Chapter 27

Diode Theory and Application

Circuit Analysis with Devices:
Theory and Practice
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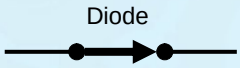
Diode Models

- Ideal model is a switch
- Forward-biased ideal model
  - Short Circuit
  - $V_D = 0$
  - $R_D = 0$



Robbins and Miller
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Diode Models

- Reverse-biased ideal model
  - Open Circuit
  - V_D = Supply Voltage
  - $R_D = \infty$

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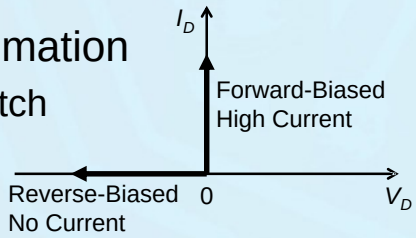
Diode Models

- Characteristic curve shows Current vs Voltage
- 1st approximation
  - Ideal Switch



Diode Models

- Circuit model – Ideal Diode

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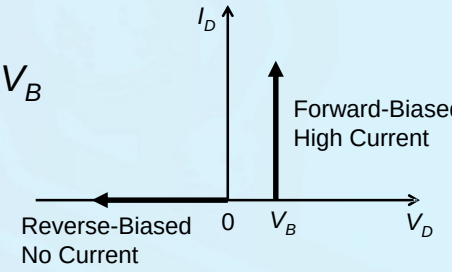
Diode Models

- 2nd approximation
  - Ideal Switch
  - Barrier potential, V_B

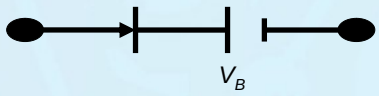
  Si ≈ 0.7 volts

  Ge ≈ 0.3 volts



Diode Models

- Circuit Model
  - Ideal Diode
  - V_B



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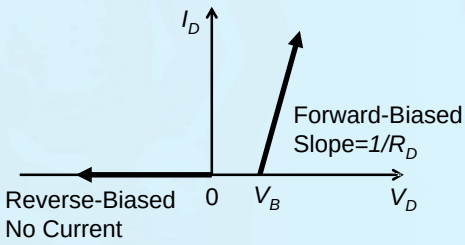
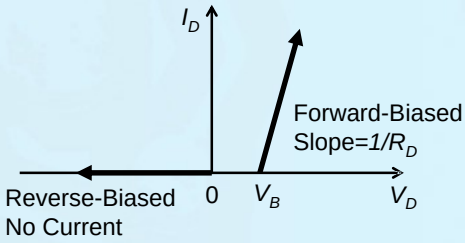
Diode Models

- 3rd approximation
  - Barrier potential, V_B
  - V_B
  - Internal Resistance



Diode Models

- Circuit Model
  - Ideal Diode
  - V_B
  - R_D



Diode Characteristic Curve

- Regions of a real diode curve
- Forward Region
  - Conduction
  - Knee
  - High resistance

Diode Characteristic Curve

- Reverse Region
  - High resistance blocking
  - Diode breakdown

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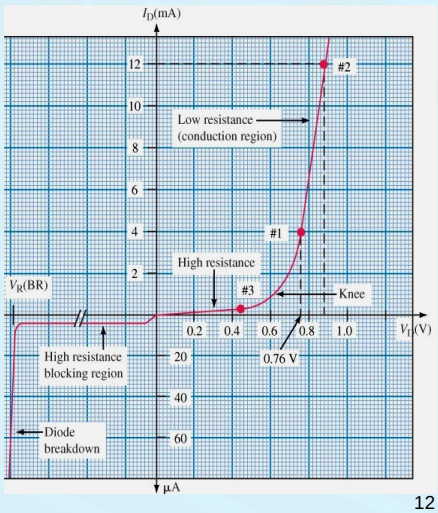
Diode Characteristic Curve

- Real Diode I/V curve



Diode Characteristic Curve

- Forward region
  - Conduction region
  - Dynamic resistance is $\frac{\Delta V}{\Delta I}$

Diode Characteristic Curve

- Reverse region
  - Small reverse voltages yield very small currents (uA)
  - Reverse breakdown voltage, $V_{R(BR)}$
  - Peak Inverse Voltage (PIV), Peak Reverse Voltage (PRV) or $V_{R(max)}$

Diode Data Sheets

- Manufacturer specifications (specs)
- Describe product electrical characteristics
  - Recommended operating conditions
  - Maximum ratings (PIV, power = I^2R)
  - ac
  - dc

Diode Data Sheets

- Part number with 1N prefix

Diode Data Sheets

- Two sections
  - Maximum ratings: limits that must not be exceeded
  - Electrical Characteristics: typical and max values during operation
    - Forward voltage drop
    - Reverse voltage

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Diode Data Sheets

- Always need a safety margin
  - At least 20% more *I or V* than your circuit
  - e.g., if PIV expected in your circuit is 150 V, choose diode with PIV of >180 V

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Diode Data Sheets

- Many manufacturers
- Many diode types (e.g. bridge, high-speed switching, small signal, Varactor, Zener)
- Data sheets on Internet

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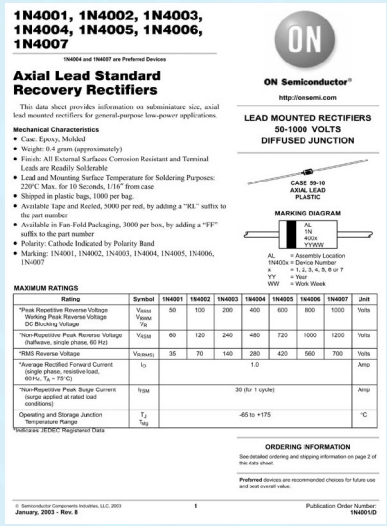
Diode Data Sheets

- Example



1N4001, 1N4002, 1N4003, 1N4004, 1N4005, 1N4006, 1N4007

1N4004 and 1N4007 are Preferred Devices

Axial Lead Standard Recovery Rectifiers

This data sheet provides information on subminiature size, axial lead mounted rectifiers for general-purpose low-power applications.

Mechanical Characteristics

- Case: Epoxy, Molded
- Weight: 0.4 gram (approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminal Leads are Readily Solderable
- Lead and Mounting Surface Temperature for Soldering Purposes: 220°C Max. for 10 Seconds, 1/16" from case
- Shipped in plastic bags, 1000 per bag.
- Available Tape and Reeled, 5000 per reel, by adding a "RL" suffix to the part number.
- Available in Fan Fold Packaging, 3000 per box, by adding a "FF" suffix to the part number.
- Polarity: Cathode Indicated by Polarity Band
- Marking: 1N4001, 1N4002, 1N4003, 1N4004, 1N4005, 1N4006, 1N4007

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http://onsemi.com

LEAD MOUNTED RECTIFIERS
50-1000 VOLTS
DIFFUSED JUNCTION

CASE 59-10
AXIAL LEAD
PLASTIC

MARKING DIAGRAM

AL
1N
400x
YYWW

AL = Assembly Location
1N400x = Device Number
x = 1, 2, 3, 4, 5, 6 or 7
YY = Year
WW = Work Week

MAXIMUM RATINGS

Rating	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
*Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
*Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	Volts
*RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
*Average Rectified Forward Current (single phase, resistive load, 60 Hz, T_A = 75°C)	I_O	1.0							Amp
*Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	30 (for 1 cycle)							Amp
Operating and Storage Junction Temperature Range	T_J T_{stg}	-65 to +175							°C

*Indicates JEDEC Registered Data

ORDERING INFORMATION

See detailed ordering and shipping information on page 2 of this data sheet.

Preferred devices are recommended choices for future use and best overall value.

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January, 2003 - Rev. 8

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Publication Order Number:
1N4001/D

Diode Data Sheets

- Reverse Voltage
  - dc
  - Repetitive sinusoidal
    - Full-wave
    - Half-wave
- Forward Current
  - Average
  - Surge

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Diode Data Sheets

- Maximum Instantaneous Forward Voltage Drop, V_F
- Maximum Full-Cycle Average Voltage Drop, $V_{F(AV)}$
- Temperature Derating
  - I^2R in diode generates heat
  - Derating curve

Diode Data Sheets

- Parameter Shifts
- Temperature increase Forward Region
  - Generates more e^- - *hole* pairs
  - Changes Barrier Potential, V_B
  - V_B decreases $\approx 2.5mV$ per 1° C increase

Diode Data Sheets

- Temperature increase Reverse Region
  - More minority carriers
  - Reverse current, $I_S \approx$ *doubles per 10° C* increase

Diode Data Sheets

- Reverse Recovery Time
  - Switching time
  - From On to Off state
  - t_{rr}
  - Nanoseconds for switching diodes
  - Microseconds for rectifier diodes

The Zener Diode

- Special purpose diode
- Operates in reverse-bias region
- Breakover voltage called Zener Voltage, V_Z

The Zener Diode

- V_Z is close to constant
  - From knee current, I_{ZK}
  - To maximum rated current, I_{ZM}
- V_Z is set by amount of doping used

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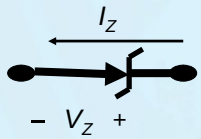
The Zener Diode

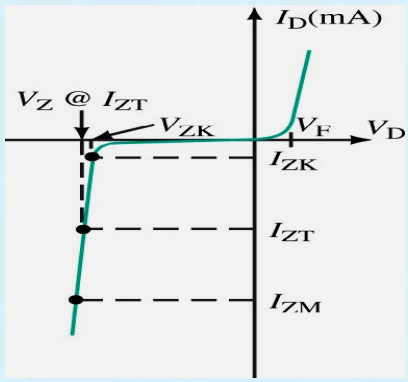
- Symbol:



- Available with *~2.4 V < V_Z < ~200 V*
- Forward direction – like a standard diode
- Reverse direction – sharp breakdown region

The Zener Diode

- Characteristic curve



The Zener Diode

- Zener Specification Sheet
  - Zener test current, I_{ZT}
  - Nominal Zener Voltage, V_Z (measured at I_{ZT})
  - Maximum Zener current, I_{ZM}
  - Knee current, I_{ZK}

The Zener Diode

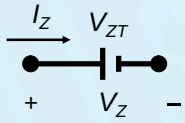
- Zener impedance, Z_Z @ I_{ZT}
  - Dynamic $Z = \frac{\Delta V}{\Delta I}$
  - 2 – 45 Ω
  - Almost constant in operating region

The Zener Diode

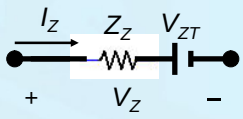
- Power Rating
  - Maximum dc power dissipation, P_{Dmax}
  - $P_{Dmax} = V_Z * I_{ZM}$ watts
  - $.25\ W < P_{Dmax} < 50\ W$
- Power Derating
  - Factor such as *6.67 mW per ° C*
  - Graph

The Zener Diode

- Modeling
  - Ideal



  - 2nd approximation



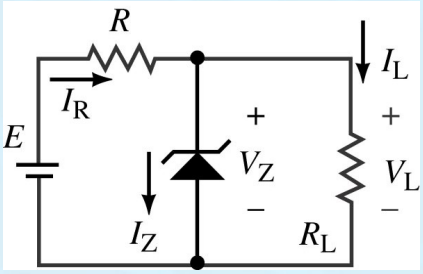
  - Open circuit if $I_Z < I_{ZT}$

The Zener Diode

- Applications
  - Use ideal model
  - Commercial Tolerance, ± 5% to 10% for V_Z
- Design
  - Determine limits imposed by I_{ZK} and I_{ZM}
  - Design circuit well within these limits

The Zener Diode

- Voltage regulator



The Zener Diode

- Current divider between Zener and Load
- $I_{ZK} < I_Z < I_{ZM}$
- Input regulation
  - Limits input voltage: $E_{min} < E_{in} < E_{max}$
- Load regulation
  - Limits load resistance: $R_{Lmin} < R_L < R_{Lmax}$

The Zener Diode

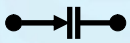
- Clippers
  - Limit amplitude of input ac waveform
    - Single sided
    - Dual sided
- Clampers
  - If $V_{in} \geq V_Z$ then $V_{out} = V_Z$

The Zener Diode

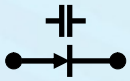
- Transient suppression
  - Greater power capability
  - Use Back-to-Back Zeners

The Varactor Diode

- Also called varicap, epicap, or tuning diode
- Voltage variable capacitor
- Symbols:



or



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The Varactor Diode

- Nonlinear *V vs C* curve
- Increase reverse Voltage decrease *C*
  - Reverse biased
  - Increase voltage decreases diode junction
  - Capacitance inversely proportional to distance between plates

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The Varactor Diode

- Normal diode operation when forward biased

Circuit Analysis with Devices:
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The Varactor Diode

- Specs
  - Nominal capacitance, C_T (given at a specific voltage)
  - Reverse breakdown voltage
  - Temperature coefficient

The Varactor Diode

- Specs
  - Figure of Merit, *Q*
  - Capacitance ratio (tuning ratio)
  - C_R e.g. if *5* pF < *C* < *30* pF, C_R = *6* (30 pF/5 pF = 6)

Circuit Analysis with Devices:
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Half-Wave and Full-Wave Rectifier Circuits

- Half-Wave rectification
  - Sine Wave input with no dc component
  - Single diode

Half-Wave and Full-Wave Rectifier Circuits

- Half-Wave output
  - Upper ½ of sine wave
    - Diode in forward direction
  - Lower ½ of sine wave
    - Diode in reverse direction
  - dc value = .318 V_m (not counting V_B)
- $PIV \approx 2 * E_m$

Circuit Analysis with Devices:
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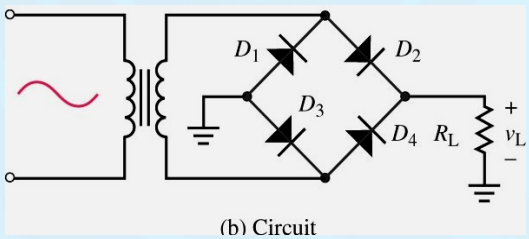
Half-Wave and Full-Wave Rectifier Circuits

- Full-Wave Bridge



(b) Circuit

Half-Wave and Full-Wave Rectifier Circuits

- Full-Wave rectification
  - Sine Wave input with no dc component
  - Center-tap transformer with two diodes
  - Full-Wave Bridge with four diodes

Circuit Analysis with Devices:
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Half-Wave and Full-Wave Rectifier Circuits

- Full-Wave output
  - Upper ½ of sine wave and inverted lower half of sine wave
  - dc value = .637 V_m (not counting V_B)
- $PIV \approx E_m$
- Bridge rectifier package (4 matched diodes)

Power Supply Filtering

- Parallel RC circuit with half-wave rectified input
  - Capacitor charges during first ¼ cycle
  - Capacitor holds during rest of cycle

Power Supply Filtering

- Output
  - Less ripple
  - Closer to steady dc
- Larger capacitor yields less ripple

Power Supply Filtering

- Parallel RC circuit with full-wave input

$$V_{dc} = \frac{V_m}{1 + \frac{T}{2R_L C}}$$

  - T = Period of Sinusoid
  - R_L = Load resistance
  - C = Filter capacitance

Power Supply Filtering

- Ripple
  - Expressed in rms volts
  - Ripple factor

$$r = \frac{rms\ ripple\ voltage}{dc\ voltage}$$

$$r = \frac{T}{2\sqrt{3}R_L C}$$

Power Supply Filtering

- Diode Forward Current
  - Repetitive surge currents
  - Maximum listed on many rectifier data sheets
- Unregulated power supplies
  - Output dc voltage varies with input voltage
- Regulated power supplies
  - Simplest regulator is a Zener diode