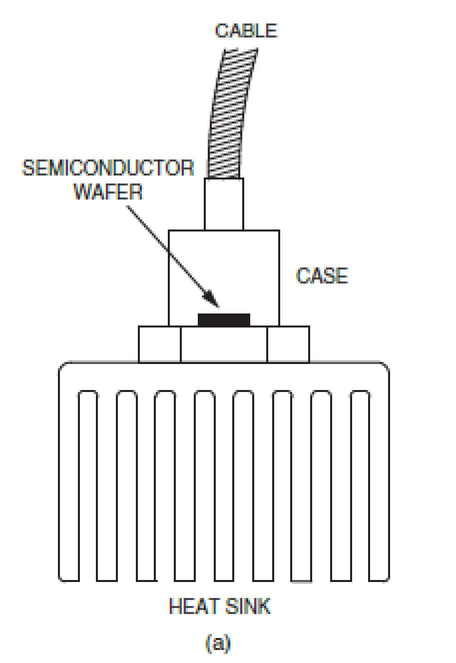
Power Electronics

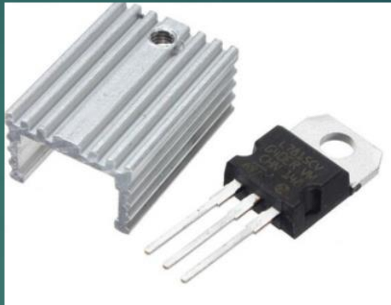
EE312


بسم الله الرحمن الرحيم

CLO4	Evaluate the gate driver circuits, thermal design, snubber circuits, and performance of AC-AC converters.	PLO02	Cognitive	5. Evaluate

Supplementary Components and Systems





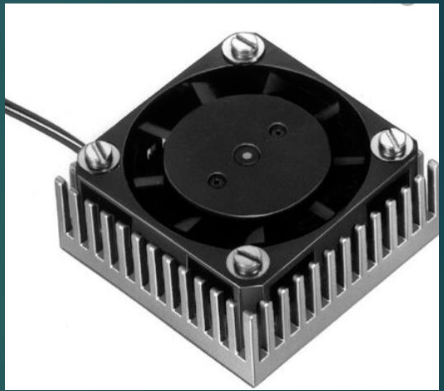
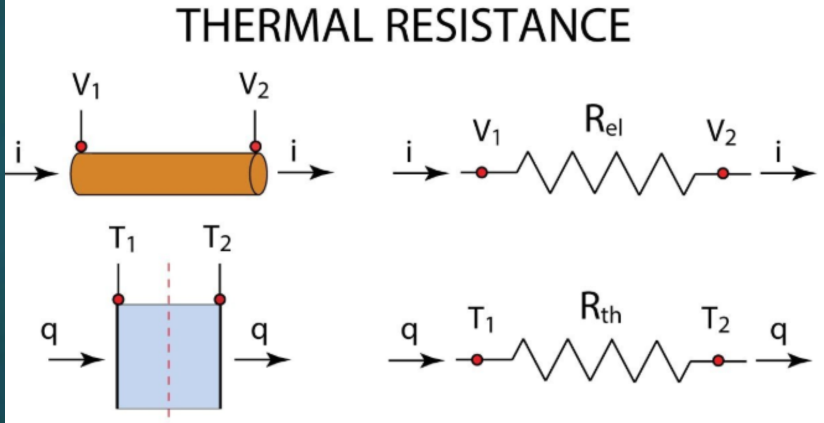
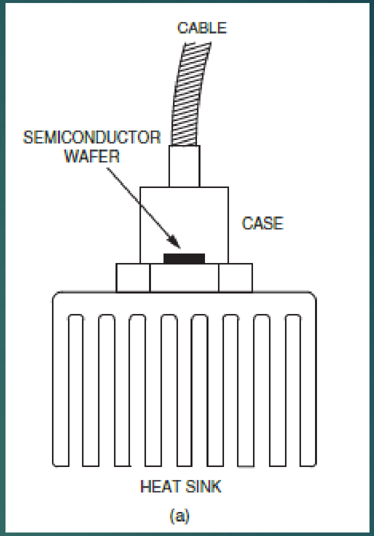


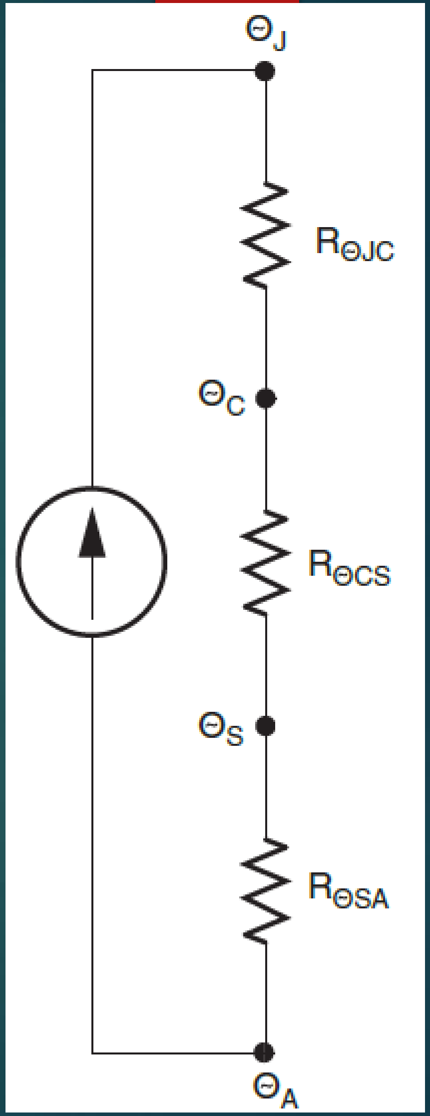
Table 3.1 Comparison of Thermal and Electrical Quantities

Thermal Quantity	*Electrical Quantity*
Amount of heat (energy), Q (J)	Electric charge, Q (C)
Heat current (power), P (W)	Electric current, I (A)
Temperature, Θ (°K)	Electric voltage, V (V)
Thermal resistance, R_Θ (°K/W)	Electric resistance, R (Ω)
Thermal capacity, C_Θ (J/°K)	Electric capacitance, C (F)
Thermal time constant, $\tau_\Theta = R_\Theta C_\Theta$(s)	Electrical time constant, $\tau = RC$ (s)



$$R_{th} = R_\theta = \frac{(T_2 - T_1)}{q}$$





Numerical # 1.

A Power Electronic Switch dissipates 4.7W heat. A heat sink is connected to it for efficient heat removal.

The ambient temperature (room temperature) is 30°C.

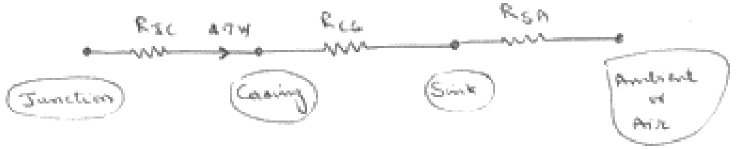
Thermal Resistances from Junction to Case (R_{JC}) from case to sink (R_{CS}) and from sink to ambient (R_{SA}) are:

$R_{JC} = 2.5\ °C/W \qquad R_{CS} = 2\ °C/W \qquad R_{SA} = 9\ °C/W$

Determine ~~maximum~~ ~~allowable~~ junction temperature.

Solution

The three resistances are in series and power flow is 4.7W.



Just like Voltage Difference = V = IR,

Temperature " = T = PR

$\therefore\ T_{SA} = (P)(R_{SA}) = (4.7)(9) = 42.3°C$

$T_{CS} = (P)(R_{CS}) = (4.7)(2) = 9.4°C$

$T_{JC} = (P)(R_{JC}) = (4.7)(2.5) = 11.75°C$

So

$T_{Junction} = T_{Ambient} + T_{SA} + T_{CS} + T_{JC}$

$= 30 + 42.3 + 9.4 + 11.75$

$= 93.45\ °C$

Numerical # 2.

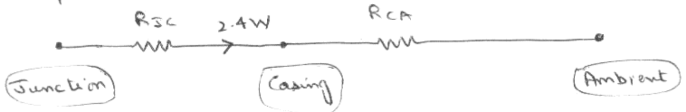
A device dissipates 2.4 Watts of heat. Without heat sink

$R_{JC} = 5.3\ °C/W$ $\quad R_{CA} = 57\ °C/W$ $\quad T_A = 35\ °C$ $\quad T_{J\text{-max-allowable}} = 150\ °C$

Evaluate the necessity of a heat sink for this device. If a heat sink is required, then further determine the value of R_{SA} if $R_{CS} = 4$ C/W

Solution.

To see if heat sink is required or not, calculate T_J.



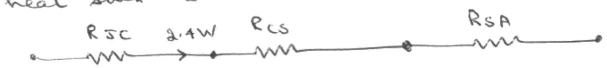
$$T_{JA} = T_J - T_A = P(R_{JA}) = P(R_{JC} + R_{CA})$$

so $T_J = P(R_{JC} + R_{CA}) + T_A = \ldots\ \underline{184.52\ °C}$

$T_J > T_{J\text{-max-allowable}}$

so heat sink is necessary to reduce T_J.

When heat sink is used the thermal model becomes



& the equation is

$$T_J - T_A = P(R_{JC} + R_{CS} + R_{SA})$$

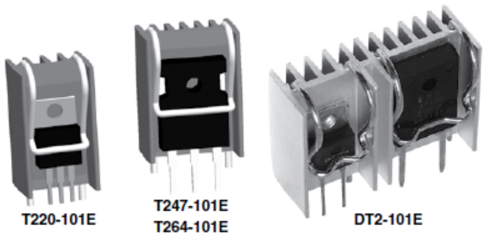
$$150 - 35 = (2.4)(5.3 + 4 + R_{SA})$$

$$R_{SA} = 38.61\ °C/W$$

So actual heat sink should have R_{SA} less than or equal to 38.61 °C/W to keep T_J less than or equal to 150 °C.

W Series Heatsinks

For TO-220, TO-247, and TO-264 devices



The unique design (patent pending) of the W Series heat sinks combines a tin plated, solderable, integral spring clip with an extruded aluminum heat sink body for an all-in-one solution to through-hole mounting of TO-220, TO-247, and TO-264 packages. These self-aligning heat sinks feature solderable feet and an integrated clip with 13.2 (lbf) of force on the center of the device to enhance thermal performance.

FEATURES

- Reduced Assembly Cost: spring clip and auto-align feature makes fasteners and fixtures obsolete, along with stray metal filings from tapped holes
- Maximum Repeatability: clamping force of the spring clip is not degraded by repeated loading and unloading
- Maximum Heat Transfer per Unit Space: maximum surface area per unit volume and consistent mounting force reduces thermal resistance
- Maximum Resistance to Shock and Vibration: light weight, resilient spring clip locks the component in place and is highly resistant to shock and vibration
- Maximum Reliability: helps prevent short circuits by eliminating metal particles from thread tapping
- RoHS Compliant

SERIES SPECIFICATIONS

Heatsink Part Number	For Package Type	Ohmite Resistor Series	Surface Area (in^2)	Weight	Thermal Resistance*
WA-T220-101E WV-T220-101E	TO-220	TBH25, TCH35	6.5	0.35 oz/10g	Rs-a=12°C/W Rs-a=13°C/W
WA-T247-101E WV-T247-101E	TO-247	TEH70, TEH100	8.4	0.42 oz/12g	Rs-a=11°C/W Rs-a=12°C/W
WA-T264-101E WV-T264-101E	TO-264	TFH85	8.4	0.42 oz/12g	Rs-a=11°C/W Rs-a=12°C/W
WA-DT2-101E WV-DT2-101E	TO-220 & TO-247	TBH25, TCH35, TEH70, TEH100	15.1	0.79 oz/22g	Rs-a=7°C/W Rs-a=8°C/W

*Natural convection at 10W heat dissipation

ABB **5SDA 11D1702**

Old part no. DA 807-1110-17

Thermal Parameters			Value	Unit
R_{thjc}	Thermal resistance junction to case	double side cooling	40	K/kW
		anode side cooling	65	
		cathode side cooling	104	
R_{thch}	Thermal resistance case to heatsink	double side cooling	10	K/kW
		single side cooling	20	

STGW39NC60VD

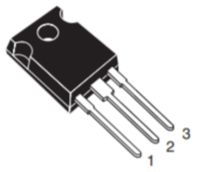
40 A - 600 V - very fast IGBT

Features

- Low C_{RES} / C_{IES} ratio (no cross conduction susceptibility)
- IGBT co-packaged with ultra fast free-wheeling diode

Applications

- High frequency inverters
- UPS
- Motor drivers



TO-247

Figure 1. Internal schematic diagram

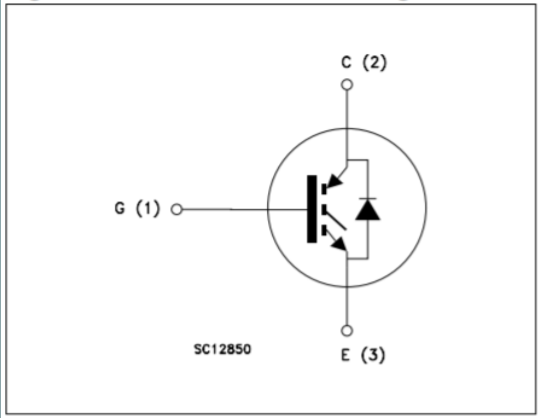


Table 2. Absolute maximum ratings

Symbol	Parameter	Value	Unit
V_{CES}	Collector-emitter voltage (V_{GE} = 0)	600	V
I_C (1)	Collector current (continuous) at 25 °C	80	A
I_C (1)	Collector current (continuous) at 100 °C	40	A
I_{CL} (2)	Turn-off latching current	220	A
I_{CP} (3)	Pulsed collector current	220	A
V_{GE}	Gate-emitter voltage	± 20	V
I_F	Diode RMS forward current at T_C = 25 °C	30	A
I_{FSM}	Surge non repetitive forward current (tp=10 ms sinusoidal)	120	A
P_{TOT}	Total dissipation at T_C = 25 °C	250	W
T_j	Operating junction temperature	– 55 to 150	°C

Table 3. Thermal resistance

Symbol	Parameter	Value	Unit
$R_{thj\text{-}case}$	Thermal resistance junction-case (IGBT) max	0.5	°C/W
$R_{thj\text{-}case}$	Thermal resistance junction-case (diode) max	1.5	°C/W
$R_{thj\text{-}amb}$	Thermal resistance junction-ambient max	50	°C/W

3.2 DRIVERS

1. Interfaces control with the power switch
2. Provides isolation

Table 2.3 Example IGCT and GTOs

Symbol:	5SHY 42L6500	5SHX 19L6020	5SHX19L6010	FG6000AU
Maker:	ABB	ABB	ABB	Mitsubishi
Type:	Asymmetric IGCT	Rev. Cond. IGCT	GTO (disc)	GTO (disc)
V_{DRM}:	6.5 kV	5.5 kV	4.5 kV	6 kV
$I_{T(av)}$:	1.29 kA	0.84 kA	1 kA	2 kA
$I_{T(rms)}$:	2.03 kA	1.32 kA	1.57 kA	3.1 kA
I_{TSM}:	40 kA	25.5 kA	25 kA	40 kA
I^2t:	2.4×10^6 A^{2}s	1.6×10^6 A^{2}s	3.1×10^6 A^{2}s	6.7×10^6 A^{2}s
V_{TM}:	3.7 V	2.9 V	4.4 V	6 V
I_{DRM}:	50 mA	50 mA	100 mA	320 mA
t_{ON}:	4 μs	3.5 μs	100 μs	10 μs
t_{OFF}:	8 μs	7 μs	100 μs	30 μs
I_{GQM}[a]:	3.8 kA	1.8 kA	1.1 kA	2.4 kA
E_{off}[b]:	44 J	11 J	14 J	N/A
Size:	429 × 173 × 41 mm	429 × 173 × 41 mm	85 × 85 × 26 mm	190 × 190 × 36 mm

[a] I_{GQM}, peak turn-off gate current.
[b] E_{off}, turn-off energy per pulse of gate current.

IGCTs
integrated gate commutated thyristor

3.2 DRIVERS

1. Interfaces control with the power switch
2. Provides isolation
3. Minimize turn-on and turn-off times
4. In on state, the driver must provide adequate drive power (e.g. Ib for BJT and Vgs for a MOSFET)

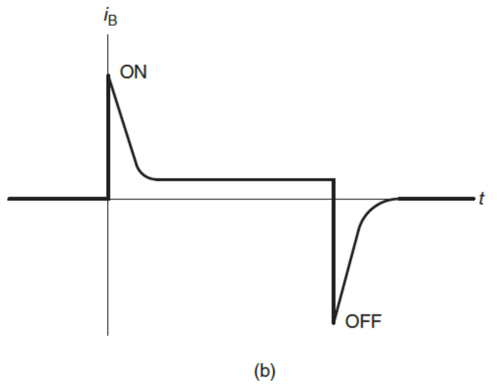


Figure 3.9 Driver for a BJT with optical isolation: (b) waveform of base current.

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Maker:	ABB	ABB	ABB	Mitsubishi
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$I_{T(rms)}$:	2.03 kA	1.32 kA	1.57 kA	3.1 kA
I_{TSM}:	40 kA	25.5 kA	25 kA	40 kA
I^2t:	2.4×10^6 A^{2}s	1.6×10^6 A^{2}s	3.1×10^6 A^{2}s	6.7×10^6 A^{2}s
V_{TM}:	3.7 V	2.9 V	4.4 V	6 V
I_{DRM}:	50 mA	50 mA	100 mA	320 mA
t_{ON}:	4 μs	3.5 μs	100 μs	10 μs
t_{OFF}:	8 μs	7 μs	100 μs	30 μs
$I_{GQM}{}^a$:	3.8 kA	1.8 kA	1.1 kA	2.4 kA
$E_{off}{}^b$:	44 J	11 J	14 J	N/A
Size:	429 × 173 × 41 mm	429 × 173 × 41 mm	85 × 85 × 26 mm	190 × 190 × 36 mm

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IGCTs
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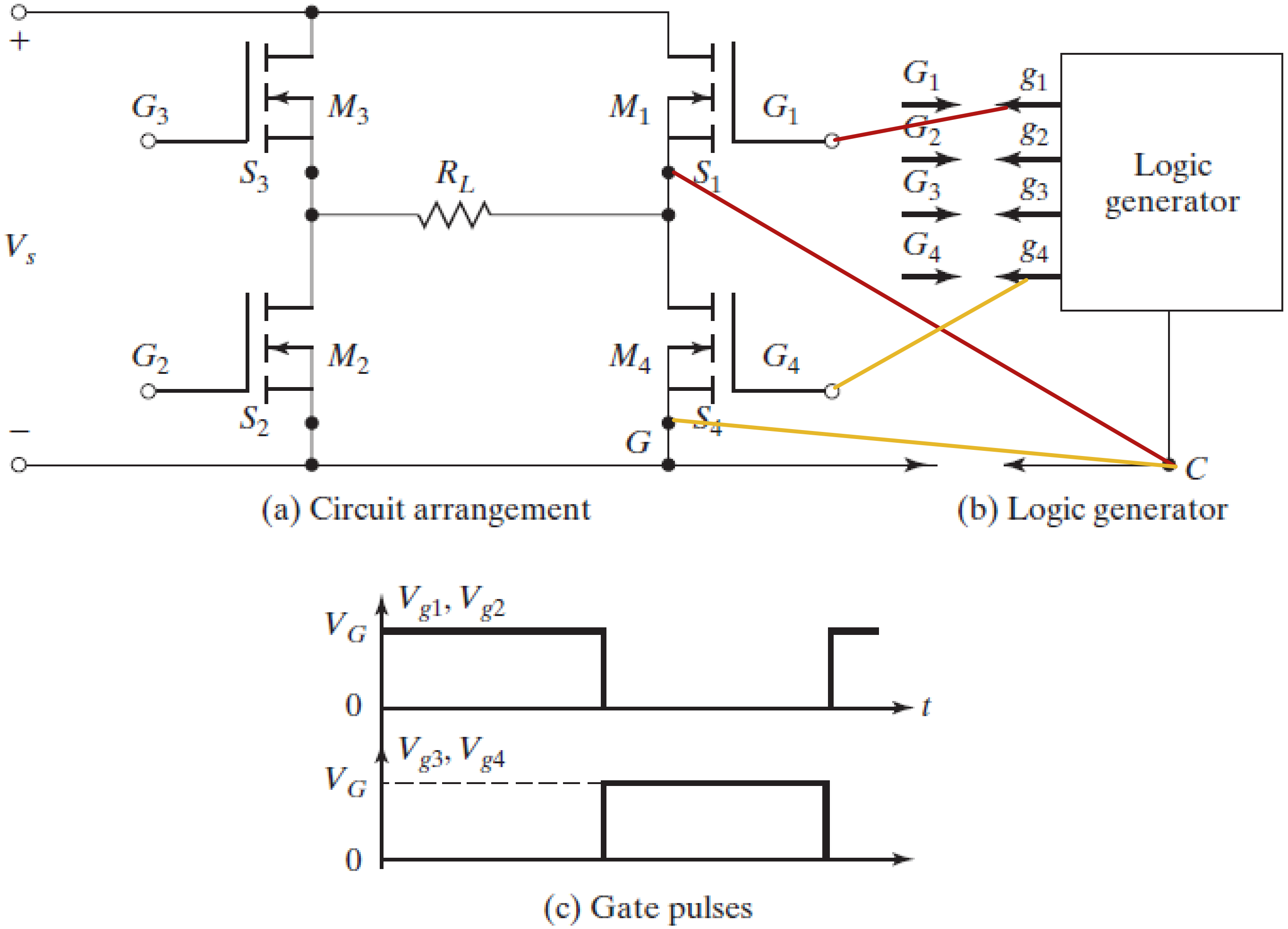


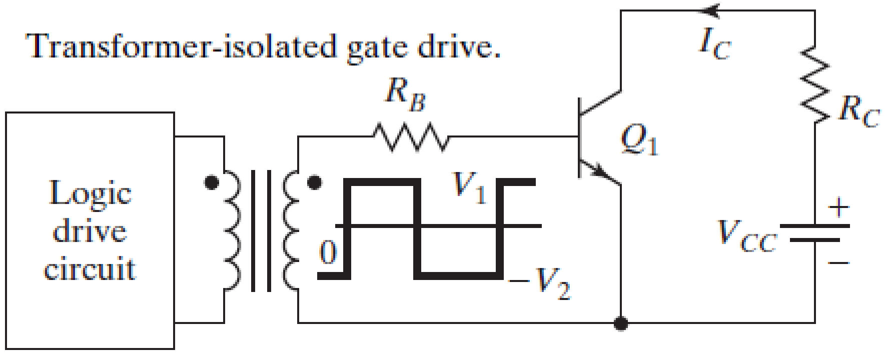
FIGURE 4.67

Single-phase bridge inverter and gating signals.

Pulse Transformers

FIGURE 4.69

Transformer-isolated gate drive.



What is a Pulse Transformer?

Definition: A transformer that is enhanced to produce electrical pulses with high velocity, as well as stable amplitude, is known as a pulse transformer. These are regularly employed while transmitting digital information as well as in transistors, mainly in gate drive circuits.

pulse-transformer

Optocouplers

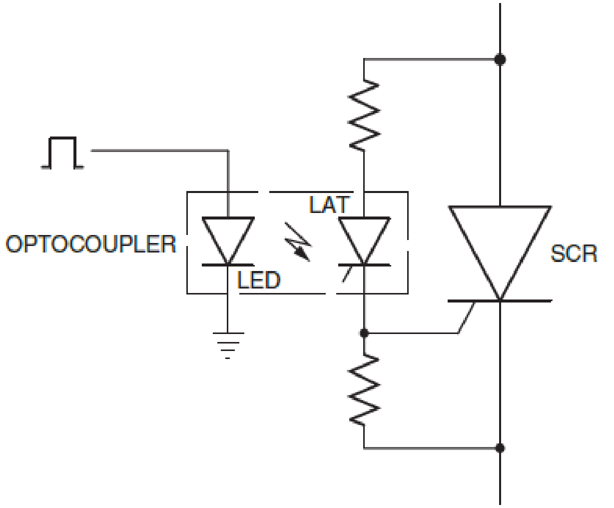
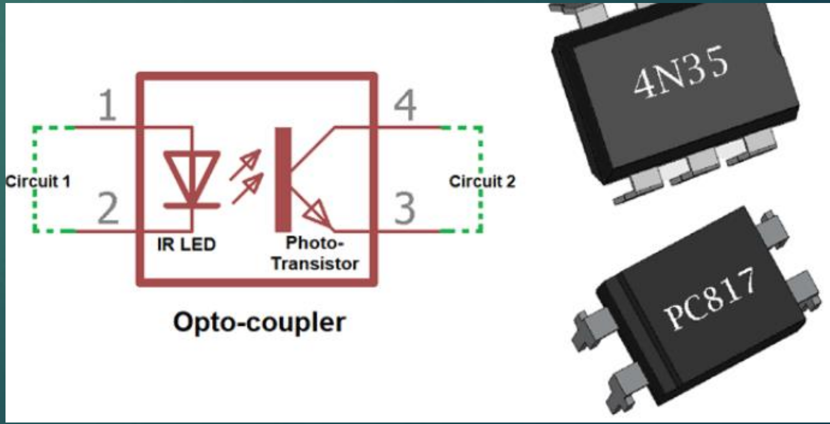


Figure 3.2 Optically isolated driver for an SCR.



Driver for BJT

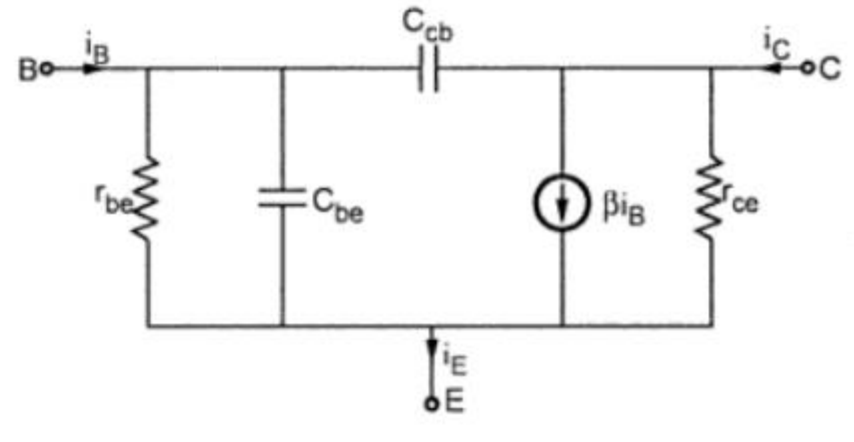
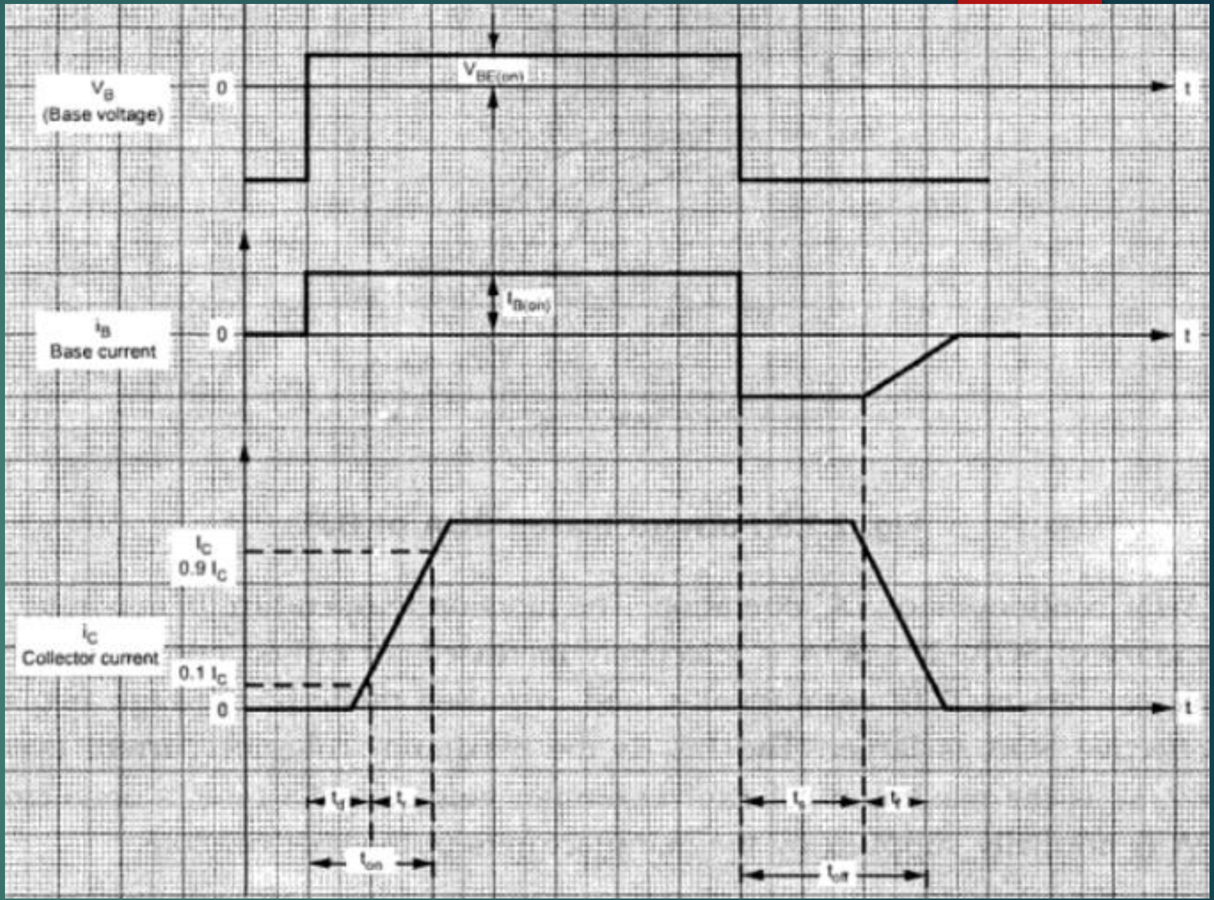
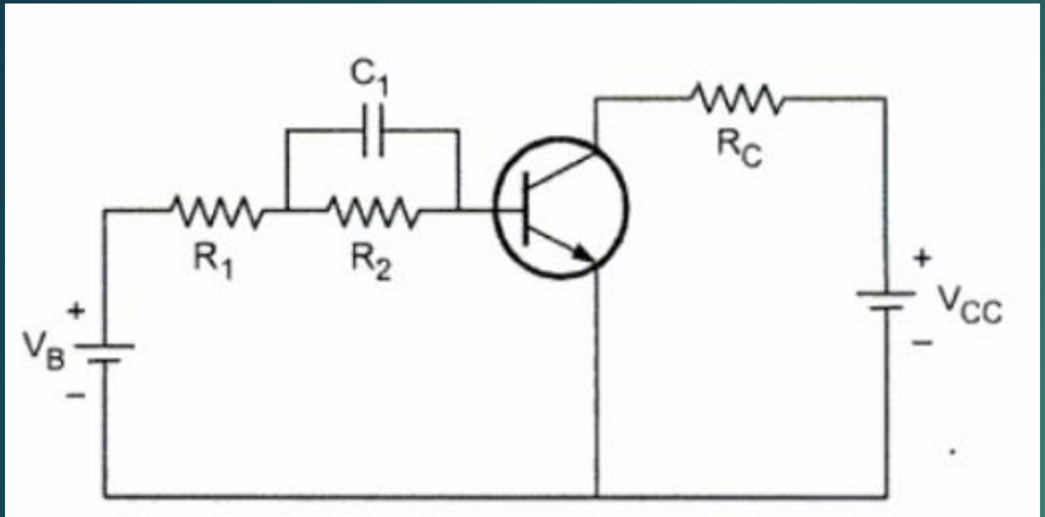


Fig. 2.2.9 Equivalent model of BJT



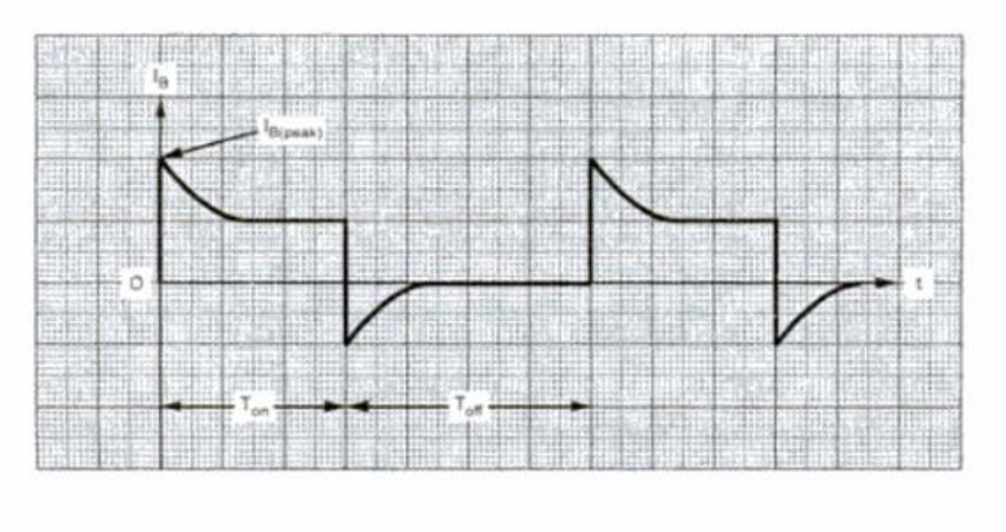


As shown in this circuit, when base drive V_B is applied, the capacitor C_1 acts as a short. Hence R_2 is virtually by passes. Therefore an initial value of base current is only limited by R_1 and it is given as,

$$I_{B(peak)} = \frac{V_B - V_{BE}}{R_1}$$

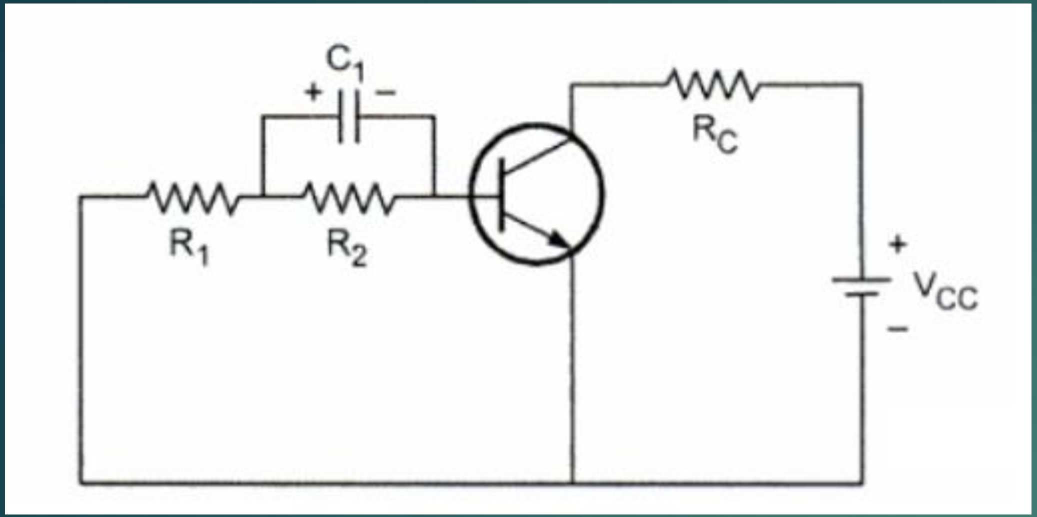
This heavy base current drives transistor into saturation for quick turn on. Once the transistor is turned on, there is no need of such large base current. This is taken care-off by R_2C_1 circuit. The capacitor C_1 starts charging and base current starts falling. This is shown in Fig. 2.2.12. Observe that there is peaking of base current at the beginning of turn on. Then the current reduces to,

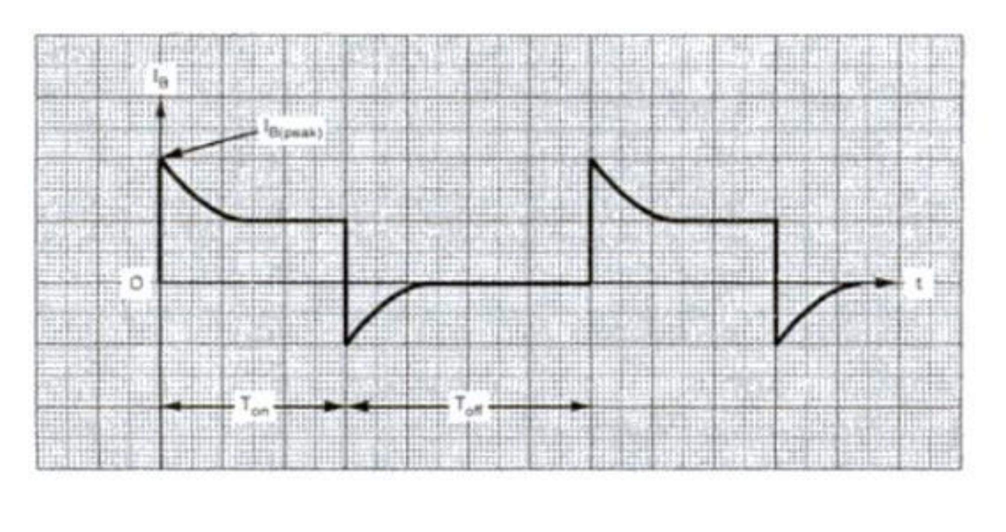
$$I_B = \frac{V_B - V_{BE}}{R_1 + R_2}$$



$$I_{B(peak)} = \frac{V_B - V_{BE}}{R_1}$$

$$I_B = \frac{V_B - V_{BE}}{R_1 + R_2}$$





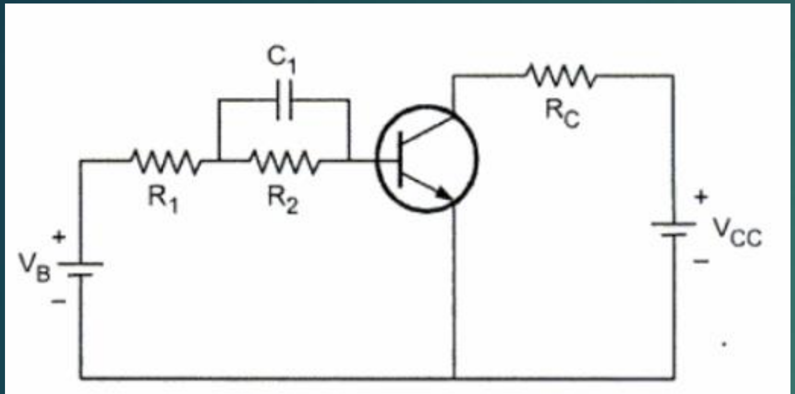
To turn-off the transistor, base voltage is made zero. Therefore capacitor voltage appears as negative voltage across base-emitter. Hence suddenly base current is reversed as shown in Fig. 2.2.12. This current slowly decays to zero after the stored charge in base region is removed. The capacitor C_1 then discharges through R_2. This discharge time constant is,

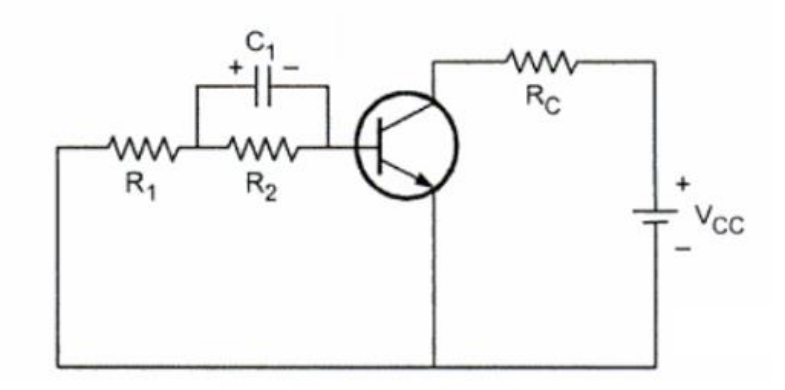
$$\tau_2 = R_2 C_1$$

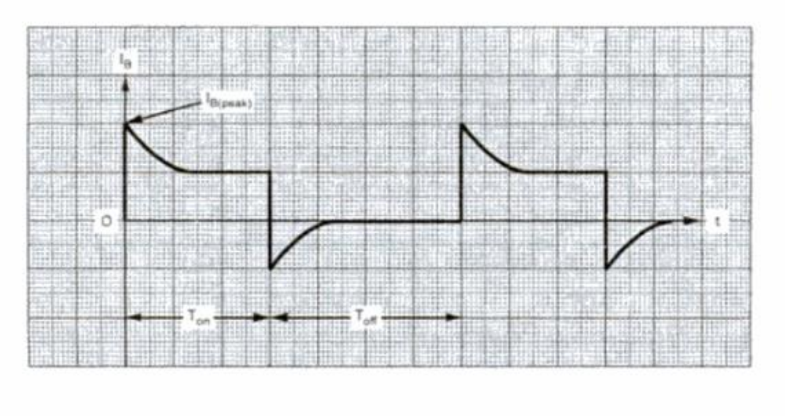
The charging time constant of the capacitor is,

$$\tau_1 = \frac{R_1 R_2 C_1}{R_1 + R_2}$$

Driver for BJT – Max switching frequency







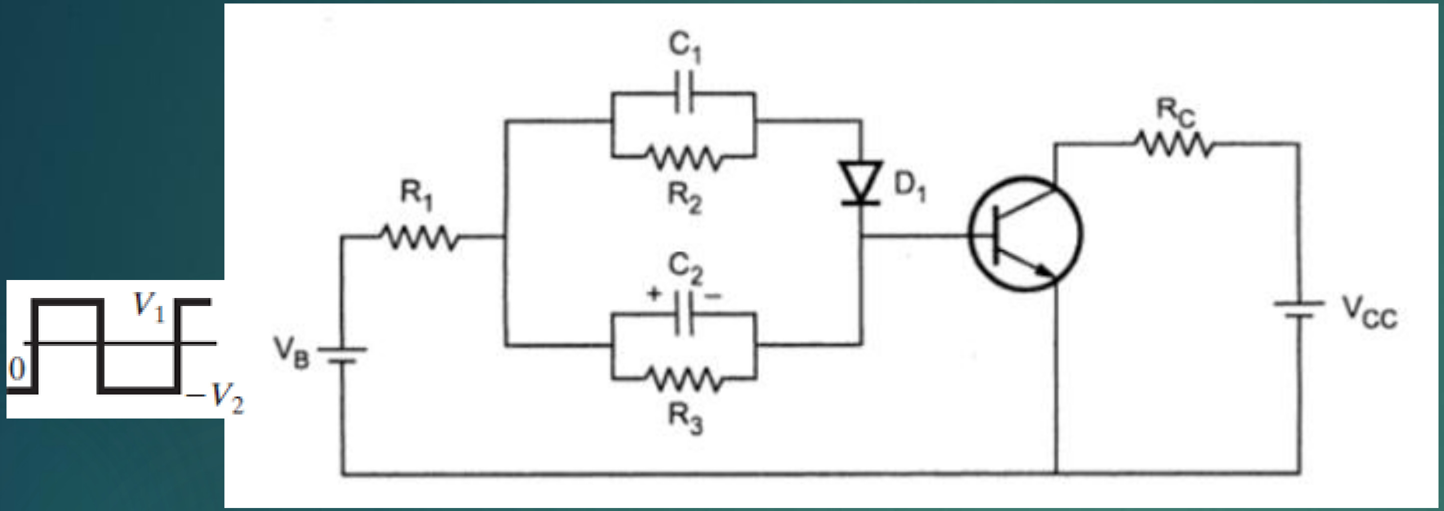
$$\tau_1 = \frac{R_1 R_2 C_1}{R_1 + R_2}$$

$$\tau_2 = R_2 C_1$$

$$T_{on(min)} > 5\tau_1 \quad \text{and} \quad T_{off(min)} > 5\tau_2$$

$$f_{s(max)} = \frac{1}{T_{on(min)} + T_{off(min)}} = \frac{1}{5\tau_1 + 5\tau_2} = \frac{1}{5(\tau_1 + \tau_2)}$$

Driver 2 for BJT – faster turn-off



Normally R3 >> R2

$$I_{B(peak)} = \frac{V_B - V_{BE}}{R_1}$$

$$I_B = \frac{V_B - V_{BE}}{R_1 + R_2}$$

Drivers for MOSFET & IGBT

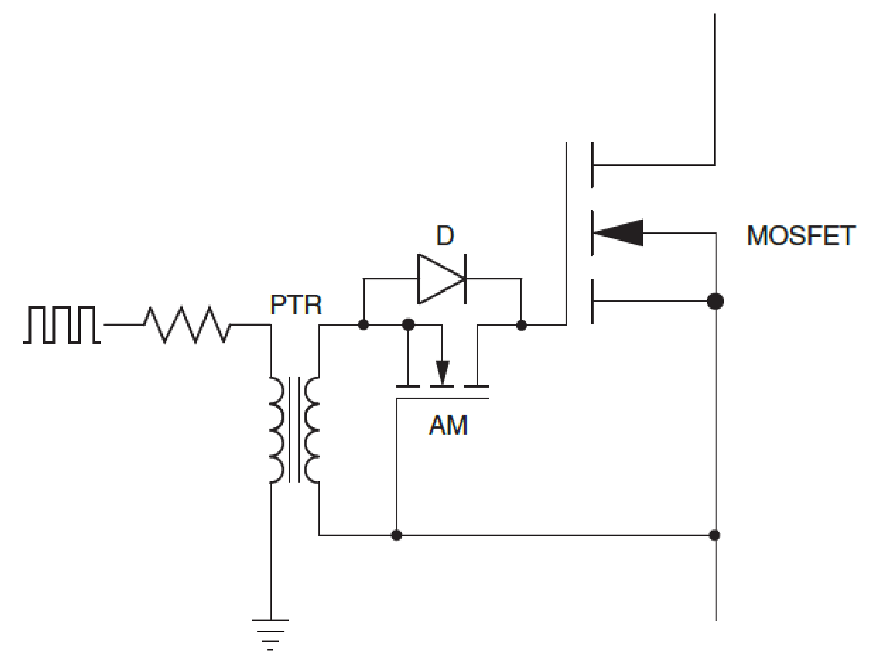
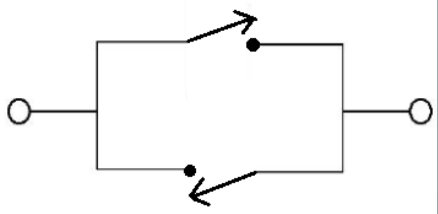


Figure 3.11 Driver for a power MOSFET with transformer isolation.



THYRISTOR FIRING CIRCUITS

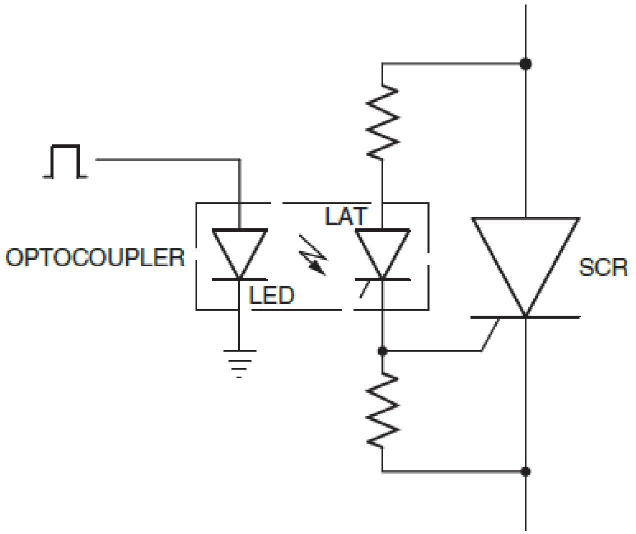
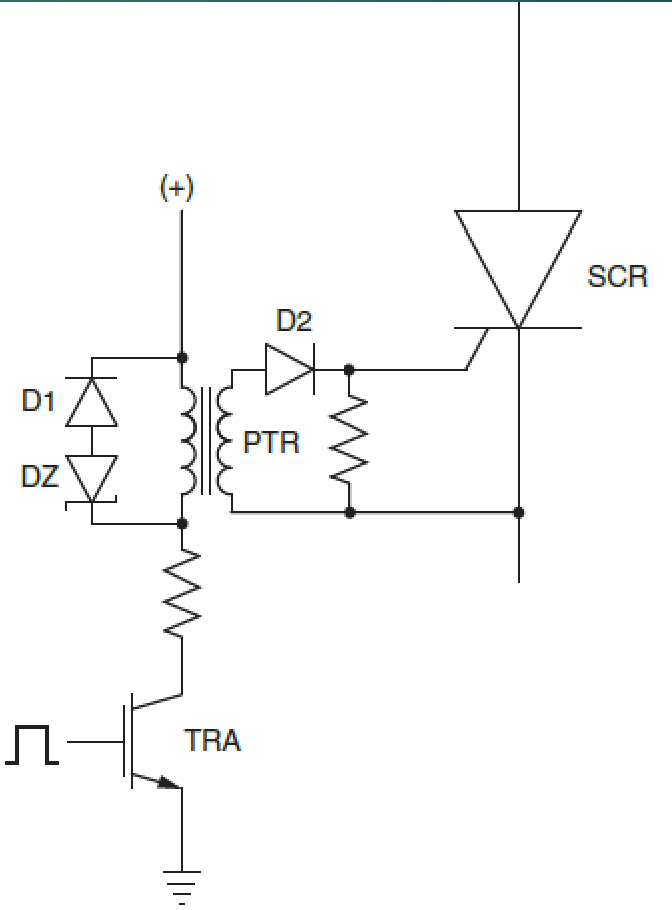


Figure 3.2 Optically isolated driver for an SCR.



10.5 TRANSISTOR SNUBBER CIRCUITS

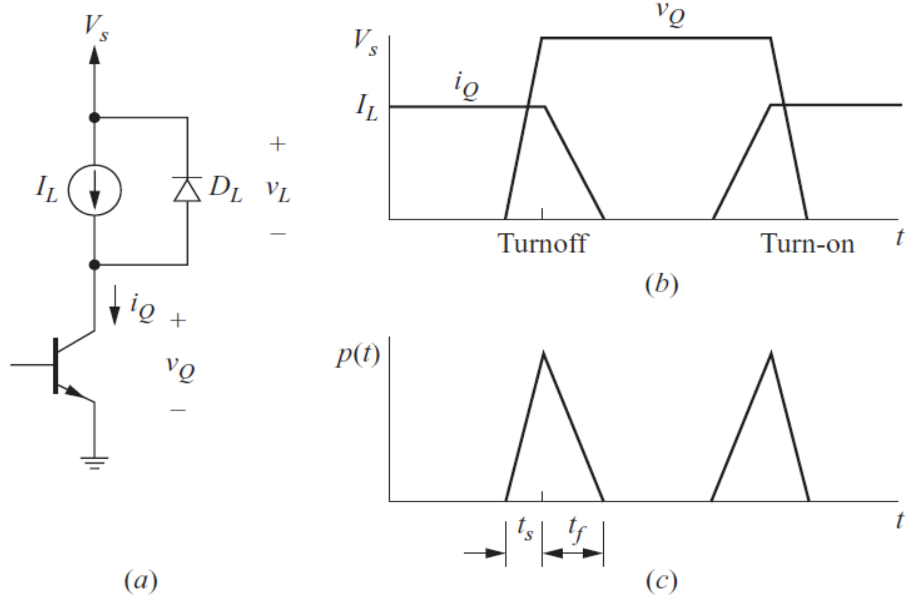
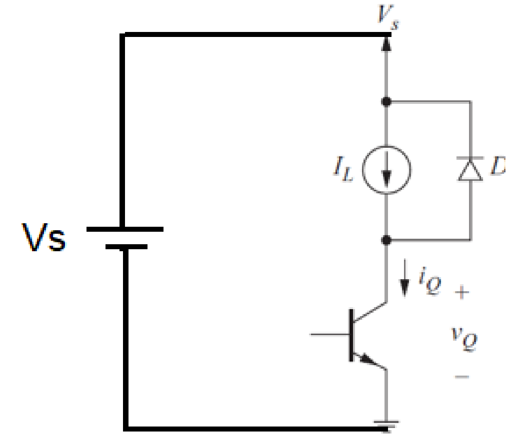


Figure 10.11 (*a*) Converter model for switching inductive loads; (*b*) Voltage and current during switching; (*c*) Instantaneous power for the transistor.



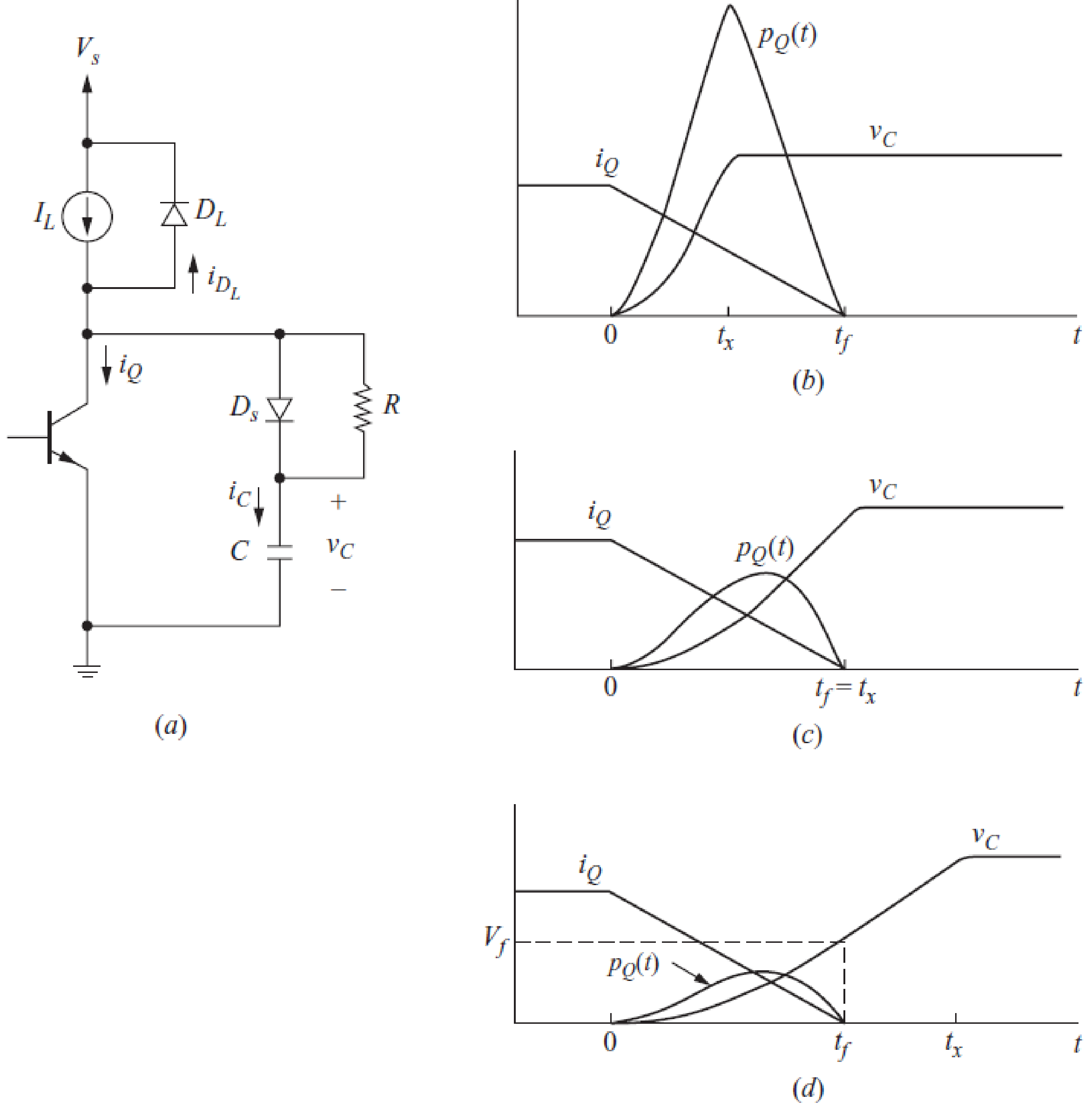


Figure 10.12 (*a*) Converter with a transistor snubber circuit; (*b–d*) Turnoff waveforms with a snubber with increasing values of capacitance.

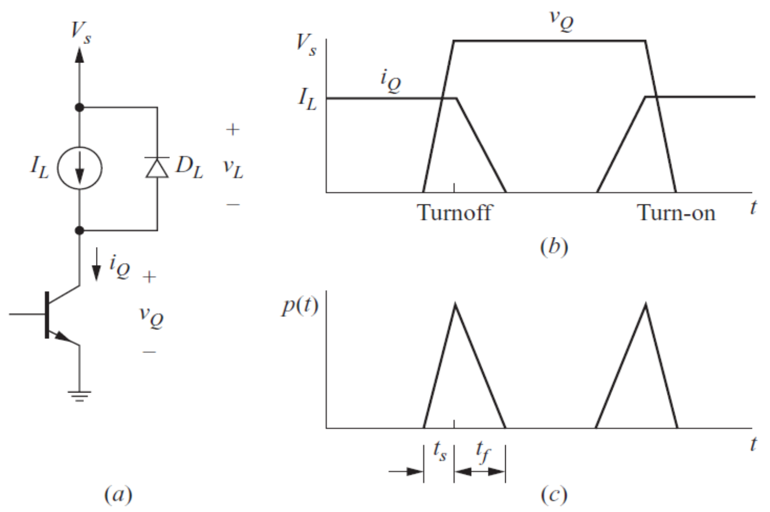


Figure 10.11 (*a*) Converter model for switching inductive loads; (*b*) Voltage and current during switching; (*c*) Instantaneous power for the transistor.

$y \quad = \quad c \quad + \quad mx$

$$i_Q(t) = \begin{cases} I_L\left(1 - \dfrac{t}{t_f}\right) & \text{for } 0 \le t < t_f \\ 0 & t \ge t_f \end{cases} \qquad (10\text{-}5)$$

b/c an approximately linear rate of decline of iQ is taken.

$$i_C(t) = \begin{cases} I_L - i_Q(t) = \dfrac{I_L t}{t_f} & 0 \le t < t_f \\ I_L & t_f \le t < t_x \\ 0 & t \ge t_x \end{cases} \qquad (10\text{-}6)$$

If Q turns off, and vC has not yet reached Vs, e.g. fig. d, Then C has to carry all load current IL.

$$v_c(t) = \begin{cases} \dfrac{1}{C}\displaystyle\int_0^t \dfrac{I_L t}{t_f}\,dt = \dfrac{I_L t^2}{2Ct_f} & 0 \le t \le t_f \\ \dfrac{1}{C}\displaystyle\int_{t_f}^t I_L\,dt + v_c(t_f) = \dfrac{I_L}{C}(t - t_f) + \dfrac{I_L t_f}{2C} & t_f \le t \le t_x \\ V_s & t \ge t_x \end{cases} \qquad (10\text{-}7)$$

$v_c(t) = \dfrac{I_L t^2}{2Ct_f}$ at t=tf this becomes $\dfrac{I_L t_f}{2C}$

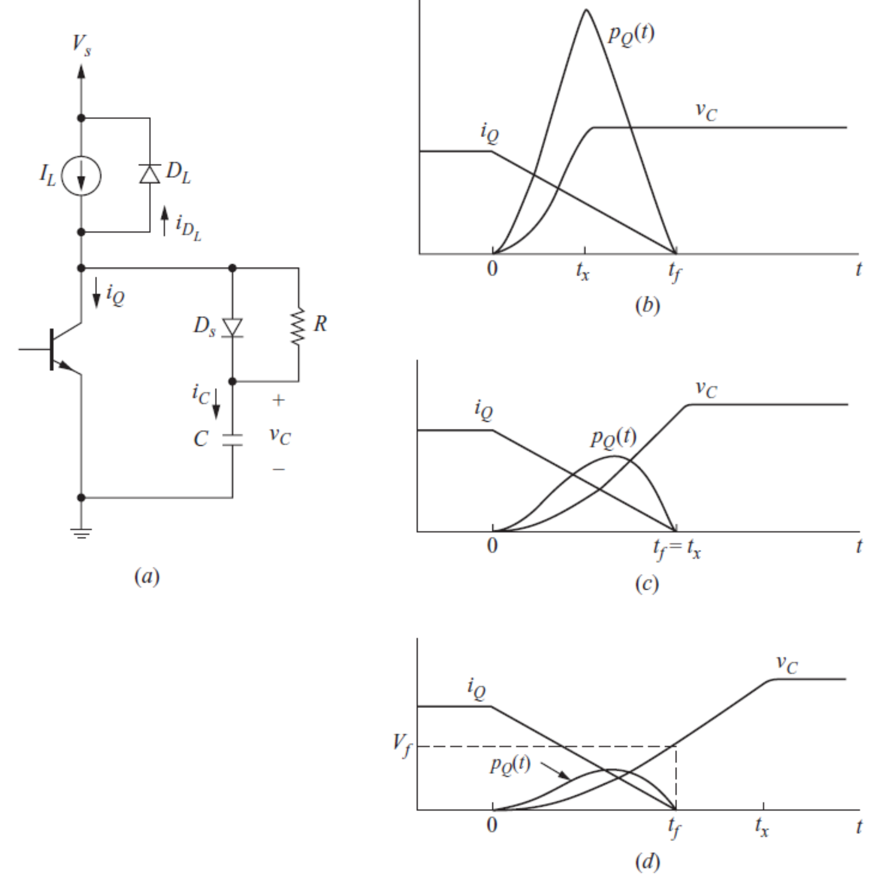


Figure 10.12 (*a*) Converter with a transistor snubber circuit; (*b–d*) Turnoff waveforms with a snubber with increasing values of capacitance.

$$v_c(t) = \begin{cases} \dfrac{1}{C}\displaystyle\int_0^t \frac{I_L t}{t_f}\,dt = \frac{I_L t^2}{2Ct_f} & 0 \le t \le t_f \\ \dfrac{1}{C}\displaystyle\int_{t_f}^t I_L\,dt + v_c(t_f) = \frac{I_L}{C}(t - t_f) + \frac{I_L t_f}{2C} & t_f \le t \le t_x \\ V_s & t \ge t_x \end{cases} \quad (10\text{-}7)$$

Letting $v_c(t_f) = V_f$,

$$V_f = \frac{I_L (t_f)^2}{2Ct_f} = \frac{I_L t_f}{2C}$$

Solving for C,

$$\boxed{C = \frac{I_L t_f}{2V_f}} \quad (10\text{-}8)$$

For Vf = Vs

$$C = \frac{I_L t_f}{2V_s} \quad (10\text{-}9)$$

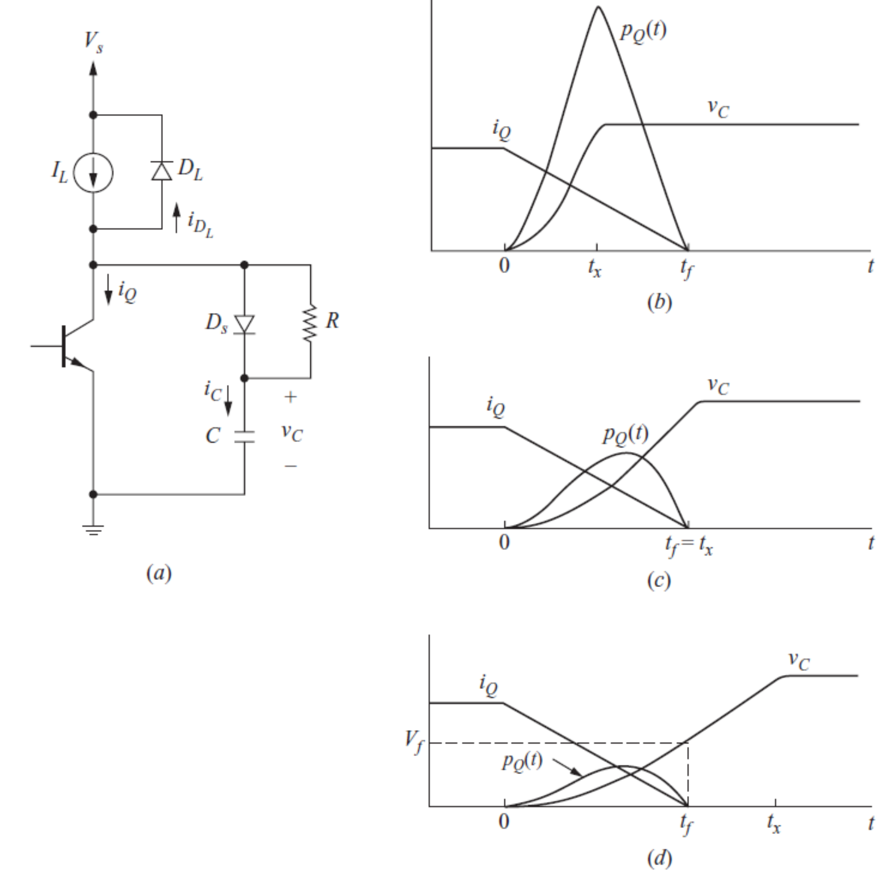


Figure 10.12 (*a*) Converter with a transistor snubber circuit; (*b–d*) Turnoff waveforms with a snubber with increasing values of capacitance.

Power dissipation without snubber

$$P_Q = \frac{1}{2} I_L V_s (t_s + t_f) f \qquad (10\text{-}11)$$

Area of triangle

Power dissipation with snubber

$$P_Q = \frac{1}{T}\int_0^T v_Q i_Q \, dt = f \int_0^{t_f} \left(\frac{I_L t^2}{2Ct_f}\right) I_L \left(1 - \frac{t}{t_f}\right) dt = \frac{I_L^2 t_f^2 f}{24C} \qquad (10\text{-}12)$$

$$i_Q(t) = \begin{cases} I_L\left(1 - \dfrac{t}{t_f}\right) & \text{for } 0 \le t < t_f \\ 0 & t \ge t_f \end{cases} \qquad (10\text{-}5)$$

$$v_c(t) = \begin{cases} \dfrac{1}{C}\displaystyle\int_0^t \frac{I_L t}{t_f}\, dt = \frac{I_L t^2}{2Ct_f} & 0 \le t \le t_f \\ \dfrac{1}{C}\displaystyle\int_{t_f}^t I_L \, dt + v_c(t_f) = \frac{I_L}{C}(t - t_f) + \frac{I_L t_f}{2C} & t_f \le t \le t_x \\ V_s & t \ge t_x \end{cases} \qquad (10\text{-}7)$$

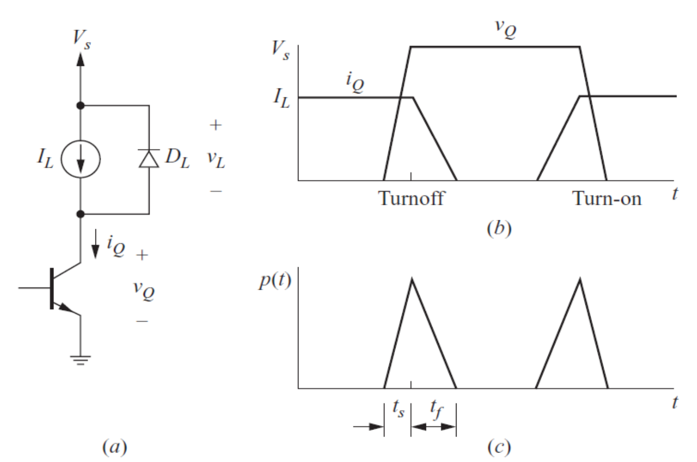


Figure 10.11 (*a*) Converter model for switching inductive loads; (*b*) Voltage and current during switching; (*c*) Instantaneous power

$$\boxed{P_Q = \frac{1}{T}\int_0^T p_Q(t)\, dt}$$

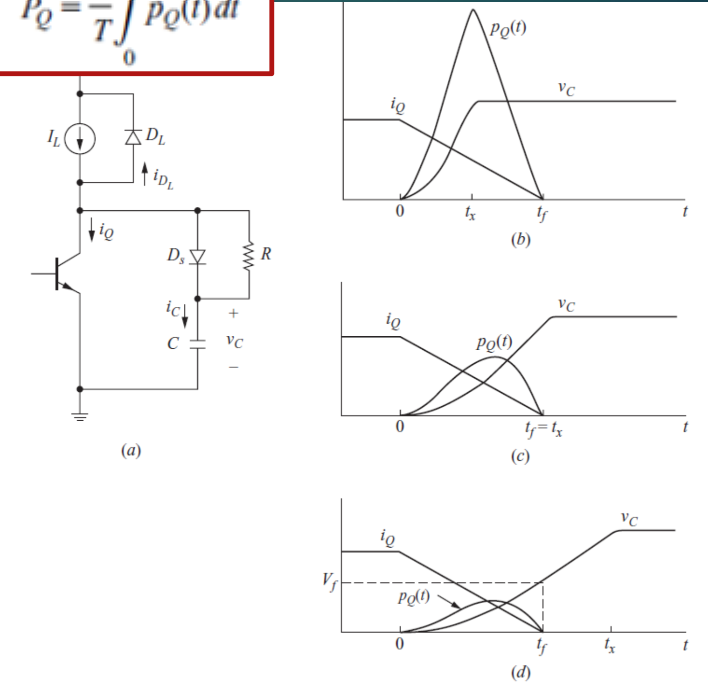


Figure 10.12 (*a*) Converter with a transistor snubber circuit; (*b–d*) Turnoff waveforms with a snubber with increasing values of capacitance.

Resistor selection and power dissipation of capacitor

$$t_{\text{on}} > 5RC$$

$$R < \frac{t_{\text{on}}}{5C}$$

$$W = \tfrac{1}{2} C V_s^2 \qquad (10\text{-}14)$$

$$P_R = \frac{\tfrac{1}{2} C V_s^2}{T} = \frac{1}{2} C V_s^2 f \qquad (10\text{-}15)$$

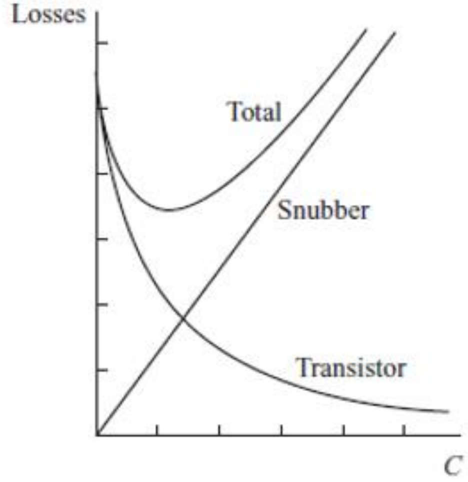


Figure 10.13 Transistor, snubber, and total turnoff losses as a function of snubber capacitance.

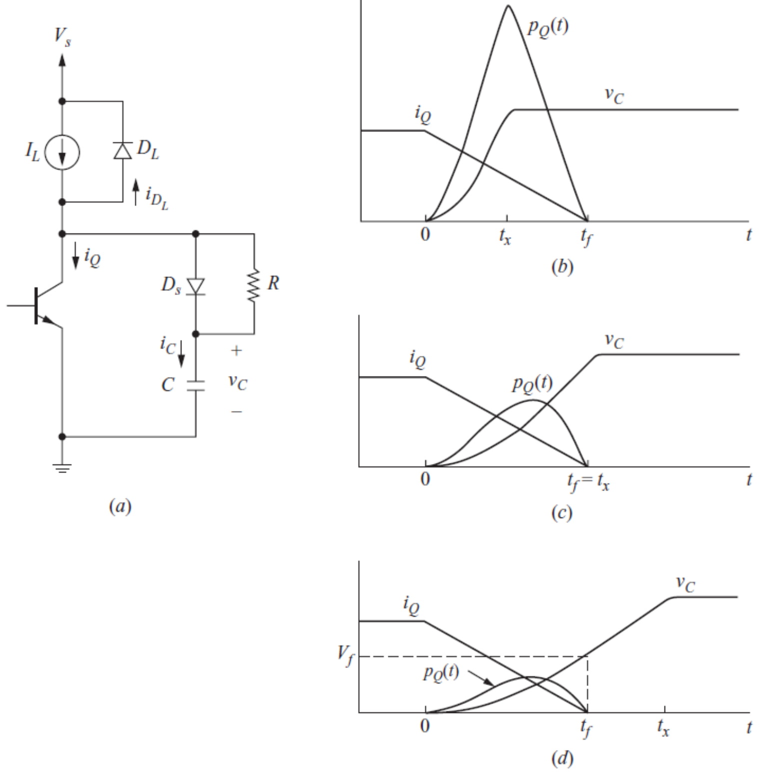


Figure 10.12 (*a*) Converter with a transistor snubber circuit; (*b–d*) Turnoff waveforms with a snubber with increasing values of capacitance.

A large capacitor reduces the power loss in the transistor [Eq. (10-12)], but at the expense of power loss in the snubber resistor.

EXAMPLE 10.4

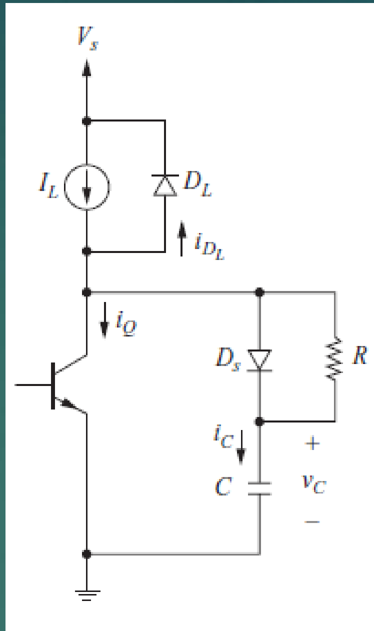
Transistor Snubber Circuit Design

The converter and snubber in Fig. 10-12*a* has $V_s = 100$ V and $I_L = 5$ A. The switching frequency is 100 kHz with a duty ratio of 50 percent, and the transistor turns off in 0.5 μs. (*a*) Determine the turnoff losses without a snubber if the transistor voltage reaches V_s in 0.1 μs. (*b*) Design a snubber using the criterion that the transistor voltage reaches its final value at the same time that the transistor current reaches zero. (*c*) Determine the transistor turnoff losses and the resistor power with the snubber added.

■ Solution

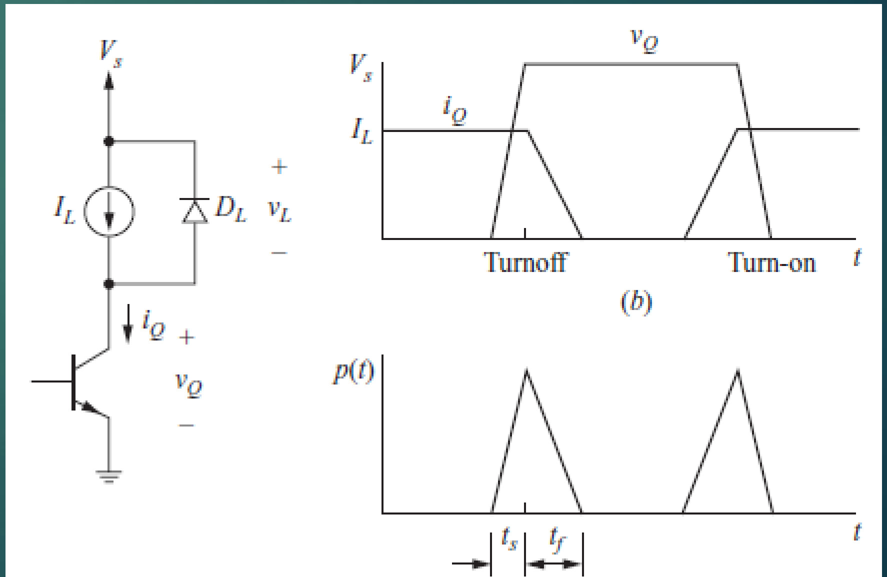
(*a*) The turnoff voltage, current, and instantaneous power waveforms without the snubber are like those of Fig. 10-11. Transistor voltage reaches 100 V while the current is still at 5 A, resulting in a peak instantaneous power of (100 V)(5 A) = 500 W. The base of the power triangle is 6 μs, making the area 0.5(500 W)(0.6 μs)= 150 μJ. The switching period is $1/f = 1/100{,}000$ s, so the turnoff power loss in the transistor is $W/T = (150)(10^6)(100{,}000) = 15$ W. Equation (10-11) yields the same result:

$$P_Q = \frac{1}{2} I_L V_s (t_s + t_f) f = \frac{1}{2}(5)(100)(0.1 + 0.5)(10^{-6})(10^5) = 15 \text{ W}$$



(*a*)

$$P_Q = \frac{1}{2} I_L V_s (t_s + t_f) f \quad (10\text{-}11)$$



(*a*) (*c*)

EXAMPLE 10.4

Transistor Snubber Circuit Design

The converter and snubber in Fig. 10-12*a* has $V_s = 100$ V and $I_L = 5$ A. The switching frequency is 100 kHz with a duty ratio of 50 percent, and the transistor turns off in 0.5 μs. (*a*) Determine the turnoff losses without a snubber if the transistor voltage reaches V_s in 0.1 μs. (*b*) Design a snubber using the criterion that the transistor voltage reaches its final value at the same time that the transistor current reaches zero. (*c*) Determine the transistor turnoff losses and the resistor power with the snubber added.

(*b*) The snubber capacitance value is determined from Eq. (10-9):

$$C = \frac{I_L t_f}{2V_s} = \frac{(5)(0.5)(10^{-6})}{(2)(100)} = 1.25(10^{-8}) = 0.0125\ \mu\text{F} = 12.5\ \text{nF}$$

The snubber resistor is chosen using Eq. (10-13). The switching frequency is 100 kHz corresponding to a switching period of 10 μs. The on time for the transistor is approximately one-half of the period, or 5 μs. The resistor value is then

$$R < \frac{t_{on}}{5C} = \frac{5\ \mu\text{s}}{5(0.0125\ \mu\text{F})} = 80\ \Omega$$

The resistance value is not critical. Since five time constants is a conservative design criterion, the resistance need not be exactly 80 Ω.

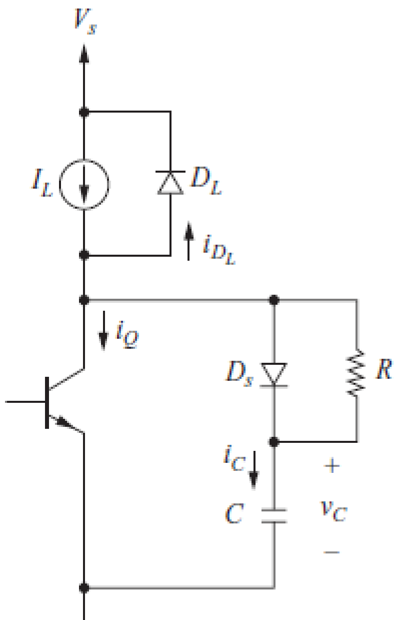
(*c*) The power absorbed by the transistor is determined from Eq. (10-12):

$$P_Q = \frac{I_L^2 t_f^2 f}{24C} = \frac{5^2[(0.5)(10^{-6})]^2(10^5)}{24(1.25)(10^{-8})} = 2.08\ \text{W}$$

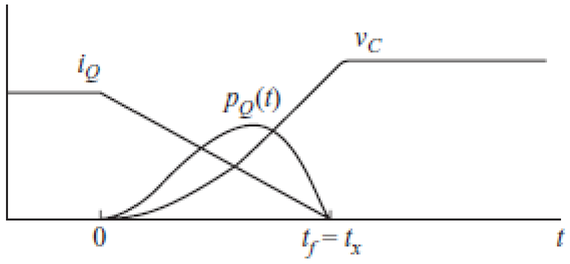
Power absorbed by the snubber resistor is determined from Eq. (10-15):

$$P_R = \frac{1}{2}CV_s^2 f = \frac{0.0125(10^{-6})(100^2)(100{,}000)}{2} = 6.25\ \text{W}$$

Total power due to turnoff losses with the snubber is 2.08 + 6.25 = 8.33 W, reduced from 15 W without the snubber. The losses in the transistor are significantly reduced by the snubber, and total turnoff losses are also reduced in this case.



(*a*)



(*c*)

$$C = \frac{I_L t_f}{2V_s} \qquad (10\text{-}9)$$

$$R < \frac{t_{on}}{5C} \qquad (10\text{-}13)$$

$$P_Q = \frac{1}{T}\int_0^T v_Q i_Q\, dt = f\int_0^{t_f}\left(\frac{I_L t^2}{2Ct_f}\right) I_L\left(1 - \frac{t}{t_f}\right) dt = \frac{I_L^2 t_f^2 f}{24C} \qquad (10\text{-}12)$$

Turn-on snubber

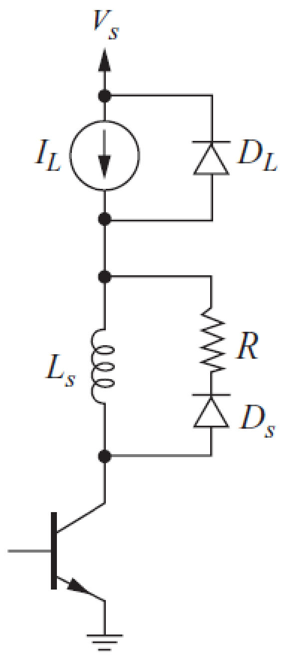


Figure 10.17 Transistor turnon snubber.

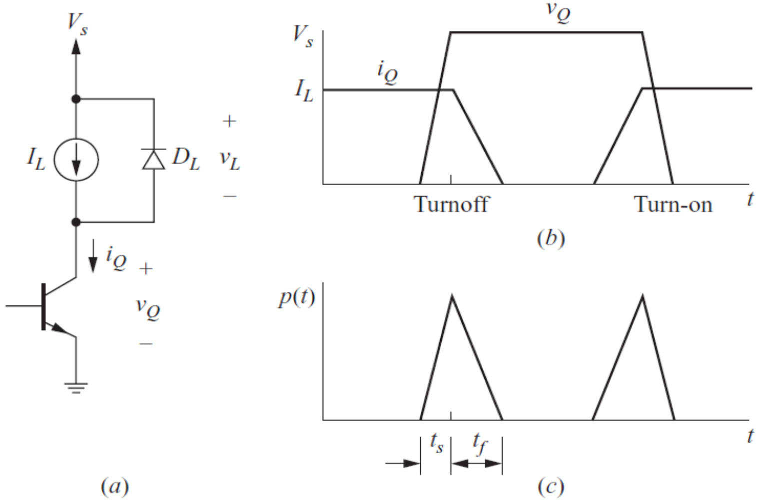


Figure 10.11 (*a*) Converter model for switching inductive loads; (*b*) Voltage and current during switching; (*c*) Instantaneous power for the transistor.

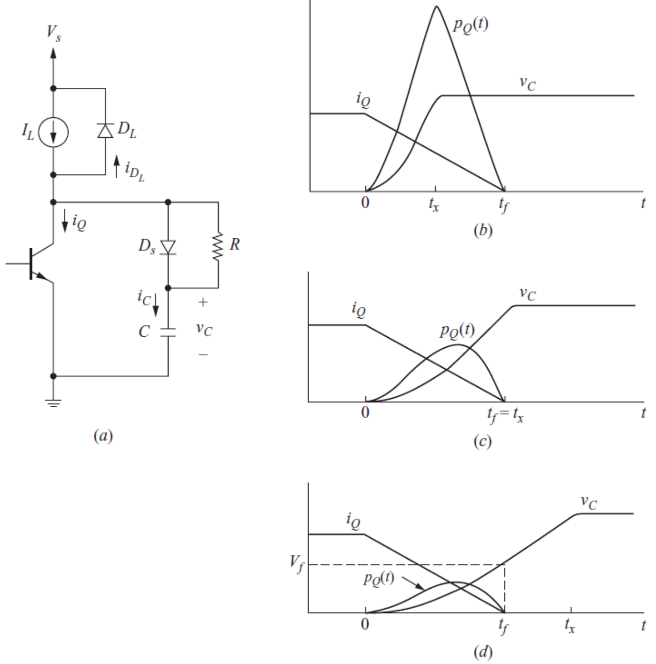


Figure 10.12 (*a*) Converter with a transistor snubber circuit; (*b*–*d*) Turnoff waveforms with a snubber with increasing values of capacitance.

switching-aid circuits called snubbers must often accompany semiconductor power switches. Their purpose is to prevent transient overvoltages and overcurrents, attenuate excessive rates of changes of voltage and current, reduce switching losses, and ensure that the switch does not operate outside its SOA.

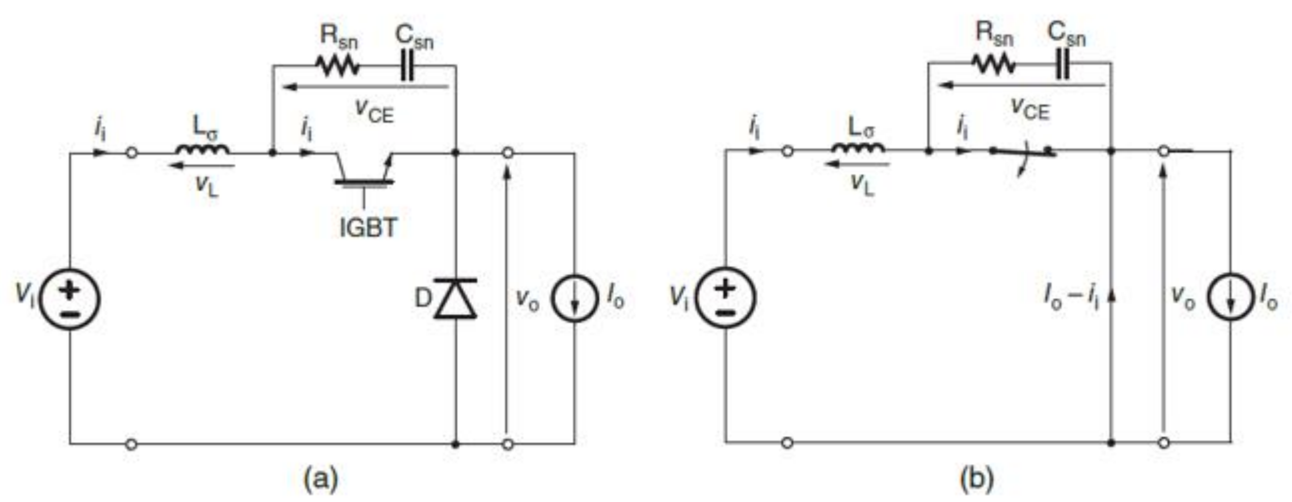
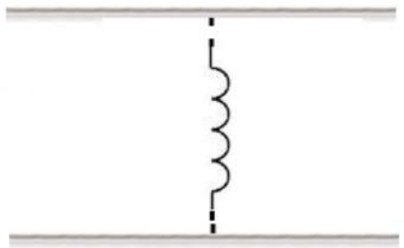


Figure 3.15 BJT-based chopper with RC snubber: (a) circuit diagram, (b) equivalent circuit in the off-state.

What is Stray Inductance?



Stray inductance is unintended and unwanted inductance in a circuit.

Inductance does not exist only within inductors. In fact, any wires or component leads that have current flowing through them create magnetic fields. When these magnetic fields are created, they can produce an inductive effect. Thus, wires or components leads can act as inductors if they are long enough. Such effects are often present within circuits (for example, between conductive runs of wire traces or components with long leads such as capacitors), even though they are not intended. This unintended inductance is referred to as stray inductance, and it can result in a disruption of normal current flow within a circuit.

Designers of circuits try to minimize stray inductance as much as possible. They do this by keeping the leads of electronic components very short and grouping components in such a way to eliminate capacitive coupling.

A good example of this is a capacitor. When buying a capacitor fresh from a manufacturer, the leads of the capacitor are usually quite long.

When you have capacitor leads this long running close together, they can exhibit an inductive effect in a circuit

http://www.learningaboutelectronics.com/Articles/What-is-stray-inductance.php#:~:text=Stray%20inductance%20is%20unintended%20and,can%20produce%20an%20inductive%20effect.

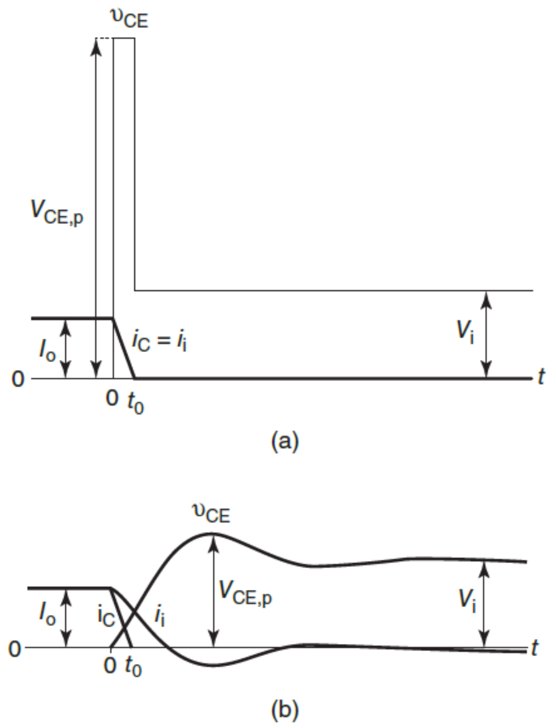


Figure 3.16 Voltage and current waveforms in the chopper of Figure 3.15: (a) without snubber, (b) with snubber.

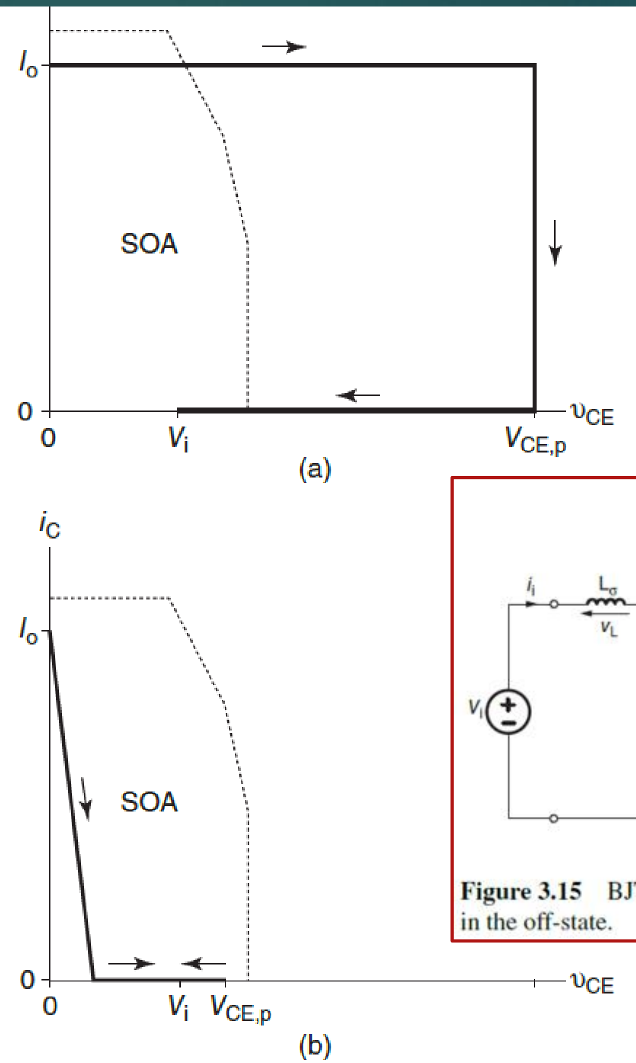


Figure 3.17 Switching trajectories of the BJT of Figure 3.15: (a) without snubber, (b) with snubber.

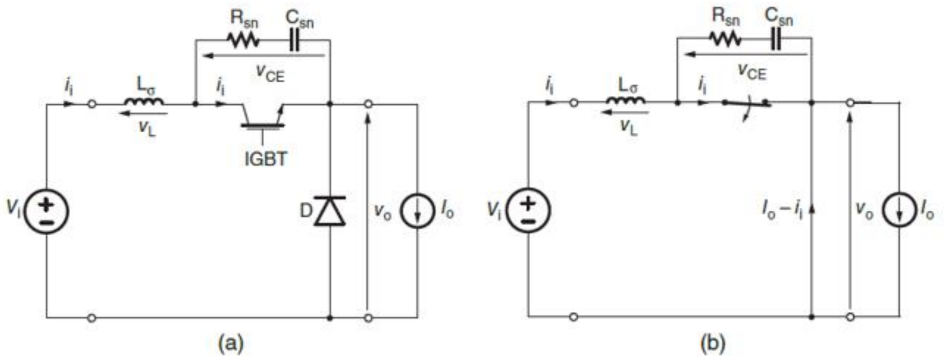


Figure 3.15 BJT-based chopper with RC snubber: (a) circuit diagram, (b) equivalent circuit in the off-state.

10.7 THYRISTOR SNUBBER CIRCUITS

If dv/dt for the thyristor is too large, the device will begin to conduct without a gate signal present. If di/dt is too large during turn-on, localized heating will result from the high current density in the region of the gate connection as the current spreads out over the whole junction.

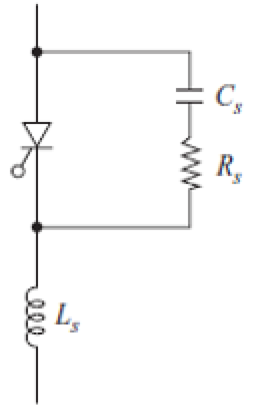


Figure 10.19 Thyristor snubber circuit.

3.4.1 Snubbers for Power Diodes, SCRs, and Triacs

The rate of rise of the reverse recovery current in power diodes is high, so that an overvoltage at turn-off is very likely, even with a small amount of stray inductance. Therefore, simple RC snubbers, such as that in Figure 3.15, are connected in parallel with the diode.

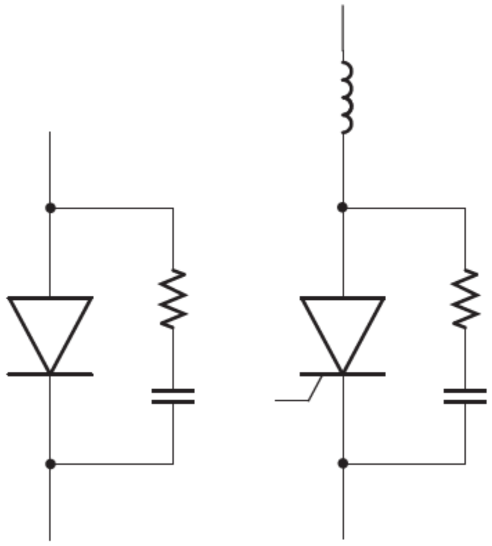


Figure 3.18 Snubbers for: (a) power diode, (b) SCR.

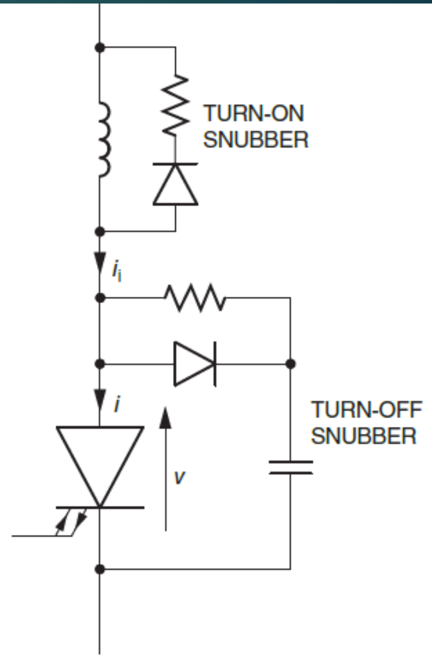


Figure 3.19 GTO with turn-on and turn-off snubbers.

Concept of Energy Recovery from snubbers

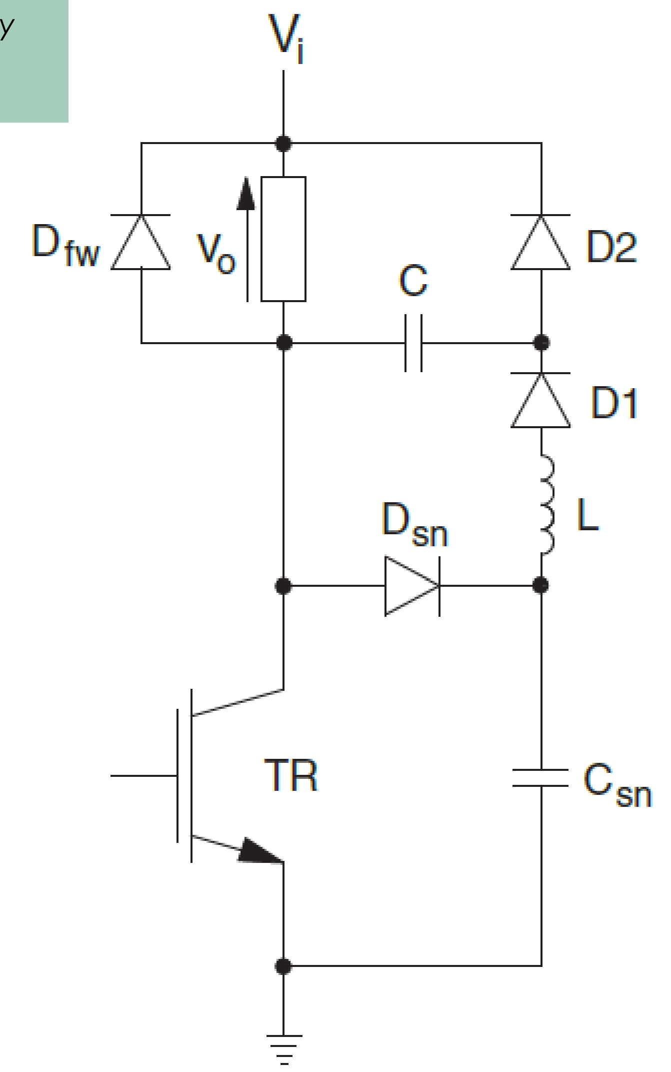


Figure 3.22 Turn-off capacitive snubber with passive energy recovery.