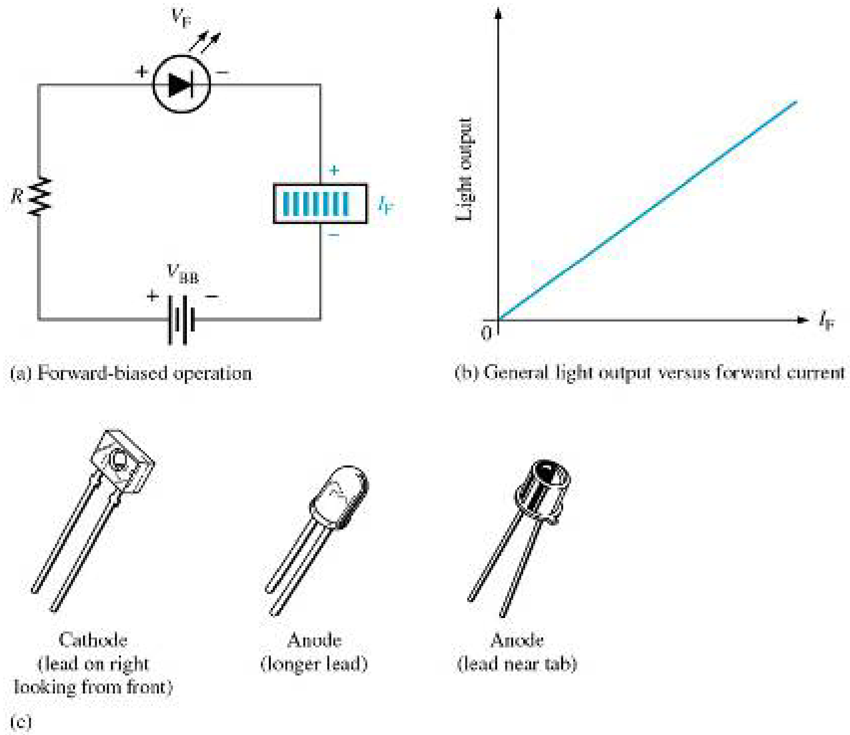
Ch. 3
Special Purpose Diodes



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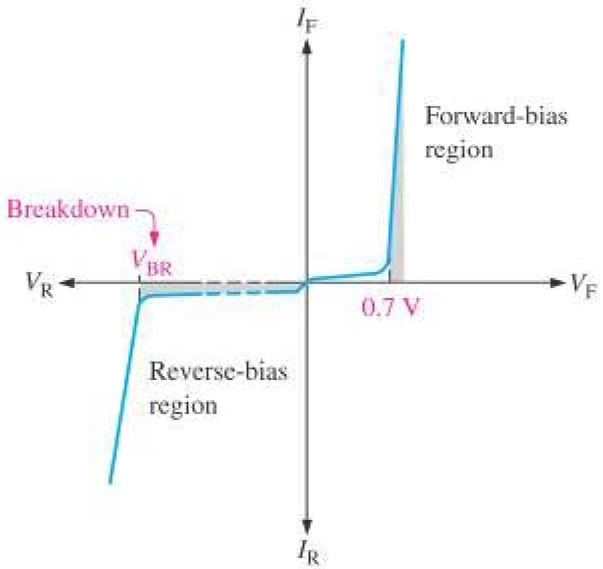
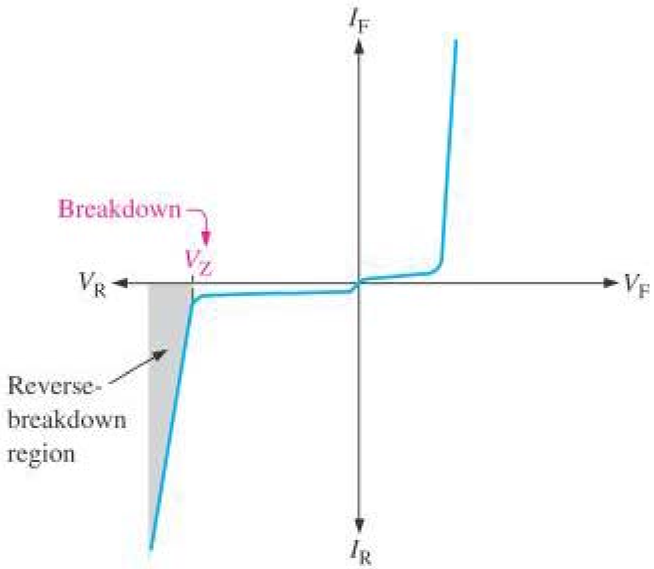
3-1. 제너 다이오드(Zener diode)

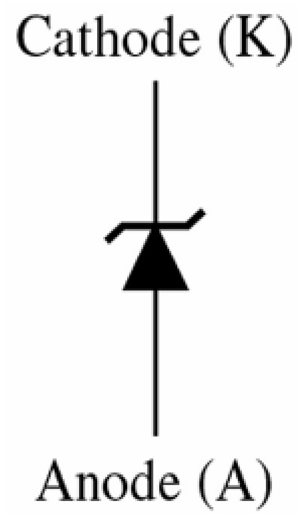
- 직류전원의 전압 안정화
- 역방향 항복에서 동작 → 불순물 도핑으로 조정
- 제너항복 (Zener Breakdown)
  - 애벌런치 breakdown: 높은 역전압 (5V 이상)에서 발생
  - 제너 breakdown: 낮은 역방향 전압에서 발생 (5V이하)
    - Doping density 증가 → 좁은 공핍층→ 강한 전계 발생 → 전류 생성



(a) The normal operating regions for a rectifier diode are shown as shaded areas.

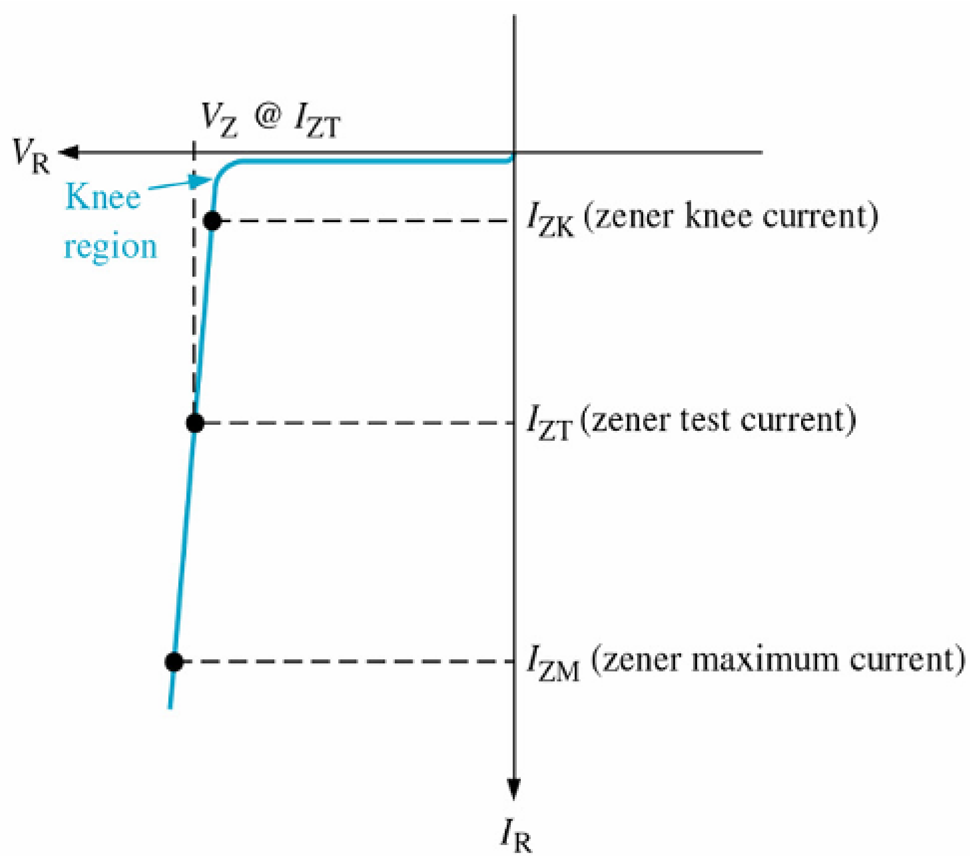


(b) The normal operating region for a zener diode is shaded.



3-1. 제너 다이오드

- 항복특성
  - V_R 증가: I_R은 변곡점 (Knee)까지 일정
  - V_Z : 제너 항복 전압 → 일정한 값 유지
  - Z_Z (zener impedance): 내부 제너 저항

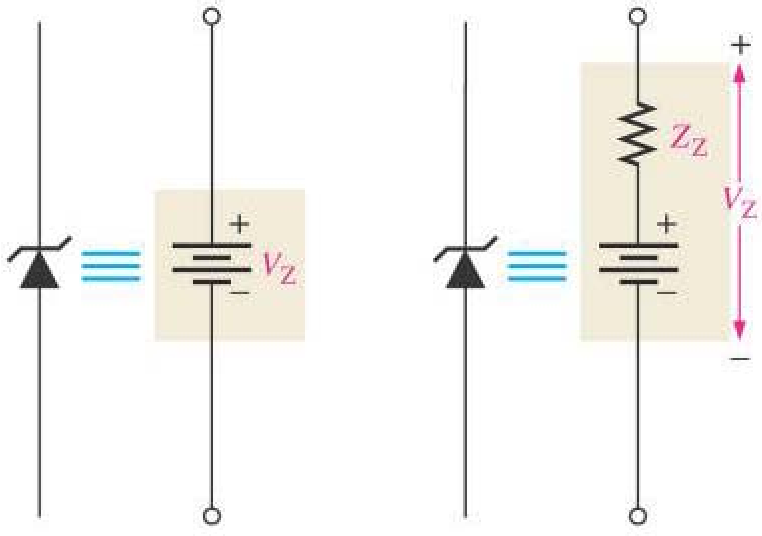


- 제너 정전압조정
  - I_{ZK}: diode를 정전압 소자로 이용하기 위한 최소 전류
  - I_{ZM}: diode가 손상되기 전의 전류

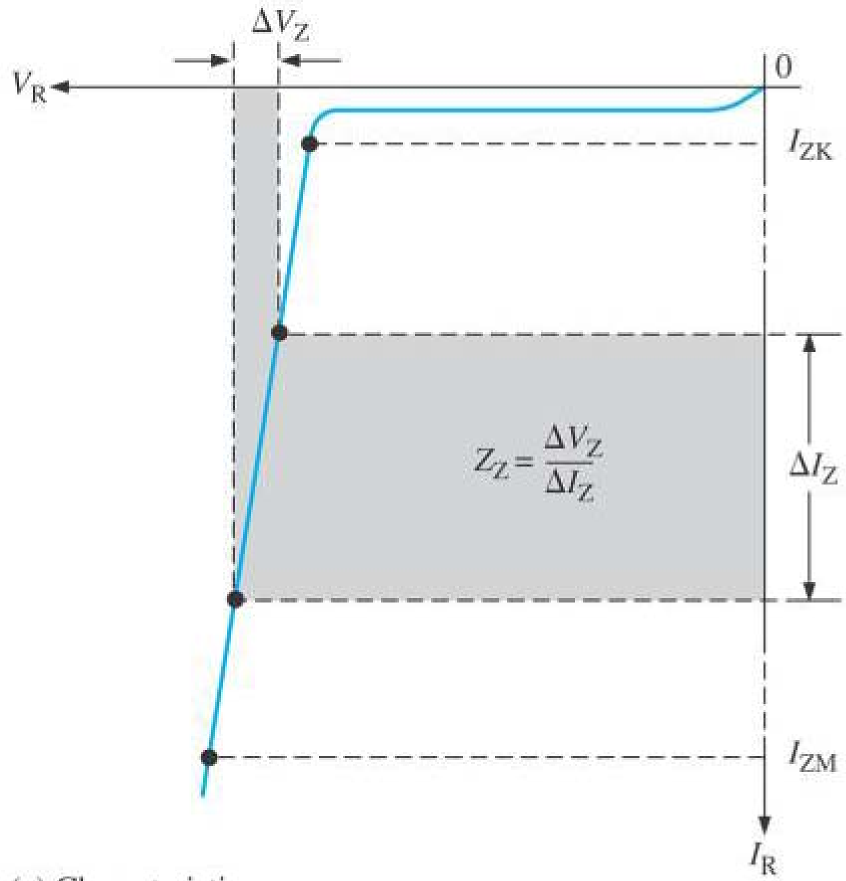
  → I_{ZK} ~ I_{ZM}: 역방향 전압이 일정하게 유지
  - I_{ZT}: 규격표에 명시
  - 양단의 전압을 일정하게 유지시킬 수 있는 능력은 제너다이오드의 중요한 특징

3-1. 제너 다이오드

- 제너 다이오드의 등가회로



(a) Ideal (b) Practical



(c) Characteristic curve

3-1. 제너 다이오드

온도계수

- 온도계수 (TC): 온도변화에 대한 제너전압의 변화 [%/°C] 또는 [mv/°C]
- 온도변화에 따른 제너전압의 변화
  - 온도계수 [%/°C] 인 경우
    - $\Delta V_Z = V_Z \times TC \times \Delta T$
    - V_Z: 25°C에 정상적인 제너전압, TC: 온도계수 %/°C, ΔT : 온도변화
  - 온도계수 [mv/°C] 인 경우
    - $\Delta V_Z = TC \times \Delta T$

예제 3-3

- V_Z = 8.2 V, TC = 0.05 %/°C 일때 60 °C 의 제너전압?

  - $\Delta V_Z = V_Z \times TC \times \Delta T = (8.2)(0.05 \times 0.01)(60-25) = 144\ mV$
  - $V_Z\ (60\ °C) = V_Z\ (25\ °C) + \Delta V_Z = 8.2 + 144m = 8.34\ V$

3-1. 제너 다이오드

- 제너 소비전력과 경감 (derating)
  - 제너다이오드의 직류 소비전력 : $P_D = V_Z \times I_Z$
  - 전력부담 경감
    - 제너다이오드의 최대 소비전력 ($P_{D(max)}$)은 전형적으로 특정온도 또는 그 이하의 온도에서 정해짐
    - 온도가 증가 → 전력 감소
    - $P_{D(derated)} = P_{D(max)} - (mW/\ ^\circ C)\ \Delta T$
      - 전력경감계수 (mW/ °C)

- 예제 3-4
  - $P_{D(max)}$= 400 mW (50 °C), 3.2 mW/ °C 일때 90 °C 의 온도에서 소비될 수 있는 최대전력?
    - $P_{D(derated)} = P_{D(max)} - (mW/^\circ C)\ \Delta T$

$$= 400m - (3.2m)(90 - 50)$$

$$= 400m - 128m = 272\ mW$$

3-1. 제너 다이오드

제너 다이오드 규격표

- 제너 전압 : V_Z @ I_{ZT}
- 최대 제너 임피던스 (Z_{ZT}) = ΔV_Z / ΔI_Z
  - 시험 전류에서 측정된 동적(교류) 임피던스
- 역누설 전류
  - 변곡점보다 적은 역전압 값에 대한 역바이어스된 제너 다이오드를 통해 흐르는 전류
- 최대 제너 전류 I_{ZM} = $P_{D(max)}$ / V_Z
- 전력 경감 (mW/°C) :
  - 온도에 따른 전력 변화량
  - 그림 3-7(b) 그래프의 데이터에서 추출
- 온도계수 (mV/°C)
  - 온도에 따른 제너전압의 변화량
  - 그림 3-7 (c) 그래프의 데이터에서 추출

3-1. 제너 다이오드

Maximum Ratings

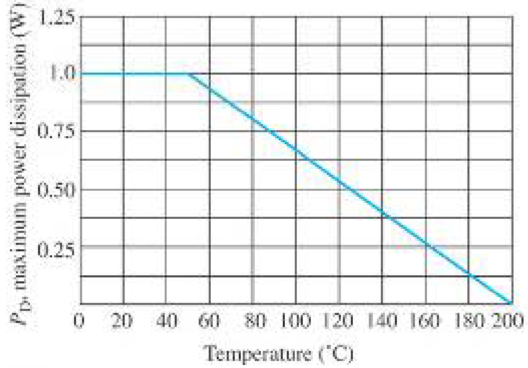
Rating	Symbol	Value	Unit
DC power dissipation @ $T_A = 50°C$ Derate above 50°C	P_D	1.0 6.67	Watt mW/°C
Operating and storage junction Temperature range	T_J, T_{stg}	−65 to +200	°C

Electrical Characteristics ($T_A = 25°C$ unless otherwise noted) $V_F = 1.2$ V max, $I_F = 200$ mA for all types.

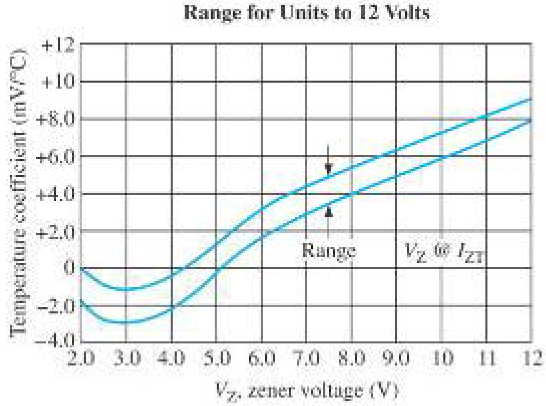
JEDEC Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts	Test Current I_{ZT} mA	Maximum Zener Impedance Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Leakage Current I_R µA Max	V_R Volts
1N4728	3.3	76	10	400	1.0	100	1.0
1N4729	3.6	69	10	400	1.0	100	1.0
1N4730	3.9	64	9.0	400	1.0	50	1.0
1N4731	4.3	58	9.0	400	1.0	10	1.0
1N4732	4.7	53	8.0	500	1.0	10	1.0
1N4733	5.1	49	7.0	550	1.0	10	1.0
1N4734	5.6	45	5.0	600	1.0	10	2.0
1N4735	6.2	41	2.0	700	1.0	10	3.0
1N4736	6.8	37	3.5	700	1.0	10	4.0
1N4737	7.5	34	4.0	700	0.5	10	5.0
1N4738	8.2	31	4.5	700	0.5	10	6.0
1N4739	9.1	28	5.0	700	0.5	10	7.0
1N4740	10	25	7.0	700	0.25	10	7.6
1N4741	11	23	8.0	700	0.25	5.0	8.4
1N4742	12	21	9.0	700	0.25	5.0	9.1
1N4743	13	19	10	700	0.25	5.0	9.9
1N4744	15	17	14	700	0.25	5.0	11.4
1N4745	16	15.5	16	700	0.25	5.0	12.2
1N4746	18	14	20	750	0.25	5.0	13.7
1N4747	20	12.5	22	750	0.25	5.0	15.2
1N4748	22	11.5	23	750	0.25	5.0	16.7
1N4749	24	10.5	25	750	0.25	5.0	18.2
1N4750	27	9.5	35	750	0.25	5.0	20.6
1N4751	30	8.5	40	1000	0.25	5.0	22.8
1N4752	33	7.5	45	1000	0.25	5.0	25.1
1N4753	36	7.0	50	1000	0.25	5.0	27.4
1N4754	39	6.5	60	1000	0.25	5.0	29.7
1N4755	43	6.0	70	1500	0.25	5.0	32.7
1N4756	47	5.5	80	1500	0.25	5.0	35.8
1N4757	51	5.0	95	1500	0.25	5.0	38.8
1N4758	56	4.5	110	2000	0.25	5.0	42.6
1N4759	62	4.0	125	2000	0.25	5.0	47.1
1N4760	68	3.7	150	2000	0.25	5.0	51.7
1N4761	75	3.3	175	2000	0.25	5.0	56.0
1N4762	82	3.0	200	3000	0.25	5.0	62.2
1N4763	91	2.8	250	3000	0.25	5.0	69.2
1N4764	100	2.5	350	3000	0.25	5.0	76.0

NOTE 1 — **Tolerance and Type Number Designation.** The JEDEC type numbers listed have a standard tolerance on the nominal zener voltage of ±10%. A standard tolerance of ±5% on individual units is also available and is indicated by suffixing "A" to the standard type number. C for ±2.0%, D for ±1.0%.

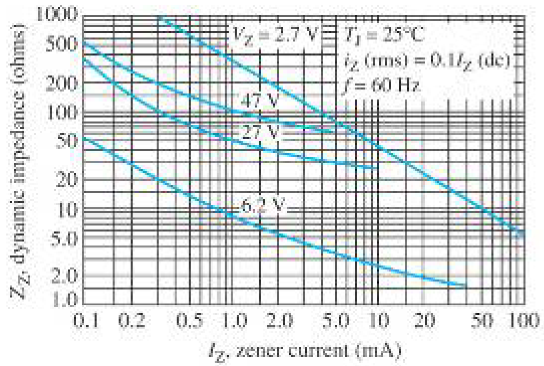
(a) Electrical characteristics



(b) Power derating



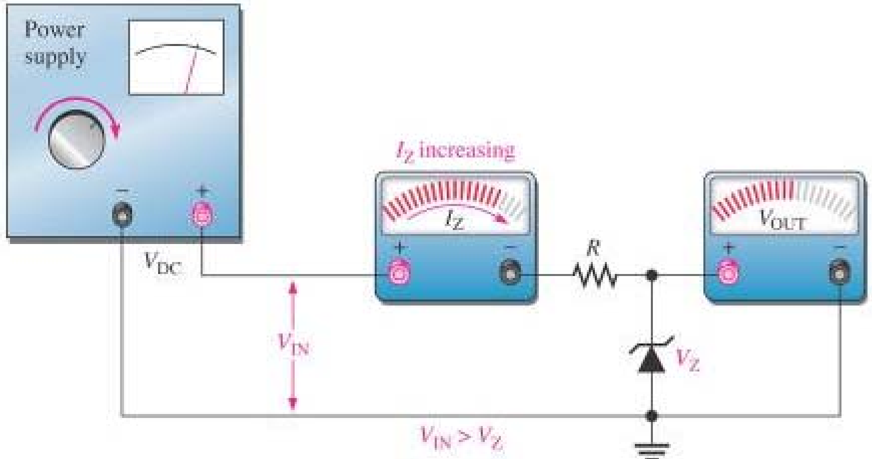
(c) Temperature coefficient



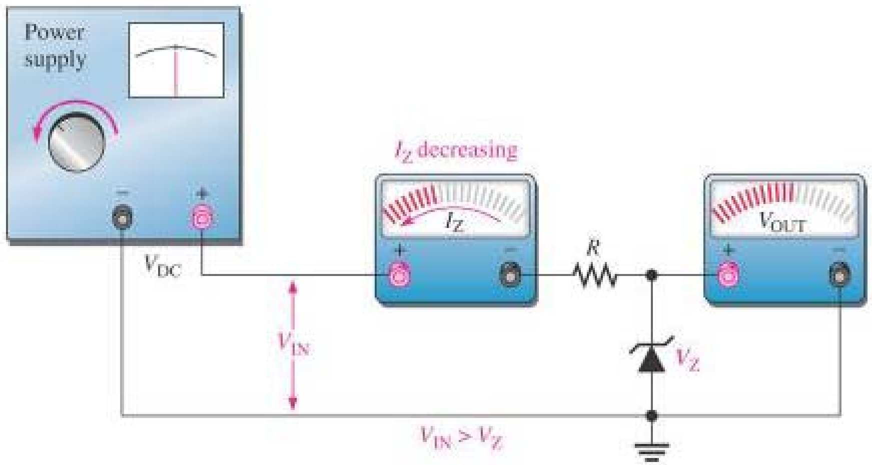
(d) Effect of zener current on zener impedance

3-2. 제너 다이오드의 응용(Zener diode applications)

- 입력 전압 안정의 변화에 따른 정전압 조정 (regulation)
  - 입력전압이 제한된 범위내에서 변화할때 제너 다이오드는 출력단자 양단의 전압을 거의 일정하게 유지



(a) As the input voltage increases, the output voltage remains constant ($I_{ZK} < I_Z < I_{ZM}$).

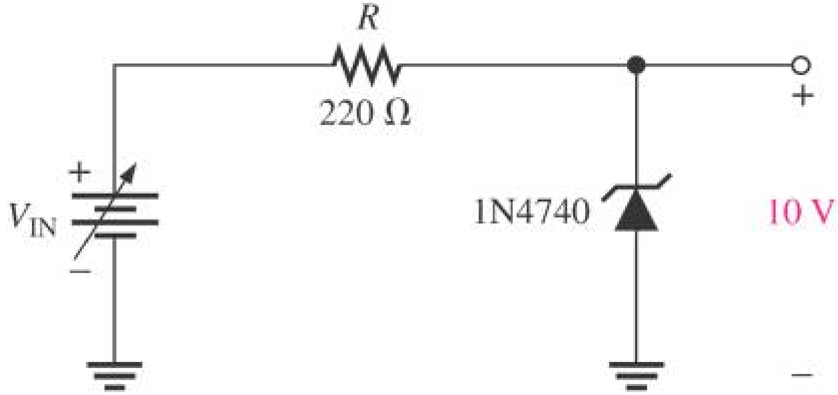


(b) As the input voltage decreases, the output voltage remains constant ($I_{ZK} < I_Z < I_{ZM}$).

3-2. 제너 다이오드의 응용

- 예제
  - IN4740 10V 제너 다이오드가 I_{ZK}=0.25mA에서 I_{ZM}=100mA까지 제너 전류의 범위에 대해 정전압을 유지할 수 있다면 입력전압의 범위는?

  (단, $P_{D(max)}$=1W, V_Z =10V)



- $I_{ZM} = P_{D(max)}/V_Z = 1W/10V = 100\ mA$
- 최소전류에 대해 220Ω저항 양단의 전압은
  - $V_R = I_{ZK}R = (0.25mA)(220\Omega) = 55mV$
  - $V_R = V_{IN} - V_Z$ 이므로
  - $V_{IN(min)} = V_R + V_Z = 55mV + 10V = 10.055V$
- 최대제너전류에 대해 220Ω저항 양단의 전압은
  - V_R = IZMR=(100mA)(220 Ω)=22V
  - $V_{IN(max)} = V_R + V_Z = 22V + 10V = 32V$
- $V_{IN} = 10.055 \sim 32\ V$

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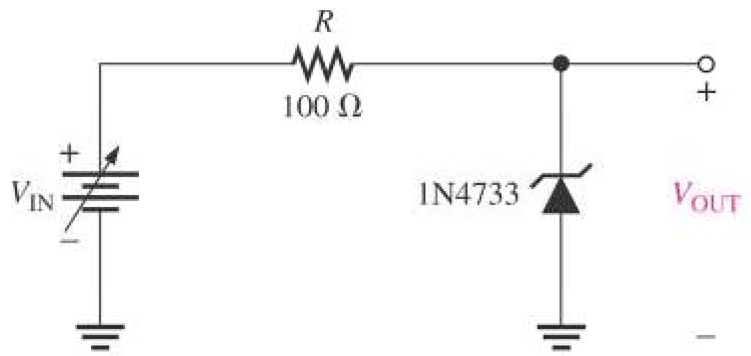
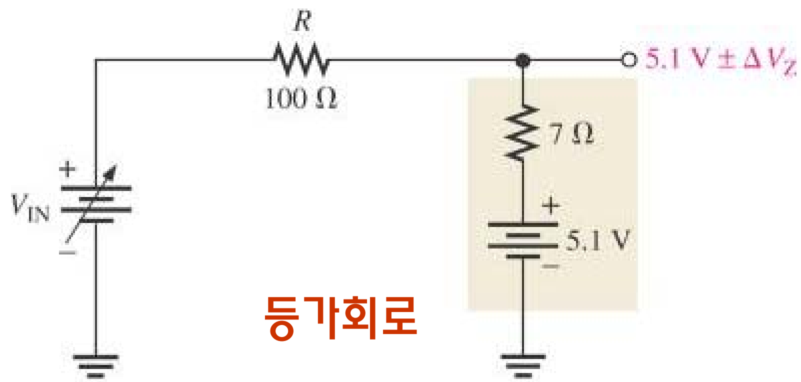
3-2. 제너 다이오드의 응용 (Example 3-5)

Q 1N4733 제너 다이오드 에서 I_{ZT} = 49mA 에서 V_Z = 5.1V, I_{ZK} = 1mA, Z_Z = 7 Ω 이고 Z_Z 은 전류값에 대해 일정하다고 가정하면 전압 안정화 시키기 위한 최대 최소 입력전압?





등가회로

- I_{ZK} 에서 출력전압을 구한 후 최소 입력전압 구함

$V_{OUT} = V_Z - \Delta V_Z$

$= 5.1 - (I_{ZT} - I_{ZK}) Z_Z$

$= 5.1 - (49m - 1m)(7) = 4.76$ V

$V_{IN(min)} = I_{ZK}R + V_{OUT}$

$= (1m)(100) + 4.76 = 4.86$ V

- 최대 입력 전압 ← 최대 제너전류 (만약 온도 < 50 ° C → $P_{D(max)}$= 1W)

$I_{ZM} = P_{D(max)}/V_Z = 1/5.1 = 196$ mA

$V_{OUT} = V_Z + \Delta V_Z$

$= 5.1 + (I_{ZM} - I_{ZT}) Z_Z$

$= 5.1 + (196m - 49m)(7) = 6.13$V

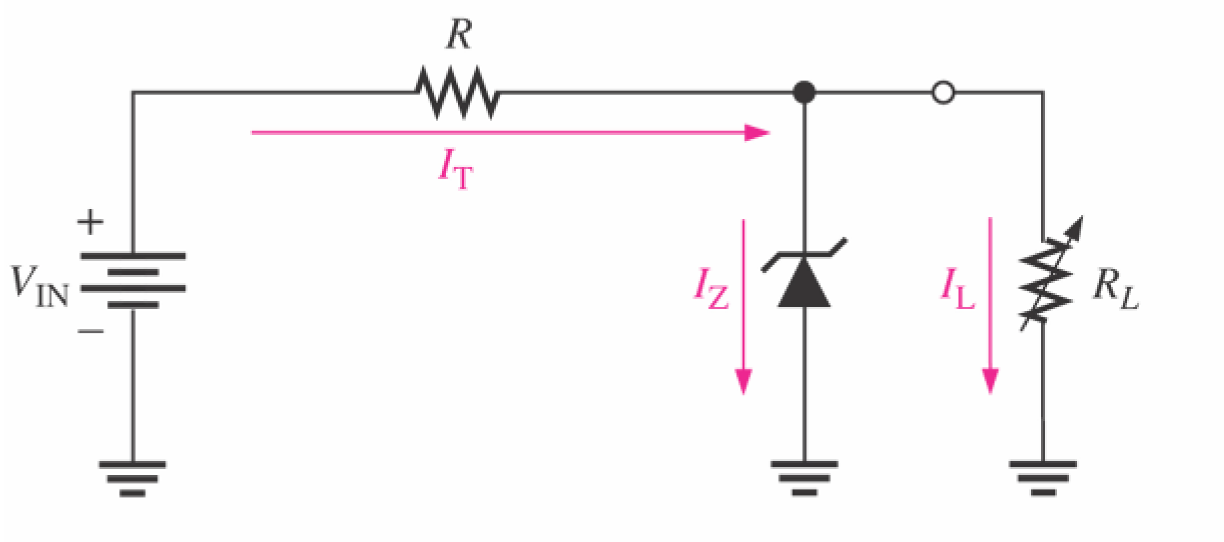
$V_{IN(max)} = I_{ZM}R + V_{OUT}$

$= (196m)(100) + 6.13 = 25.7$ V

3-2. 제너 다이오드의 응용

- 부하변화에 따른 제너 정전압조정 (load regulation)
  - I_{ZK} ~ I_{ZM} 사이의 I_Z에서 R_L의 전압을 일정하게 유지

- 무부하 대 전부하
  - $R_L = \infty$: I_L = 0A → I_z는 최대
  - R_L감소 → I_L 증가 → I_z 감소
  - I_z = I_{ZK} 일때 I_L 최대

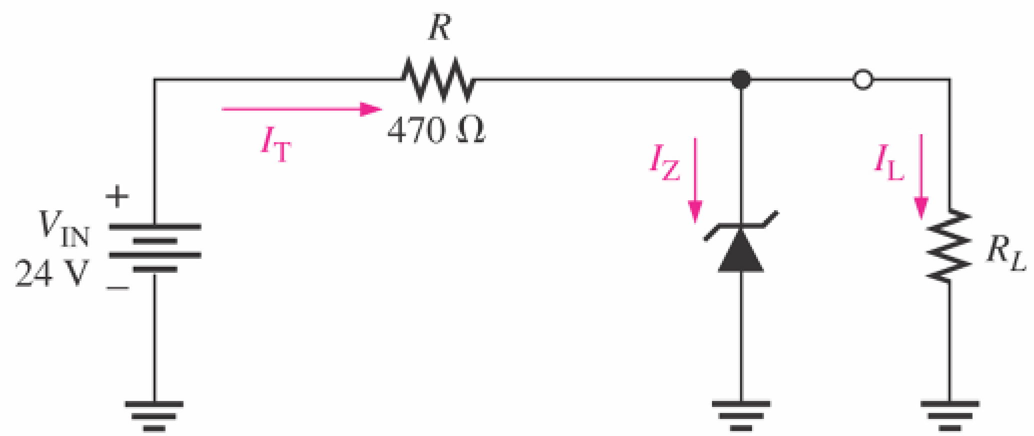


3-2. 제너 다이오드의 응용 (Example 3-6)

Yun SeopYu

Q R = 470 Ω, V_{IN} = 24V , V_Z = 12V, I_{ZK} = 1mA, I_{ZM} = 50mA, Z_Z = 0 Ω, 안정화를 위한 최대 최소 부하전류?

- $R_L = \infty$ 이면 I_L최소, I_Z최대 ($I_{L(min)}$ = 0A → $I_{z(max)}$)
  - $I_{z(max)} = I_T = (V_{IN} - V_Z)/R = (24-12)/470 = 25.5$ mA (다이오드 동작범위 내에 있음)
- I_z는 최소 이면 I_L 은 최대
  - 최소 $I_z = I_{ZK}$
  - $I_{L(max)} = I_T - I_{ZK} = 25.5$ m – 1m = 24.5 mA (V_Z 일정하므로 I_T 일정)
    → $R_{L(min)} = V_Z/I_{L(max)} = 12/24.5\text{m} = 490$ Ω
- R_L이 490Ω 이하가 되면 부하전류가 증가 → I_z는 I_{ZK} 이하가 되어 안정화 기능 상실



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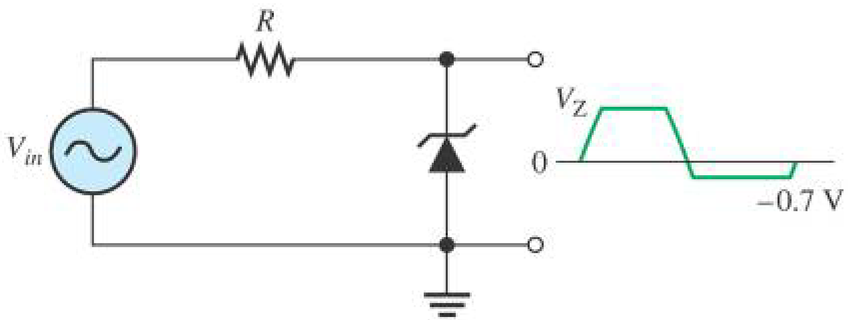
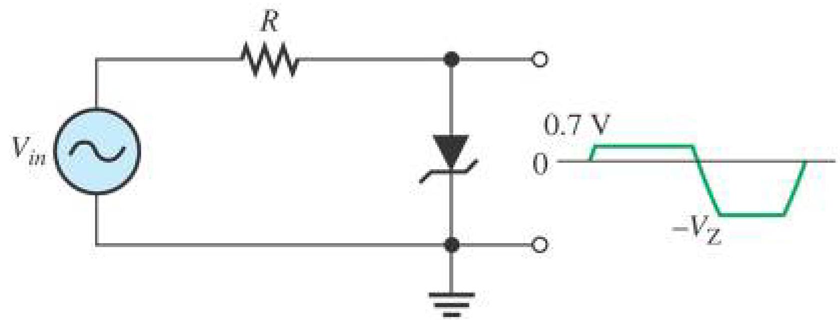
3-2. 제너 다이오드의 응용

제너 다이오드 제한작용

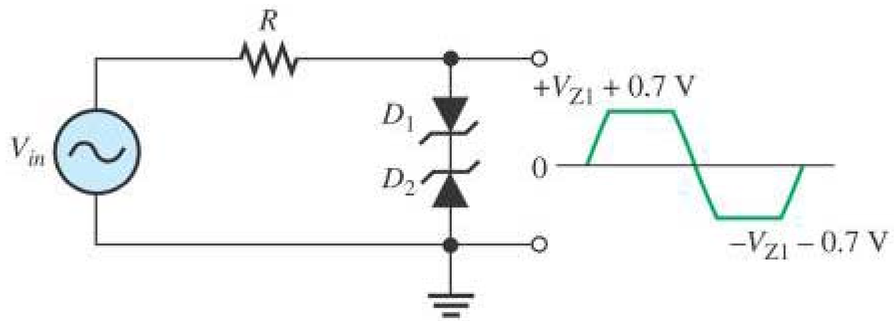
- 교류응용에 사용하여 전압의 진동폭을 원하는 레벨로 제한할 수 있다.



(a)



(b)

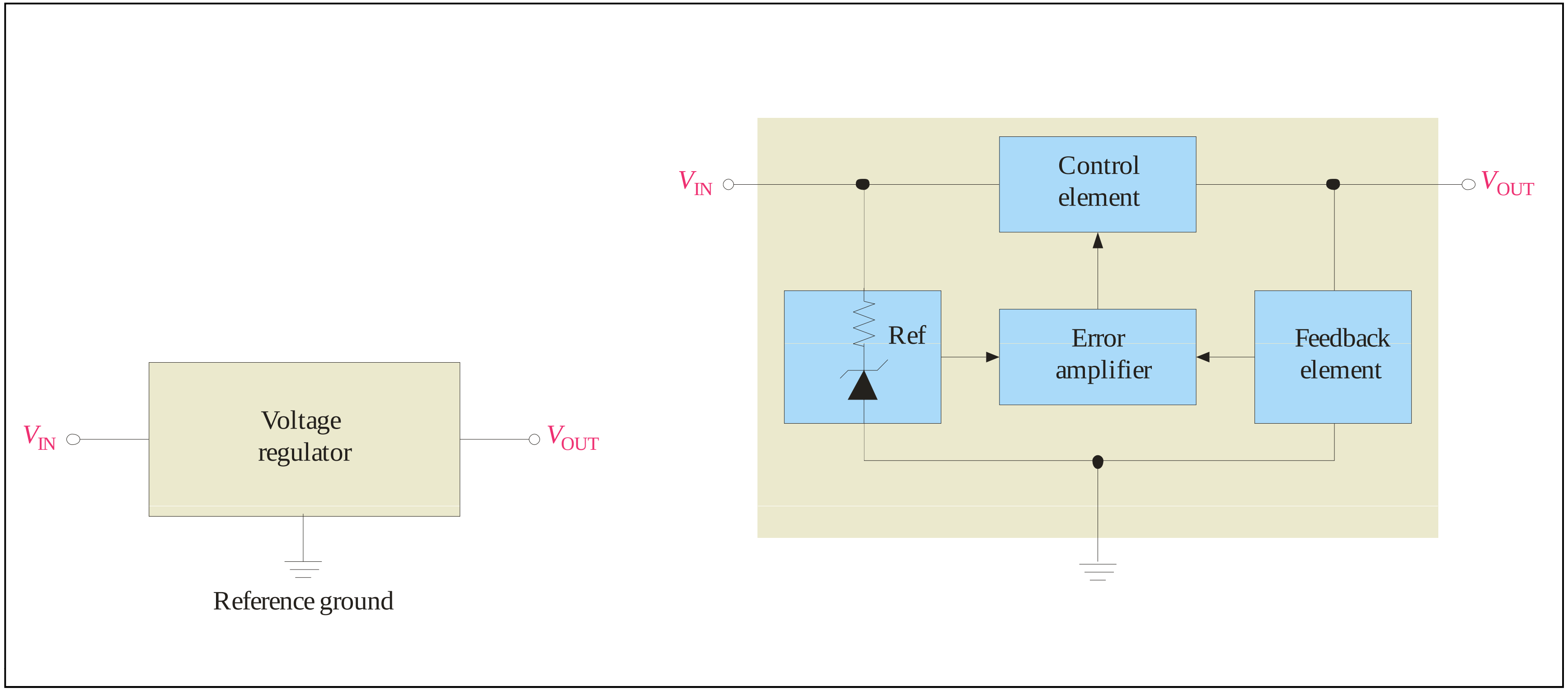


(c)

3-2. 제너 다이오드의 응용

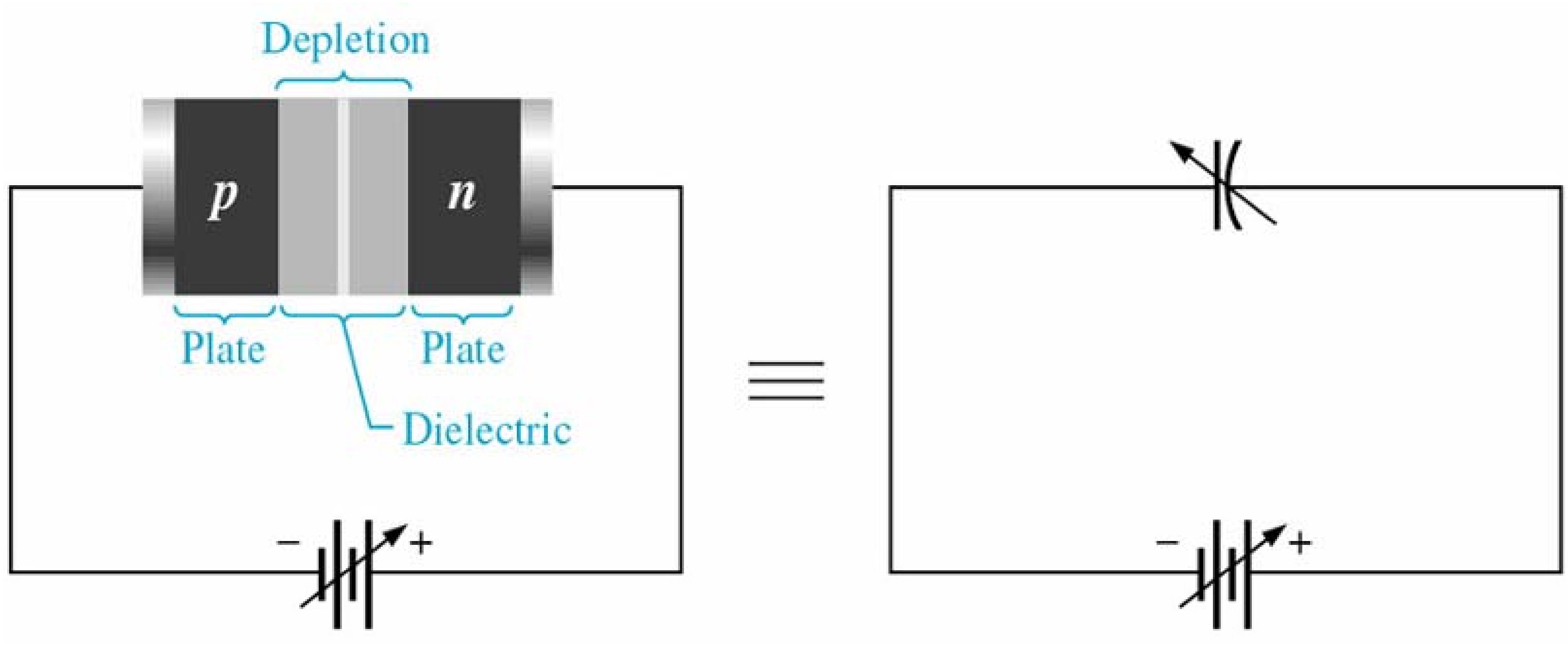
Yun SeopYu

- Zeners are used in three-terminal regulators to establish a reference voltage. These circuits are capable of much larger load currents than basic zener regulators.



3-3. 버렉터 다이오드(Varactor diode)

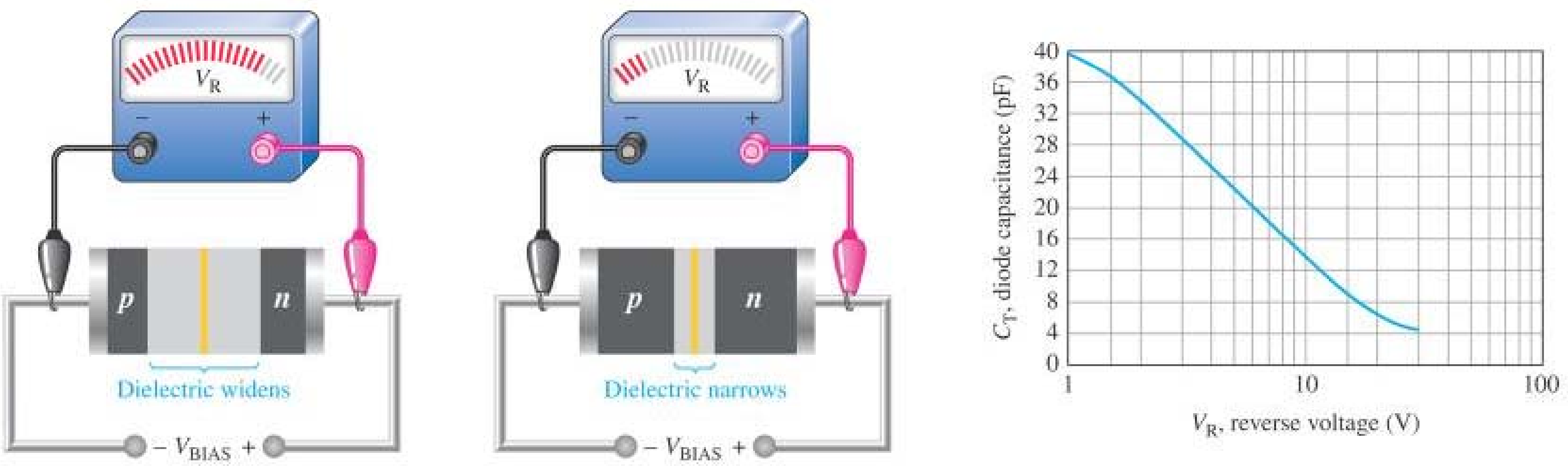
- 역방향 바이어스에서 동작
- 역방향바이서스에 의해 넓어진 공핍층은 비전도 특성 때문에 유전체와 같이 작용
- PN 접합 공핍층의 고유 정전용량이 최대가 되도록 도핑
- 접합 정전용량이 역방향 바이어스의 양에 따라 변화 (가변 정전용량 다이오드)



3-3. 버렉터 다이오드(Varactor diode)

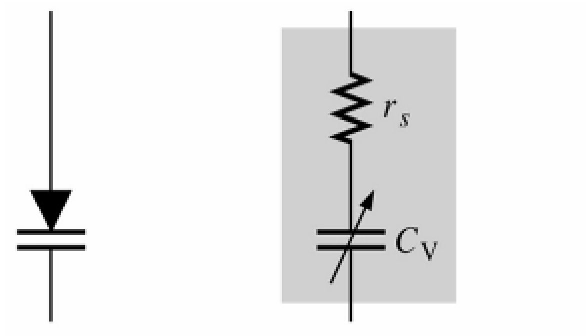
기본동작

- 역방향 바이어스 증가 → 공핍층 증가 → 캐패시턴스 감소
- 캐패시턴스 C = (Aε)/d 단, A: 극판면적, ε: 유전체 상수, d: 유전체 두께



(a) Greater reverse bias, less capacitance (b) Less reverse bias, greater capacitance (c) Graph of diode capacitance versus reverse voltage

기호 및 등가회로

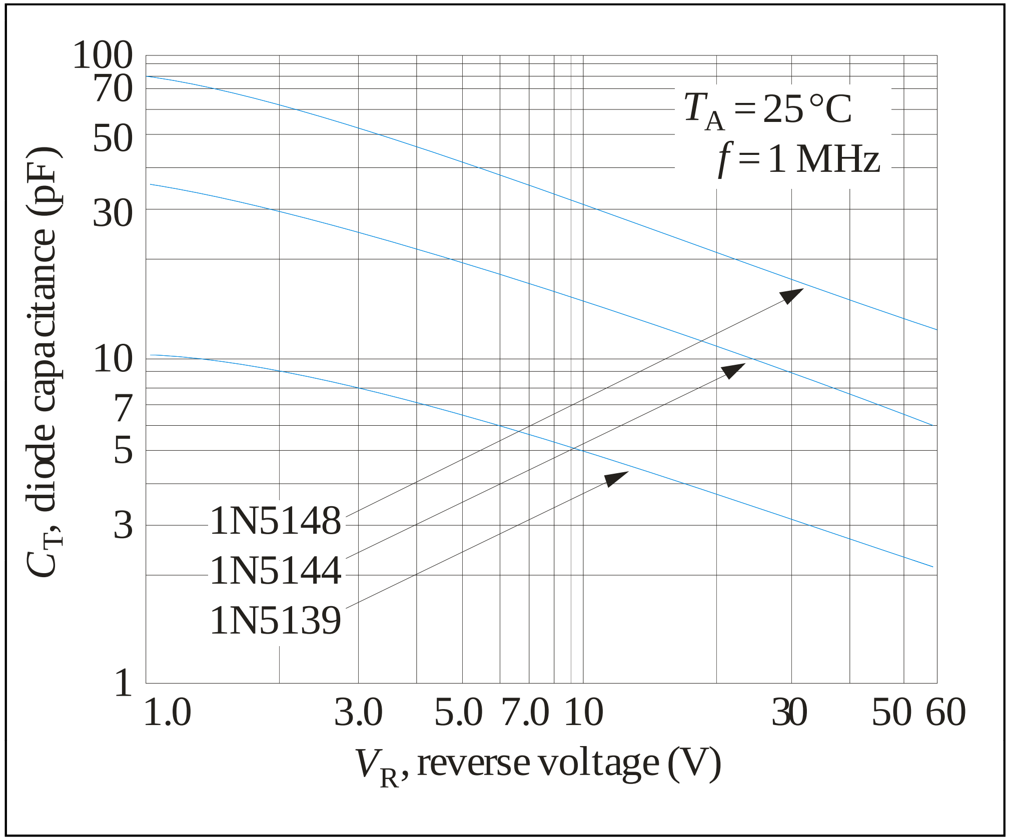


(a) Symbol (b) Equivalent circuit

3-3. 버렉터 다이오드(Varactor diode)

- **Capacitance tolerance range** are the range of values of capacitance for a given varactor. The data sheet will show the minimum nominal and maximum values, which are often plotted on a graph.

For example, you can use this graph to read the capacitance as a function of reverse voltage for various diodes.



3-3. 버렉터 다이오드(Varactor diode)

- The **capacitance ratio** is the ratio of the diode's capacitance at the minimum reverse voltage (largest *C*) to the diode's capacitance at the maximum reverse voltage (smallest *C*).

Data sheets also include parameters such as maximum ratings for current, power and temperature.

Maximum Ratings (T_C = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Reverse voltage	V_R	60	Volts
Forward current	I_F	250	mA
RF power input*	P_{in}	5.0	Watts
Device dissipation @ T_A = 25 °C Derate above 25°C	P_D	400 2.67	mW mW/°C
Device dissipation @ T_C = 25°C Derate above 25°C	P_C	2.0 13.3	Watts mW/°C
Junction temperature	T_J	+175	°C
Storage temperature range	T_{stg}	–65 to +200	°C

*The RF power input rating assumes that an adequate heat sink is provided

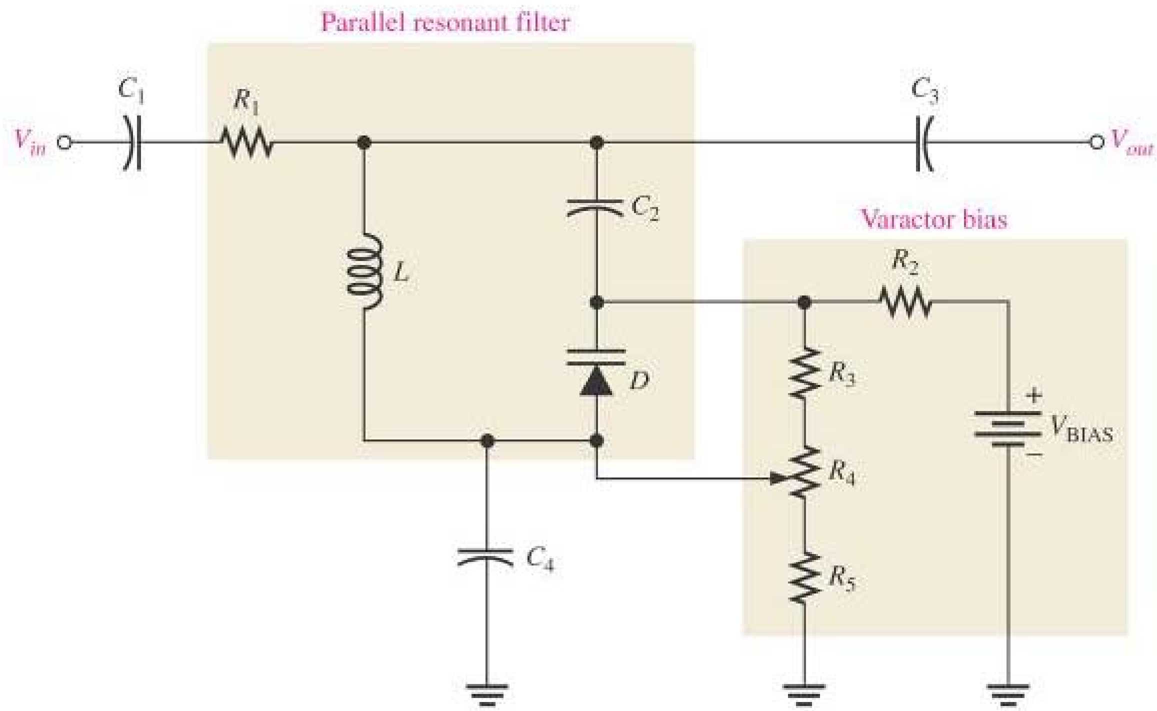
3-3. 버렉터 다이오드(Varactor diode)

응용

동조회로에 응용

- 공진회로에서 전압레벨을 조절하여 커패시터스를 가변시켜 공진 주파수를 조절
- C_1, C_2, C_3, C_4: 직류 바이어스 제거
- 병렬 공진 주파수

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$



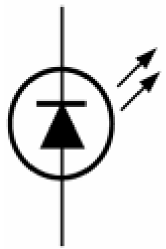
3-4. 광학 다이오드 (Optical diodes)

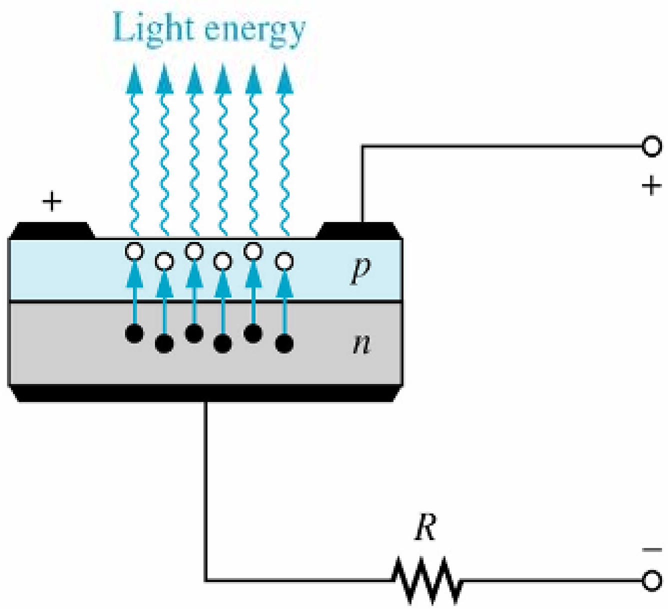
- 광학다이오드
  - 광 방출 다이오드(LED) : 빛을 방출하는 다이오드
  - 광 다이오드(Photodiode) : 빛을 검출하는 다이오드
- 광방출 다이오드 (LED: light emitting diode)
  - 전계 발광 (electroluminescence):
    - 순방향 바이어스: n영역의 자유전자 → p 영역으로 이동, 정공과 재결합 → 광과 열 에너지 방출 → 표면 photon (광자) 발생
    - Doping 물질에 따라서 색을 결정
      - GaAs: 적외선 (Infrared: IR)
      - GaAsP: Yellow or red
      - GaP: Green or red

Cathode (lead on right looking from front)

Anode (longer lead)

Anode (lead near tab)





3-4. 광학 다이오드 (Optical diodes)

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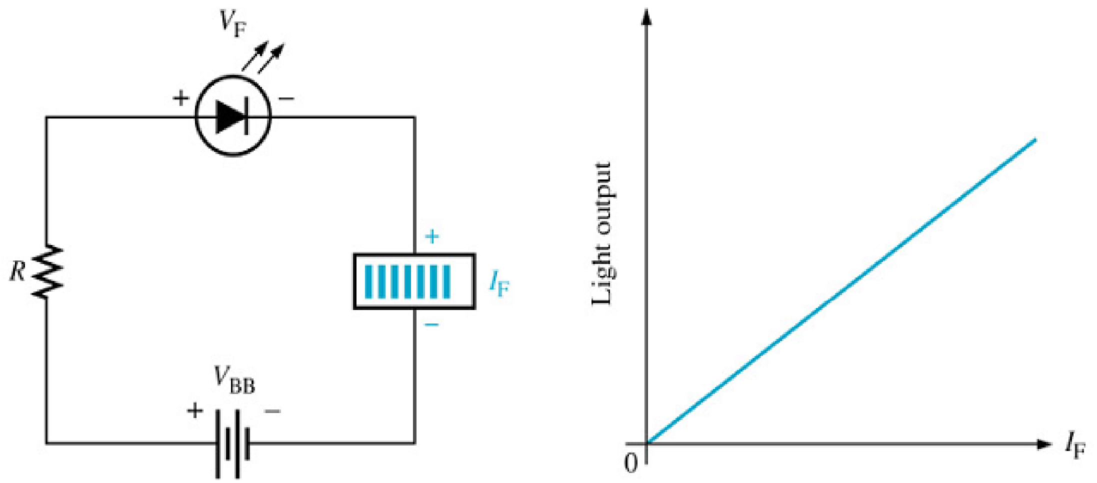
- LED
  - LED 바이어스: 1.2 ~ 3.2 V



(a) Forward-biased operation (b) General light output versus forward current

  - 광방출: 빛의 파장 (wavelength: λ)

    → 가시광선인지 적외선인지 결정

    - 가시광: 590 nm(yellow), 540 nm(green), 660nm(red)
    - 적외선: 940 nm
  - LED 방사패턴: 방사패턴이 좁을수록 특정방향에 조사

3-4. 광학 다이오드 (Optical diodes)

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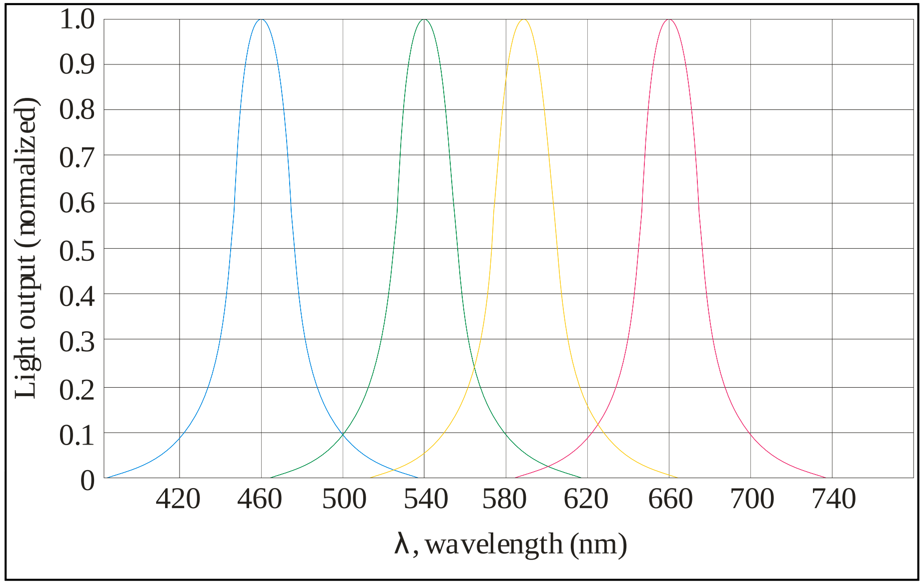
- LED

LEDs emit a specific range of wavelengths which depend on the construction and dye material used. The wavelength is given on the specification sheet. LEDs are available for visible light and infrared.



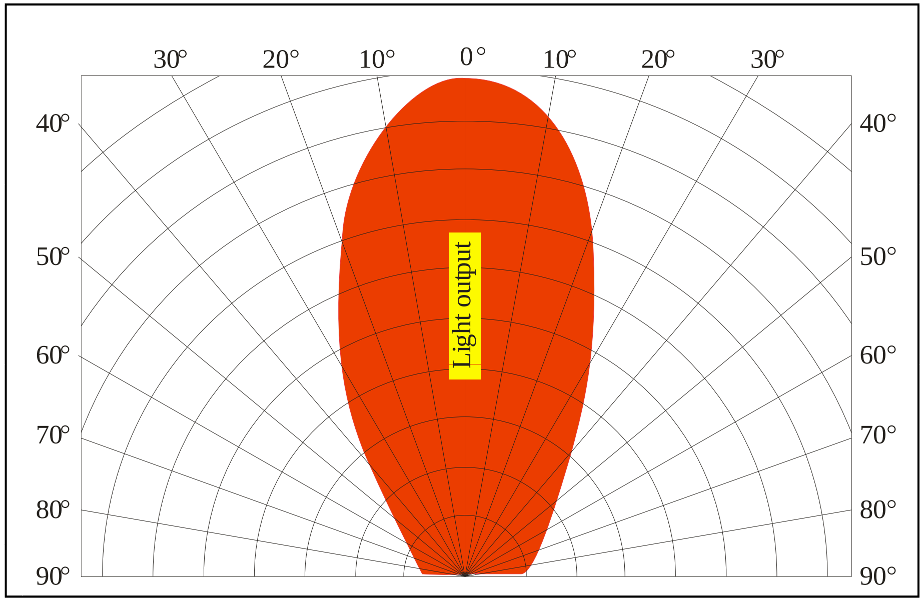
Q: peak wavelength of a green LED?

3-4. 광학 다이오드 (Optical diodes)

- LED

Another characteristic shown in specification sheets is the radiation pattern for the LED. This plot is an example of a typical pattern in which light is concentrated in one direction.

A wider viewing angle will show a wider pattern such as the TLDR5400:



3-4. 광학 다이오드 (Optical diodes)

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LED 규격표

- 최대역전압, 최대 순방향 전류, 순방향 전압 강하
- 그래프: 파장, 방사패턴
- 복사광도와 발광
  - 복사강도(axial radiant intensity) I_e: 출력전력/steradian
    - 5 mW/sr (at IF = 20 mA), sr은 고체각 측정단위
  - 발광(Irradian: E): 전력/mW/cm^2 → $E = I_e/d^2$
- 예제 3-10 LED 데이터 (그래프)로 부터
  - 최대출력 = 35 mW → 910 nm에서 복사강도?
    - I_e = (0.25)(35 mW) = 8.75 mW ← 그림 (c)
  - I_F = 20mA → 순방향 전압강하? V_F = 1.25 V (I_F = 20mA) ← 그림 (b)
  - I_F = 40mA → 복사강도? $I_e \approx$ 10 mW/sr ← 그림 (e)
  - d = 10 cm → 최대 발광? $E = I_e/d^2$ = (35 mW/sr)/(10cm)^2 = 0.35mW/cm^2

3-4. 광학 다이오드 (Optical diodes)

TSMF 1000 data sheet

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)				
PARAMETER	**TEST CONDITION**	**SYMBOL**	**VALUE**	**UNIT**
Reverse voltage		V_R	5	V
Forward current		I_F	100	mA
Peak forward current	$t_p/T = 0.5$, $t_p = 100$ µs	I_{FM}	200	mA
Surge forward current	$t_p = 100$ µs	I_{FSM}	0.8	A
Power dissipation		P_V	180	mW
Junction temperature		T_j	100	°C
Operating temperature range		T_{amb}	- 40 to + 85	°C
Storage temperature range		T_{stg}	- 40 to + 100	°C
Soldering temperature	$t \leq 5$ s	T_{sd}	260	°C
Thermal resistance junction/ambient	Soldered on PCB, pad dimensions: 4 mm x 4 mm	R_{thJA}	400	K/W

BASIC CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)						
PARAMETER	**TEST CONDITION**	**SYMBOL**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Forward voltage	$I_F = 20$ mA	V_F		1.3	1.5	V
	$I_F = 1$ A, $t_p = 100$ µs	V_F		2.4		V
Temperature coefficient of V_F	$I_F = 1$ mA	TK_{VF}		- 1.8		mV/K
Reverse current	$V_R = 5$ V	I_R			10	µA
Junction capacitance	$V_R = 0$ V, f = 1 MHz, E = 0	C_j		160		pF
Radiant intensity	$I_F = 20$ mA	I_e	2.5	5	13	mW/sr
	$I_F = 100$ mA, $t_p = 100$ µs	I_e		25		mW/sr
Radiant power	$I_F = 100$ mA, $t_p = 20$ ms	ϕ_e		35		mW
Temperature coefficient of ϕ_e	$I_F = 20$ mA	$TK\phi_e$		- 0.6		%/K
Angle of half intensity		φ		± 17		deg
Peak wavelength	$I_F = 20$ mA	λ_p		890		nm
Spectral bandwidth	$I_F = 20$ mA	$\Delta\lambda$		40		nm
Temperature coefficient of λ_p	$I_F = 20$ mA	$TK\lambda_p$		0.2		nm/K
Rise time	$I_F = 20$ mA	t_r		30		ns
Fall time	$I_F = 20$ mA	t_f		30		ns
Cut-off frequency	$I_{DC} = 70$ mA, $I_{AC} = 30$ mA pp	f_c		12		MHz
Virtual source diameter		d		1.2		mm

3-4. 광학 다이오드 (Optical diodes)

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TSMF 1000 data sheet

(b)

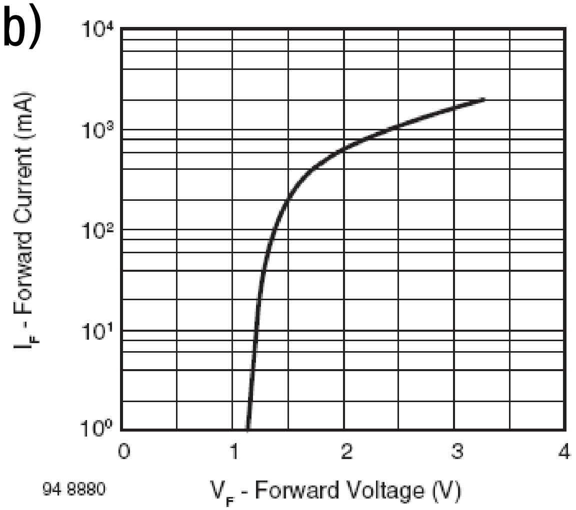

Fig. 4 - Forward Current vs. Forward Voltage

(c)

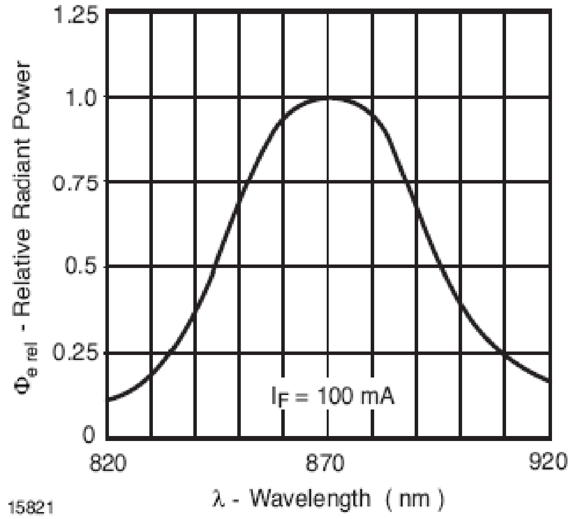

Figure 9. Relative Radiant Power vs. Wavelength

(d)

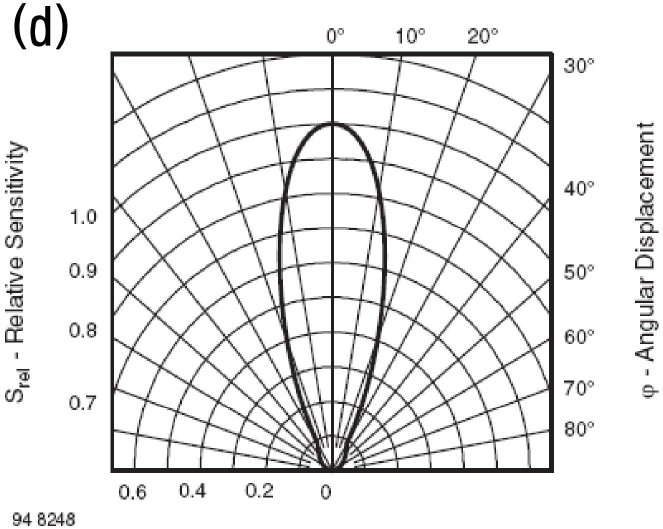

Fig. 9 - Relative Radiant Intensity vs. Angular Displacement

(e)

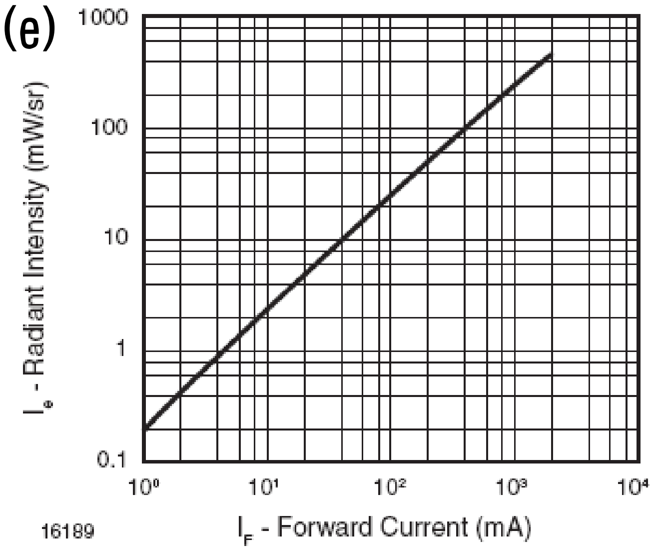

Fig. 5 - Radiant Intensity vs. Forward Current

3-4. 광학 다이오드 (Optical diodes)

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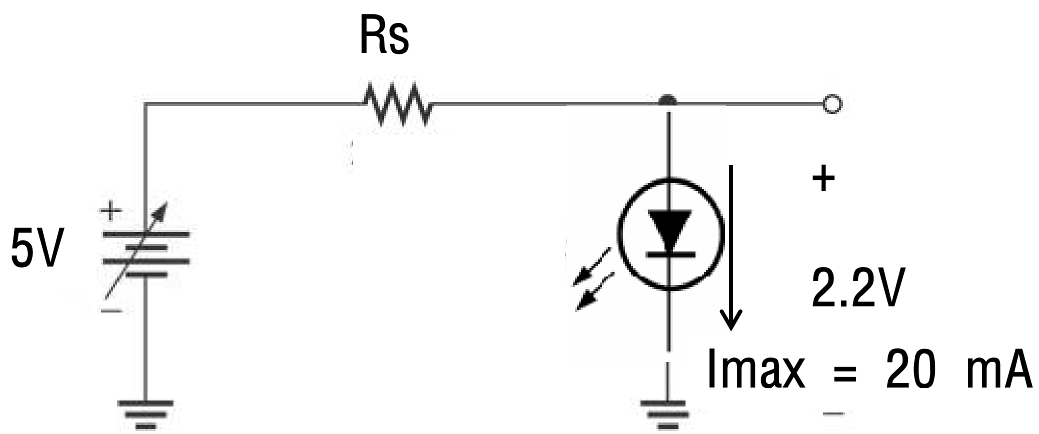
- LED

Example: A certain bright red LED drops 2.2 V at a maximum current of 20 mA. What series resistor is required to limit the current to 20 mA from a 5.0 V source?



Solution:

$$R = \frac{V_s - V_{LED}}{I} = \frac{5.0\ \text{V} - 2.2\ \text{V}}{20\ \text{mA}} = 180\ \Omega$$

3-4. 광학 다이오드 (Optical diodes)

Yun SeopYu

LED

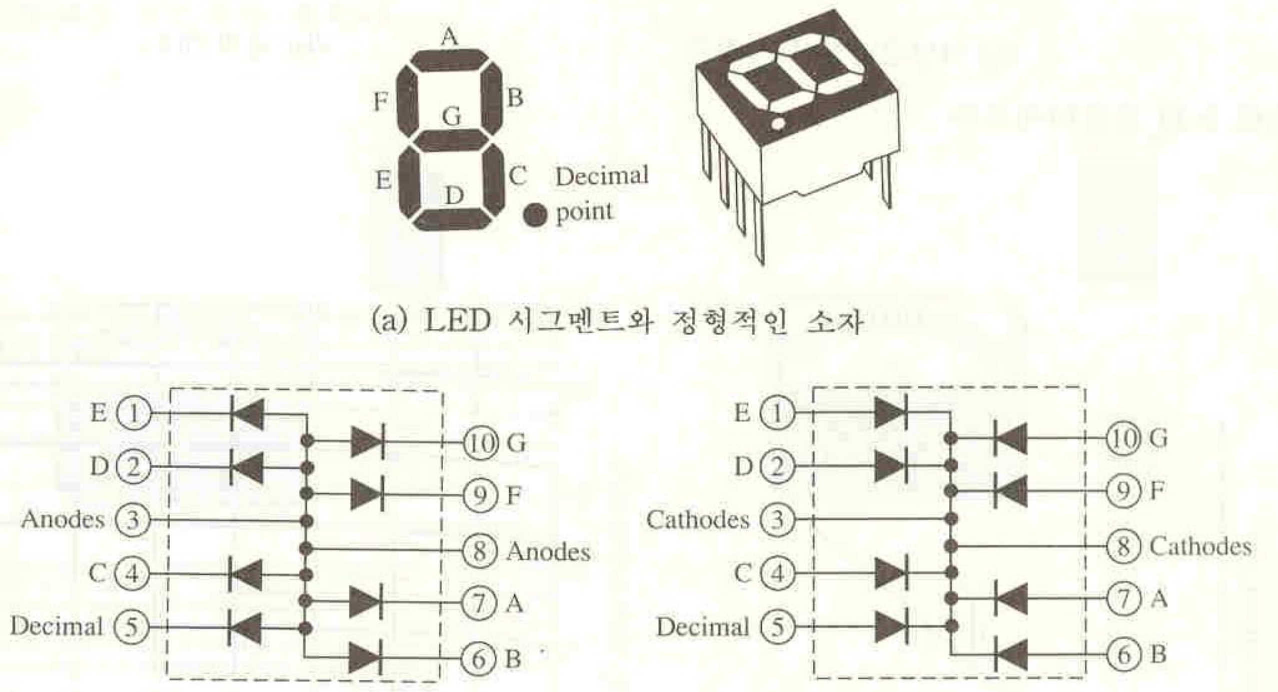
Example: A certain bright red LED drops 2.2 V at 20 mA. What power is dissipated by the LED?

Solution:

$$P = IV = (20\ \text{mA})(2.2\ \text{V}) = \quad 44\ \text{mW}$$

광 다이오드

- 응용: 7-segment DISPLAY



(a) LED 시그멘트와 정형적인 소자

(b) 공통양극

(c) 공통음극

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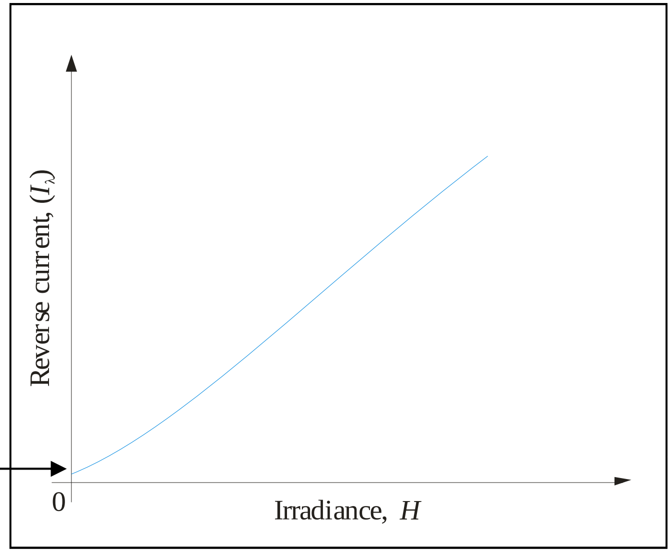
3-4. 광학 다이오드 (Optical diodes)

- 광 다이오드 (Photodiode)
  - 역방향 바이어스로 동작하는 소자
  - PN접합이 광에 노출될 때 역방향 전류 발생
  - 광의 강도에 따라 전류 증가
  - 암전류 (dark current)
    - 조사되는 빛이 없을 때 역방향 전류로 거의 무시

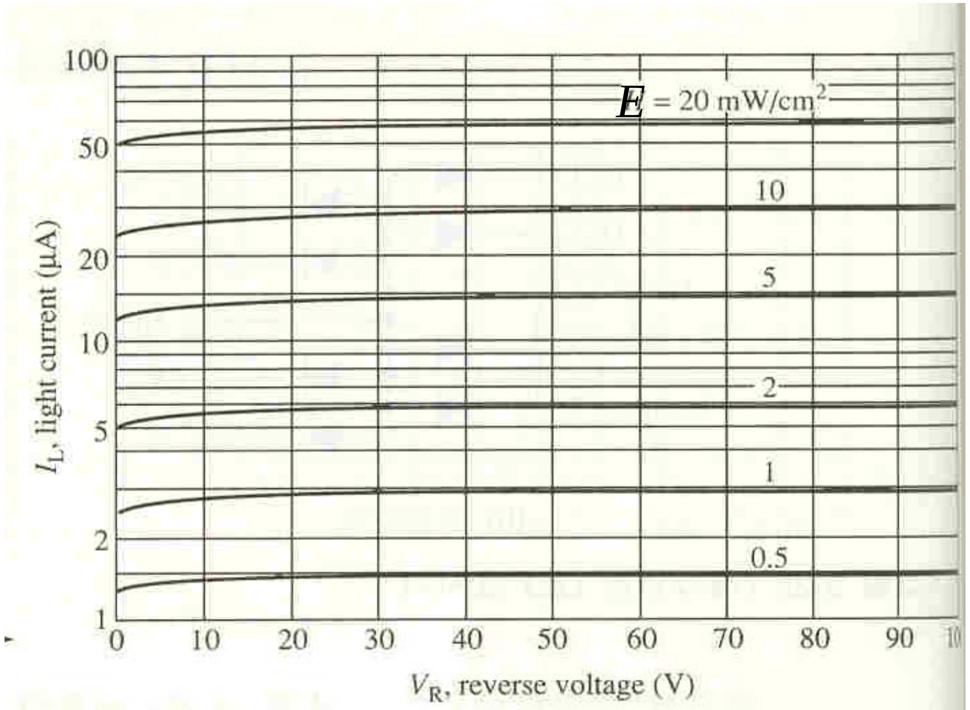


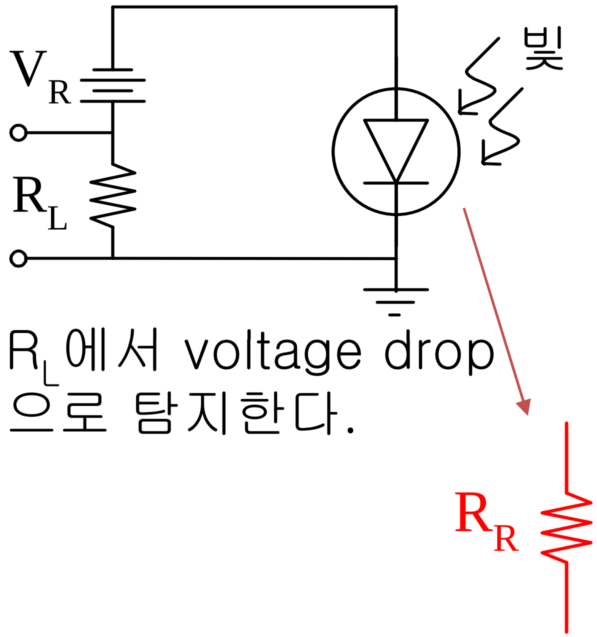
(a) Reverse-bias operation (b) Typical devices (c) Alternate symbol

3-4. 광학 다이오드 (Optical diodes)

- 광 다이오드 (Photodiode): 그래프 해석
  - V_R = 10V, I_λ(light current), 소자 저항(device resistance) R_R?
    - Irradiance E = 0.5 mW/cm² → $I_\lambda \approx$ 1.4 μA → $R_R = V_R/I_\lambda$ = 10/1.4μ = 7.14 MΩ
    - E = 20 mW/cm² → $I_\lambda \approx$ 55μA → R_R = 10/55μ = 182 kΩ

→ 빛의 강도로 제어되는 가변저항 소자





R_L에서 voltage drop으로 탐지한다.

3-4. 광학 다이오드 (Optical diodes)

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TEMD 1000 data sheet

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)				
PARAMETER	**TEST CONDITION**	**SYMBOL**	**VALUE**	**UNIT**
Reverse voltage		V_R	60	V
Power dissipation	$T_{amb} \leq 25$ °C	P_V	75	mW
Junction temperature		T_j	100	°C
Operating temperature range		T_{amb}	- 40 to + 85	°C
Storage temperature range		T_{stg}	- 40 to + 100	°C
Soldering temperature	$t \leq 5$ s	T_{sd}	< 260	°C

BASIC CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)						
PARAMETER	**TEST CONDITION**	**SYMBOL**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Forward voltage	I_F = 50 mA	V_F		1	1.3	V
Breakdown voltage	I_R = 100 μA, E = 0	$V_{(BR)}$	60			V
Reverse dark current	V_R = 10 V, E = 0	I_{ro}		1	10	nA
Diode capacitance	V_R = 5 V, f = 1 MHz, E = 0	C_D		1.8		pF
Reverse light current	E_e = 1 mW/cm², λ = 870 nm, V_R = 5 V	I_{ra}	6.0	10	13.0	μA
	E_e = 1 mW/cm², λ = 950 nm, V_R = 5 V	I_{ra}		12		μA
Temperature coefficient of I_{ra}	V_R = 5 V, λ = 870 nm,	TK_{Ira}		0.2		%/K
Absolute spectral sensitivity	V_R = 5 V, λ = 870 nm	s(λ)		0.60		A/W
	V_R = 5 V, λ = 950 nm	s(λ)		0.55		A/W
Angle of half sensitivity		φ		± 15		deg
Wavelength of peak sensitivity		λ_p		940		nm
Range of spectral bandwidth		$\lambda_{0.5}$		790 to 1050		nm
Rise time	V_R = 10 V, R_L = 50 Ω, λ = 820 nm	t_r		4		ns
Fall time	V_R = 10 V, R_L = 50 Ω, λ = 820 nm	t_f		4		ns

3-4. 광학 다이오드 (Optical diodes)

TEMD 1000 data sheet

(b)

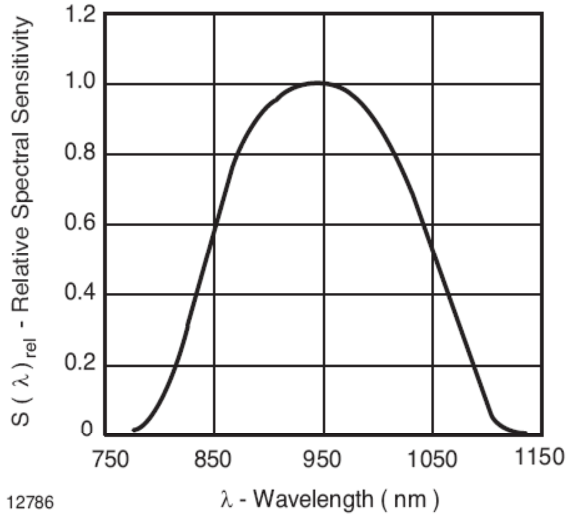

Figure 5. Relative Spectral Sensitivity vs. Wavelength

(c)

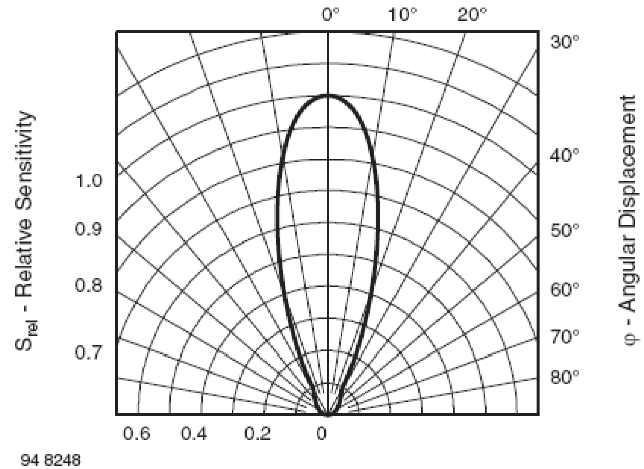

Fig. 6 - Relative Radiant Sensitivity vs. Angular Displacement

(d)

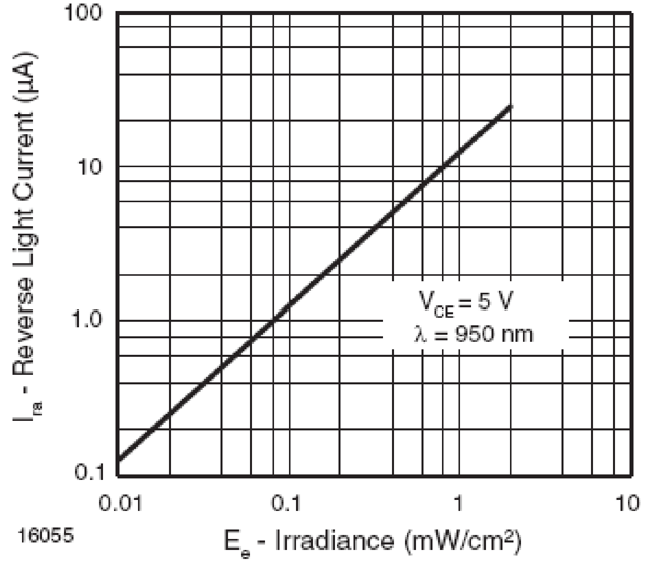

Fig. 3 - Reverse Light Current vs. Irradiance

3-4. 광학 다이오드 (Optical diodes)

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- 광 다이오드 (Photodiode)
- Ex 3-12. TEMD 1000 photodiode datasheet
  - V_R = 10 V에서 Maximum dark current?

    Solution: datasheet Basic characteristics 참고

    → Reverse dark current I_{ro} = 10 nA (최대)

  - 파장(λ)이 850 nm에서 irradiance (발광) 1mW/cm²에 대한 reverse light current? 단, device angle = 10° (maximum irradiance 기준)이고 reverse voltage = 5V.

Solution: datasheet 그림 (d) 참고

→ 최대 상대 감도(=1)인 파장이 950 nm에서 reverse light current = 12 μA

datasheet 그림 (b) 참고

→ 파장 850nmdml 상대 감도(relative spectral sensitivity) = 0.6

→ $I_\lambda = I_{ra} = 0.6 \times 12\ \mu A = 7.2\ \mu A$

datasheet 그림 © 참고

→ device angle 10° 는 0.82이므로

→ $I_\lambda = I_{ra} = \underline{0.82} \times 7.2\ \mu A = \underline{5.9\ \mu A}$

3-5. 기타 다이오드 (Other types of diodes)

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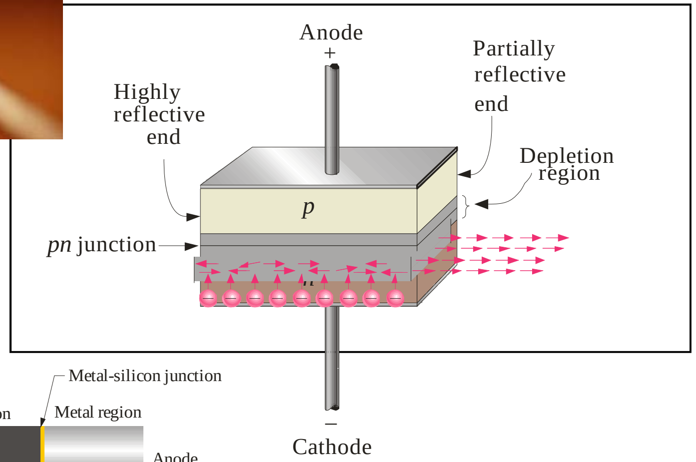
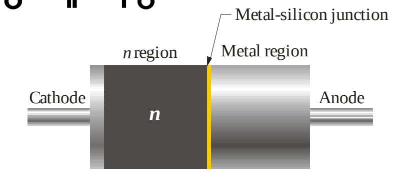
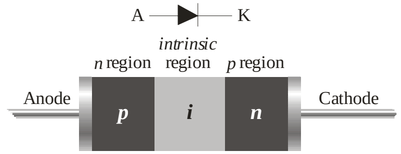
- 레이져 다이오드 (Laser diode)
  - Laser 다이오드 : Coherent light-협대역파장 방출
  - LED : Incoherent light –광대역파장 방출



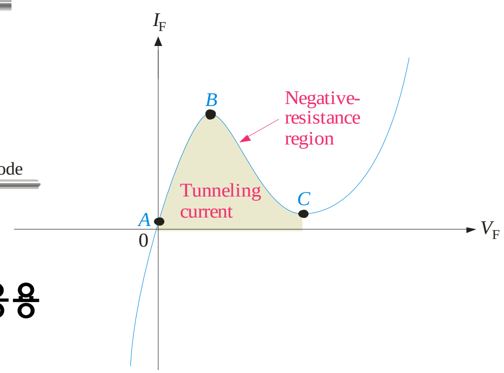
- 쇼트키 다이오드 (Schottky diode)
  - 바이어스변화에 빠른 속도로 응답, 고주파, 고속스위칭 에 사용



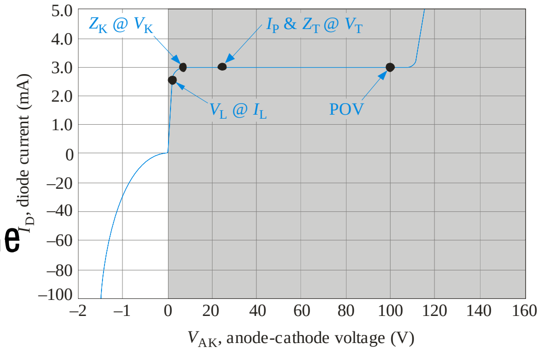
- 핀 다이오드 (PIN diode)
  - 역방향바이어스 : 일정한 커패시터처러 동작
  - 순방향 바이어스: 가변저항 처럼 동작



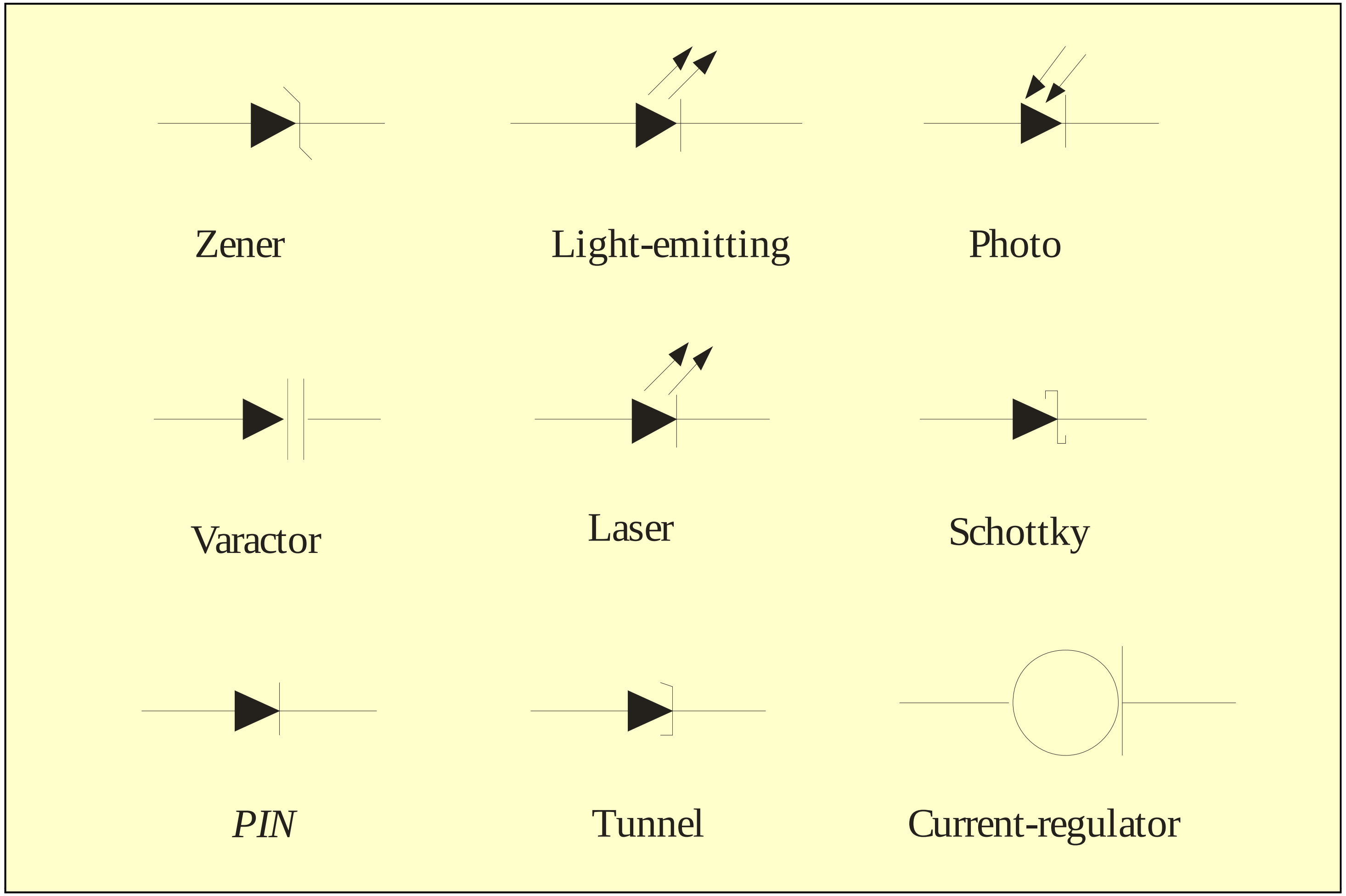
- 터널 다이오드 (tunnel diode)
  - 부성 저항 (negative resistance) 특성갖음, 발진기와 마이크로파 증폭기 응용



- 전류 안정 다이오드 (current regulator diode): 일정 전류를 유지
  - cf. 제너 다이오드: 일정 전압 유지
- 계단복구 다이오드 (Step-recovery diode)
  - 순방향→ 역방향 일때 축적된 전하를 빨리 방출 → fast switching time
  - VHF와 빠른 스위칭 응용



Common Diode Symbols



Homework (P. 163-166)

- All Examples
- Selected Problems: 1, 2, 5, 8, 10, 11, 12, 16, 18, 20, 21, 25, 26

PROBLEMS

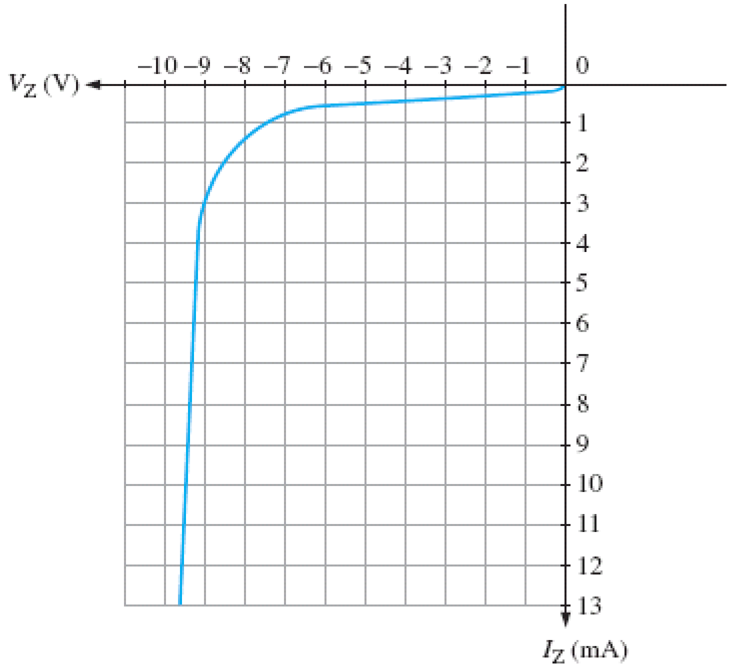
Answers to all odd-numbered problems are at the end of the book.

BASIC PROBLEMS

Section 3–1 **The Zener Diode**

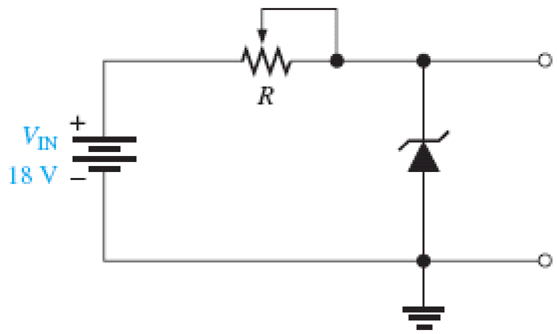
1. A certain zener diode has a $V_Z = 7.5$ V and an $Z_Z = 5\ \Omega$ at a certain current. Draw the equivalent circuit.
2. From the characteristic curve in Figure 3–67, what is the approximate minimum zener current (I_{ZK}) and the approximate zener voltage at I_{ZK}?

▶ FIGURE 3–67



5. A certain zener diode has the following specifications: $V_Z = 6.8$ V at 25°C and $TC = +0.04\%/°C$. Determine the zener voltage at 70°C.

FIGURE 3–69

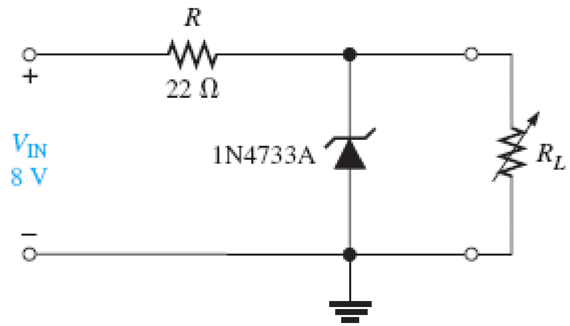


8. To what value must R be adjusted in Figure 3–69 to make $I_Z = 40$ mA? Assume $V_Z = 12$ V at 30 mA and $Z_Z = 30\ \Omega$.

10. A loaded zener regulator is shown in Figure 3–70. $V_Z = 5.1$ V at $I_Z = 49$ mA, $I_{ZK} = 1$ mA, $Z_Z = 7\ \Omega$, and $I_{ZM} = 70$ mA. Determine the minimum and maximum permissible load currents.

FIGURE 3–70

Multisim file circuits are identified with a logo and are in the Problems folder on the companion website. Filenames correspond to figure numbers (e.g., F03-70).

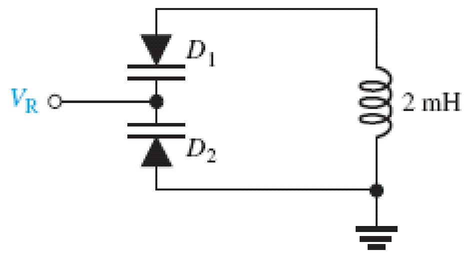


11. Find the load regulation expressed as a percentage in Problem 10. Refer to Chapter 2, Equation 2–15.

12. Analyze the circuit in Figure 3–70 for percent line regulation using an input voltage from 6 V to 12 V with no load. Refer to Chapter 2, Equation 2–14.

18. What capacitance value is required for each of the varactors in Figure 3–72 to produce a resonant frequency of 1 MHz?

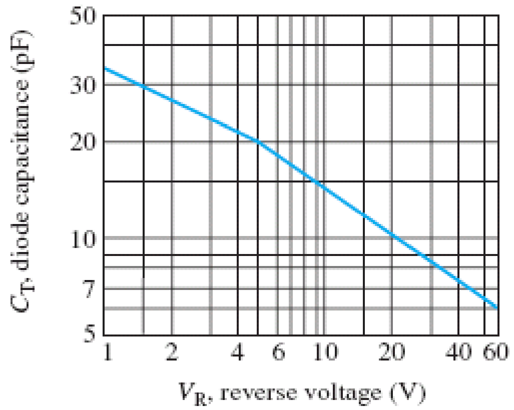
FIGURE 3–72



16. Figure 3–71 is a curve of reverse voltage versus capacitance for a certain varactor. Determine the change in capacitance if V_R varies from 5 V to 20 V.

pYu

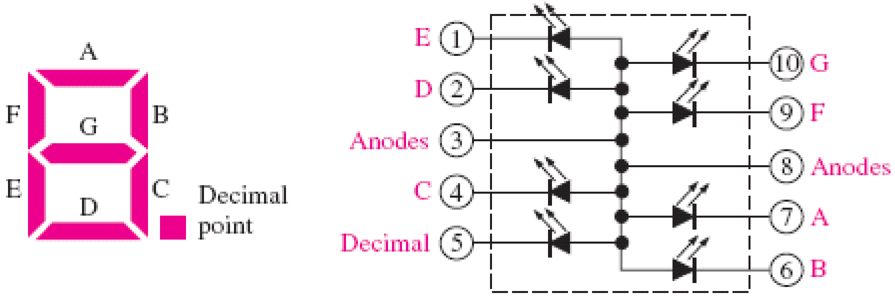
▶ FIGURE 3–71



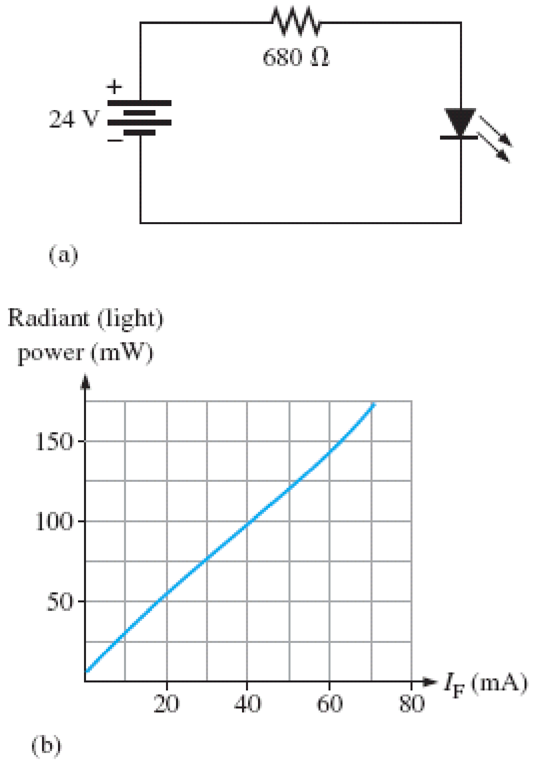
20. The LED in Figure 3–73(a) has a light-producing characteristic as shown in part (b). Neglecting the forward voltage drop of the LED, determine the amount of radiant (light) power produced in mW.

21. Determine how to connect the seven-segment display in Figure 3–74 to display "5." The maximum continuous forward current for each LED is 30 mA and a +5 V dc source is to be used.

▶ FIGURE 3–74



▶ FIGURE 3–73



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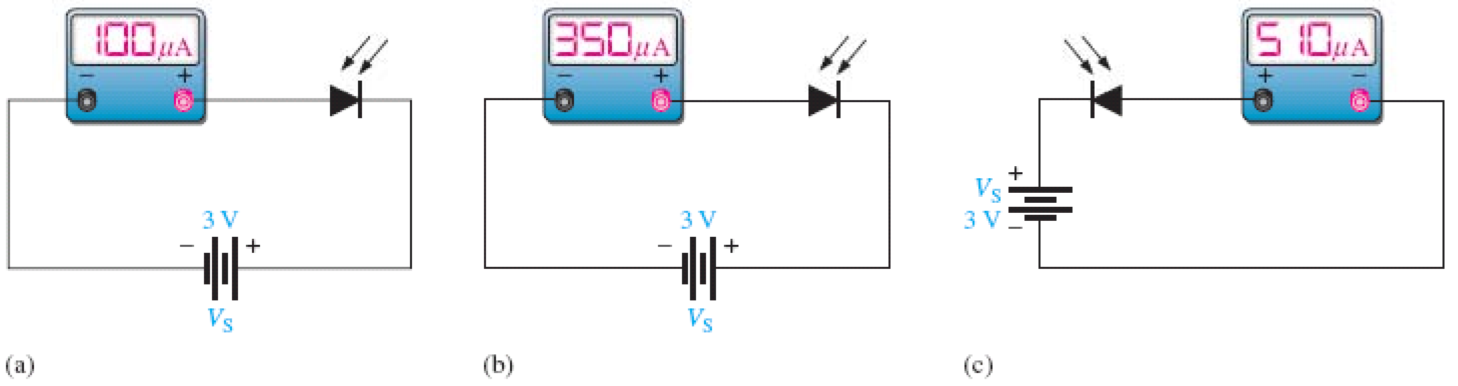

▲ FIGURE 3–75

25. What is the resistance of each photodiode in Figure 3–75?

26. When the switch in Figure 3–76 is closed, will the microammeter reading increase or decrease? Assume D_1 and D_2 are optically coupled.

▶ FIGURE 3–76