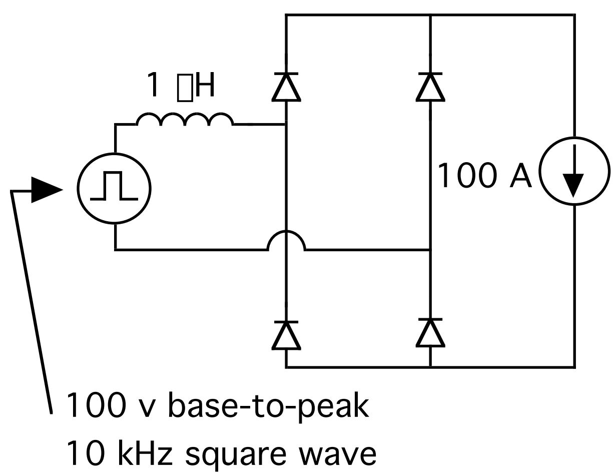
D_f	S_w
Lifetime $\square$= 0.5 microseconds	Maximum instantaneous current = 250 A
Snappiness S =1	Blocking voltage = 500 V
	$t_{ri} = t_{fi} = 0.5\ \square\text{s} = t_{fv} = t_{rv}$



a. Show that a turn-on snubber is required in this circuit.

b. Estimate values for L_s and R_{Ls} for the turn-off snubber.

S27.5. Consider the diode rectifier circuit shown below. The diode characteristics are also given below.



Diode Parameters

Reverse recovery time t_{rr} = 10 s
Snappiness factor S = 0.25

a. What is the magnitude of the overvoltage across the diodes due to the reverse recovery current?

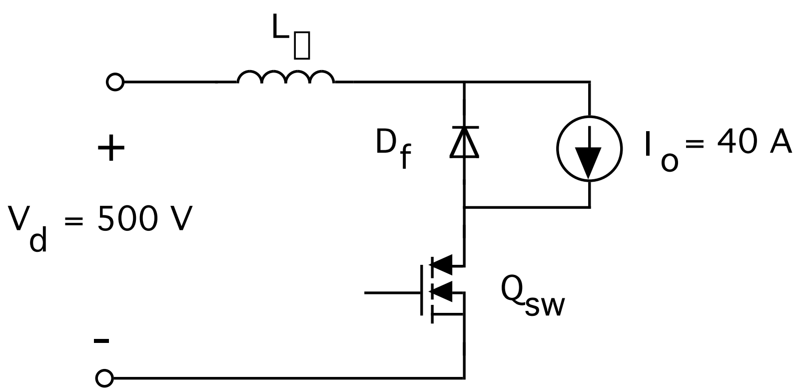
b. Design a snubber circuit to limit the overvoltage. Indicate the placement of the snubber circuit as well as the component values.

c. How much power is dissipated in the snubber resistance?

S27.6. Consider the step-down converter shown below. It is switched at a 20 kHz rate and it has a 33% duty cycle. The stray inductance $L_{\square}$ = 100 nH. The IGBT specifications are given below. Assume that the free-wheeling diode is ideal

BV_{DSS} = 700 V ; $I_{D,max}$ = 200 A ; $t_{ri} = t_{fv}$ = 200 nsec ; $t_{rv} = t_{fi}$ = 500 nsec

$R_{\square ja}$ = 1 °C/W ; $T_{j,max}$ = 150 °C ; $V_{DS,on} = 0.8 + (0.01)I_D$



a. Is the IGBT being overstressed? Specify the overstress quantitatively.

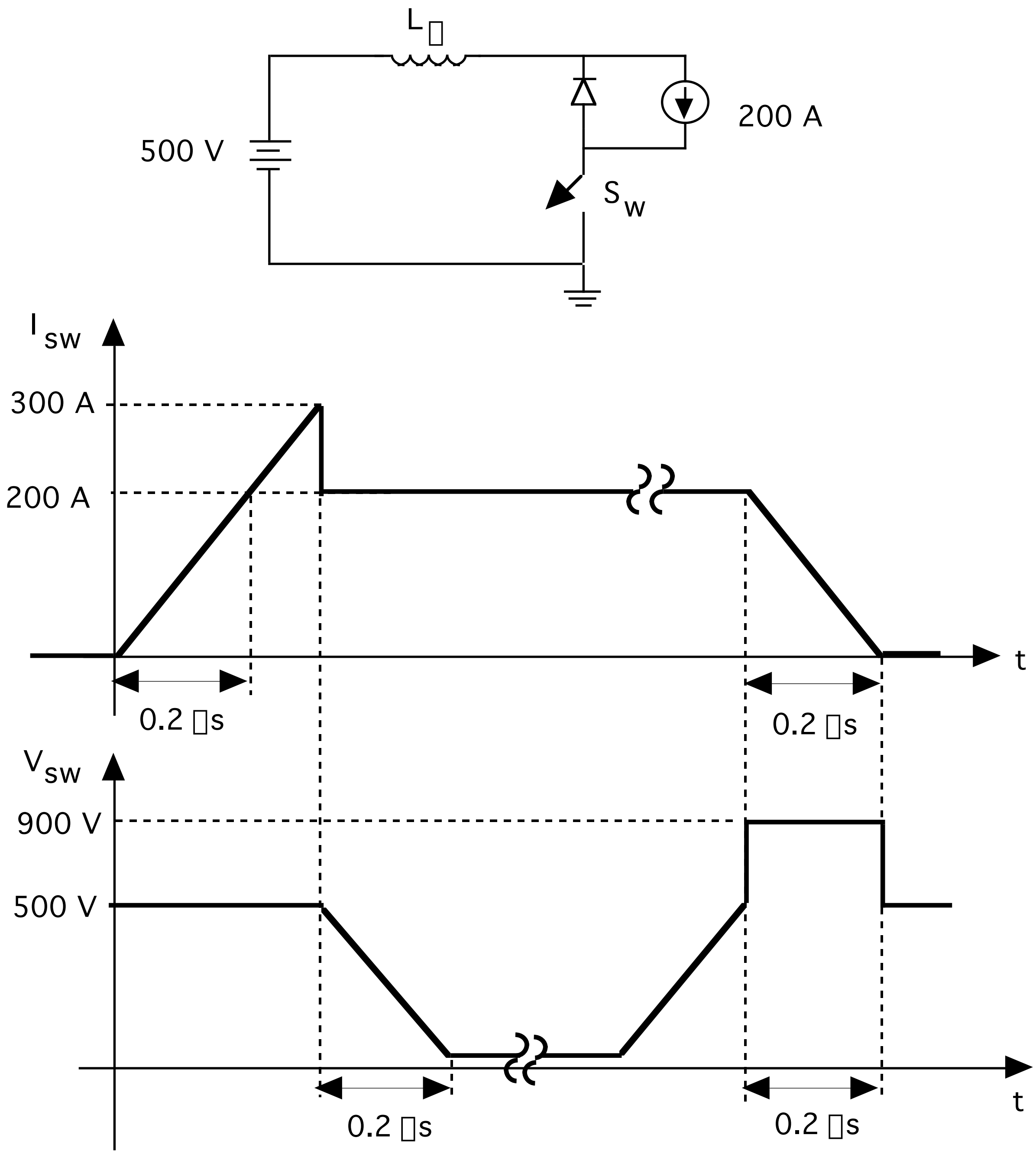
b. Specify the type or types of snubber circuits needed in this circuit for reducing the stresses on the transistor to a safe level. The number of snubber circuits should be minimized. Justify your choices.

S27.7. A turn-off snubber is to be designed for the circuit of problem #S27.6.

a. Specify the values of capacitance C_s and resistance R_s.

b. How much are the turn-off losses in the IGBT reduced by the turn-off snubber?

S27.8. A step-down converter operating at a switching frequency of 20 kHz is shown below. The waveforms for the switch current and switch voltage for one switching cycle are also shown below. The switch is rated for amaximum instantaneous current of $I_{sw,max}$ = 250 A and a maximum instantaneous voltage of $V_{sw,max}$ = 700 V.



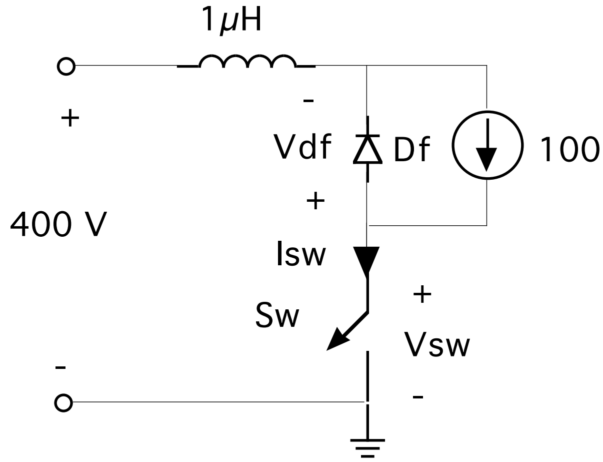
a. What is magnitude of the stray inductance in the circuit?

b. What is the reverse recovery current of the free-wheeling diode?

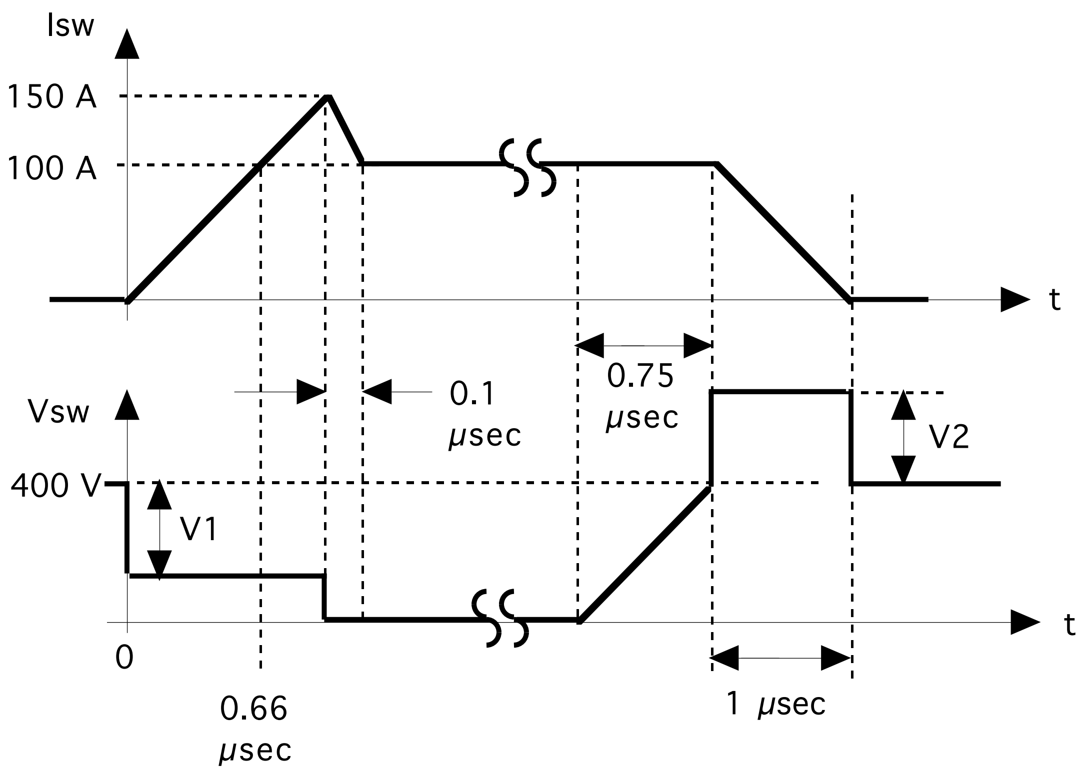
c. Does the switch require any snubbers to protect it? Specify the type or types needed, if any.

d. Design a snubber to limit the peak switch voltage to 600 V.

S27.9. Consider the stepdown converter shown below. Specifications for the switch and free-wheeling diode are included below. The voltage and current waveforms for the switch Sw are also shown.



Quantity	Sw	Df
Maximum voltage [V]	600	700
Maximum current [A]	175	200
$R_{\theta ja}$ [°C/W]	5	4
$T_{j,max}$ [°C]	150	175
dV/dt max. [V/μsec]	100	200
dI/dt max [A/μsec]	800	900



a. Estimate the magnitudes of the voltages V1 and V2 shown in the waveforms.

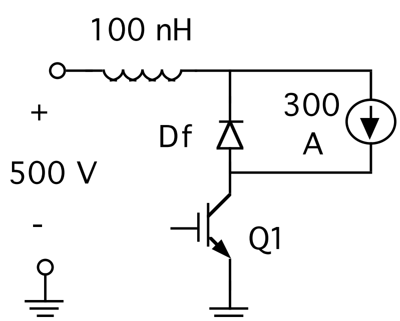
b. Sketch and dimension the voltage Vdf across the diode.

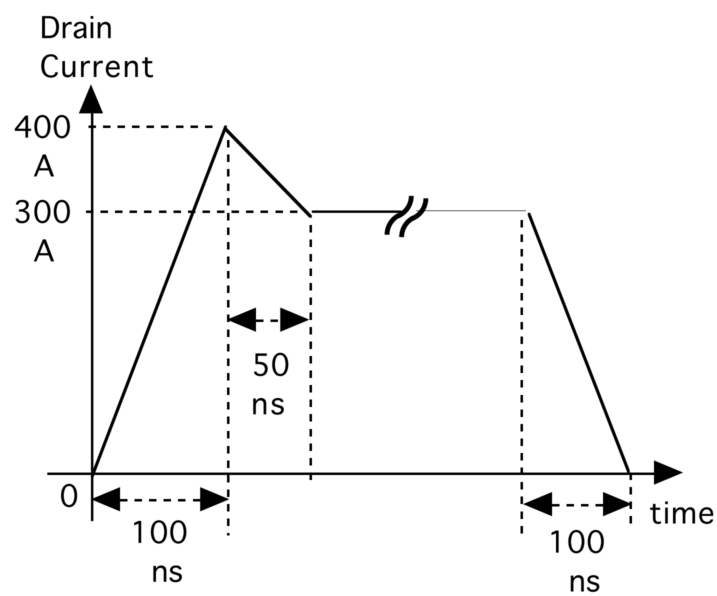
c. Does either the switch or the diode require a snubber? Justify your answer.

d. Design a snubber for the diode Df.

S27.10. Consider the IGBT-based step down converter shown below. Important specifications for the diode and the IGBT are given below. The drain current of the IGBT as a function through one complete turn-on and turn-off sequence is also shown below.

<u>IGBT Data</u>	<u>Df data</u>
$V_{DS,max} = 700$ V	$V_{RM} = 800$ V
$I_{D,max} = 400$ A	$I_{max} = 400$ A
$T_{j,max} = 150$ °C	$T_{j,max} = 150$ °C
$R_{\theta,ja} = 1$ °C/W	$R_{\theta,ja} = 1$ °C/W
$R_{on} = 0.01$ ohms	$R_{on} = 0.005$ ohms





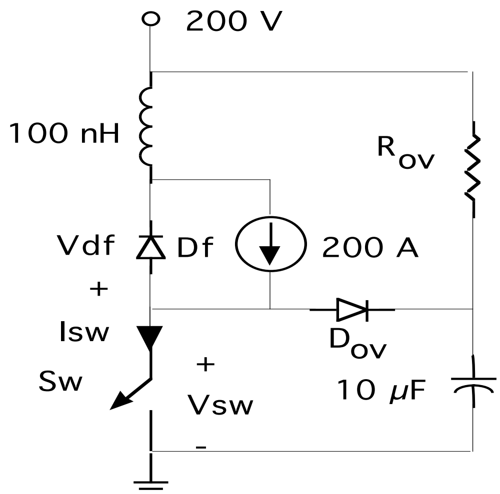
a. (Sketch and dimension the drain-source voltage of Q1 as a function of time. You may assume that the voltage across the MOSFET can change instantaneously and is only limited by the external circuit.

b. Sketch and dimension the diode voltage as a function of time.

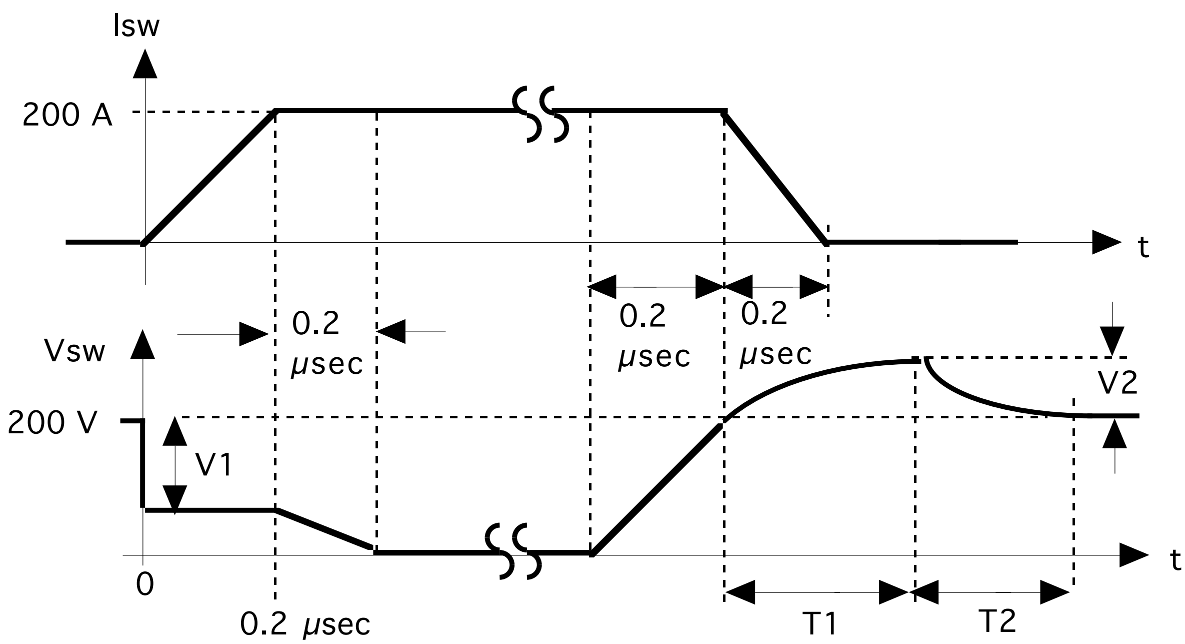
c. Are either the diode or the IGBT overstressed with respect to voltage? If so, specify by how much?

d. Design an overvoltage snubber that will limit the maximum voltage across the IGBT to 550 V. Show the circuit topology of the snubber and specify component values. The switching frequency is 20 kHz and the duty cycle is 50%.

S27.11.



Consider the stepdown converter shown to the left. An overvoltage snubber is included in the circuit. The voltage and current waveforms for the switch Sw are shown below.



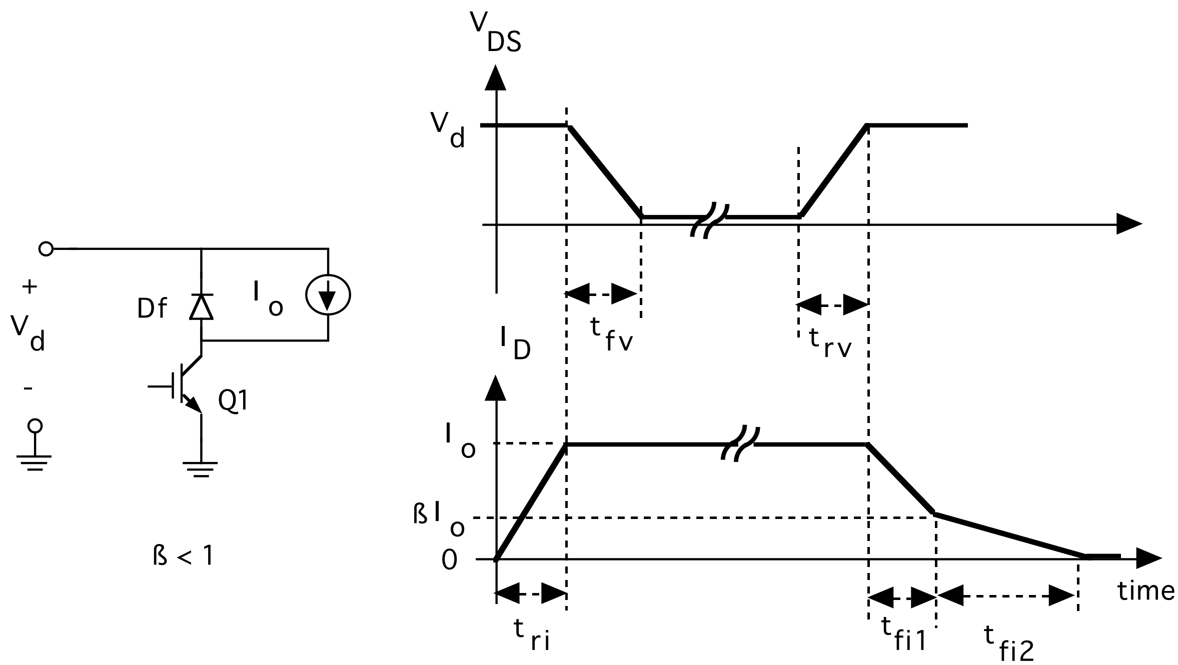
a Estimate the voltages V1 and V2.

b. Estimate the time T1 it takes for the switch voltage to reach its peak off-state value.

c. The converter is to operate at a frequency of 20 kHz at a maximum duty cycle of 50%. Choose a value for R_{ov} which is compatible with this requirement.

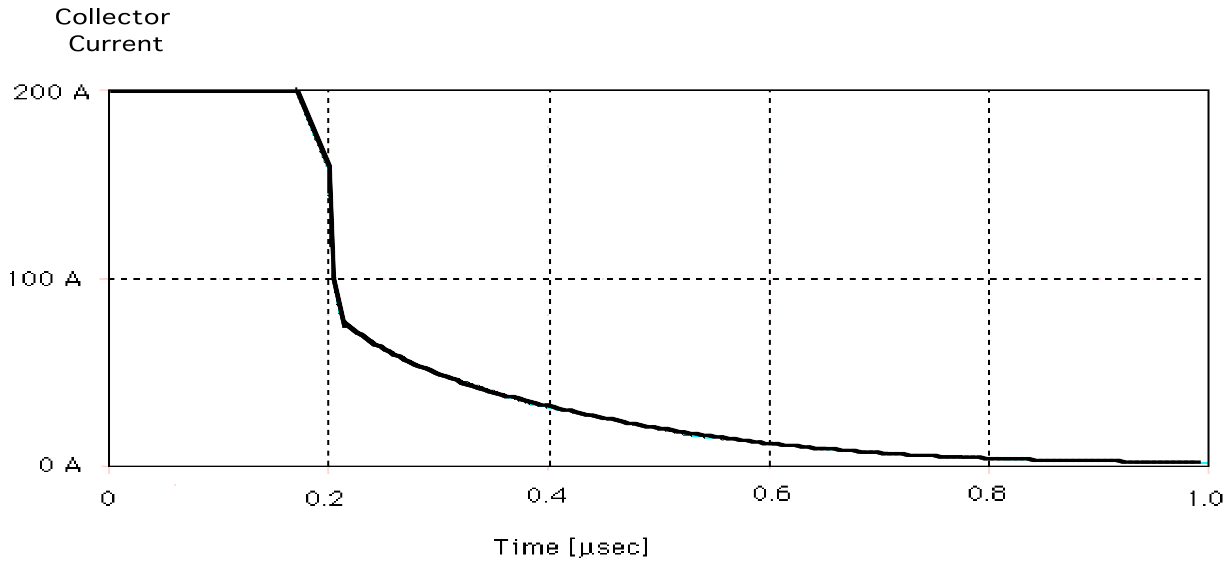
d. Estimate the reduction in switching losses (not on-state losses) caused by the presence of the overvoltage snubber. Your answer should be expressed in watts. Assume a switching frequency of 20 kHz.

S27.12. Consider the stepdown converter using an IGBT which is shown below. The hard-switched (no snubbers) waveforms are also shown.

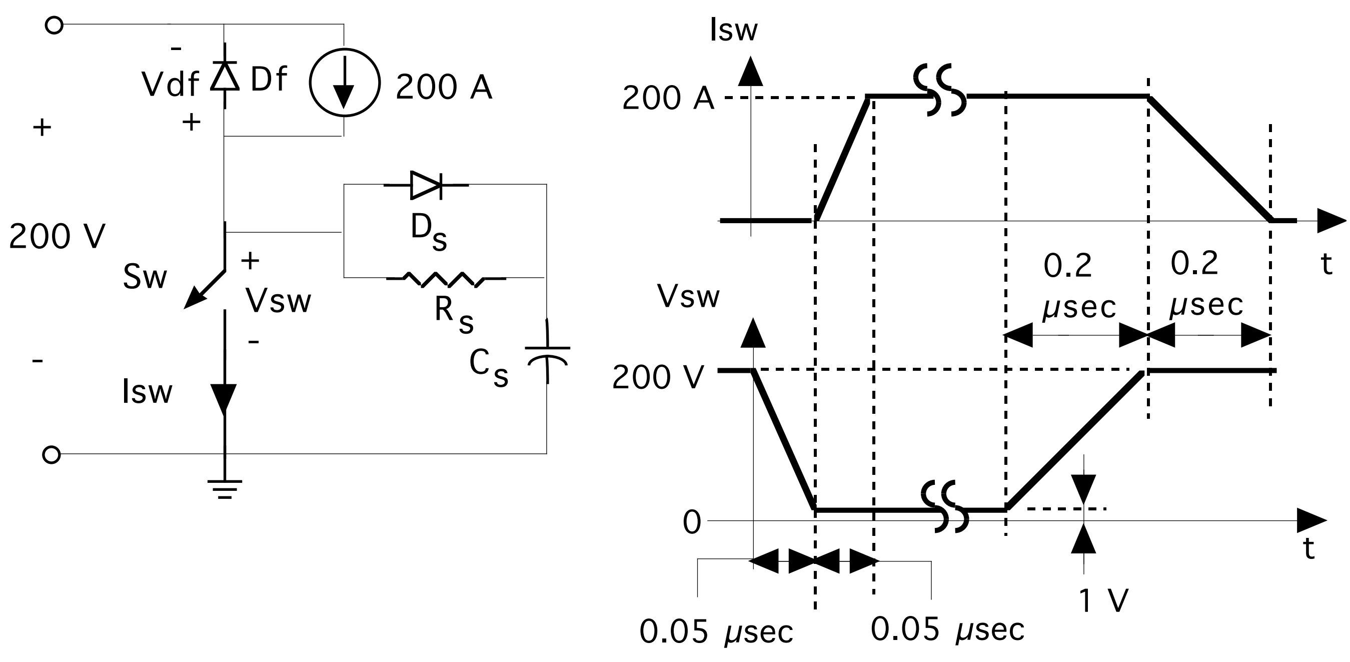


a. The current tailing at turn-off causes excessive switching losses. A turn-off snubber would normally be used to control these losses. However the normal turn-off snubber design procedure does not consider current tailing. Modify the conventional turn-off snubber design procedure to take into account current tailing and derive a modified formula for the turn-off snubber capacitor value.

b. Shown below is the turn-off portion of the drain current of an IGBT in a stepdown converter circuit. The circuit is powered by a V_d = 400 V. Use the results of part (a) to come up with a value for a turn-off snsubber capacitor. If you are unsure that you did part (a) correctly, then use the standard design procedure.



S27.13. A stepdown converter is shown below along with the switch current and voltage waveforms. The current rise and fall times are unaffected by the presence of the snubber. The freewheeling diode is ideal (no reverse recovery current). The switching frequency is 50 kHz.

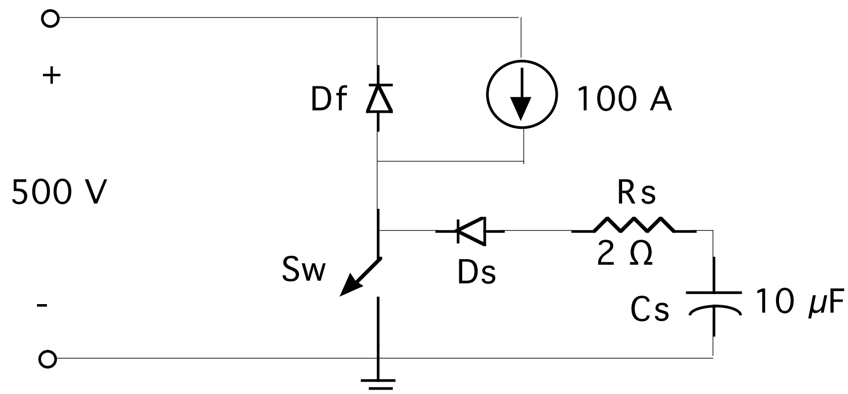


a. What should be the value of the snubber capacitor C_s?

b. Choose the value of the snubber resistance R_s. The duty cycle of the converter can be as large as 75%.

c. Estimate the average power dissipated in the switch and in the snubber resistor. You may assume that the snubber reduces the turn-off losses in the switch by a factor of six compared to the same losses without the snubber.

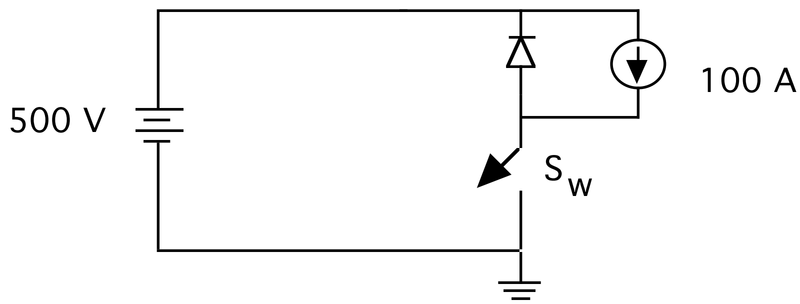
S27.14. Consider the stepdown converter shown below. The switching frequency is 100 kHz and the duty cycle can range from 40% to 80%. The snubber (composed of Ds, Rs, and Cs) shown with the converter does not operate properly. List what is wrong with the snubber and what corrective action is required. Be quantitative where possible. There are multiple errors in the design of the snubber. The switching times of the switch Sw are $t_{ri} = t_{fv} = t_{fi} = t_{rv} = 200$ nsec.

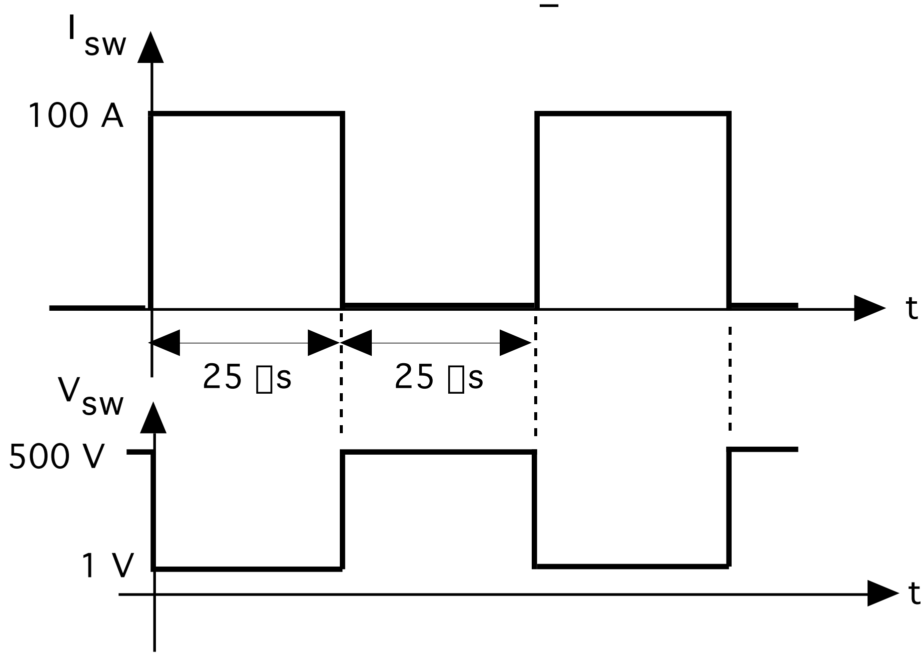


- R_s pwr rating = 75 W
- D_s breakdown voltage rating = 250 V

Chapter 29 - Component Temperature Control and Heat Sinks

S29.1. A step-down converter is shown below along with the switch current and voltage waveforms. The switch has a maximum junction temperature, $T_{j,max}$ =150 °C and a junction-to-case thermal resistance $R_{\theta jc}$= 1 °C/W.





a. How much power is dissipated in the switch?

b. The converter operates in an ambient of 30 °C and the switch is mounted on a heatsink. Specify the value of thermal resistance that the heatsink should have.

c. Specify the required surface area A of the heatsink. Assume $d_{vert} = \sqrt{A}$ and make any other reasonable approximations to simplify the calculations.

S29.2. A power electronic converter requires a semiconductor switch that will dissipate 20 watts of power. The converter will operate in ambient temperatures as large as $T_a = 40$ °C. Three devices are available which have the thermal characteristics listed below.

Device A $T_{j,max} = 175$ °C ; $R_{\theta jc} = 2.5$ °C/W
Device B $T_{j,max} = 150$ °C ; $R_{\theta jc} = 0.5$ °C/W
Device C $T_{j,max} = 125$ °C ; $R_{\theta jc} = 0.4$ °C/W

a. The space available for a heatsink is limited, so the size (area) of the heatsink should be minimized. Choose the device (A, B, or C) that requires the smallest heatsink. Justify your choice.

b. Specify the required heatsink area. Assume $d_{vert} = \sqrt{A}$ and that the heatsink is made from black anodized aluminum (emissivity = 0.9). Make any other reasonable approximations to simplify the calculations.

S29.3. A power electronic converter uses an IGBT with specifications given below. In this converter, the power dissipated in the IGBT is given by

$P_{diss} = 10 + 10^{-3} f_s$ [W] where f_s is the switching frequency.

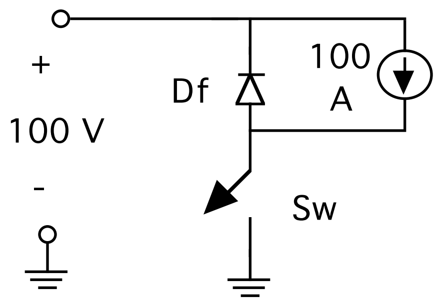
IGBT Data: $R_{\theta jc} = 1$ °C/W ; $R_{\theta ja} = 5$ °C/W ; $T_{j,max} = 150$ °C

a. Assume that the maximum ambient temperature $T_a = 40$ °C. What is the largest switching frequency the IGBT can be operated at without a heat sink?

b. It is desired to operate the converter at a switching frequency of 40 kHz. This requires a heat sink in order to safety dissipate the increased switching losses. Specify the required value of the thermal resistance, $R_{\theta sa}$, of the heat sink.

c. Assume $R_{\theta sa} = 2.5$ °C/W and model the heat sink as a cube of side d. What should be the value of the side d?

S29.4. The step down converter shown below is operating a a switching frequency of 50 kHz and a duty cycle of 40%. The diode Df is ideal and switch characteristics are listed below. The voltage and current waveforms for the switch Sw are also shown below.

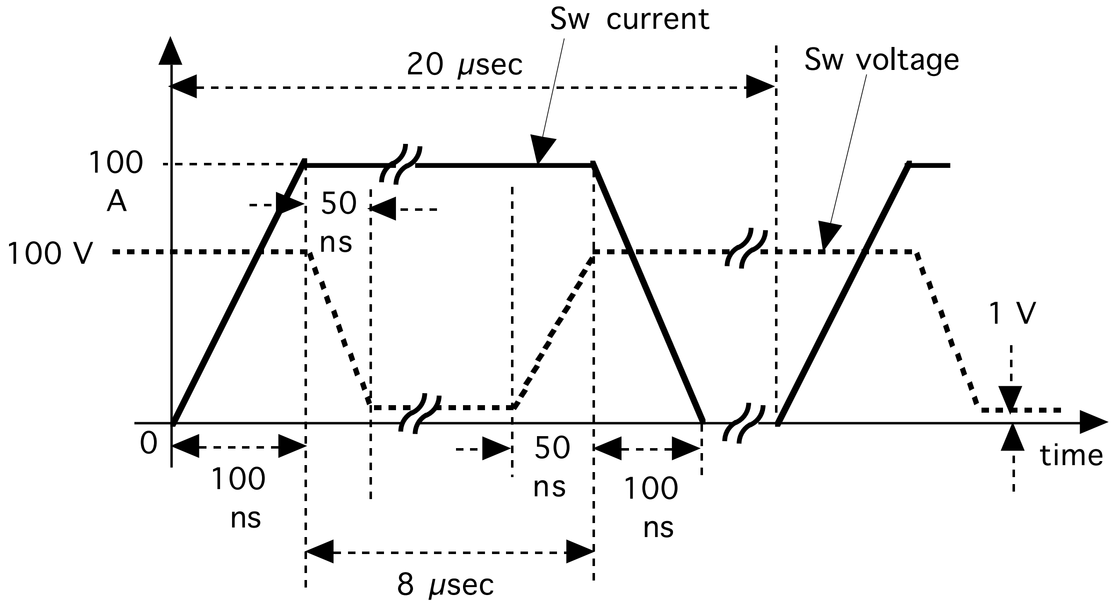


<u>Sw characteristics</u>

$R_{\theta jc}$ = 0.3 °C/W ; jc = junction-to-case

$R_{\theta ja}$ = 2 °C/W ; ja = junction-to-ambient

$T_{j,max}$ = 175 °C



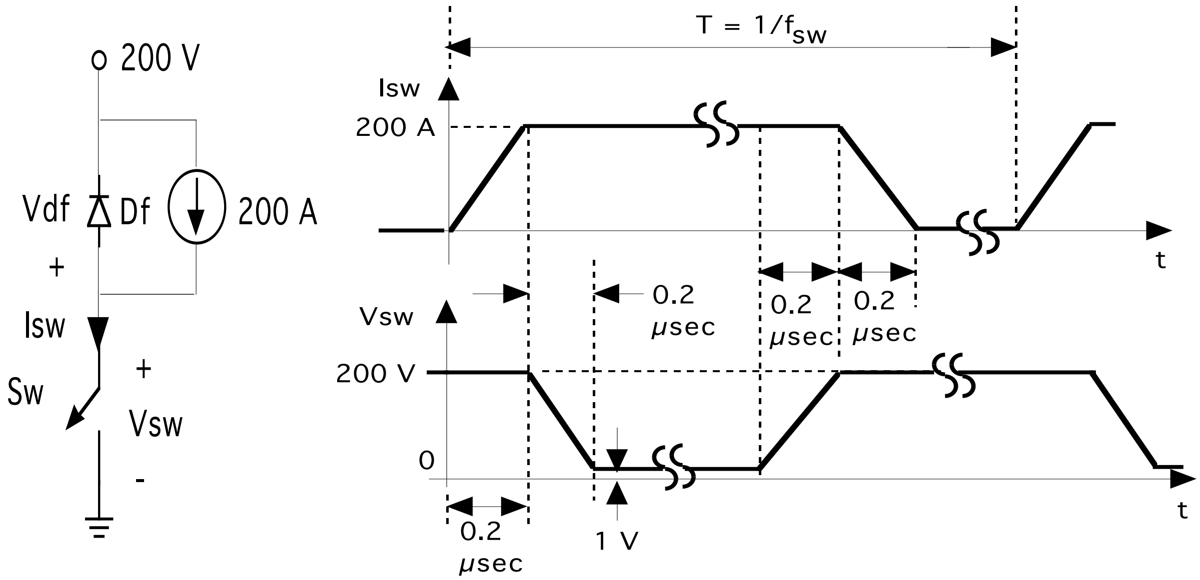
a. How much power is dissipated in the switch?

b. Show quantitatively that a heat sink is needed for the switch. Specify the required thermal resistance, $R_{\theta,sa}$, of the heat sink. Assume an ambient temperature of 30 °C.

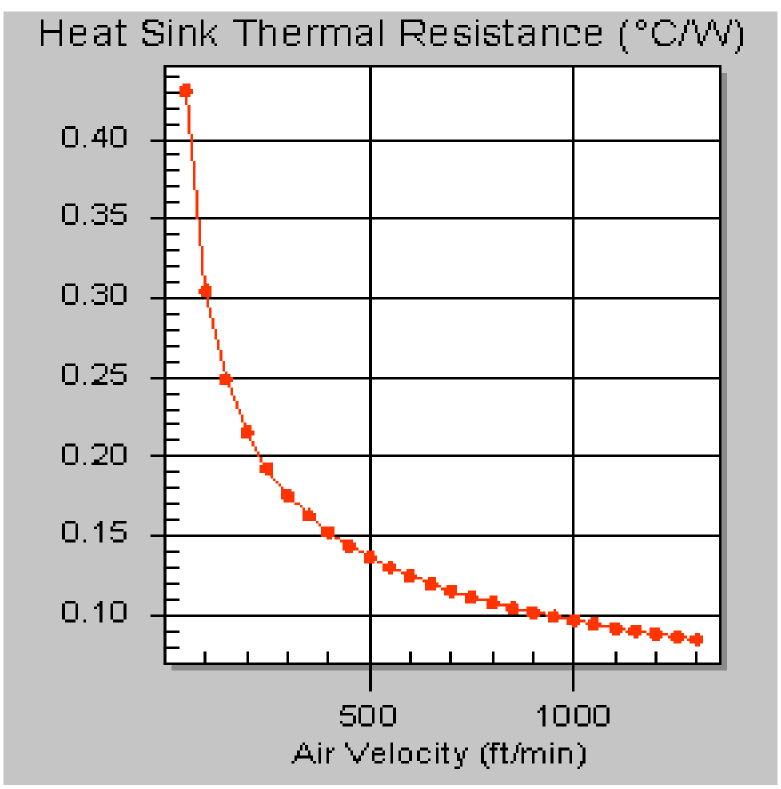
c. Assume $R_{\theta,sa}$ = 1 °C/W. Approximately estimate the required surface area of the heat sink.

S29.5. Consider the stepdown converter show below. The current and voltage waveforms for the switch are also shown.

a. The switch has a junction-to-case thermal resistance $R_{\theta,jc}$ = 0.1 °C/W. The switch is to be mounted on a heat sink with a sink-to-ambient thermal resistance $R_{\theta,sa}$ = 0.3 °C/W. Estimate the junction temperature of the switch if the ambient temperature is 30 °C, the switching frequency is 10 kHz, and the duty cycle is 50%.



b. The switching frequency must be increased to 22 kHz (keeping the duty cycle at 50%) and hence the power dissipation in the switch will increase. A fan is available to blow air over the heat sink and thus increase its cooling capability. The variation of $R_{\theta,sa}$ with air speed is shown below. Estimate the air flow rate the fan must produce if the junction temperature in the switch must not exceed 120 °C when the ambient is 30 °C?

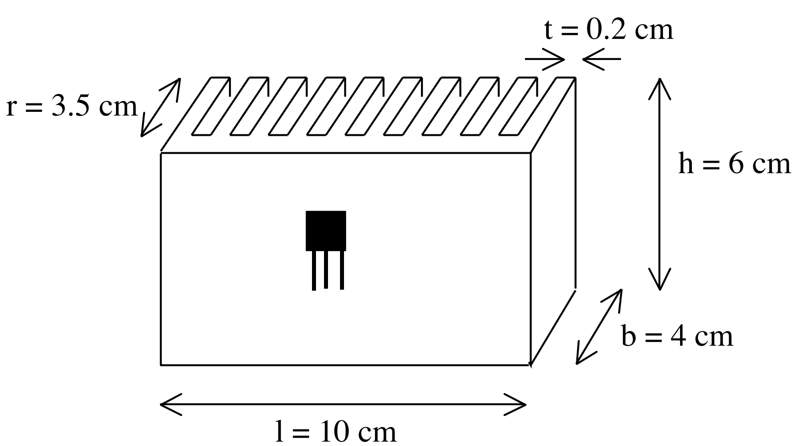


S29.6. An n-channel power mosfet, a VMO 400-02F made by IXYS, is to be used in a converter. The mosfet is to conduct 300 amps of current when on and the switching frequency is 10 kHz with a 50% duty cycle. The internal junction temperature is not to exceed 100 °C and the maximum temperature will not exceed 35 °C.

a. Specify the thermal resistance of the required heat sink. Assume only conduction losses in the on-state contribute to the temperature rise and ignore switching losses.

b. Find a commercially available heat sink that will meet the requirements. Include not only the company (such as Aavid Thermal Technologies, Inc.) that makes the heat sink and part number but also a specification sheet for the heat sink that shows that the required thermal resistance is meet by the part you choose. Note the air flow requirements if forced air cooling is necessary.

S29.7 As shown on the figure, a transistor is mounted on a heat sink. The thickness of the cooling fins is constant along the entire length, and the spacing between the fins is equal. In between the transistor and the heat sink there is an insulating layer (not shown on the drawing).



Transistor data:
$T_{j,max}$ = 175 [ºC]
$R_{\theta,jc}$ = 0,6 [ºC/W]

Insulating material data:
T_{max} = 150 [ºC]
$R_{\theta,cs}$ = 0,3 [ºC]

Assume that the entire heat sink has the same temperature level. It is made of a material with an emissivity of 0.8. Ambient temperature is held constant at 20 ºC. The heat sink is freely standing in an optimum orientation.

(a) Draw the thermal equivalent circuit for this figure in a stationary condition, and explain all parameters.

(b) Can it be justified that the entire heat sink is on the same temperature level?

(c) Can the transistor and the insulating layer stand a power loss of 50 W, if one assumes that heat sink temperature is 100 ºC?

(d) What is the resulting thermal resistance from the heat source to ambient air? Assume that the heat sink temperature still is 100 ºC. Take into consideration convection, cooling, and reduction factor.

(e) Which two simplifications are done in the assumptions in (b) and (c)?

(f) What is the temperature on the transistor and insulating layer if one cannot do these simplifications? (This question demands some work)

Chapter 30 - Design of Magnetic Components

S30.1. An inductor is to be designed to meet the following specifications.L = 4 millihenries ; I_{rms} = 2 A sinewave ; f = 200 kHz ;T_s = 90 °C and T_a = 30 °C . The inductor is to be fabricated on a double-E core made from 3F3 ferrite. The windings are be made with foil conductors which have k_{cu} = 0.6. A core size of a = 2 cm is chosen for the design.

a. Show that the allowable power dissipation density, P_{sp}, in the inductor is $P_{sp} \approx$ 100 mW/cm^3. You may assume the emissivity E of the surface of the completed inductor equals 0.9 and that the vertical height is 3a.

b. Determine the conductor cross-sectional area, A_{cu}, and number of turns N. Ignore eddy currents and the proximity effect.

c. Specify the length of the airgaps in the core. Assume four distributed airgaps.

S30.2. A transformer is needed for a converter. The specifications for the transformer are listed below.

I_{pri} = 9 A rms ; V_{pri} = 500 V rms ; turns ratio = 4 = N_{pri}/ N_{sec} ; waveform = sinwave ; frequency = 100 kHz ; maximum ambient temperature = 40 °C ; maximum surface temperature on transformer = 100 °C ; transformer to be passively (naturally) cooled.

Another transformer designed for a different application is available which has wound on a double-E core (a = 2 cm) made from 3F3 ferrite. The windings are made from Litz wire with 32 turns in the primary and 8 turns in the secondary. The copper conductor areas are $A_{cu,pri}$ = 2.5 mm^2 and $A_{cu,sec}$ = 10 mm^2. The transformer has a thermal resistance $R_{\theta sa}$ = 2.7 °C/W. Can this transformer be used for the new application? Justify your answer quantitatively. Be neat and organized in your answers.

S30.3. An inductor of 1 mH is to be designed for carrying an rms current of 5 amps. The maximum ambient temperature $T_{a,max}$ = 35 °C and the maximum allowable surface temperature of the inductor is to be105 °C. The windings are to be made of round copper conductors (k_{cu} = 0.6) The inductor surface is to be black with an emissivity of 0.9. Double-E cores made of 3F3 ferrite and having the sizes shown below are available.

Core size (a in cm)	A_cA_w (cm^4)	$R_{\theta sa}$ (°C/W)	J_{rms} (A/mm^2)	B_{ac} (mT)	$k_{cu}A_cA_w J_{rms} B_{ac}$ (joules)
0.5					
1	2.1	9.8	6	240	0.0069
1.5					
2					

a. Needed core parameters are shown in the table for the core size a = 1 cm and for round copper conductors. Compute and fill in the corresponding parameters for the the rest of the core sizes in the table.

b. What is the most appropriate core size (value of a) from the choices listed in the table? Justify your answer quantitatively.

c. For the core size chosen in part b, design the winding by finding the value of the copper conductor cross-sectional area A_{cu} and the number of turns N in the winding.

S30.4. An inductor is needed for a power electronic converter. The design requirements for the inductor are listed below.

Inductance value = 1mH
Operating frequency = 100 kHz
Maximum rms current = 3 A. Waveform is triangular with $I_{peak} = \sqrt{3}\, I_{rms}$
Maximum ambient temperature = 35 °C
Maximum surface temperature = 100 °C

The vertical space above the circuit board on which the inductor is to be mounted is very limited, but the lateral area on the circuit board is unrestricted. Hence the inductor is to be designed as a so-called planar inductor or matrix inductor. In essence, the desired inductance is realized by the series connection of N smaller inductor sections. Each inductor section is significantly smaller in the vertical dimension than an inductor of the desired value wound on a single core.

In this problem you will design a planar inductor composed of N = 10 inductor sections. Each section will use a double-E core made from 3F3 ferrite and wound with round copper conductors (k_{cu} = 0.6). Skin effects and proximity effects in the winding can be neglected.

a. Determine the core size which is required for the inductor sections by finding the value of the scaling dimension a.

b. What is the cross-sectional area, A_{cu}, of the copper conductor and how many turns N_w are there in the winding of an inductor section?

c. What is the length of the airgap in the inductor section? Assume 4 distributed gaps in each core.

S30.5. An inductor is to be designed to meet the following specifications. L = 1 millihenry ; I_{rms} = 3 A sinewave ; f = 200 kHz ;T_s = 90 °C and T_a = 30 °C . The inductor is to be fabricated on a double-E core made from 3F3 ferrite. The windings are to be made with copper foil conductors whose thickness is one skin depth and which have k_{cu} = 0.6. The only core size available is a = 2 cm. Some useful nformation is listed below.

$P_{c,sp} = 1.5\text{x}10^{-6}\ f^{1.3}\ [B_{ac}]^{2.5}$ mW/cm^3 ; f in kHz and B in mT

$P_{w,sp} = k_{cu}\ \rho_{cu}\ (J_{rms})^2$; ρ_{cu} at 100 °C = 2.2x10^{-8} ohm-m

Characteristic	Relative Size
Core area A_{core}	1.5 a^2
Winding area A_w	1.4 a^2
Area product AP = $A_w A_c$	2.1 a^4
Core volume V_{core}	13.5 a^3
Winding volume V_w	12.3a^3
Total surface area of assembled core and winding	59.6 a^2

a. Show that this core can be used to make the inductor. You may assume that the surface-to-ambient thermal resistance $R_{\theta,sa}$ of inductors wound on double-E cores is given approximately by $R_{\theta,sa} \approx 600/A$ °C/W where A is the surface area in cm^2.

b. Approximately estimate the number of turns N and conductor area A_{cu} required for the inductor. What percent of the winding window is occupied with conductors?

S30.6. A transformer is needed for a power electronic application at a switching frequency of 300 kHz. The maximum primary voltage, V_{pri} = 200 V rms (sinewave), and the corresponding primary current I_{pri} = 5 A rms (sinewave). The only available core is a double-E core made from 3F3 ferrite. The core has the scaling dimension a = 1 cm. The transformer is to operate in an ambient temperature as high as 40 °C and the surface temperature of the transformer is not to exceed 100 °C.

a. The application requires that the maximum secondary voltage V_{sec} = 2000 V rms (sinewave). Show that the core can be used for this transformer. Assume windings made from round copper conductors with k_{cu} = 0.6. You may assume eddy currents and proximity effects can be neglected.

b. Specify the number of primary (N_{pri}) and secondary (N_{sec}) turns required and the conductor cross-sectional areas A_{pri} and A_{sec}.

c. Does the transformer have any overcurrent capacity? Briefly explain without going into extensive calculations.

S30.7. The molybemum-permalloy powder core shown below is to be used for fabricating an inductor which is to carry a maximum ac current of 2 A rms at a frequency of 100 kHz. The inductor must operate in ambient temperatures as high as 35 °C and the surface temperature of the inductor should not exceed 90 °C. You are to estimate the maximum inductance that can be achieved with this core. The core losses are given as $W = 0.07f^{1.6}B^{2.3}$ where W is the loss in watts per pound, the frequency f is in kHz, and the flux B is in kilogauss. The density of the core material is 8.5 g/cm^3. Since the core is made from a powder, it effectively has a distributed air gap and rather than speaking of an air gap length, it is common practice to refer to an effective magnetic permeability for the core.

The various parts of the problem specified below will take you through the basic steps to estimate the maximum inductance, in essence compiling the core "database" as is done in the text for a double E core.

a. Estimate the core area A_c and winding window area A_w. Assume that a clearance hole of diameter ID/2 where ID is the inner diameter of the core, must be left in the middle of the winding window so that the winding could be done by machine.

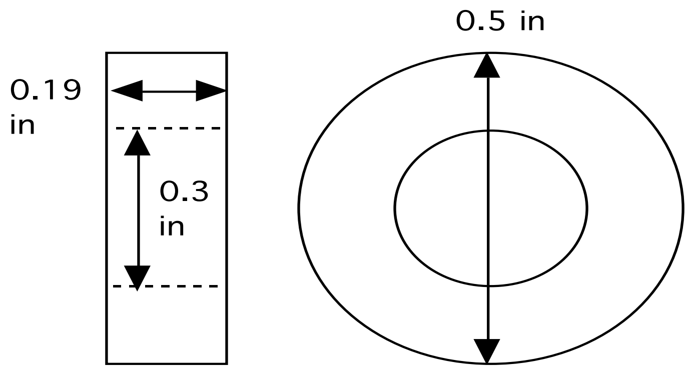
b. Estimate the core volume V_c, the winding volume V_w, and the surface area of the assembled inductor.

c. Estimate the thermal resistance from surface to ambient of the assembled inductor.

d. Estimate the maximum values of flux density and current density.

e. Estimate the maximum inductance.

f. Specify the required effective permeability of the core so that the maximum current generates the maximum flux density.



S30.8. A transformer is needed which has the following specifications:
Vpr = 50 V rms, Ipri = 5 A rms Vsec = 10 V rms, Isec = 25 A rms Freq. = 40 kHz
For simplicity assume the waveforms are sinewaves for voltage and current.
Ts = 65°C, Ta = 35°C

A U33/22/9 U-core made from 3F3 ferrite is available. Is this core suitable for this transformer application. Assume kcu = 0.3.Justify your answer by quantitative calculations. A simple yes/no guess is not acceptable.

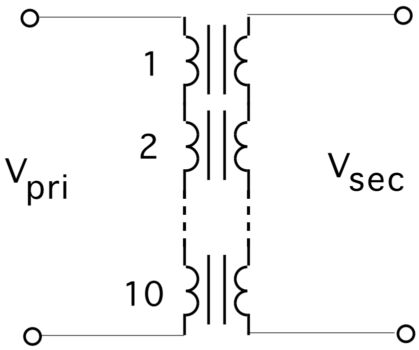
S30.9. A transformer with a step-down ratio 5:1 is to be fabricated using a double-E core with a = 0.5 cm and made from a ferrite having a specific loss given by $P_{sp,core} = 1x10^{-6} f\ B^2$ [mW/cm^3] with f in kHz and B in mT. The transformer is to operate at a frequency of 100 kHz (assume the waveform is a sinewave) with a maximum temperature differential $\Delta T = T_s - T_a = 30$ °C. Leitz wire ($k_{cu} = 0.3$) is used for the windings. The smallest available Leitz wire bundle has an area of $2x10^{-5}$ cm^2. The minimum number of turns is one. Useful information about the double-E core is shown below.
You may assume $R_\theta = 1/[hA_s]$ where h is the heat transfer coefficient and A_s is the surface area. h = 10 W/[m^2-°C] ; ρ_{cu} at 100 °C = $2.2x10^{-8}$ ohm-m

Characteristic	Relative Size
Core area A_{core}	1.5 a^2
Winding area A_w	1.4 a^2
Area product AP = $A_w A_c$	2.1 a^4
Core volume V_{core}	13.5 a^3
Winding volume V_w	12.3a^3
Total surface area of assembled core and winding	59.6 a^2

a. Estimate the maximum allowable current density J_{rms} in the winding and peak ac core flux density B_{ac}.

b. What is the maximum output current (base-to-peak) that the transformer can be designed to produce?

S30.10. A transformer having the specifications listed below is needed for a power electronics converter.



V_{pri} = 50 V rms ; I_{pri} = 100 A rms
V_{sec} = 500 V rms ; I_{sec} = 10 A rms
Switching frequency f_{sw} = 200 kHz
Sinewave waveform
T_A = 40 °C ; $T_{surface}$ = 100 °C

The transformer is to be wound on E-cores made from 3F3 ferrite. The specific core loss of 3F3 is given by $P_{sp,core} = 1.5x10^{-6}\ f^{1.3}\ B^{2.5}$. However instead of using a single E core, the transformer is to made from 10 smaller E cores connected in series as above to make up the complete transformer. Litz wire (k_{cu} = 0.3) is used for the windings so that eddy currents and proximity effects can be neglected. This so-called distributed or matrix transformer has advantages with respect to overall size and weight. A table summarizing E-core characteristics is given below. The thermal resistance of the core $R_{\theta,sa} = 1/(hA_s)$ where h = 10 W/(°C-m^2) and A_s = surface area of completed core plus winding.

Characteristic	**Relative Size**
Core area A_{core}	$1.5\ a^2$
Winding area A_w	$1.4\ a^2$
Area product AP = A_wA_c	$2.1\ a^4$
Core volume V_{core}	$13.5\ a^3$
Winding volume V_w	$12.3a^3$
Total surface area of assembled core and winding	$59.6\ a^2$

a. Show that a core with a = 8 mm can be used.

b. Specify the number of primary and secondary turns needed on each of the ten cores.

c. Specify the cross-sectional areas of the primary and secondary conductors.

S30.11 Table 30-3, page 762 in "*Power Electronics*", illustrates a database of core characteristics for a double E-core with; a = 1cm, f = 100kHz, T_s = 100°C, and T_a = 40°C.

Use optimum dimensions, and create corresponding databases with:

(a) a = 1.25 cm

(b) a = 1.5 cm

(c) a = 1.75cm

(d) a = 2.0 cm

Develop a corresponding table, like table 30-3 (page 762), for each of the above a-values. Include in the table AP, $R_{\square}$, P_{sp} J_{rms}, B_{as} and the design product.

S30.12. An inductor to be designed with the following design inputs:

$L = 0.5mH$

$\hat{I} = 8.49A$ (sinusoidal current)

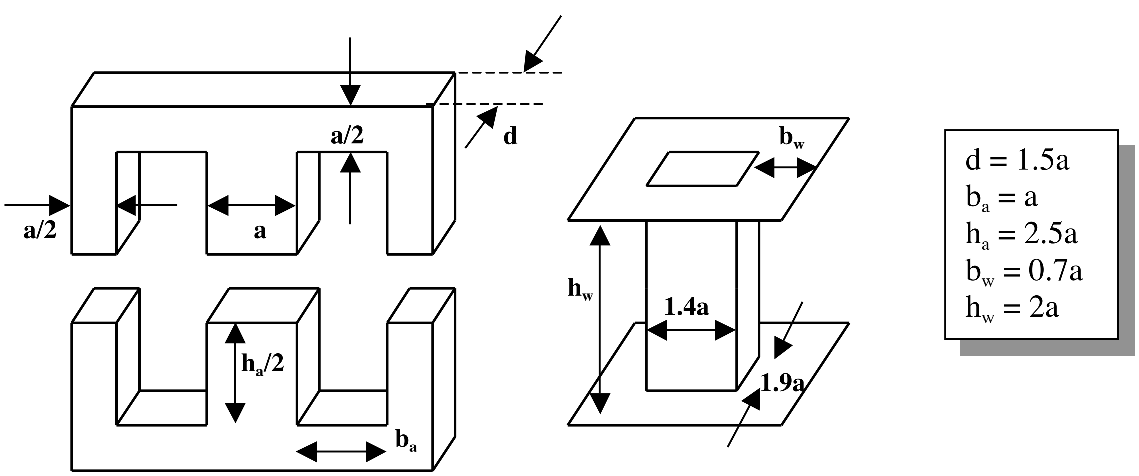
$I_{rms} = 6A$

$Frequency = 100kHz$

$T_a = 40°C$

$T_s = 100°C$

Because of lowest eddy current loss at high frequencies like 100kHz, a *Litz Wire* will be used, and it results in a copper fill factor of 0.3.



(a) Which core material should be used, and why?

The task is to design the coil.
The inductance of the coil must be within +/- 10 % of the design goal.

(b) Find the size of the core that can be used on the basis of $LI_{rms}\hat{I}$.

(c) Calculate $\hat{B}$, J_{rms}, A_{cu}, and N (number of turns).

(d) Find the inductance and the air gap of the coil.

$$\sum g \approx \frac{A_{core}}{\dfrac{A_{core}\hat{B}_{core}}{\mu_0 N\hat{I}} - \dfrac{a+d}{N_g}},$$

,use $N_g = 4$, $\mu_0 = 4\pi 10^{-7}$

(e) If the criterion is not fulfilled, which adjustments can be done?