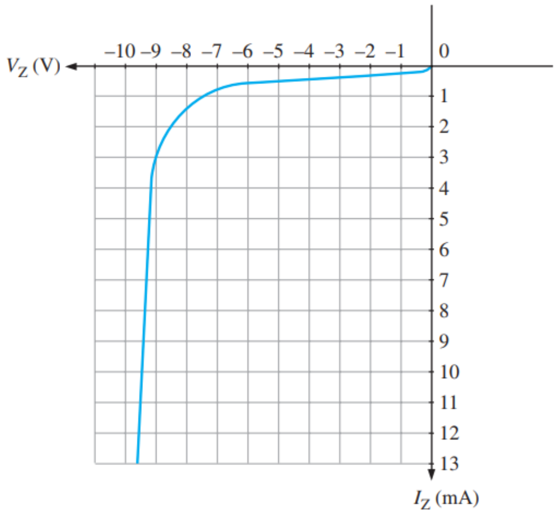
XMUT204 Electronic Design

Tutorial 3: Special Purpose Diodes

Section A: Zener Diode

1. Describe three differences of Zener diode compared with conventional diode. [3 marks]

2. From the characteristic curve in the figure given below, what is the approximate minimum Zener current (I_{ZK}) and the approximate Zener voltage at I_{ZK}. [2 marks]



3. Sketch the equivalent circuit models of Zener diode. [2 marks]

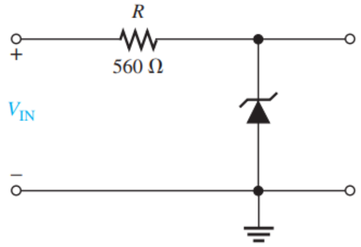
4. A certain Zener diode has $V_z = 7.5$ V and $Z_z = 5$ V at a certain current. Draw the equivalent circuit. [2 marks]

5. When the reverse current in a particular Zener diode increases from 20 mA to 30 mA, the Zener voltage changes from 5.6 V to 5.65 V. What is the impedance of this device? [2 marks]

6. A Zener has an impedance of 15 Ω. What is its terminal voltage at 50 mA if $V_Z = 4.7$ V at $I_Z = 25$ mA? [4 marks]

7. 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. [4 marks]

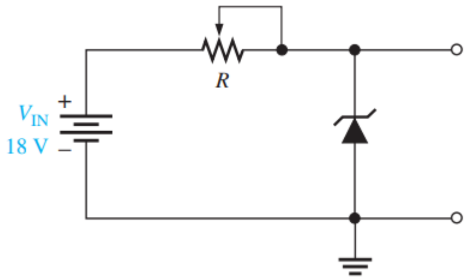
8. For the circuit given in the figure below.



a. Determine the minimum input voltage required for regulation to be established in the figure below. Assume an ideal Zener diode with $I_{ZK} = 1.5\text{ mA}$ and $V_Z = 14\text{ V}$. [4 marks]

b. Repeat for $Z_Z = 20\ \Omega$ and $V_Z = 14\text{ V}$ at 30 mA. [6 marks]

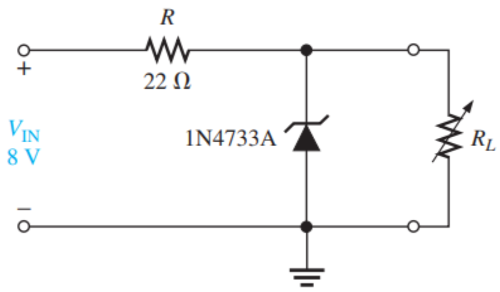
9. For the given Zener diode circuit shown in the figure below.



a. To what value must R be adjusted to make $I_Z = 40\text{ mA}$? Assume $V_Z = 12\text{ V}$ at 30 mA and $Z_Z = 30\ \Omega$. [8 marks]

b. A 20 V peak sinusoidal voltage is applied to the circuit in place of the dc source. Draw the output waveform. Use the parameter values established in (a). [6 marks]

10. A loaded Zener regulator is shown in the figure below.



a. Determine the minimum and maximum permissible load current. [14 marks]

b. Find the load regulation expressed as a percentage. [6 marks]

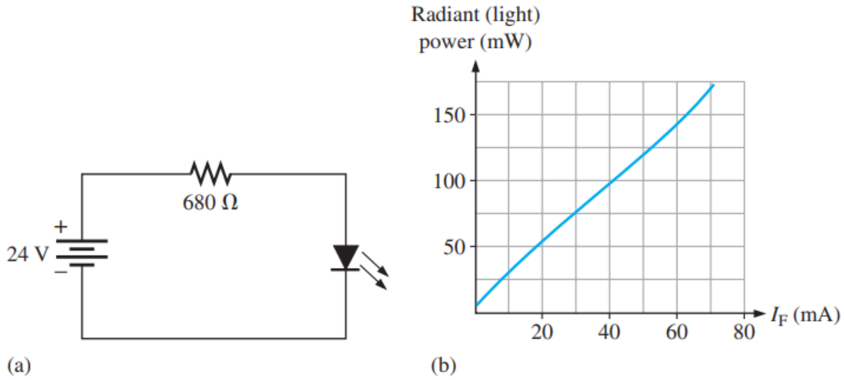
11. The no-load output voltage of a certain Zener regulator is 8.23 V, and the full-load output is 7.98 V. Calculate the load regulation expressed as a percentage? [2 marks]

12. In a certain Zener regulator, the output voltage changes 0.2 V when the input voltage goes from

5 V to 10 V. What is the input regulation expressed as a percentage? [2 marks]

Section B: LED Diode

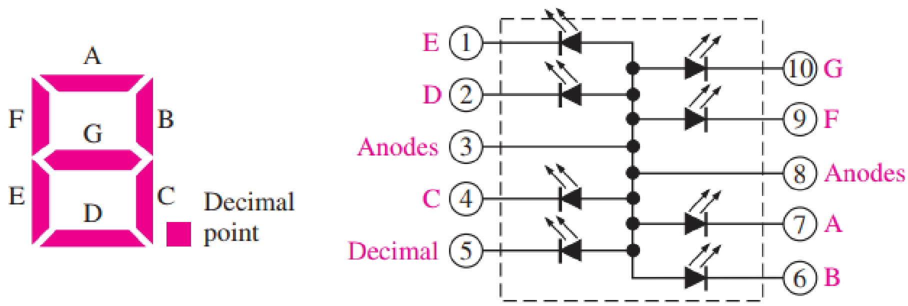
1. The LED in the circuit in part (a) of the figure given below has a light-producing characteristic as shown in part (b). Taking into account the forward voltage drop of the LED (i.e. 2 V for a red LED), determine the amount of radiant (light) power produced in mW. [4 marks]



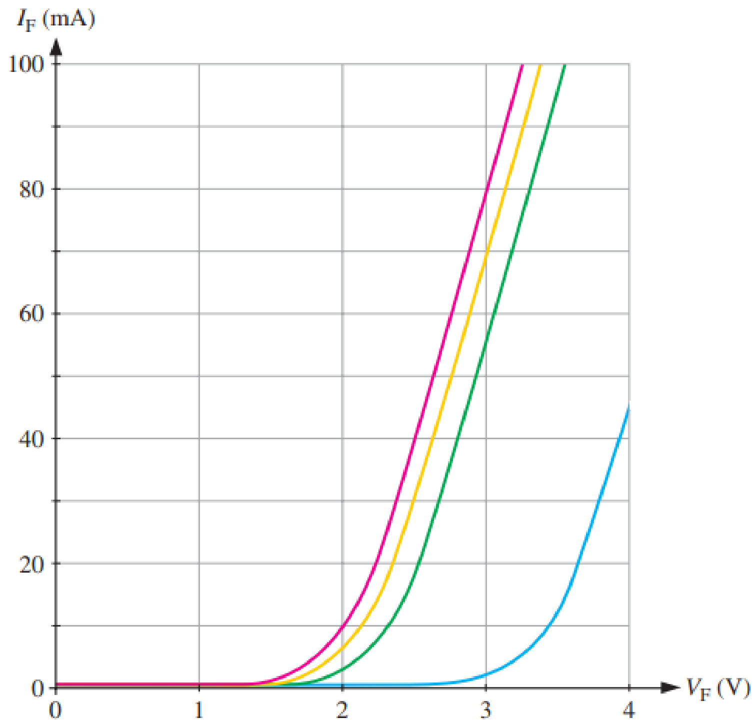
2. Referring to the TSMF1000 LED datasheet (see Appendix).

   a. Can 9 V be applied in reverse across a TSMF1000 LED? [2 marks]
   b. Determine the typical value of series resistor for TSMF1000 when a voltage of 5.1 V is used to forward-bias the diode with $I_F = 20$ mA. [4 marks]
   c. Assume the forward current is 50 mA and the forward voltage drop is 1.5 V at an ambient temperature of 15 °C. Is the maximum power rating exceeded? [4 marks]
   d. Determine the radiant intensity for a forward current of 40 mA. [2 marks]
   e. What is the radiant intensity at an angle of 20° from the axis if the forward current is 100 mA? [8 marks]

3. Determine how to connect the seven-segment display in the figure given below to display "5". The maximum continuous forward current for each LED is 30 mA and a +5 V dc source is to be used. [8 marks]



4. By referring to the V-I curve of a given diode in the figure below, specify the number of limiting resistors and their value for a series-parallel array of 48 red LEDs using a 9 V dc source for a forward current of 20 mA. [14 marks]



5. Develop a yellow LED traffic-light array using a minimum number of limiting resistors that operates from a 24 V supply and consists of 100 LEDs with $I_F = 30\ \mathrm{mA}$ and an equal number of LEDs in each parallel branch. Show the circuit and the resistor values. [12 marks]

Section C: Photo Diode

1. Referring to the TEMD1000 photodiode datasheet (see Appendix).

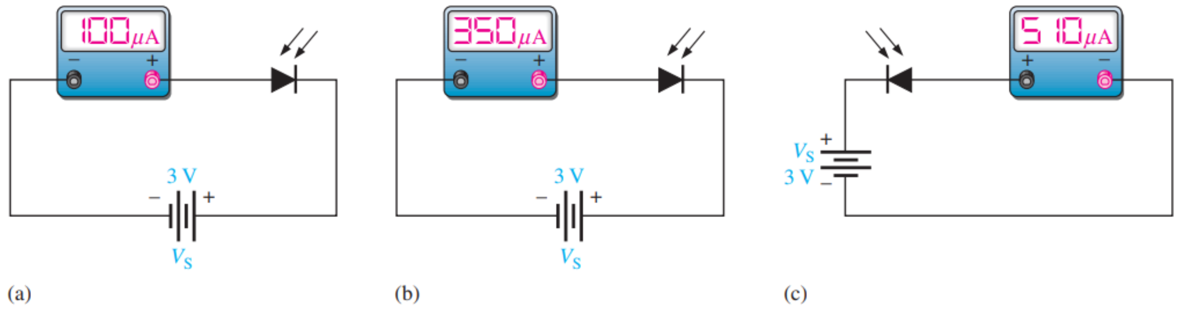
   a. A TEMD1000 photodiode is connected in series with a 1 kΩ resistor and a reverse-bias voltage source. There is no incident light on the diode. What is the maximum voltage drop across the resistor? [2 marks]

   b. At what wavelength will the reverse current be the greatest for a given irradiance? [2 marks]

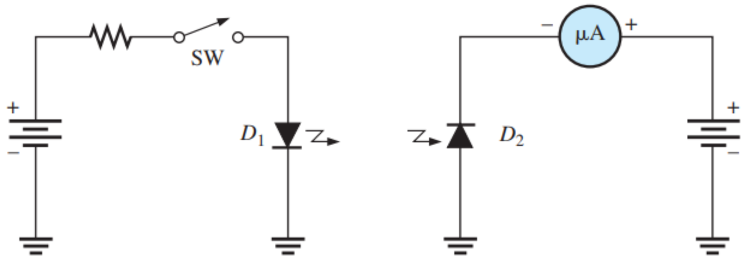
   c. At what wavelength is relative spectral sensitivity of the TEMD1000 equals to 0.4? [2 marks]

2. For a certain photodiode at a given irradiance, the reverse resistance is 200 kΩ and the reverse voltage is 10 V. What is the current through the device? [2 marks]

3. What is the resistance of each photodiode given in the figure below? [6 marks]



4. When the switch in the figure given below is closed, will the micro-ammeter reading increase or decrease? Assume D_1 and D_2 are optically coupled. [2 marks]



Section D: Solar Cells

1. What are the four elements of a solar power system? [4 marks]

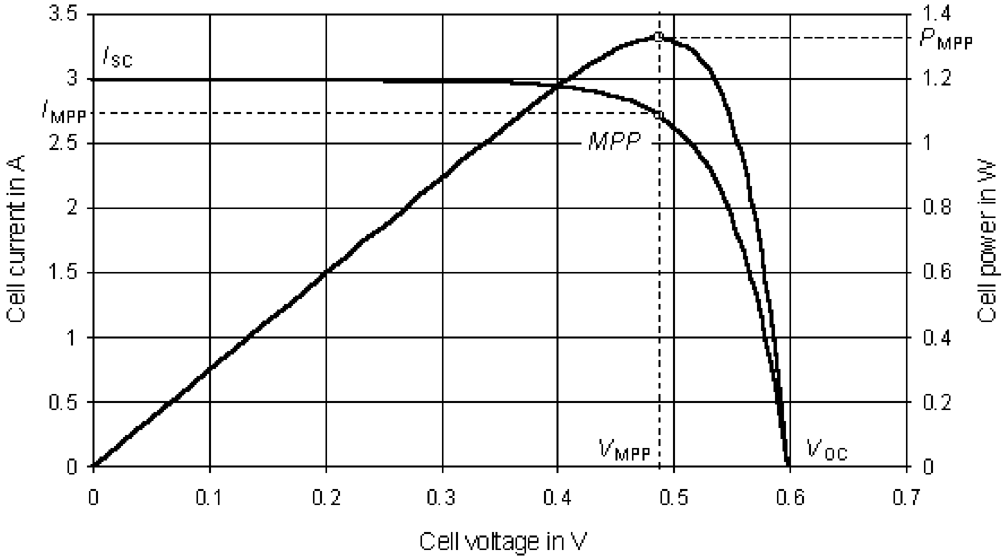
2. The solar cells are the main building block of installation of the solar power system. Assume that a solar cell is rated at 0.5 V and 2 A, suggest the most feasible arrangement of 48 pieces of solar cell for a load of 12 V battery having a 1 kVAh capacity (note: assume that there is some power loses in the distribution of the solar system unit). [4 marks]

3. Describe the photoelectrical generation processes in a given solar cell. [6 marks]

4. Outline the main construction of a typical solar cell panel. [4 marks]

5. Describe the V-I curve characteristics of a solar cell as compared with V-I curve characteristics of a conventional diode. [4 marks]

6. Installation of solar power systems requires analysis using the Maximum Power Point (MPP) curve graph.



Use the MPP curve as given in the figure above to estimate and calculate the following design parameters specified for a solar power unit (note that the graph is based on the one solar cell characteristics instead of characteristics of a unit of cells):

a. The voltage and current at extreme points (e.g. open circuit voltage and short circuit current). [4 marks]
b. The maximum power point (e.g. current and voltage at this point). [4 marks]
c. The maximum power delivered by a unit of 10 solar cells connected in series. [2 marks]
d. The load resistance at the maximum power transfer. [2 marks]
e. The fill factor of the unit (i.e. 10 cm x 10 cm solar cell with P-incident-light = 1 kW/m^2). [2 marks]
f. The efficiency of the unit. [8 marks]

Section E: Solar Power Systems

Solar Systems

1. What are the functions of the four elements of a solar power system? [4 marks]
2. How must solar cells be connected to increase output voltage? [2 marks]
3. What is the function of the charge controller? [2 marks]
4. What is the function of the inverter? [2 marks]
5. What range of solar panels in terms of output voltage and power are available? [4 marks]

Charge Controller and Batteries

6. Why must deep-cycle batteries be used in solar power systems? [2 marks]

7. Why should a 12 V battery be charged at a higher than its rated voltage? [2 marks]
8. Which type of charge controller is the most efficient? [2 marks]
9. What range in terms of power is commercially available in charge controllers? [4 marks]
10. Two 12 V, 250 Ah batteries are connected in series and then connected in parallel with two more series-connected batteries of the same type. What is the total output voltage and Ah rating of the battery array? [4 marks]

Inverter Systems

11. What is the difference between a stand-alone inverter and a grid-tie inverter? [2 marks]
12. What are three types of inverters in terms of the output waveforms? [3 marks]
13. How much average power should a solar power system for your home produce for the month of January? Hint: Use your utility bill. [4 marks]
14. Is net metering available in your area? [2 marks]
15. What is the range of inverters in terms of power that are commercially available? [4 marks]

Tracking Systems

16. What are two types of solar trackers in terms of the way they move? [2 marks]
17. What is the difference between azimuth and elevation? [2 marks]
18. On what date does the winter solstice occur? [2 marks]
19. On what date does the summer solstice occur? [2 marks]
20. Would you recommend a single-axis or a dual-axis tracker for a flat-panel collector? Why? [2 marks]

Appendix 1 – Key Formulas

Description	**Formulae**
Radiant power of LED	$P_D = V_F \times I_F$
Radiant intensity of LED	Radiant Intensity = $I_F(\theta) \times V_F(\theta), \theta$ = angle
Wavelength of photo diode	Refer to datasheet (this depends on spectral sensitivity)
MPP Power (P_{MAX})	$P_{MAX} = V_{MPP} \times I_{MPP}$
Fill factor of solar cells	$\text{Fill factor} = \frac{P_{MAX}}{I_{SC} \times V_{OC}}$
Panel Area	$A_{Panel} = \text{Number of Cell} \times A_{Cell}$
% Efficiency	$\%\text{eff} = \frac{P_{MAX}}{P_{100}}\%$
Power consumed per day	$\text{Power/day} = \text{Total Power} \times \text{Hours}$
Cost per day	Cost/day = Total Power x Hours x $/kWh
Line regulation	$\text{Line Regulation} = \left(\frac{\Delta V_{out}}{\Delta V_{in}}\right) \times 100\%$
Load regulation	$\text{Load Regulation} = \left(\frac{V_{NL} - V_{FL}}{V_{FL}}\right) \times 100\%$

Appendix 2 – Datasheet of 1N4733A Zener Diode

FAIRCHILD SEMICONDUCTOR®

June 2007

1N4728A - 1N4758A Zener Diodes

Absolute Maximum Ratings * T_a = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
P_D	Power Dissipation @ TL ≤ 50°C, Lead Length = 3/8"	1.0	W
	Derate above 50°C	6.67	mW/°C
T_J, T_{STG}	Operating and Storage Temperature Range	-65 to +200	°C

* These ratings are limiting values above which the serviceability of the diode may be impaired.

Electrical Characteristics T_a = 25°C unless otherwise noted

Device	V_Z (V) @ I_Z (Note 1)			Test Current	Max. Zener Impedance			Leakage Current	
	Min.	Typ.	Max.	I_Z (mA)	Z_Z @ I_Z (Ω)	Z_{ZK} @ I_{ZK} (Ω)	I_{ZK} (mA)	I_R (μA)	V_R (V)
1N4728A	3.315	3.3	3.465	76	10	400	1	100	1
1N4729A	3.42	3.6	3.78	69	10	400	1	100	1
1N4730A	3.705	3.9	4.095	64	9	400	1	50	1
1N4731A	4.085	4.3	4.515	58	9	400	1	10	1
1N4732A	4.465	4.7	4.935	53	8	500	1	10	1
1N4733A	4.845	5.1	5.355	49	7	550	1	10	1
1N4734A	5.32	5.6	5.88	45	5	600	1	10	2
1N4735A	5.89	6.2	6.51	41	2	700	1	10	3
1N4736A	6.46	6.8	7.14	37	3.5	700	1	10	4
1N4737A	7.125	7.5	7.875	34	4	700	0.5	10	5
1N4738A	7.79	8.2	8.61	31	4.5	700	0.5	10	6
1N4739A	8.645	9.1	9.555	28	5	700	0.5	10	7
1N4740A	9.5	10	10.5	25	7	700	0.25	10	7.6
1N4741A	10.45	11	11.55	23	8	700	0.25	5	8.4
1N4742A	11.4	12	12.6	21	9	700	0.25	5	9.1
1N4743A	12.35	13	13.65	19	10	700	0.25	5	9.9
1N4744A	14.25	15	15.75	17	14	700	0.25	5	11.4
1N4745A	15.2	16	16.8	15.5	16	700	0.25	5	12.2
1N4746A	17.1	18	18.9	14	20	750	0.25	5	13.7
1N4747A	19	20	21	12.5	22	750	0.25	5	15.2
1N4748A	20.9	22	23.1	11.5	23	750	0.25	5	16.7
1N4749A	22.8	24	25.2	10.5	25	750	0.25	5	18.2
1N4750A	25.65	27	28.35	9.5	35	750	0.25	5	20.6
1N4751A	28.5	30	31.5	8.5	40	1000	0.25	5	22.8
1N4752A	31.35	33	34.65	7.5	45	1000	0.25	5	25.1
1N4753A	34.2	36	37.8	7	50	1000	0.25	5	27.4
1N4754A	37.05	39	40.95	6.5	60	1000	0.25	5	29.7
1N4755A	40.85	43	45.15	6	70	1500	0.25	5	32.7
1N4756A	44.65	47	49.35	5.5	80	1500	0.25	5	35.8
1N4757A	48.45	51	53.55	5	95	1500	0.25	5	38.8
1N4758A	53.2	56	58.8	4.5	110	2000	0.25	5	42.6

Appendix 3 – LED Datasheet (TSMF1000)

Absolute Maximum Ratings

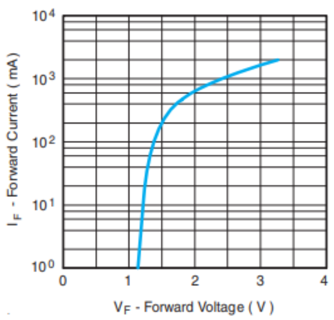
T_{amb} = 25°C, unless otherwise specified

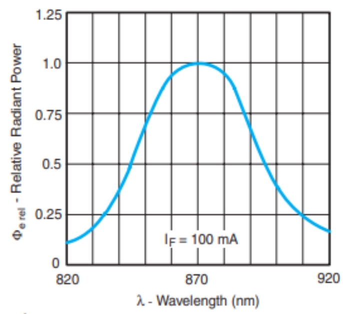
Parameter	Test condition	Symbol	Value	Unit
Reverse Voltage		V_R	5	V
Forward current		I_F	100	mA
Peak Forward Current	t_p/T = 0.5, t_p = 100 µs	I_{FM}	200	mA
Surge Forward Current	t_p = 100 µs	I_{FSM}	0.8	A
Power Dissipation		P_V	190	mW
Junction Temperature		T_j	100	°C
Operating Temperature Range		T_{amb}	- 40 to + 85	°C

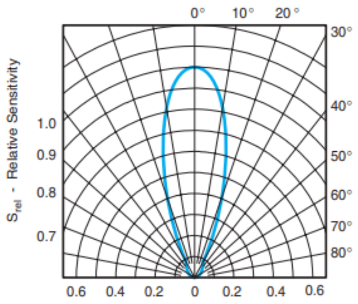
Basic Characteristics

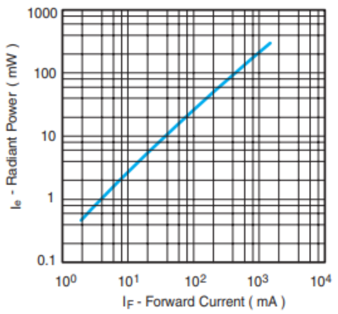
T_{amb} = 25°C, unless otherwise specified
T_{amb} = 25°C, unless otherwise specified

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
Temp. Coefficient of V_F	I_F = 1.0 mA	TK_{VF}		- 1.7		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
Temp. 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		870		nm
Spectral Bandwidth	I_F = 20 mA	$\Delta\lambda$		40		nm
Temp. 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
Virtual Source Diameter		∅		1.2		mm









Appendix 4 – Photodiode Datasheet (TEMD1000)

Absolute Maximum Ratings

T_{amb} = 25°C, unless otherwise specified

Parameter	Test condition	Symbol	Value	Unit
Reverse Voltage		V_R	60	V
Power Dissipation	$T_{amb} \le 25°C$	P_V	75	mW
Junction Temperature		T_j	100	°C
Storage Temperature Range		T_{stg}	- 40 to + 100	°C
Operating Temperature Range		T_{stg}	- 40 to + 85	°C
Soldering Temperature	$t \le 5$ s	T_{sd}	< 260	°C

Basic Characteristics

T_{amb} = 25 °C, unless otherwise specified
T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Min	Typ.	Max	Unit
Forward Voltage	I_F = 50 mA	V_F		1.0	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}		10		µA
	E_e = 1 mW/cm², λ = 950 nm, V_R = 5 V	I_{ra}	5	12		µA

Parameter	Test condition	Symbol	Min	Typ.	Max	Unit
Temp. Coefficient of I_{ra}	V_R = 5 V, = 870 nm	TK_{Ira}		0.2		%/K
Absolute Spectral Sensitivity	V_R = 5 V, = 870 nm	s(λ)		0.60		A/W
	V_R = 5 V, = 950 nm	s(λ)		0.55		A/W
Angle of Half Sensitivity		ϕ		±15		deg
Wavelength of Peak Sensitivity		λ_p		900		nm
Range of Spectral Bandwidth		$\lambda_{0.5}$		840 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