# Drive Circuits

Outline

- Drive circuit design considerations
- DC-coupled drive circuits
- Isolated drive circuits
- Protection measures in drive circuits
- Component/circuit layout considerations

# Functionality of Gate/Base Drive Circuits

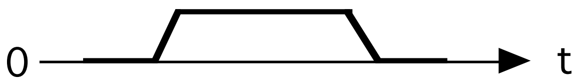
- Turn power switch from off-state to on-state
  - Minimize turn-on time through active region where power dissipation is large
  - Provide adequate drive power to keep power switch in on-state
- Turn power switch from on-state to off-state
  - Minimize turn-off time through active region wherepower dissipation is large
  - Provide bias to insure that power switch remains off
- Control power switch to protect it when overvoltages or overcurrents are sensed
- Signal processing circuits which generate the logic control signals not considered part of the drive circuit
  - Drive circuit amplifies control signals to levels required to drive power switch
  - Drive circuit has significant power capabilities compared to logic level signal processing circuits
- Provide electrical isolation when needed between power switch and logic level signal processing/control circuits

# Drive Circuit Design Considerations

- Drive circuit topologies

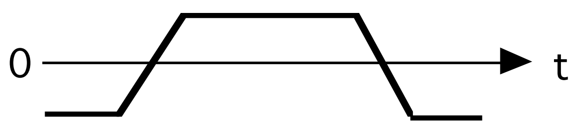
  - Output signal polarity - unipolar or bipolar
  - AC or DC coupled
  - Connected in shunt or series with power switch

- Output current magnitude
  - Large $I_{on}$ shortens turn-on time but lengthens turn-off delay time
  - Large $I_{off}$ shortens turn-off time but lengthens turn-on delay time




Unipolar

- Provisions for power switch protection
  - Overcurrents
  - Blanking times for bridge circuit drives




Bipolar

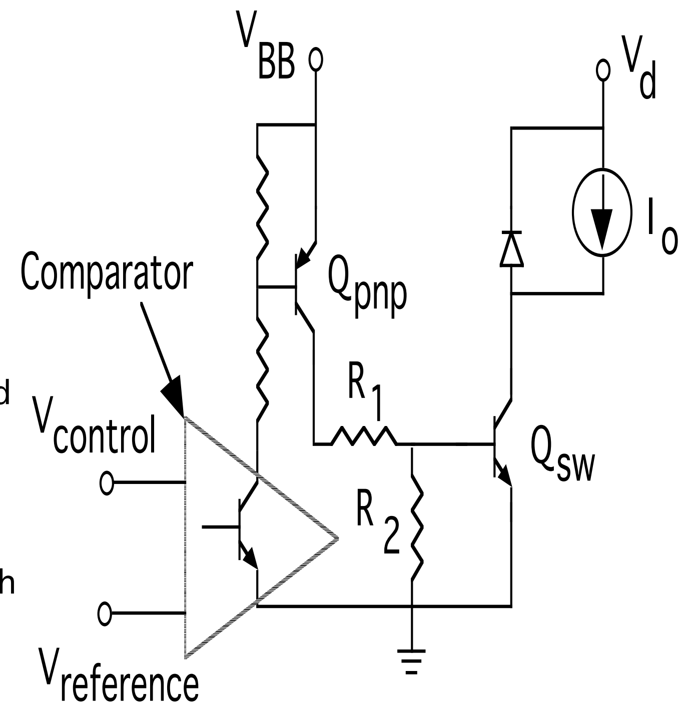
- Waveshaping to improve switch performance
  - Controlled $di_B/dt$ for BJT turn-off
  - Anti-saturation diodes for BJT drives
  - Speedup capacitors
  - Front-porch/backporch currents

- Component layout to minimize stray inductance and shielding from switching noise

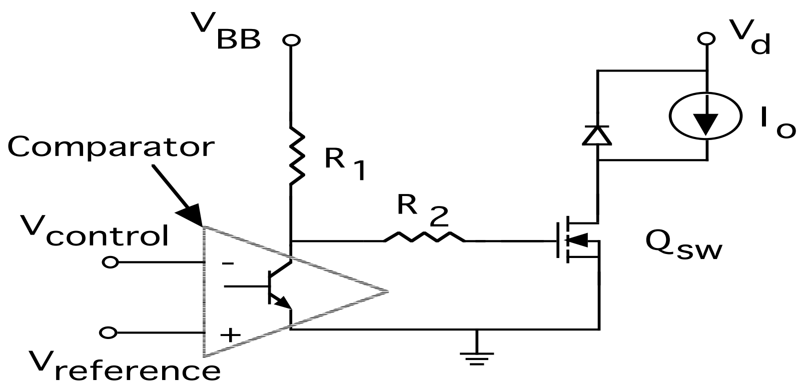
# Unipolar DC-coupled Drive Circuit - BJT Example

- Circuit operation
  - $V_{control} > V_{reference}$ - BJT at comparator output on which puts $Q_{pnp}$ and $Q_{sw}$ on
  - $V_{control} < V_{reference}$ - BJT at comparator output off which turns $Q_{pnp}$ off and thus $Q_{sw}$ off

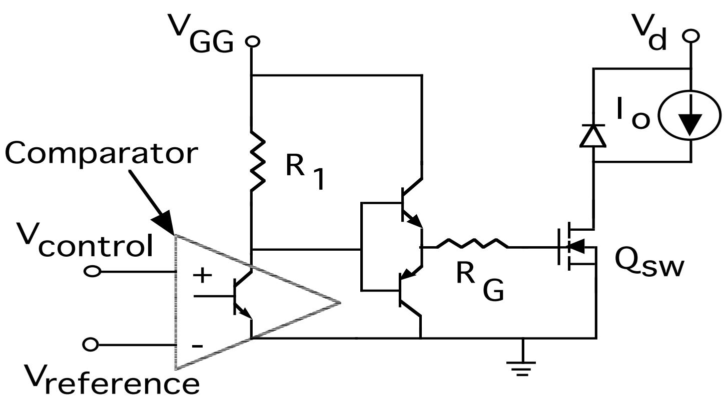
- Design procedure
  - $R_2 = \frac{V_{BE,off}}{I_{B,off}}$ ; $I_{B,off}$ based on desired turn-off time.
  - $I_{pnp} = I_{B,on} + \frac{V_{BE,on}}{R_2}$ ; $I_{B,on}$ value based on BJT beta and value of $I_o$.
  - $V_{BB} = V_{CE,on}(Q_{pnp}) + R_1\, I_{C,pnp} + V_{BE,on}(Q_{sw})$
  - $V_{BB}$ = 8 to 10 V ; compromise between larger values which minimize effects of $V_{BE}$ variations and smaller values which minimize power dissipation in drive circuit



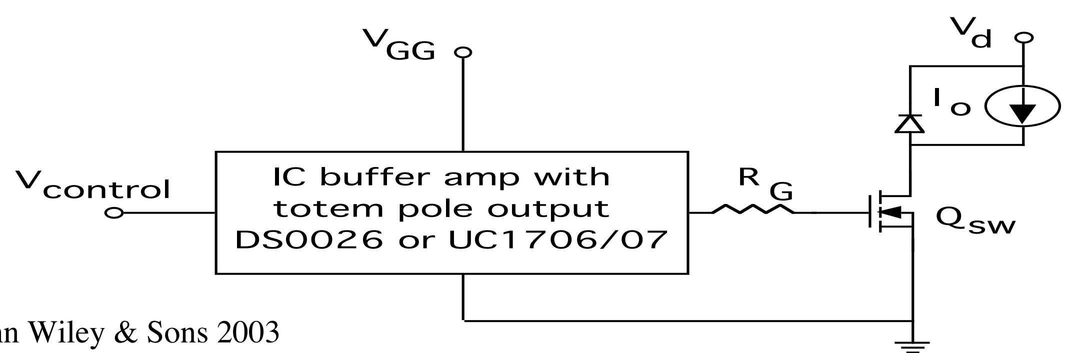
# Unipolar DC-coupled Drive Circuits- MOSFET examples



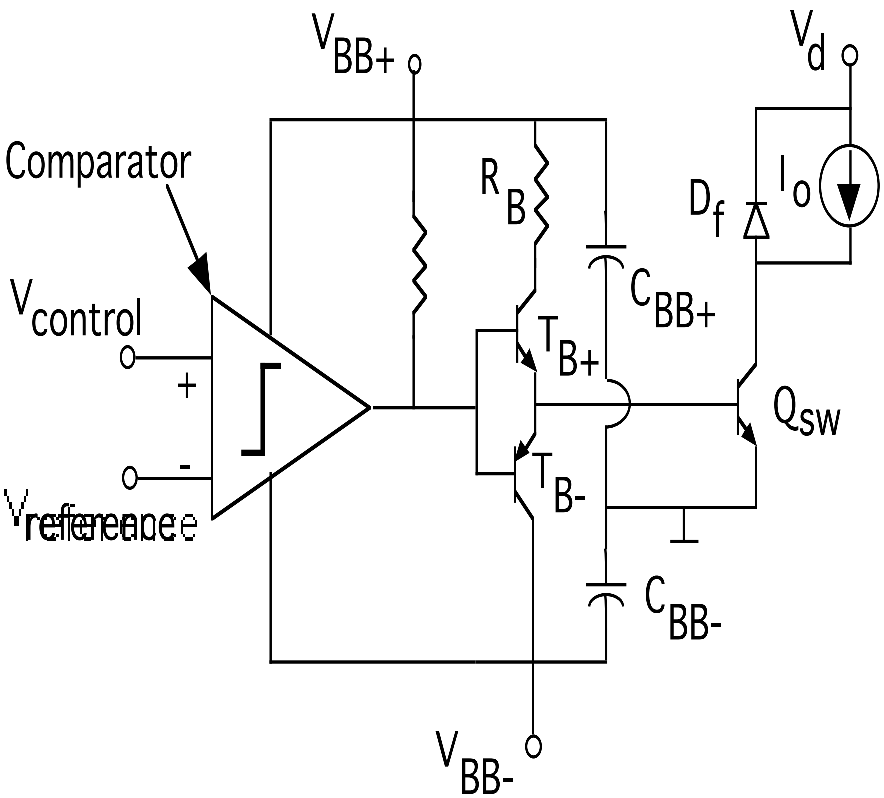

- $V_{control} > V_{reference}$ comparator output high and $Q_{sw}$ on
- $V_{control} < V_{reference}$ comparator output low and $Q_{sw}$ off




- $V_{control} > V_{reference}$ comparator output high putting $Q_{npn}$ on and thus $Q_{sw}$ on
- $V_{control} < V_{reference}$ comparator output low putting $Q_{pnp}$ on and thus $Q_{sw}$ off

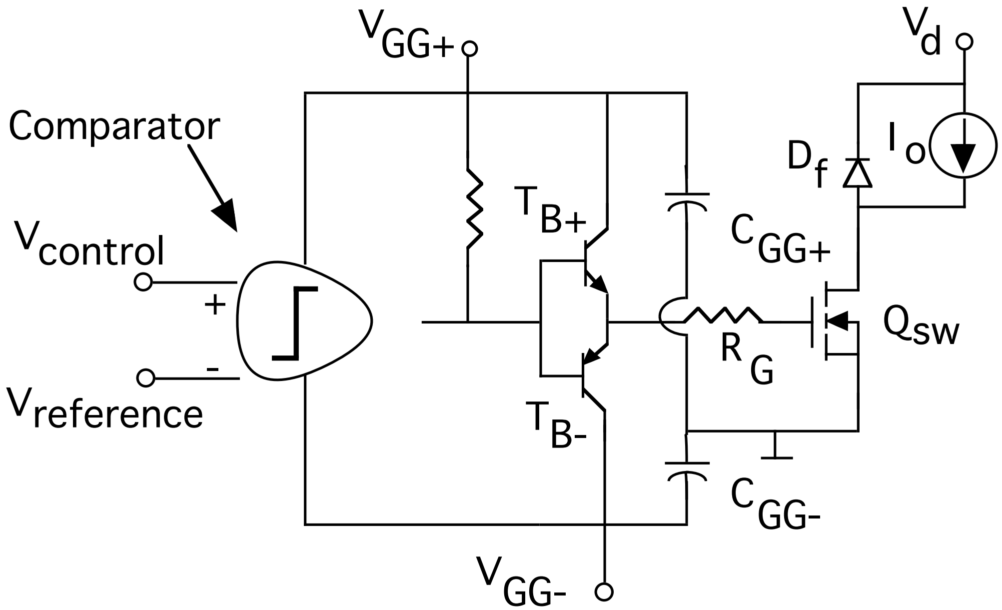


# Bipolar DC-coupled Drive Circuit- BJT Example

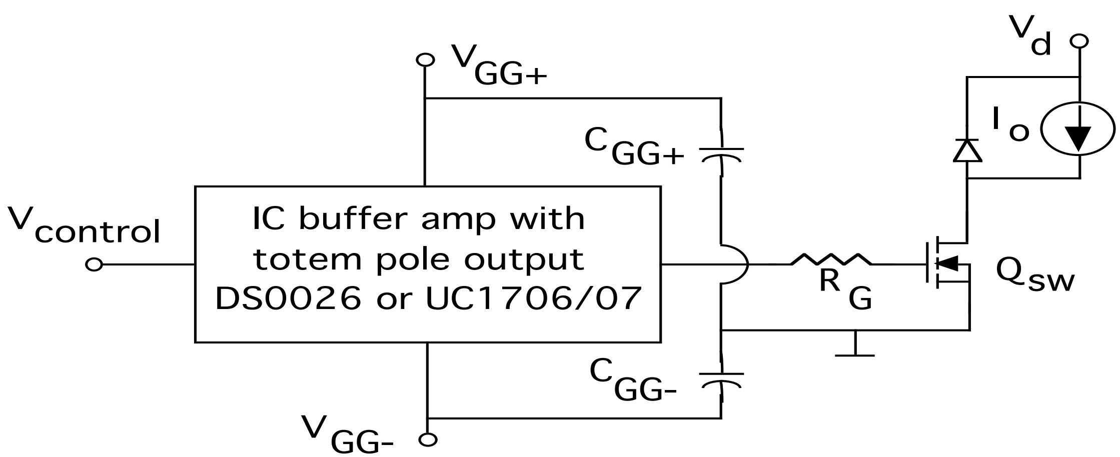



- $V_{control} < V_{reference}$ - comparator output low, $T_{B-}$ on and $Q_{sw}$ off.
- Large reverse base current flows to minimize turn-off time and base-emitter of $Q_{sw}$ reversed biased to insure off-state.
- $V_{control} > V_{reference}$ - comparator output high, $T_{B+}$ on and $Q_{sw}$ on.
- Large forward base current to minimize turn-on time and to insure saturation of $Q_{sw}$ for low on-state losses

# Bipolar DC-coupled Drive Circuit- MOSFET Example



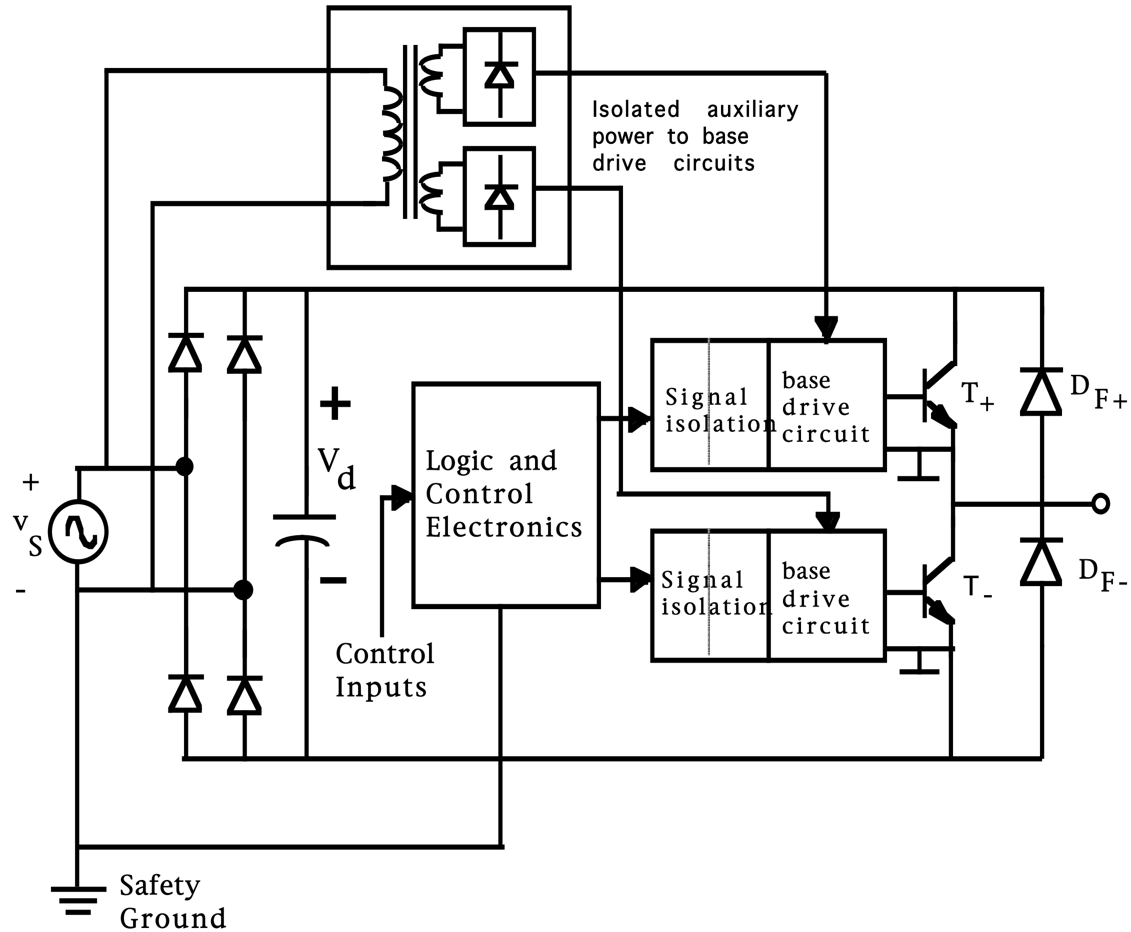

- Bipolar drive with substantial output current capability



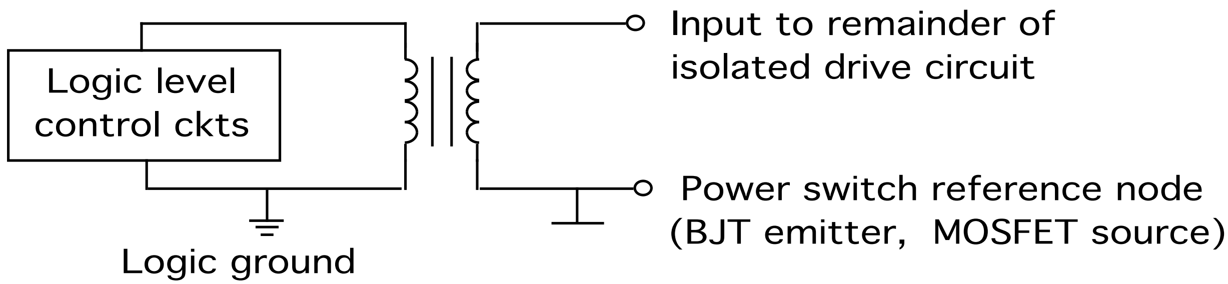

- Simple bipolar drive circuit with moderate (1 amp)output current capability

# Need for Electrical Isolation of Drive Circuits

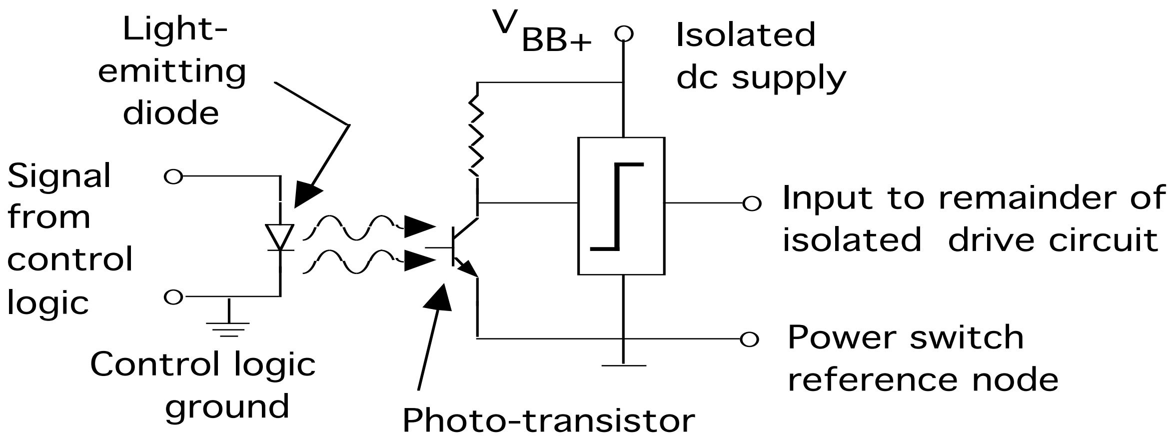
- Negative half cycle of $v_s(t)$ - positive dc rail near safety ground potential. $T_-$ emitter potential large and negative with respect to safety and logic ground
- Postive half cycle of $v_s(t)$ - negative dc rail near safety ground potential. $T_+$ emitter substantially positive with espect to safety ground if $T_-$ is off
- Variation in emitter potentials with respect to safety and logic ground means that electrical isolation of emitters from logic ground is needed.



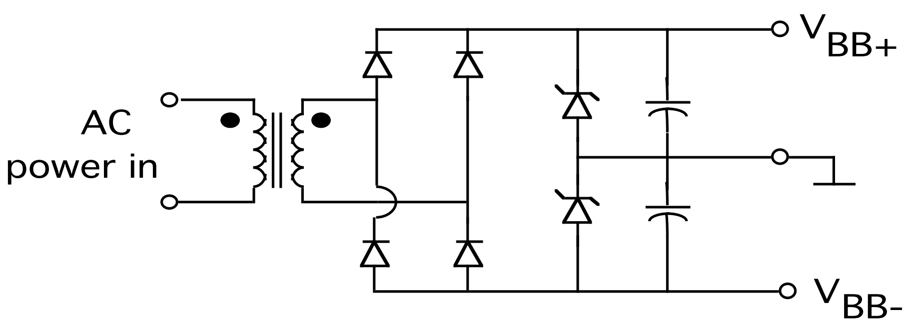
# Methods of Control Signal Isolation




- Transformer isolation

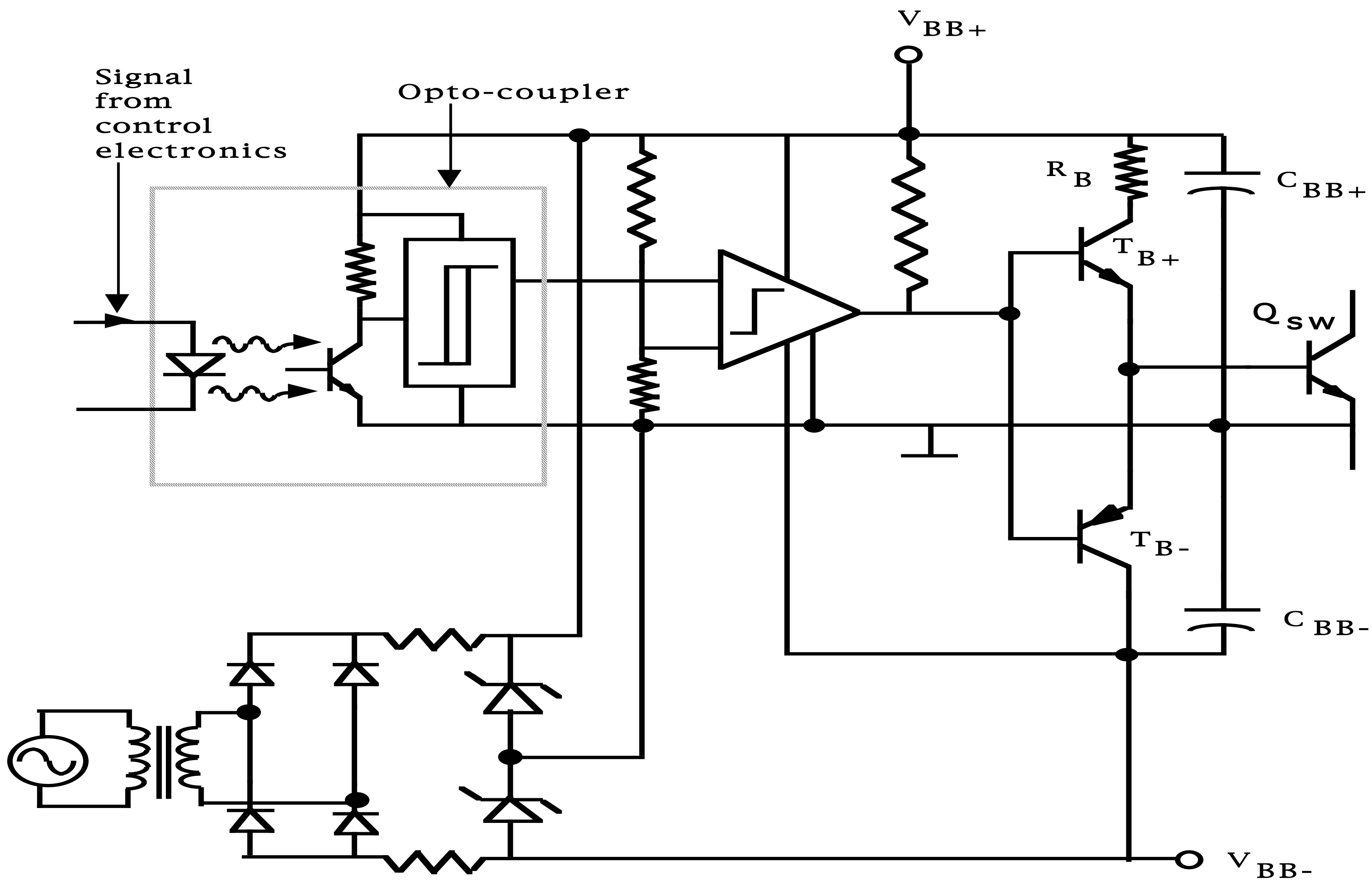



- Opto-coupler isolation

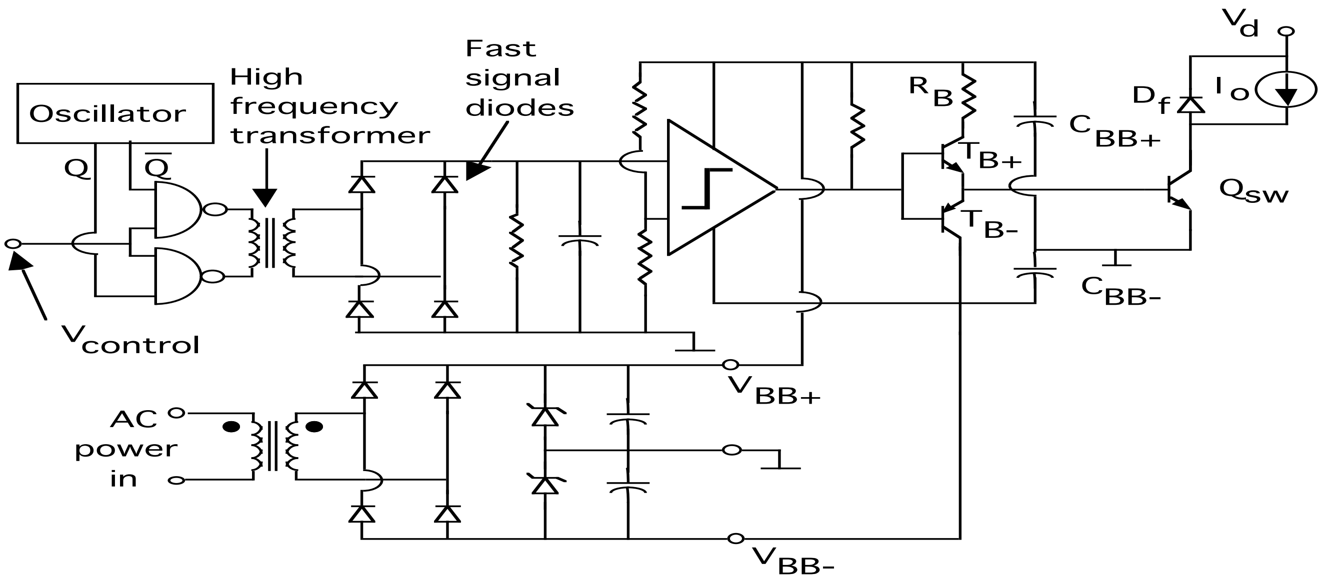


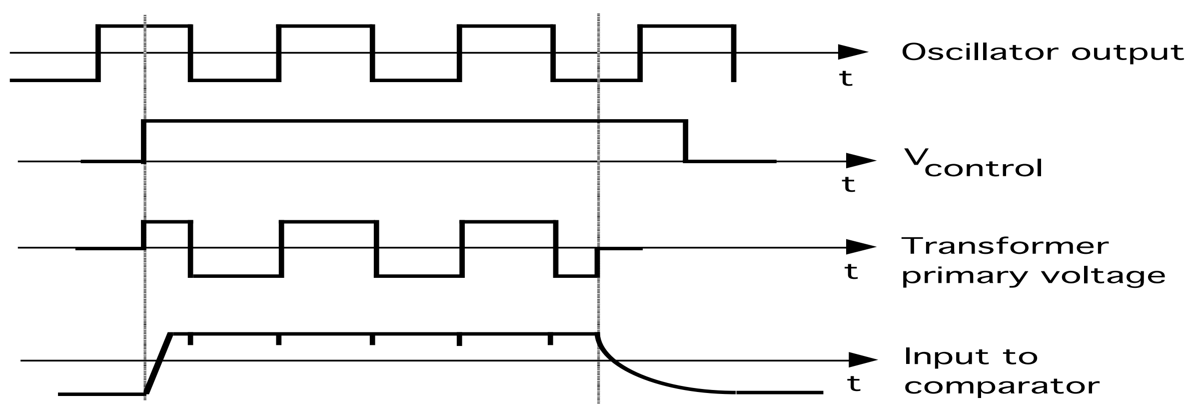

- Isolated dc power supplies for drive circuits

# Opto-Coupler Isolated BJT Drive

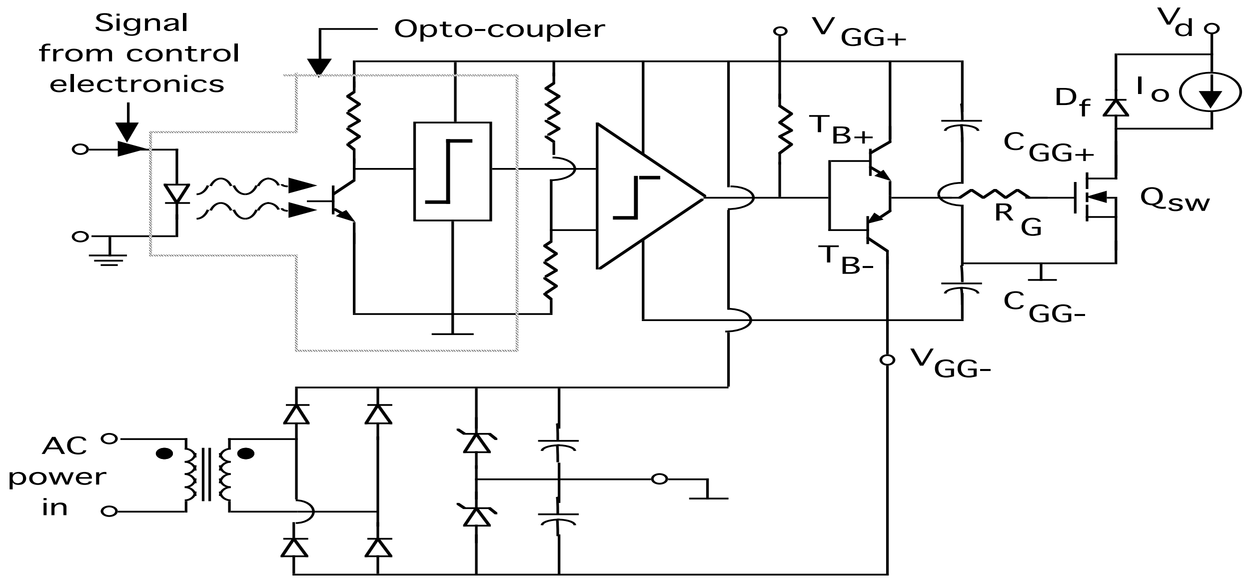


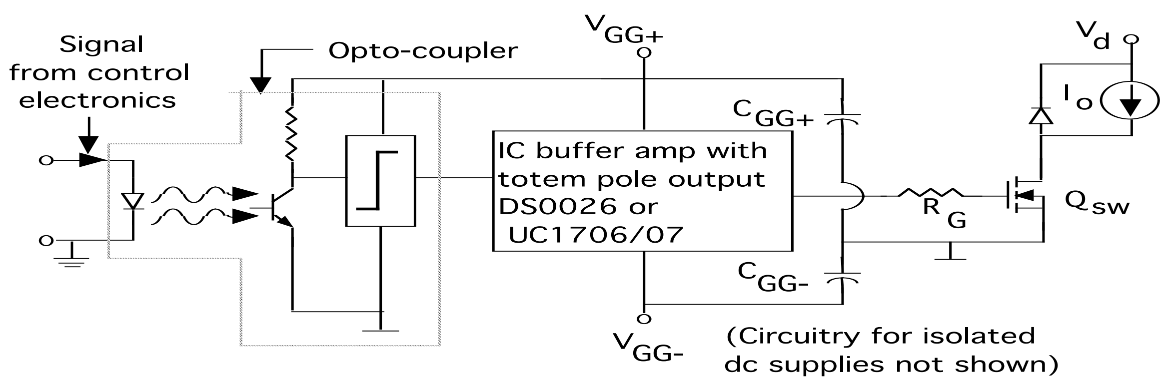
# Transformer-coupled BJT Drive



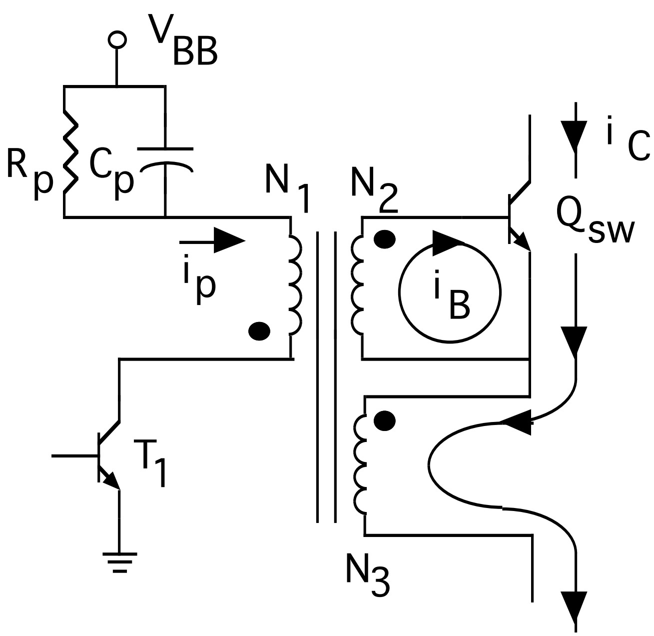



# Opto-Coupler Isolated MOSFET Drives



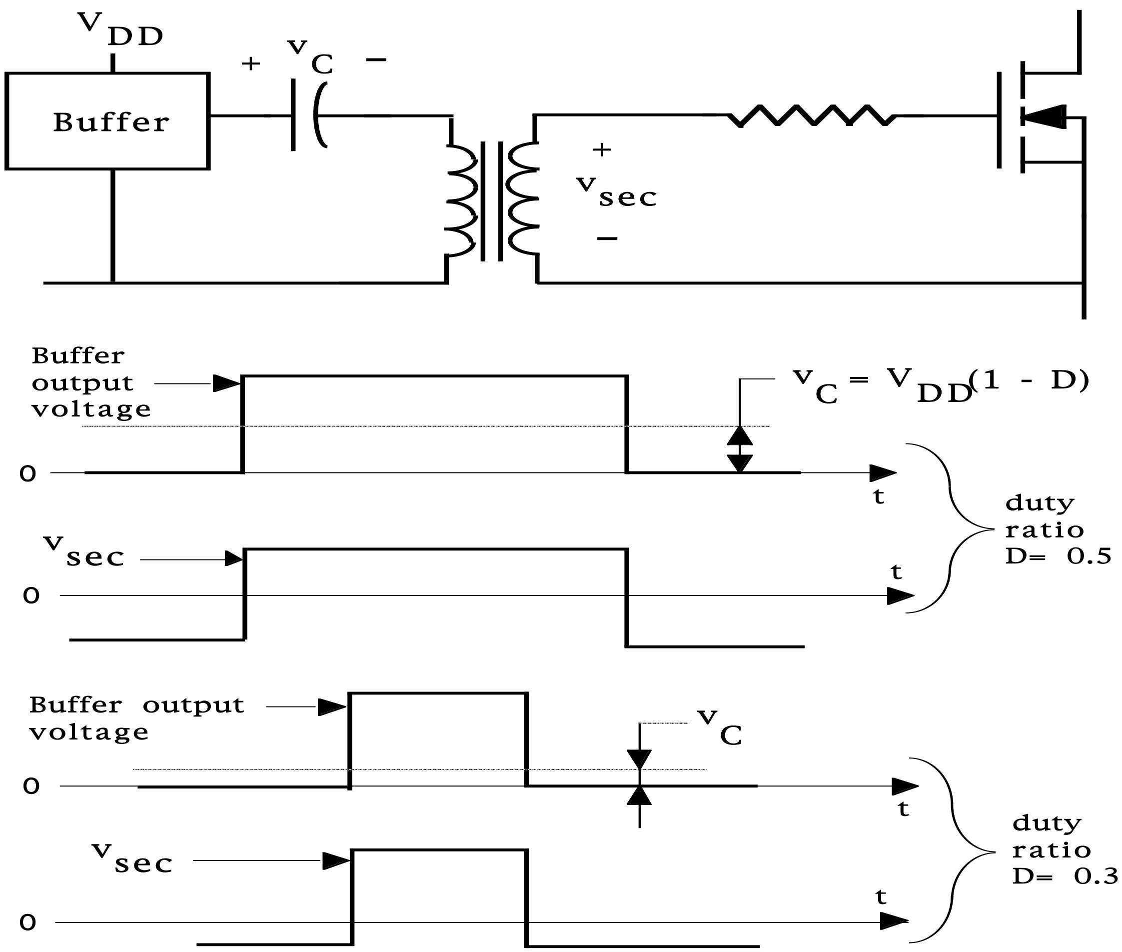



# Isolated Drives Without Auxiliary DC Supplies - Proportional Flyback BJT Example



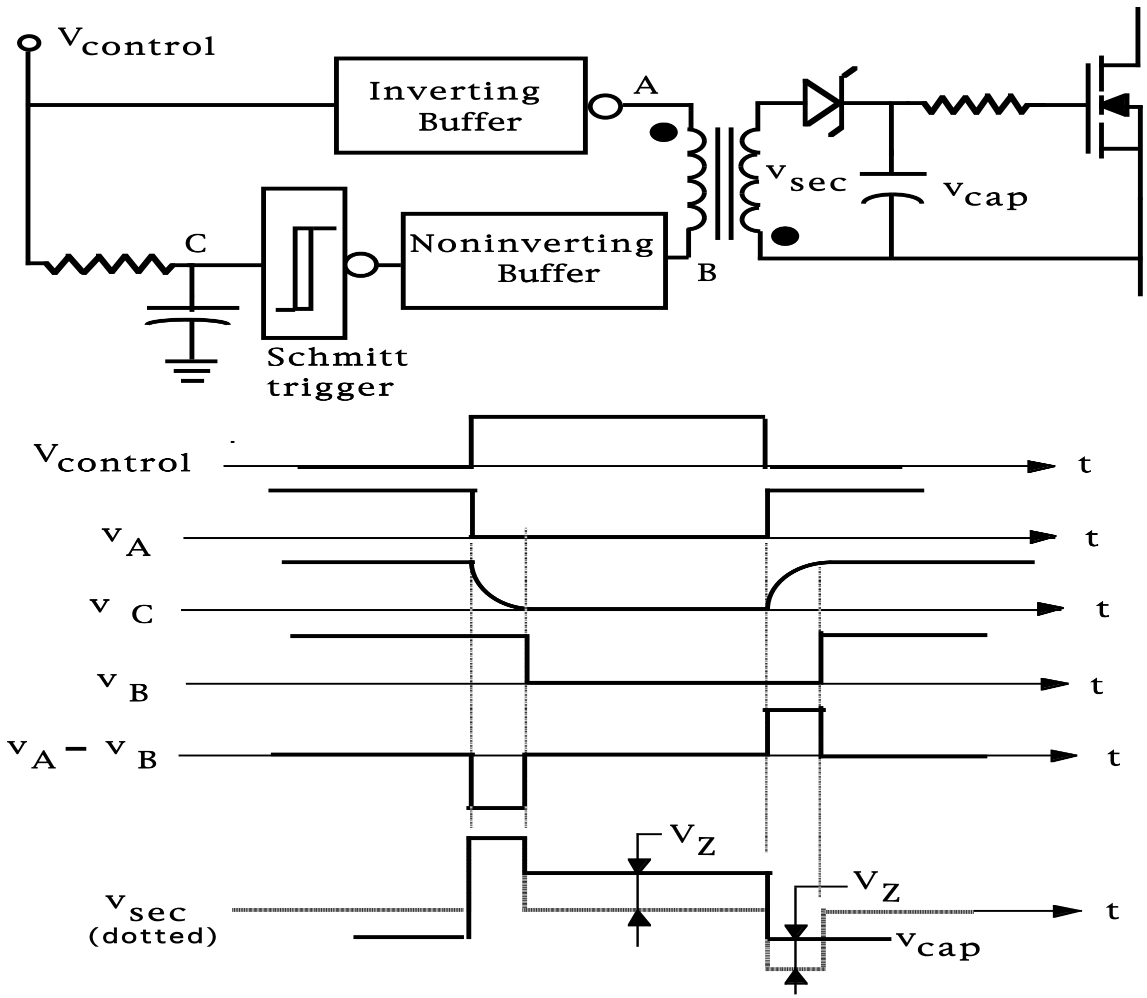

- Regenerative circuit operation
  - $T_1$ on - current $i_p = V_{BB}/R_p$ and $Q_{sw}$ off
  - $T_1$ turned off - stored energy in gapped transformer core induces positive base current $i_B$ in $Q_{sw}$ causing it to go active and collector current $i_C$ begins to flow
  - Regenerative action of transformer connections supplies a base current $i_B = N_3 i_C/N_2$ which keeps $Q_{sw}$ on even with $i_p = 0$
  - $T_1$ turned on - positive current $i_p$ causes a base current $i_B = N_3 i_C/N_2 - N_1 i_p/N_2$ in $Q_{sw}$
    - Initially $i_p$ quite large ($i_p(0^+) =$ □$i_{B1}(0^+)$) so $Q_{sw}$ turned off
- Circuit design must insure turn-off $i_B$ has adequate negative magnitude and duration
  - Best suited for high frequency operation - lower volt-second requirements on transformer.
  - Also best suited for limited variations in duty cycle

# Isolated Drives Without Auxiliary DC Supplies - MOSFET Example



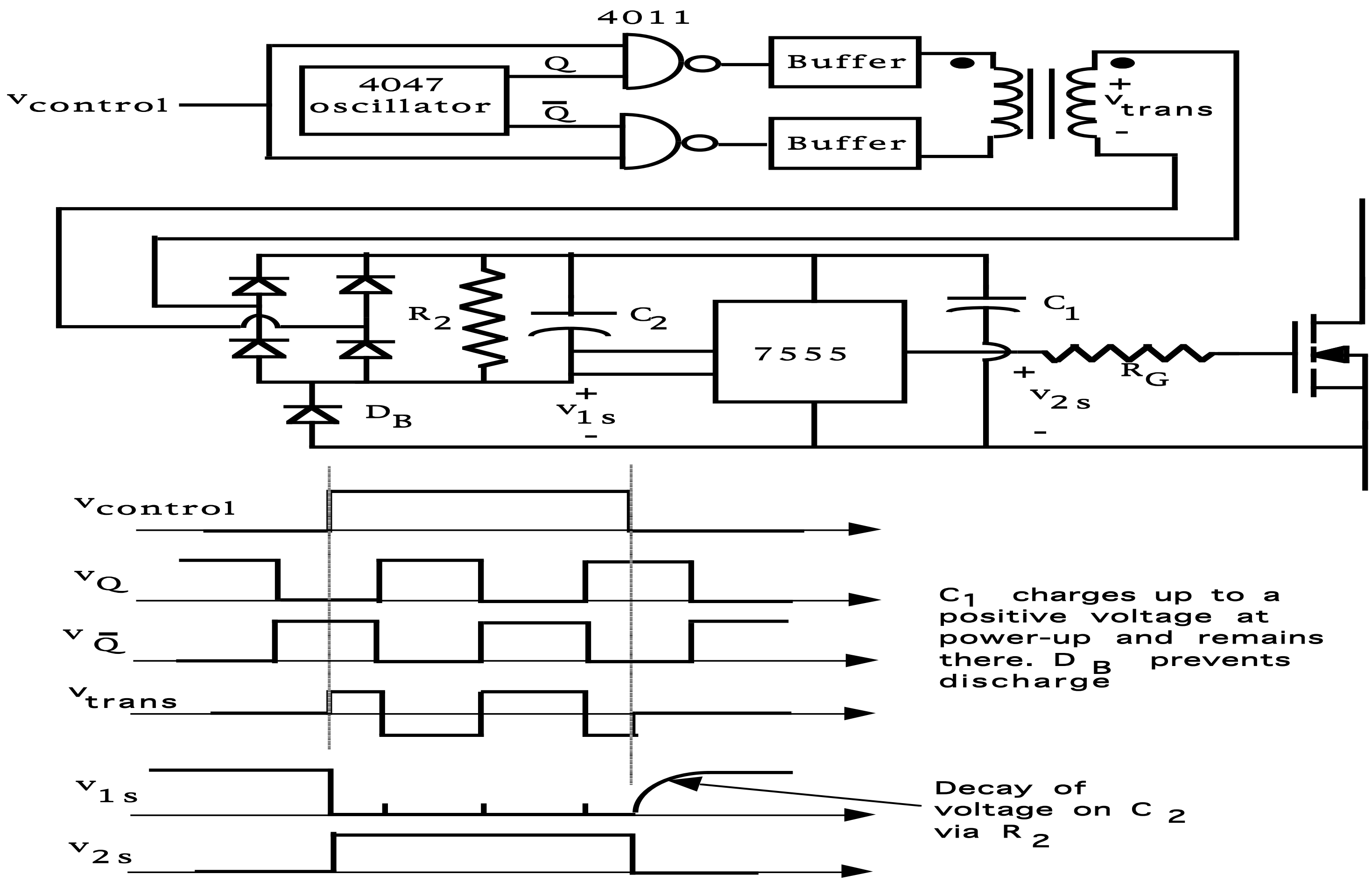

Most suitable for applications where duty cycle D is 50% or less. Positive-going secondary voltage decreases as D increases.

# Isolated Drive Without Auxiliary DC Supplies - MOSFET Example

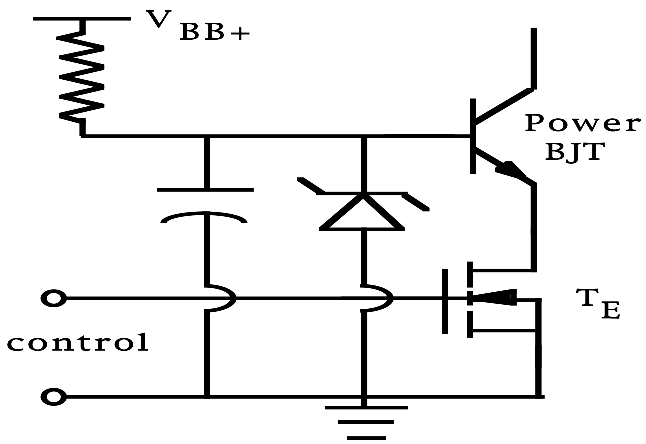


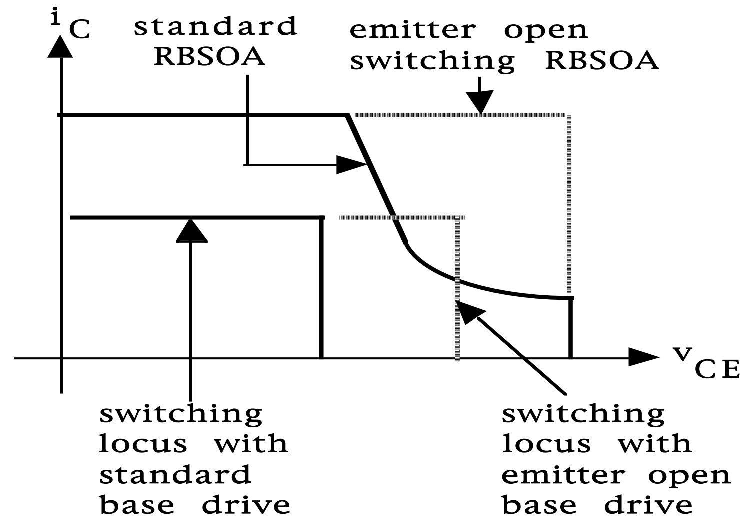

Zener diode voltage $V_Z$ must be less than negative pulse out of transformer secondary or pulse will not reach MOSFET gate to turn it off.

# Isolated Drive Without Auxiliary DC Supplies - MOSFET Example



# Emitter-Open Switching of BJTs



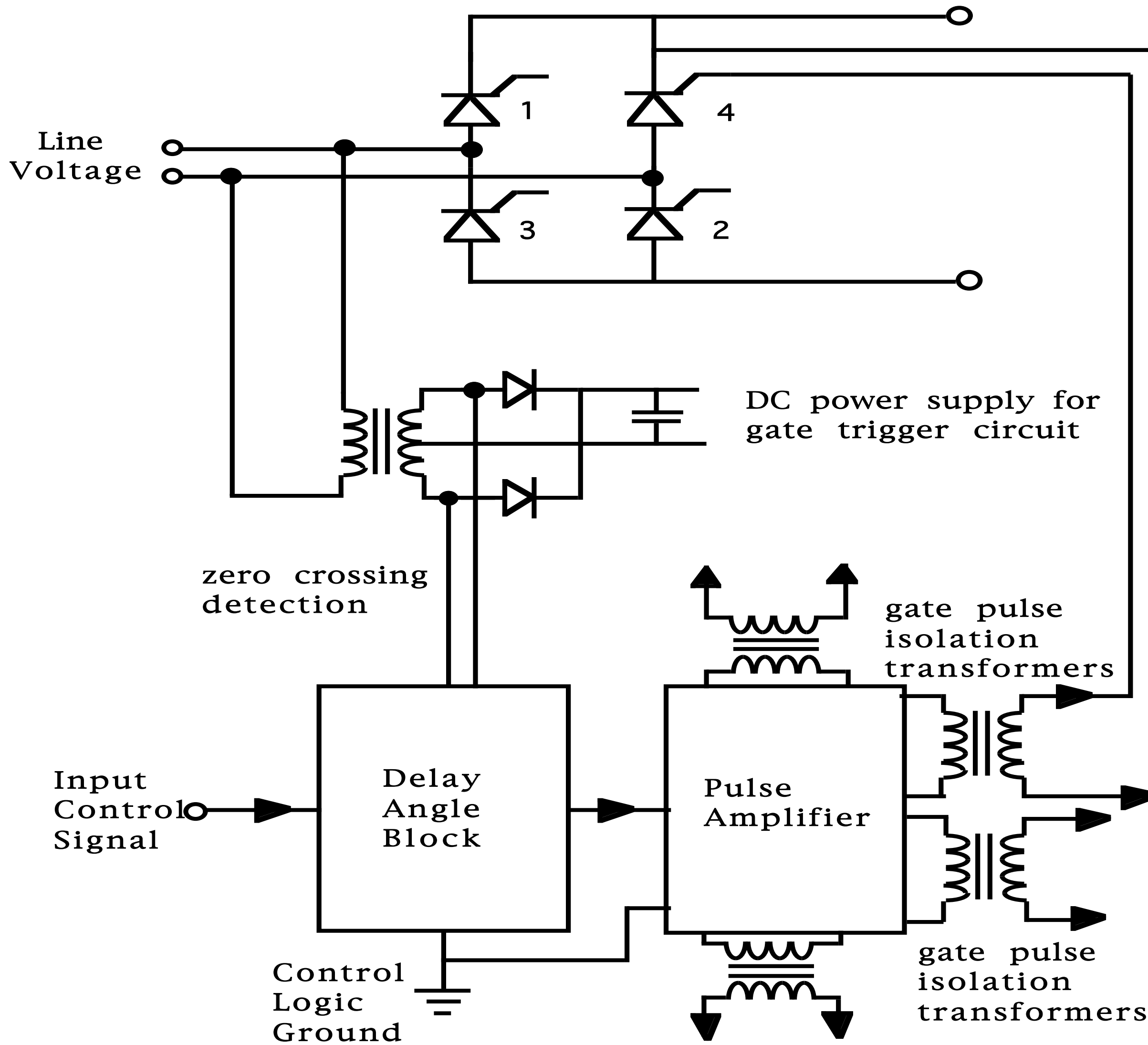




- Circuit operation
  - Turn on power BJT by turning on MOSFET $T_E$.
  - Turn off power BJT by turning off MOSFET $T_E$.
    - Collector current flows out base as negative base current.
  - Greater $i_B$(off) compared to standard drive circuits $i_C$ = b $i_B$(off) removes stored charge much faster
    - Turn off times reduced (up to ten times).

- On-state losses of series combination of MOSFET and BJT minimized.
  - Low voltage MOSFET which has low losses can be used. Maximum off-state MOSFET voltage limited by Zener diode.
  - BJT base emitter junction reverse biased when $T_E$ off so breakdown rating of BJT given by $BV_{CBO}$ instead o of $BV_{CEO}$. With lower $BV_{CEO}$ rating, BJT losses in on-state reduced.

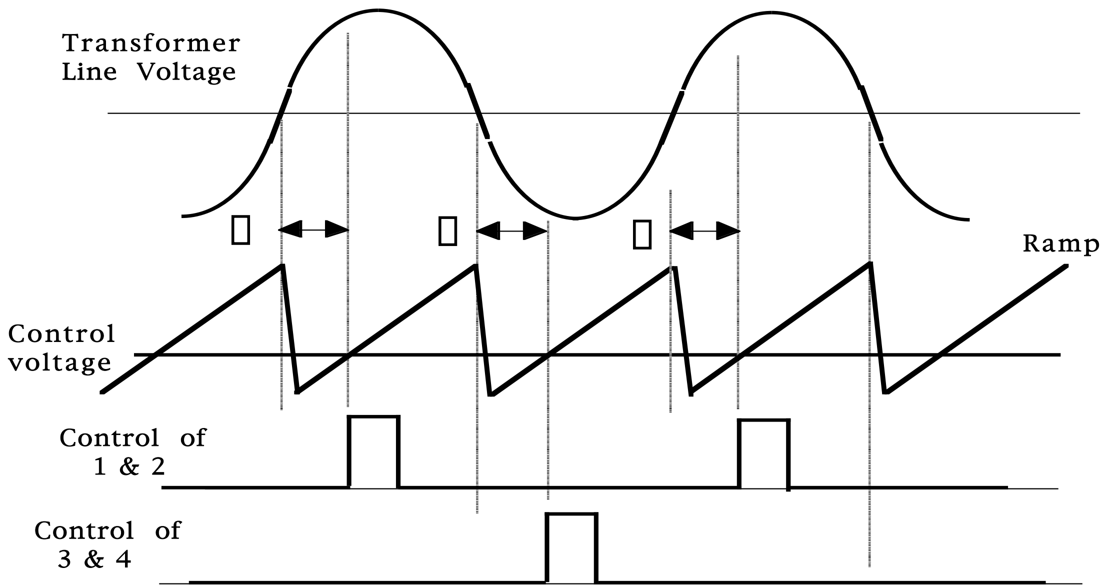
- Circuit also useful for GTOs and FCTs.

# Thyristor Gate Drive Circuit

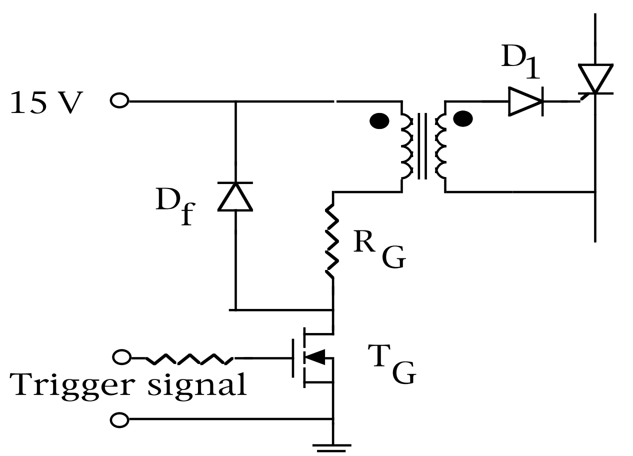



Delay angle block is commercially available integrated circuit - TCA780 circuit family

# Thyristor Gate Drive Circuit (cont.)

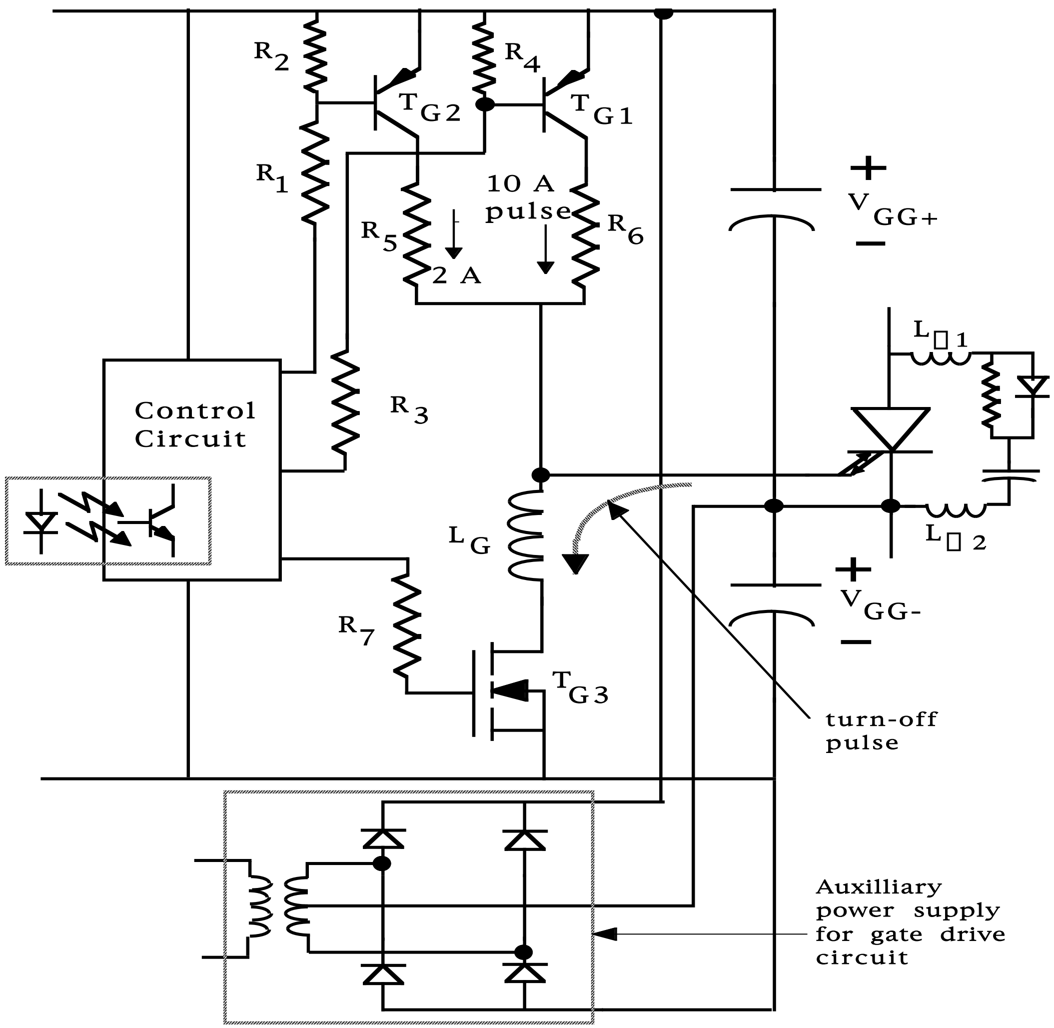



**Thyristor gate drive waveforms**



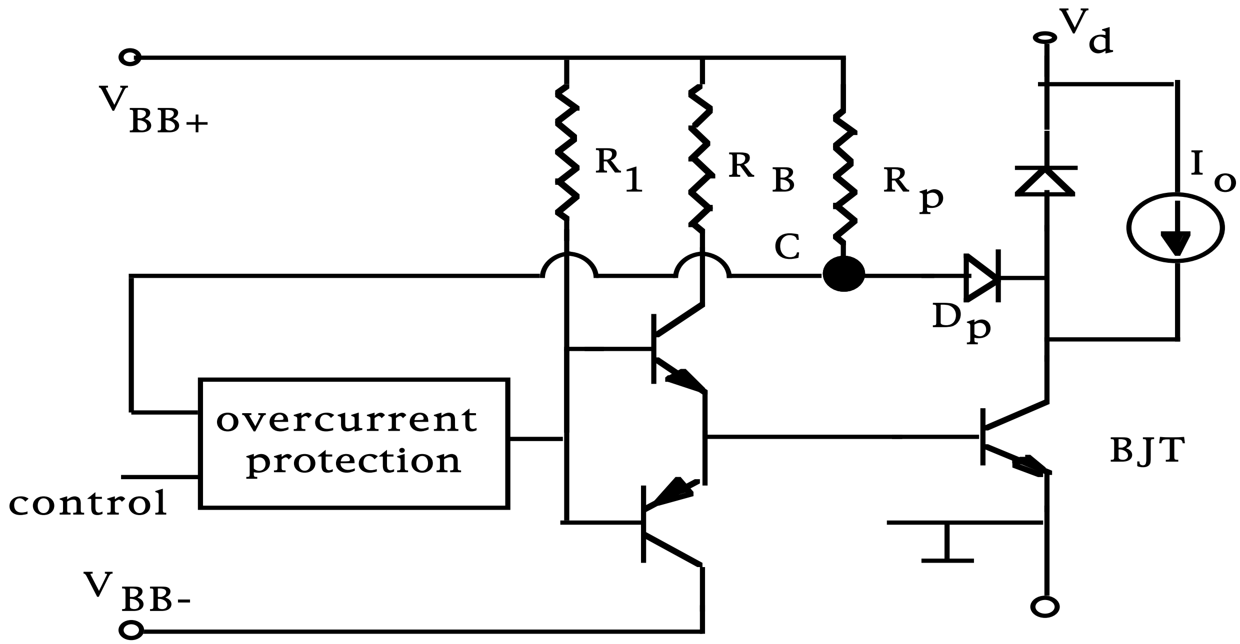

**Gate pulse amplifier**

# GTO Gate Drive Circuit




- **Turn on $T_{G1}$ and $T_{G2}$ to get large front-porch current**
- **Turn off $T_{G1}$ after some specified time to reduce total gate current to back-porch value.**

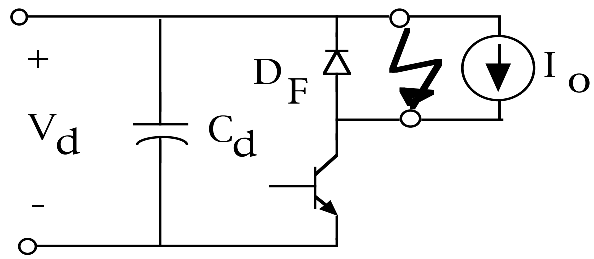
# Overcurrent Protection With Drive Circuits



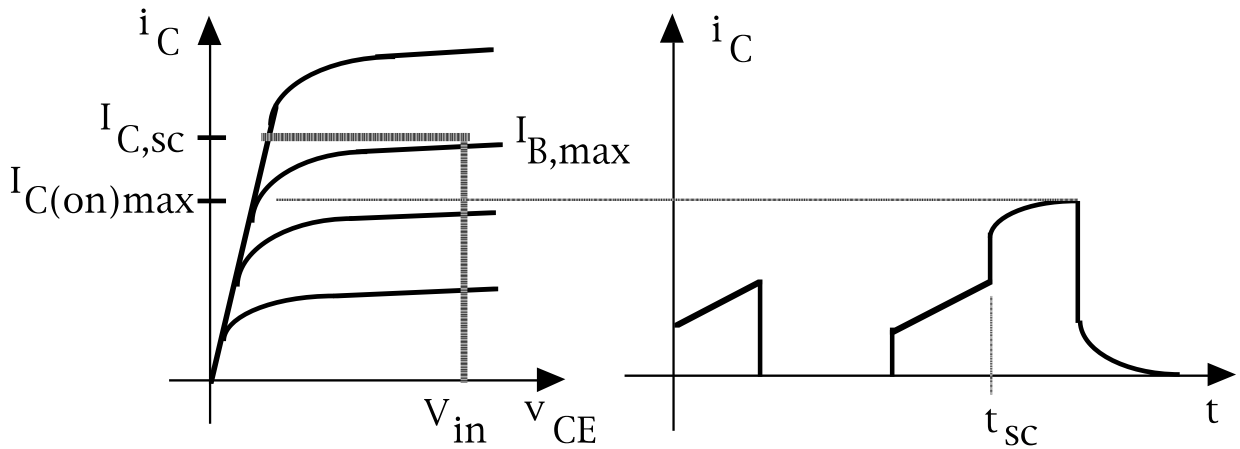

- Point C one diode drop above $V_{CE(sat)}$ when BJT is on. Overcurrent will increase $V_{CE}$ and thus potential at C.

- If C rises above a threshold value and control signal is biasing BJT on, overcurrent protection block will turn off BJT. Conservate design would keep BJT off until a manual reset had been done.

# Limiting Overcurrents by Limiting On-state Base Current

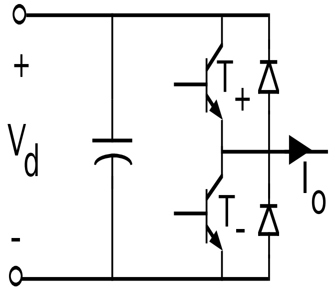



- Stepdown converter with short curcuit at $t = t_{sc}$

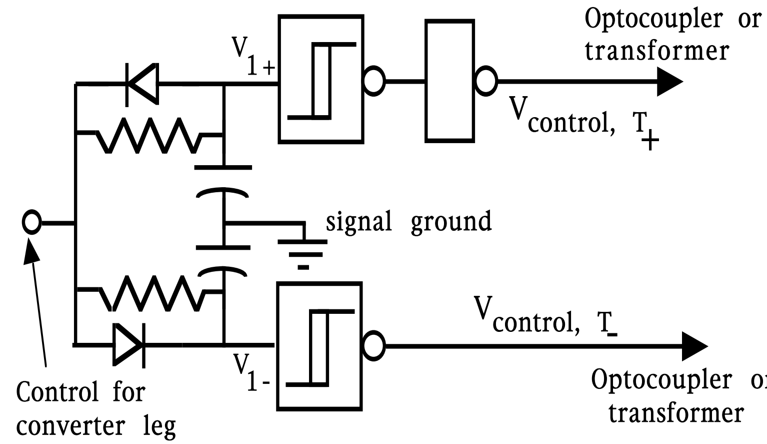


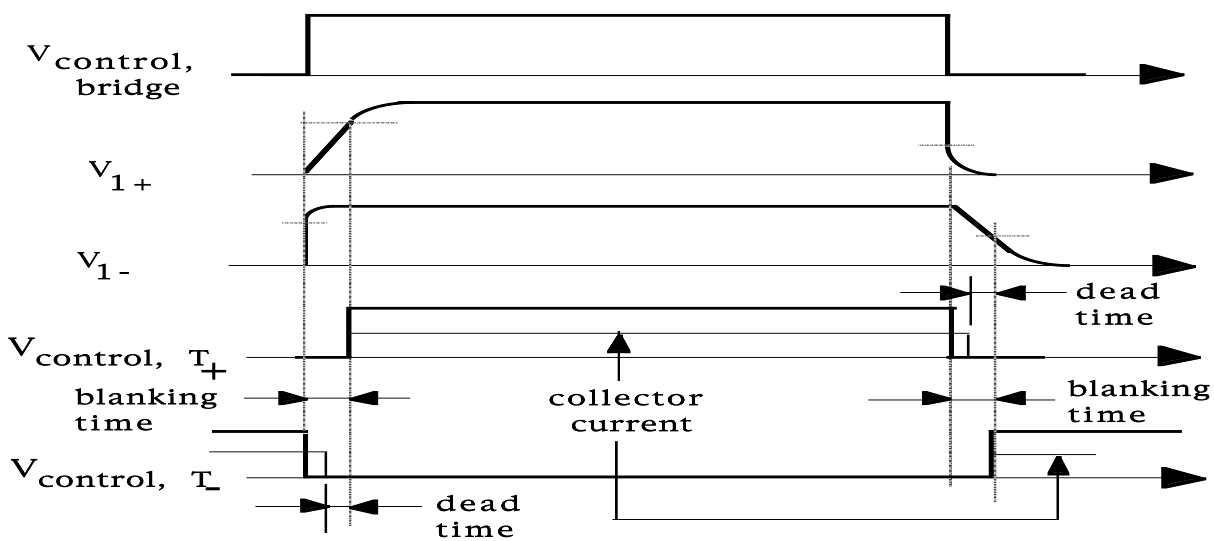

- Overcurrent limited to $I_{C(on)max} < I_{C,sc}$ by keeping $I_{B,max} < I_{C,sc}/b$
- $I_{C,sc}$ = maximum allowable instantaneous collector current
- Same approach can be used with MOSFETs and IGBTs. $V_{GS}$ mustbe restricted to keep drain current to safe values.

# Blanking Times in Bridge Circuit Drives

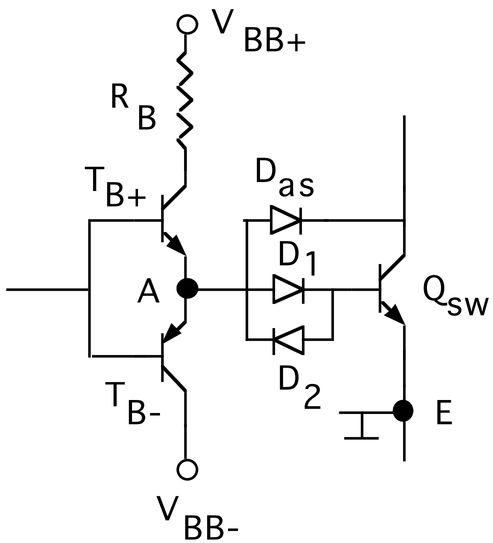



- Turn off T+ before turning on T- in order to avoid cross -conduction (shorting out of Vd)



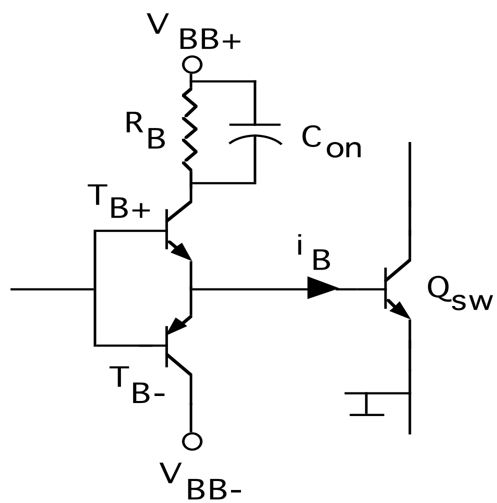



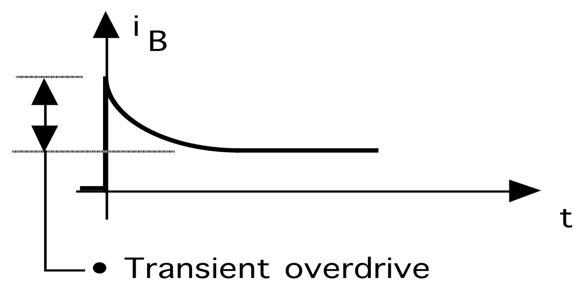
# Drive Circuit Waveshaping for Improved Operation




- Anti-saturation diode $D_{as}$ keeps $Q_{sw}$ active.
  - $V_{AE} = V_{BE(on)} + V_{D1} = V_{CE(on)} + V_{das}$
  - $V_{CE(on)} = V_{BE(on)} > V_{CE(sat)}$ because $V_{D1} = V_{das}$
- $D_s$ provides path for negative base current at $Q_{sw}$ turn-off.
- Storage delay time at turn-off reduced but on-state losses increase slightly.

Speed-up capacitors

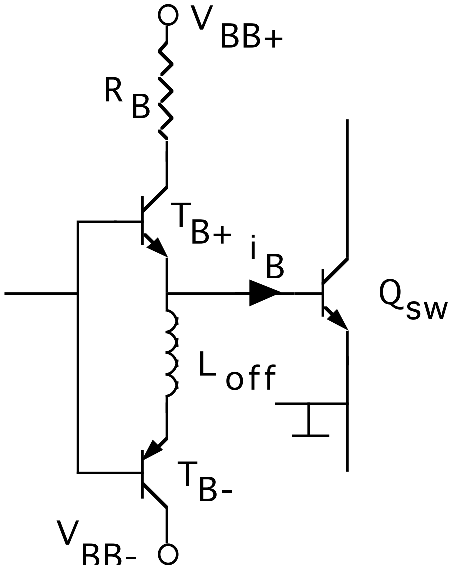



- Transient overdrive provided via C on for faster turn-on of switch

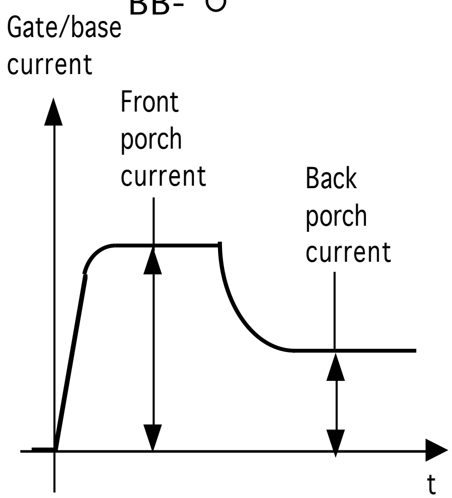
- Same concept can be applied to MOSFET and IGBT drive circuits

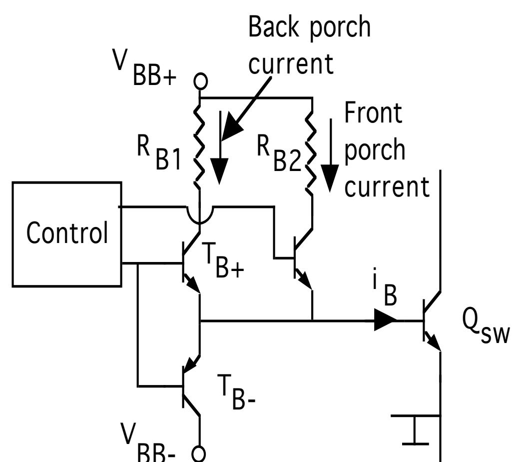
# Drive Circuit Waveshaping (cont.)




Controlled rate of change of turn-off base current

- Excessively long collector current tailing time at BJT turn-off if $di_B(off)/dt$ is too large.
- Inductor $L_{off}$ restricts $di_B(off)/dt$ to $- V_{BB}/L_{off}$

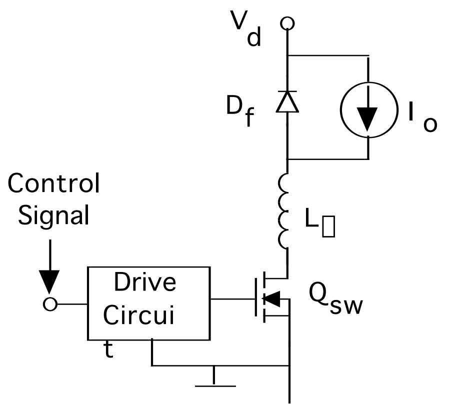


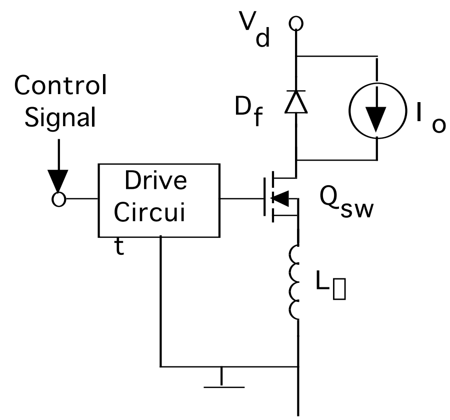




Front porch, back porch gate/base currents at turn-on

- Faster turn-on without putting device deeply into on-state where turn-off delay time will be substantially increased.
- Applicable to BJTs, MOSFETs, IGBTs, and GTOs.

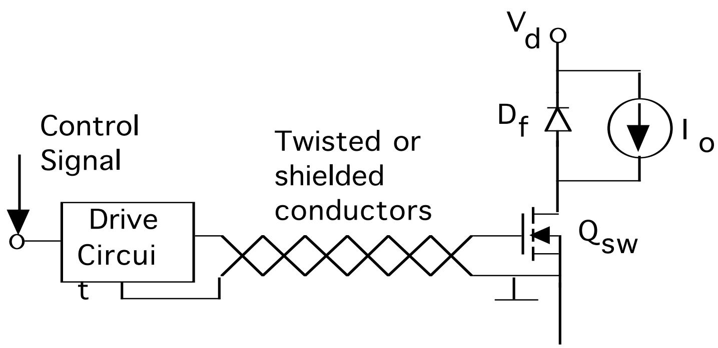
# Circuit/Component Layout Considerations



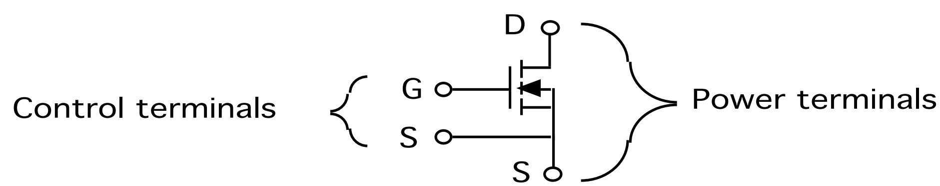




Prime consideration is minimizing stray inductance

- Stray inductance in series with high-voltage side of power device $Q_{sw}$ causes overvoltage at turn-off.
- Stray inductance in series with low-voltage side power device $Q_{sw}$ can cause oscill-ations at turn-on and turn-off.
- One cm of unshielded lead has about 5 nH of series inductance.
- Keep unshielded lead lengths to an absolute minimum.




Use shielded conductors to connect drive circuit to power switch if there must be any appreciable separation (few cm or more) between them




Some power devices provided with four leads, two input leads and two power leads, to minimize stray inductance in input circuit.