Chapter 33

Thyristors and Optical Devices

Circuit Analysis with Devices:
Theory and Practice
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Introduction to Thyristors

- Thyristors
  - Switch
  - On-state, off-state
  - Unilateral or bilateral
  - Latching
  - High power

Robbins and Miller

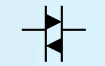
Introduction to Thyristors

- Thyristors
  - Sinusoidal
    - Firing angle
    - Conduction angle

Triggering Devices

- Used to pulse switching devices
- Diac
  - 3-layer
  - Bi-directional conduction
  - Breakover voltage
  - Blocking region

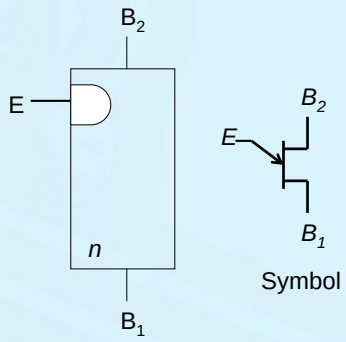
Symbols



Triggering Devices

- Unijunction Transistor (UJT)
  - 3-terminal device
  - Intrinsic standoff ratio

$$\eta = \frac{R_{B1}}{R_{B1} + R_{B2}} = \frac{R_{B1}}{R_{BB}}$$



Symbol

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Triggering Devices

- UJT
  - $0.5 < \eta < 0.9$
  - Emitter region heavily doped
  - $V_E - B_1 = 0$, *p-n* junction reverse biased
  - Increase $V_E - B_1$, reach peak point (maximum current)

Triggering Devices

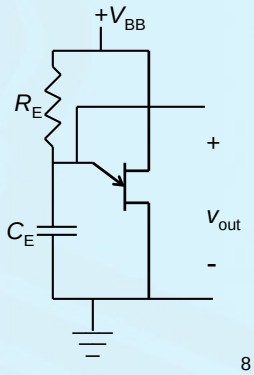
- UJT
  - Continue increase, reach valley point
  - Further increase V_E – B_1, UJT is saturated

Triggering Devices

- UJT relaxation oscillator

$$T = R_E C_E \ln\left(\frac{1}{1-\eta}\right)$$

$$f = \frac{1}{T}$$



Silicon Controlled Rectifiers (SCRs)

- 4-layer device, *p-n-p-n*
- Anode (A)
  - Cathode (K)
  - Gate (G)
- Unidirectional

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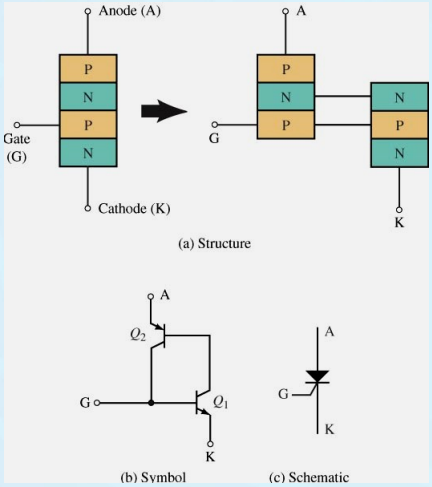
Silicon Controlled Rectifiers (SCRs)

- High-power (*I* up to 2500 A, *V* up to 2500 V)
- Phase control
- Small V_{AK} when On

SCRs



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SCRs

- Operation
  - $I_G = 0$, no anode current
  - $I_G > I_{GT} \rightarrow$ regenerative feedback $\rightarrow$ high I_{AK}
  - $I_{AK} < I_H \rightarrow$ turn off $\rightarrow I_{AK} = 0$

SCRs

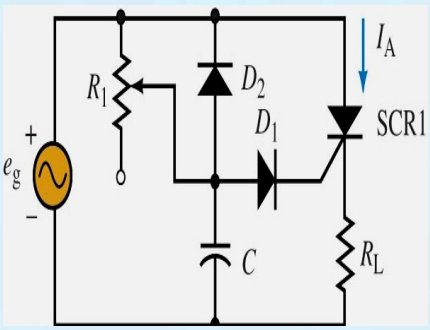
- Can cause SCR turn-on
  - High temperature
  - High $\Delta V/\Delta t$ (noise)
  - Radiation

SCRs

- Specifications
  - V_{DRM} or V_{RRM} Peak Repetitive Off-state Voltage
  - $I_{T(RMS)}$ On-State RMS current (maximum)
  - I_{TSM} Peak Non-Repetitive Surge current
  - I_{GT} Gate trigger current
  - I_L Latching current
  - I_H Holding current

SCRs

- SCR phase control



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SCRs

- Small R_1
  - Short *RC* time constant
  - SCR turns on rapidly, close to 0°
- Large R_1
  - long *RC* time constant
  - SCR turns on slowly, close to 180°

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SCRs

- Too large R_1
  - SCR does not turn on

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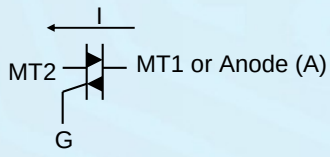
Triacs

- 3-terminal switch
- Bi-directional current
- Symbol



- Gate trigger may be either + or – pulse

Triacs

- Characteristics
  - Direct replacement for mechanical relays
  - Trigger circuit for full-wave control
  - 4 modes
  - Remains on in either direction until $I < I_H$
  - Blocking region, $I \approx \mu$ amps
  - Small voltage across Triac when On

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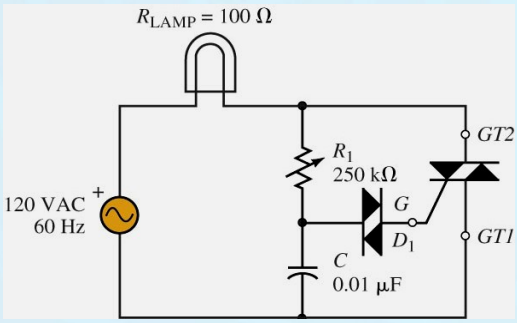
Triacs

- Specifications
  - Similar to SCR
  - P_{GM} Peak Gate Power
  - $P_{G(AV)}$ Average Gate Power
  - V_{GM} Peak Gate Voltage
  - V_{GT} Gate trigger voltage
  - t_{gt} Turn-On Time

Robbins and Miller

Triacs

- Phase control light dimmer



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Triacs

- Circuit operation
  - Turn-off due to small load current
  - Capacitor charges/discharges through load
  - DIAC is bi-directional
  - *RC* time constant → 0° to 180° turn on in each direction

Power Control Fundamentals

- Review equations
- Control
  - Lamp intensity
  - Heat from a resistive heater
  - Speed of a motor

Power Control Fundamentals

$$P = \frac{V_{rms}^2}{R}$$

$$V_{rms} = \sqrt{\frac{\int_0^T [V(t)]^2 \, dt}{T}}$$

$$V_{rms(FW)} = \frac{V}{\sqrt{2}} \qquad V_{rms(HW)} = \frac{V}{2}$$

Power Control Fundamentals

- Delayed turn-on, full-wave signal

$$V_{rms(FW)} = \sqrt{\frac{\int_{\theta_F}^{T} [V \sin\theta]^2 \, d\theta}{\pi}}$$

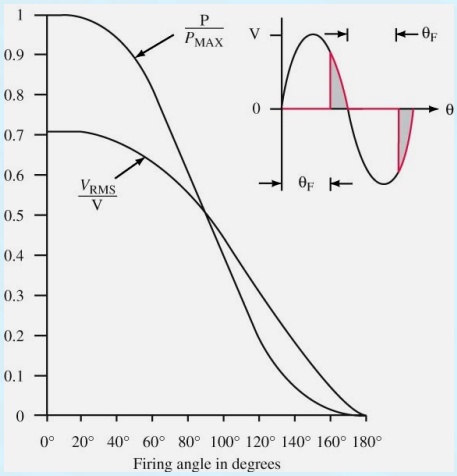
- Delayed turn-on, half-wave signal

$$V_{rms(HW)} = \sqrt{\frac{\int_{\theta_F}^{\pi} [V \sin\theta]^2 \, d\theta}{2\pi}}$$

25

Power Control Fundamentals

- *V* and *P* curves for full-wave control



26

Introduction to Optical Devices

- Opto-electronic devices wavelength
  - Current → light
  - Light → current
  - c = speed of light in a vacuum
  - c = 3 x 10^8 m/s

λ =

$$\lambda = \frac{c}{f}$$

Circuit Analysis with Devices:
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Introduction to Optical Devices

- Electromagnetic spectrum
  - Visible (380 < λ (nm) < 750)
  - Infrared region (750 < λ (nm) < 1000)

1 Å = 1×10^{-10} m = 0.1 nm

Introduction to Optical Devices

- LED is a diode
  - When forward biased
  - Electron-hole recombination energy
  - Photons released: $E = hf$, h is Planck's constant
  - $h = 6.626 \times 10^{-34}$ Joules·seconds
  - High energy → visible spectrum
  - Lower energy → IR spectrum

Circuit Analysis with Devices:
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Introduction to Optical Devices

- LED advantages
  - Low voltage
  - Rapid change in light output with input V change
  - Long life
  - LED output can be matched to photodetector

Introduction to Optical Devices

- LED disadvantages
  - Easily damaged
  - Brightness dependent on temperature
  - Chromatic dispersion
  - Inefficient compared to LCDs

Circuit Analysis with Devices:
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Photodetectors

- *R* varies with light intensity
  - Photoresistors
- Voltage or current varies with light intensity
  - Photodiodes
  - Phototransistors
  - Light-Activated SCRs (LASCRs)

Photodetectors

- Photodiodes
  - Reverse biased
  - Low ambient light → very small current, I_D (small leakage current)
  - High ambient light → increased current, I_D (increase in minority carriers)

Circuit Analysis with Devices:
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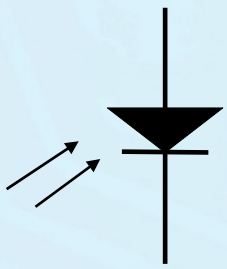
Photodetectors

- Photodiodes
  - Symbol



Photodetectors

- Phototransistor
  - Base open
  - Light on reverse-biased CB junction
  - Increase minority carriers
  - Increase I_C

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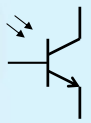
Photodetectors

- Phototransistor
  - Usually used as a switch
    - Off $\rightarrow I_C = 0$
    - On $\rightarrow I_C > 0$



Photodetectors

- LASCR
  - Light-Activated SCR or photo-SCR
  - Symbol
  - Light turns LASCR on
  - Open gate or resistor on gate to control sensitivity

Circuit Analysis with Devices:
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Optocouplers

- Couple two circuits
  - LED and Photodetector in single circuit
- Electrical isolation
  - Medical equipment
  - High voltage circuit to digital circuit

Robbins and Miller

Optocouplers

- Use as
  - Linear device
  - Digital buffer

Circuit Analysis with Devices:
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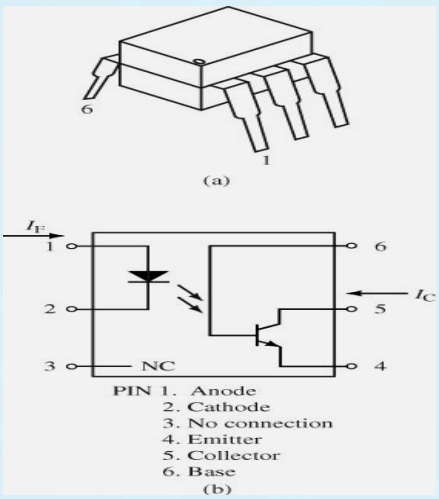
Optocouplers

- Phototransistor optocoupler



Optocouplers

- Current transfer ratio
- 0.1 < CTR < 1

$$\text{CTR} = \frac{I_C}{I_F}$$

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Optocouplers

- Operation
  - High diode current in input circuit yields
  - High diode light output which yields
  - High collector current in output circuit

Semiconductor LASERs

- Light Amplification through Stimulated Emission of Radiation
- Operation
  - Similar to LEDs
  - Monochromatic (same frequency)
    - Coherent (same phase) output
  - Small pulse dispersion