1.1. Summary of Types
Optoelectronic semiconductor devices

Types so far available		New types
Photovoltaic cells		
Silicon photovoltaic cells	BP 100, BPX 79, BPY 11, BPY 47, BPY 48, BPY 64, TP 60, TP 61,	
Photodiodes		
Silicon differential photodiodes	BPX 48	
Silicon photodiodes	BPX 60, BPX 63, BPX 65, BPX 90, BPX 91, BPX 92, BPX 93, ■ BPY 12	**BPW 32, BPW 33, BPW 34, BPX 61, BPX 66**
Phototransistors		
Silicon phototransistors	BP 101, BP 102, BPX 38, BPX 43, BPX 62, BPX 81, BPY 61, BPY 62	**BP 103**
Silicon phototransistor arrays	BPX 80 to BPX 89	
Light emitting diodes (LEDs)		
GaAs infrared emitting diodes	CQY 17, ■ CQY 18, LD 261	**CQY 57, CQY 77, CQY 78, LD 241**
GaAs infrared emitting diode arrays	LD 260 to LD 269	
GaAsP light emitting diodes (red light)	■ LD 40, LD 461, LD 50	**CQY 26 A, LD 30 A, C, LD 41 A, LD 461 A**
GaAsP light emitting diode arrays (red light)	LD 460 to LD 469	
GaP light emitting diodes (green light)	LD 471	**CQY 28 A, LD 37 A, LD 57 A, LD 471 A**
GaP light emitting diode arrays (green light)	LD 470 to LD 479	
GaP light emitting diodes (yellow light)		**CQY 29 A, LD 35 A, LD 55 A, LD 481 A**
GaP light emitting diode arrays (yellow light)		**LD 480 to LD 489**
Optoelectronic couplers	CNY 17, CNY 18	
Photoconductive cells	RPY 60, RPY 61, RPY 62, RPY 63, RPY 64	**FW 9801, FW 9802**
Threshold switch for optoelectronic applications		**TPV 63**

■ Not for new equipment

Summary of Types

Silicon photovoltaic cells

Type	Sensitivity S (μA/lux)	Open circuit voltage at E_v = 100 lux V_L (mV)	10 000 lux V_L (mV)	Dark current I_R at T_{amb} = 25°C I_R (μA)	Page
BP 100	0.025 (≧ 0.019)	170 (≧ 120)	≧ 200[1])	3 (≦ 10)	61
BPX 79	0.135 (≧ 0.1)	320 (≧ 220)	≧ 310[1])	0.3 (≦ 50)	66
BPY 11	0.04 (≧ 0.028)	220 (≧ 180)	≧ 260[1])	1 (≦ 10)	70
BPY 11/I	0.04 (≧ 0.028)	220 (≧ 180)	≧ 260[1])	1 (≦ 10)	70
BPY 11/II	0.04 (≧ 0.028)	220 (≧ 180)	≧ 260[1])	1 (≦ 10)	70
BPY 11/III	0.04 (≧ 0.028)	220 (≧ 180)	≧ 260[1])	1 (≦ 10)	70
BPY 47	1.3 (≧ 0.9)	300 (≧ 150)	≧ 450	–	75
BPY 48	0.43 (≧ 0.3)	300 (≧ 150)	≧ 450	–	80
BPY 64	0.23 (≧ 0.16)	300 (≧ 150)	≧ 450	–	85
TP 60	1.0 (≧ 0.7)	300 (≧ 140)	≧ 440	–	90
TP 61	1.0 (≧ 0.7)	300 (≧ 140)	≧ 440	–	90

1) E_v = 1000 lux

Silicon differential photodiodes

Type	Sensitivity S (nA/lux)	Reverse voltage V_R (V)	Dark current I_R at T_{amb} = 25°C (μA)	Page
BPX 48	32 (≧ 15)	10	0.1 (≦ 0.2)	48

Silicon photodiodes

Type	Sensitivity S (nA/lux)	Reverse voltage V_R (V)	Dark current I_R at T_{amb} = 25°C (nA) [pA]	Page
▼ **BPW 32**	10	7	[15]	103
▼ **BPW 33**	50 (≧ 35)	7	[20 (≦ 100)]	108
▼ **BPW 34**	70 (≧ 50)	32	[2 (≦ 30)]	113
BPX 60	50 (≧ 35)	32	7 (≦ 300)	118
▼ **BPX 61**	70 (≧ 50)	32	2 (≦ 30)	123
BPX 63	10	7	[0.15]	128
BPX 65	10 (≧ 7)	50	1 (≦ 5)	133
▼ **BPX 66**	9 (≧ 5)	50	0.15 (≦ 0.3)	138
BPX 90	40 (≧ 25)	32	5 (≦ 200)	143
BPX 91	50 (≧ 35)	32	7 (≦ 300)	148
BPX 92	7 (≧ 4)	32	1 (≦ 100)	153
BPX 93	8 (≧ 5)	32	0.5 (≦ 50)	158
■ **BPY 12**	≧100	20	100 (≦ 1000)	162

The illuminance indicated refers to unfiltered radiation of a tungsten filament lamp at a colour temperature of 2856 K (standard light A in accordance with DIN 5033 and IEC publ. 306-1).

▼ New type ■ Not for new rquipment

1.1. Summary of Types
Silicon phototransistors

Type	Photocurrent I_P at V_{CE} = 5 V, E_v = 1000 lux I_P (mA)	Collector-emitter reverse voltage V_{CE} (V)	Collector-emitter leakage current at V_{CE}= 25 V, [30 V] E = 0; I_{CEO} (nA)	Page
BP 101/I	0.063 to 0.125	32	[5 (≤ 100)]	171
BP 101/II	0.1 to 0.2	32	[5 (≤ 100)]	171
BP 101/III	0.16 to 0.32	32	[5 (≤ 100)]	171
BP 101/IV	0.25 to 0.5	32	[5 (≤ 100)]	171
BP 102/I	0.16 to 0.32	32	[5 (≤ 100)]	176
BP 102/II	0.25 to 0.5	32	[5 (≤ 100)]	176
BP 102/III	0.4 to 0.8	32	[5 (≤ 100)]	176
BP 102/IV	0.63 to 1.25	32	[5 (≤ 100)]	176
▼ **BP 103/I**	0.16 to 0.32	100	[5 (≤ 100)]	181
▼ **BP 103/II**	0.25 to 0.5	100	[5 (≤ 100)]	181
▼ **BP 103/III**	0.4 to 0.8	100	[5 (≤ 100)]	181
▼ **BP 103/IV**	0.63 to 1.25	100	[5 (≤ 100)]	181
BPX 38/I	0.4 to 0.8	50	5 (≤ 200)	186
BPX 38/II	0.63 to 1.25	50	8 (≤ 200)	186
BPX 38/III	1.0 to 2.0	50	12 (≤ 500)	186
BPX 38/IV	1.6 to 3.2	50	20 (≤ 500)	186
BPX 43/I	1.6 to 3.2	50	5 (≤ 200)	191
BPX 43/II	2.5 to 5.0	50	8 (≤ 200)	191
BPX 43/III	4.0 to 5.0	50	12 (≤ 500)	191
BPX 43/IV	6.3 to 12.5	50	20 (≤ 500)	191
BPX 62/I	0.4 to 0.8	50	10 (≤ 100)	196
BPX 62/II	0.63 to 1.25	50	10 (≤ 100)	196
BPX 62/III	1.0 to 2.0	50	10 (≤ 100)	196
BPX 62/IV	1.6 to 3.2	50	10 (≤ 100)	196
BPX 81/I	0.63 to 1.25	32	25 (≤ 200)	200
BPX 81/II	1.0 to 2.0	32	25 (≤ 200)	200
BPX 81/III	1.6 to 3.2	32	25 (≤ 200)	200
BPX 81/IV	2.5 to 5.0	32	25 (≤ 200)	200
BPY 61/I	0.8 to 1.6	32	5 (≤ 100)	208
BPY 61/II	1.25 to 2.5	32	5 (≤ 100)	208
BPY 61/III	2.0 to 4.0	32	5 (≤ 100)	208
BPY 61/IV	3.2 to 6.3	32	5 (≤ 100)	208
BPY 62/I	1.25 to 2.5	32	5 (≤ 100)	212
BPY 62/II	2.0 to 4.0	32	5 (≤ 100)	212
BPY 62/III	3.2 to 6.3	32	5 (≤ 100)	212

The illuminance indicated refers to unifiltered radiation of a tungsten filament lamp at a colour temperature of 2856 K (standard light A in accordance with DIN 5033 and IEC publ. 306-1).

▼ New type

1.1. Summary of Types

Silicon phototransistor arrays

Type (number of phototransistors per array)	Photocurrent I_P at V_{CE} = 5 V, E_V = 1000 lx I_P (mA)	Collector-emitter reverse voltage V_{CE} (V)	Collector-emitter leakage current at V_{CE} = 25 V, E = 0, I_{CEO} (nA)	Page
BPX 81 (1)[1]	0.41 to 6.3	32	25 (≦ 200)	204
BPX 82 (2)		32		204
BPX 83 (3)		32		204
BPX 84 (4)		32		204
BPX 85 (5)		32		204
BPX 86 (6)		32		204
BPX 87 (7)		32		204
BPX 88 (8)		32		204
BPX 89 (9)		32		204
BPX 80 (10)		32		204

The illuminance indicated refers to unfiltered radiation of a tungsten filament lamp at a colour temperature of 2856 K (standard light A in accordance with DIN 5033 and IEC publ. 306-1).

GaAs infrared emitting diodes

Type	Radiant intensity I_e[2] I_F = 100 mA [50 mA] (mW/sr) I_e	Radiant flux I_F = 100 mA [50 mA] Φ_e (mW) Φ_e at	φ	Φ_e total	Half angle φ (for 50% $I_{v\,max}$) (degree)	Max. perm. forward current I_F (mA)	Page
CQY 17/IV		1.1 to 2.8	15°	4	13	100	221
CQY 17/V		1.8 to 4.5	15°	6.3	13	100	221
■ **CQY 18/III**		0.8 to 2.0	30°	2.5	45	100	226
■ **CQY 18/IV**		1.25 to 3.2	30°	4	45	100	226
■ **CQY 18/V**		2 to 5.0	30°	6.3	45	100	226
▼ **CQY 57/I**	[0.5 to 1.0]			[1.0]	12	100	231
▼ **CQY 57/II**	[0.8 to 1.6]			[1.6]	12	100	231
▼ **CQY 57/III**	[1.25 to 2.5]			[2.5]	12	100	231
▼ **CQY 57/IV**	[2.0 to 4.0]			[4.0]	12	100	231
▼ **CQY 77/I**	8 to 16			2.5	6	230	236
▼ **CQY 77/II**	12.5 to 25			4.0	6	230	236
▼ **CQY 77/III**	20 to 40			6.3	6	230	236
▼ **CQY 78/I**	1.0 to 2.0			2.5	40	230	241
▼ **CQY 78/II**	1.6 to 3.2			4.0	40	230	241
▼ **CQY 78/III**	2.5 to 5.0			6.3	40	230	241
▼ **LD 241/I**	1.0 to 2.0			4.0	60	230	246
▼ **LD 241/II**	1.6 to 3.2			6.3	60	230	246
▼ **LD 241/III**	2.5 to 5.0			10	60	230	246
LD 261/I		[0.28 to 0.71]	30°	[1.0]	30	60	251
LD 261/II		[0.45 to 1.112]	30°	[1.6]	30	60	251
LD 261/III		[0.71 to 1.8]	30°	[2.5]	30	60	251
LD 261/IV		[1.12 to 2.8]	30°	[4.0]	30	60	251

1) I_p spread within one array ≦ 1 : 2 (matching factor 0.5) closer spread values upon request
2) Measured with HP radiant flux meter 8334A (option 013) measuring distance ≧ 70 mm.

▼ New type ■ Not for new equipment

1.1. Summary of types

GaAs Infrared emitting diode arrays

Type (Number of diodes per array)	Radiant flux I_F = 50 mA Φ_e (mW) Φ_e at	φ	Φ_e total	Half angle φ (for 50% $I_{v\,max}$) degree	Max. perm. forward current I_F (mA)	Page
LD 261 (1)[1]						256
LD 262 (2)						256
LD 263 (3)						256
LD 264 (4)						256
LD 265 (5)	0.32 to 2.50	30°	2.0	30	50	256
LD 266 (6)						256
LD 267 (7)						256
LD 268 (8)						256
LD 269 (9)						256
LD 260 (10)						256

1) I_e spread within one array ≦ 1 : 2 (matching factor 0.5) closer spread values upon request

GaAsP light emitting diodes (red light)

Type	Luminous intensity at I_F = 20 mA I_v (mcd)	Half angle φ (for 50% $I_{v\,max}$) degree	Case colour	Reverse current at V_R = 3 V I_R (µA)	Page
▼ **CQY 26 A**	0.8	30	red diffuse	0.01 (≦ 10)	265
▼ **CQY 26/I**	1.5 (≧ 1.0)	30	red diffuse	0.01 (≦10)	265
▼ **CQY 26/II**	2.5 (≧ 2.0)	30	red diffuse	0.01 (≦ 10)	265
▼ **LD 30 A**	0.8	35	red diffuse	0.01 (≦ 10)	271
▼ **LD 30/I**	1.5 (≧ 1.0)	35	red diffuse	0.01 (≦ 10)	271
▼ **LD 30/II**	2.5 (≧ 2.0)	35	red diffuse	0.01 (≦ 10)	271
▼ **LD 30 C**	2.5 (≧ 1.0)	25	glass clear	0.01 (≦ 10)	271
■ **LD 40/I**	0.7 (≧ 0.3)	40	red diffuse	0.01 (≦ 10)	275
■ **LD 40/II**	1.2 (≧ 0.8)	40	red diffuse	0.01 (≦ 10)	275
▼ **LD 41 A**	0.8	30	red diffuse	0.01 (≦ 10)	279
▼ **LD 41/I**	1.5 (≧1.0)	30	red diffuse	0.01 (≦ 10)	279
▼ **LD 41/II**	2.5 (≧ 2.0)	30	red diffuse	0.01 (≦ 10)	279
LD 50/I	3.0 (≧ 2.0)	12	red diffuse	0.01 (≦ 10)	284
LD 50/II	6.0 (≧ 4.0)	12	red diffuse	0.01 (≦ 10)	284
LD 461	1 (≧ 0.6)	50	white diffuse	0.01 (≦ 10)	289
▼ **LD 461 A**	≧ 0.4	50	white diffuse	0.01 (≦ 10)	289

GaAsP light emitting diode arrays (red light)

Type (Number of LEDs per array)	Luminous intensity at I_F = 20 mA I_v (mcd)	Half angle φ (for 50% $I_{v\,max}$) degree	Case colour	Reverse current at V_R = 3 V I_R (µA)	Page
LD 462 (2)					295
LD 463 (3)					295
LD 464 (4)					295
LD 465 (5)					295
LD 466 (6)	0.6 to 1.2	50	white diffuse	0.01 (≦ 10)	295
LD 467 (7)					295
LD 468 (8)					295
LD 469 (9)					295
LD 460 (10)					295

▼ New type; ■ Not for new equipment

1.1. Summary of Types

GaP light emitting diodes (green light)

	Type	Luminous intensity at I_F = 20 mA I_v (mcd)	Half angle φ (for 50% $I_{v\,max}$) (degree)	Case colour	Reverse current at V_R = 3 V I_R (μA)	Page
▼	CQY 28 A	1.2	25	green diffuse	0.01 (≦ 10)	299
▼	CQY 28/I	3.0 (≧ 2.5)	25	green diffuse	0.01 (≦ 10)	299
▼	CQY 28/II	5.5 (≧ 4.0)	25	green diffuse	0.01 (≦ 10)	299
▼	LD 37 A	1.0	35	green diffuse	0.01 (≦ 10)	304
▼	LD 37/I	2.5 (≧ 2.0)	35	green diffuse	0.01 (≦ 10)	304
▼	LD 37/II	5.0 (≧ 3.0)	35	green diffuse	0.01 (≦ 10)	304
▼	LD 57 A	1.2	25	green diffuse	0.01 (≦ 10)	309
▼	LD 57/I	3.0 (≧ 2.5)	25	green diffuse	0.01 (≦ 10)	309
▼	LD 57/II	5.5 (≧ 4.0)	25	green diffuse	0.01 (≦ 10)	309
	LD 471	4.5 (≧ 3.2)	50	green diffuse	0.1 (≦ 10)	314
▼	LD 471 A	≧ 1.25	50	green diffuse	0.1 (≦ 10)	314

GaP light emitting diode arrays (green light)

Type (Number of LEDs per array)	Luminous intensity at I_F = 20 mA I_v (mcd)	Half angle φ (for 50% $I_{v\,max}$) (degree)	Case colour	Reverse current at V_R = 3 V I_R (μA)	Page
LD 472 (2)	3.2 to 6.3	50	green diffuse	0.1 (≦ 10)	319
LD 473 (3)					319
LD 474 (4)					319
LD 475 (5)					319
LD 476 (6)					319
LD 477 (7)					319
LD 478 (8)					319
LD 479 (9)					319
LD 470 (10)					319

GaP light emitting diodes (yellow light)

	Type	Luminous intensity at I_F = 20 mA I_v (mcd)	Half angle φ (for 50% $I_{v\,max}$) (degree)	Case colour	Reverse current at V_R = 3 V I_R (μA)	Page
▼	CQY 29 A	1.5	25	yellow diffuse	0.01 (≦ 10)	324
▼	CQY 29/I	4.0 (≧ 3.0)	25	yellow diffuse	0.01 (≦ 10)	324
▼	CQY 29/II	7.0 (≧ 5.0)	25	yellow diffuse	0.01 (≦ 10)	324
▼	LD 35 A	1.5	35	yellow diffuse	0.01 (≦ 10)	329
▼	LD 35/I	3.5 (≧ 2.5)	35	yellow diffuse	0.01 (≦ 10)	329
▼	LD 35/II	6.0 (≧ 4.0)	35	yellow diffuse	0.01 (≦ 10)	329
▼	LD 55 A	1.5	25	yellow diffuse	0.01 (≦ 10)	334
▼	LD 55/I	4.0 (≧ 3.0)	25	yellow diffuse	0.01 (≦ 10)	334
▼	LD 55/II	7.0 (≧ 5.0)	25	yellow diffuse	0.01 (≦ 10)	334
▼	LD 481	7 (≧ 4)	50	yellow diffuse	0.1 (≦ 10)	339

▼ New type

1.1. Summary of Types

GaP light emitting diode arrays (yellow light)

Type (Number of diodes per array)	Luminous intensity at I_F = 20 mA I_v (mcd)	Half angle φ (for 50% $I_{v\,max}$) degree	Case colour	Page
▼ LD 482 (2)	4 to 8	50	yellow diffuse	344
▼ LD 483 (3)				344
▼ LD 484 (4)				344
▼ LD 485 (5)				344
▼ LD 486 (6)				344
▼ LD 487 (7)				344
▼ LD 488 (8)				344
▼ LD 489 (9)				344
▼ LD 480 (10)				344

Optoelectronic couplers

Type	Current transfer ratio in % I_C/I_F (10 mA)	Insulation test voltage V_{is} (V)	GaAs LED		Phototransistor		Page
			Forward current I_F (mA)	Reverse voltage V_R (V)	Collector current I_C (mA)	Collector voltage V_{CEO} (V)	
CNY 17/I	40–80	4000 =	60	3	100	70	351
CNY 17/II	63–125	4000 =	60	3	100	70	351
CNY 17/III	100–200	4000 =	60	3	100	70	351
CNY 17/IV	160–320	4000 =	60	3	100	70	351
CNY 18/I	10–20	800 =	60	3	100	32	357
CNY 18/II	16–32	800 =	60	3	100	32	357
CNY 18/III	25–50	800 =	60	3	100	32	357
CNY 18/IV	40–80	800 =	60	3	100	32	357

Photoresistors

Type	Operating voltage V_a (V)	Dark resistance R_0 (Ω)	Light resistance R_{1000} (Ω) [R_{20}]	Wavelength of the max. sensitivity $\lambda_{S\,max}$ (nm)	Page
▼ **FW 9801**	100	$\geqq 8 \cdot 10^5$	[600]	575	363
▼ **FW 9802**	200	$\geqq 8 \cdot 10^5$	[1800]	575	363
RPY 60	100	$\geqq 1 \cdot 10^8$	300 to 800	720	365
RPY 61	50	$\geqq 1 \cdot 10^6$	300 to 800	650	368
RPY 62	100	$\geqq 1 \cdot 10^8$	3500	550	371
RPY 63	50	$\geqq 1 \cdot 10^6$	300 to 800	550	374
RPY 64	100	$\geqq 1 \cdot 10^8$	3500	550	377

Threshold switch for optoelectronic applications

Type	Max. operating voltage V_{batt}	Input current I_E (pA)	Switching threshold V_{ES} (V)	Rise time $\frac{dV_A}{dt}$ $\frac{(V)}{\mu s}$	Temperature coefficient TC (%/K)	Page
▼ **TPV 63**	± 10	20	0.8	3	– 0.6	383

▼ New type

1.2. Symbols, alphabetically

A	Anode
A	Radiant sensitive area
B	Base terminal
B	Static current gain, emitter circuit
C	Collector terminal
C	Capacitance
C_0	Capacitance at $V_R = 0$ V
C_{10}	Capacitance at $V_R = 10$ V
C_D	Diode capacitance
C_{CB}	Collector-base capacitance
C_{CE}	Collector-emitter capacitance
C_{EB}	Emitter-base capacitance
C_j	Junction capacitance
C_E	Input capacitance
C_K	Coupling capacitance
cd	Candela (unit of luminous intensity I_v)
D^*	Detection limit
E	Emitter terminal
E_e	Irradiance (unit: W/m^2)
E_v	Illuminance (unit: lx)
η	Quantum yield
η	Efficiency (%)
f	Frequency
f_g	Cut-off frequency
I_B	Base current
I_C	Collector current
I_{CEO}	Collector-emitter leakage current (open base, $I_B = 0$)
I_{EAV}	Emitter current at a given integrated time t_{av}
I_{EBO}	Emitter base leakage current (open collector, $I_e = 0$)
i_{FS}	Surge current
I_F	Forward current
I_E	Emitter current
I_e	Radiant intensity (unit: W/sr)
I_K	Short circuit current
I_{K25}	Short circuit current at $T_{amb} = 25°C$
I_v	Luminous intensity (unit: cd or mcd)

I_P	Photocurrent
I_R	Reverse current
K	Cathode
L_v	Luminance (cd/m^2)
λ	Wavelength (nm)
$\lambda_{S\,max}$	Wavelength of the max. sensitivity
λ_{peak}	Wavelength at peak emission
ν	Duty cycle
NC	Not connected contact
NEP	Noise equivalent power $\left(\frac{W}{\sqrt{Hz}}\right)$
P_{tot}	Power dissipation
φ	Half angle
Φ_e	Radiant flux (radiant power) (W)
R_H	Light resistance Luminous flux (lm) Lumen
R_{HT}	Light resistance at temperature T
$R_{H\,25°}$	Light resistance at temperature $T = 25°C$
R_{1000}	Light resistance at $E_v = 1000$ lx
R_L	Load resistance
R_O	Dark resistance 1 min after darking
R_s	Series resistance
R_{th}	Thermal resistance junction (heat source) – case at unlimited good heat dissipation from case ($T_{case} = T_{amb}$)
R_{thL}	Thermal resistance, junction (heat source) – static ambient air when using a cooling plate of definite size
R_{thJamb}	Thermal resistance, junction (heat source) – ambient static air
$R_{thJcase}$	Thermal resistance, junction – case
R_{thJL}	Thermal resistance, junction – solder pin connection
S	Spectral sensitivity
S_{rel}	Relative spectral sensitivity
t	Time
t_{on}	Turn-on time
t_{off}	Turn-off time
t_f	Fall time
t_r	Rise time
t_d	Delay time
t_s	Storage time
T	Temperature

T_{case}	Case temperature
T_j	Junction temperature
TC	Temperature coefficient
T_s	Soldering temperature
T_{stor}	Storage temperature
T_{amb}	Ambient temperature
T_F	Colour temperature
ΔT	Temperature deviation
V_{batt}	Voltage
V_{op}	Operating voltage
V	Battery voltage
V_{out}	Output voltage
V_{BR}	Breakdown voltage
V_{CE}	Collector-emitter voltage
V_{CEO}	Collector-emitter junction voltage, open base ($I_B = 0$)
V_{CEsat}	Collector-emitter saturation voltage
V_{EBO}	Emitter-base junction voltage, open emitter ($I_E = 0$)
V_{ES}	Switching threshold
V_F	Forward voltage
V_{IS}	Insulation voltage
V_L	Open circuit voltage
V_{L25}	Open circuit voltage at $T_{amb} = 25°C$
V_P	Photovoltage
V_R	Reverse voltage
V_{leak}	Leakage voltage
ϱ	Resistivity of base material (Ω/cm)

2. General

2.1. Introduction

Optoelectronic components are increasingly used in modern electronics. Main fields of application are light barriers for production control and safety devices, light control and regulating equipment like twilight switches, fire detectors and facilities for optical heat supervision, scanning of punched cards and perforated tapes, positioning of machine tools (for measuring length, angle and position), of optical apparatus and ignition processes, for signal transmission at electrically separated input and output, as well as conversion of light into electrical energy.

Lately, new fields of application opened up for optoelectronic components in the photo industry in form of exposure and aperture control and for automatic electronic flashes. IR sound transmission and IR remote control are new modes in the radio industry. Computer diagnosis and LED displays in instrument panels are possible applications in the automotive industry.

In data processing couplers electrically separate computer and peripherals. Ultimately LED and numerical indicator tubes won wide application in the measuring and control technique.

Depending upon the application either photovoltaic cells, photodiodes or
are used. Wherever amplifiers with high input impedance are required, photodiodes are to be preferred.

Phototransistors are predominantly used in connection with transistor circuits or to drive integrated circuits, whereas photovoltaic cells are preferred to scan large surfaces, if a strictly linear relation between light and signal level or optimum reliability is required.

Apart from photoelectric detectors also light emitters on a semiconductor basis find application, the light emitting diodes. One differentiates between light emitters on the basis of GaAs (gallium arsenide) which operate in conjunction with the photo detectors described and are spectrally attuned to them and those based on GaAsP (gallium arsenide phosphide) or GaP (gallium phosphide) which emit visible light and mainly serve as signal indicators.

Light emitting diodes and alphanumerical displays in red, green, and yellow replace the conventional indication by lamps in an ever increasing scale.

Components comprising both emitter and sensor are termed optically coupled isolators or optoelectronic couplers. They are used to transmit electrical signals at electrical isolation.

In the following the various topics will be handled in detail as to technology, special characteristics and application possibilities. Thereafter comes a chapter devoted to the measuring technique of optoelectronic components togehter with the most essential tables and performance charts, finally quality specifications, mounting and soldering instructions.

2.2 Silicon photovoltaic cells

Photovoltaic cells are active two-poles with a comparably low internal resistance that has its cause in the voltage of the voltaic cell, which may only be some tenth of a volt. For practical application, this characteristic requires special attention.

The open circuit voltage V_L rises almost logarithmically as a function of the illuminance and, particularly in case of planar photovoltaic cells, reaches high values already at very low illuminances. It is independent of the size of the photovoltaic cell.

The short circuit current I_K increases linearly with the illuminance. It is proportional to the size of the exposed photosensitive area at uniform illuminance.

The maximum energy of the photovoltaic cell is yielded in a load resistance R_L of approx $\frac{V_L}{I_K}$.

Practical short circuit operation and thus proportionality between optical and electrical signal is given at load resistance up to $\frac{V_L}{2\,I_K}$. This relation can be applied to an open circuit voltage of ≧ 100 mV.

In any type of application the highest value of I_K has to be used. A simple procedure to gain information on the load resistance required is to measure V_L and I_K at given illumination conditions, irrespective of the radiation source.

In case the voltage yielded by the photovoltaic cell is insufficient it can also be used in diode operation at reverse voltages up to 1 V. In such case the flowing dark current has to be taken into consideration.

The rise time of a signal voltage delivered to a load resistor by the voltaic cell primarily depends on the operating conditions. There are two distinctive borderline cases:

1. Load resistor smaller than the matching resistor (tendency toward short circuit operation)
2. Load resistor larger than the matching resistor (tendency to open circuit operation).

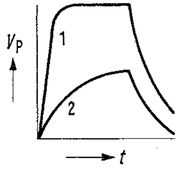
In case 1) the photovoltage rise is analogous to the charging of a capacitor via a resistor from a constant voltage source. In photovoltaic cells the junction capacitance C_j must be charged. The rise occurs by the time constant $\tau = R_L \cdot C_j$, R_L being the load resistor (the low ohmic resistance of the photovoltaic cell is considered negligible).

In case 2) the photovoltage rise is similar to the charging of a capacitor by a constant current mode. The rise time t_r of the photovoltage follows the equation

$$t_r = \frac{V_P \cdot C_j}{I_K}$$

I_K is the short-circuit current under given illumination conditions. This relation only holds true for values of V_P less than 80% of the final value of the open circuit voltage.

The principal characteristic of the rise time of photovoltaic cells is shown in the following diagram:



Case 1) Rise time according to the equation

$$V_P = I_K \cdot R_L \cdot \left(1 - e^{-\frac{t}{R_L \cdot C_j}}\right)$$

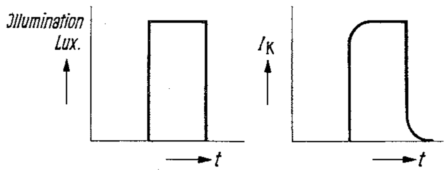
Time constant $\tau = R_L \cdot C_j$.

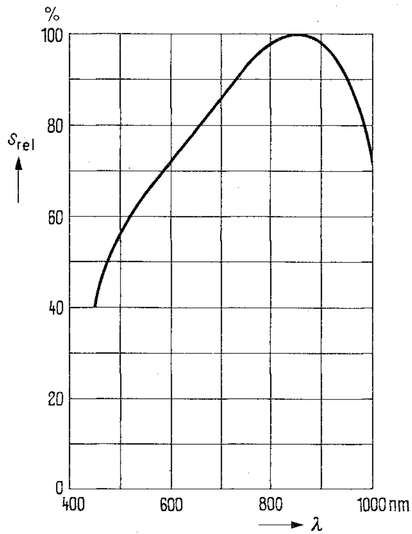
Case 2) Rise time $t_r = \dfrac{V_P \cdot C_j}{I_K}$

fall time in both cases $\tau = R_L \cdot C_j$

Modulation transients can, under certain conditions, lead to a modification of the above diagram.

E.g. At very low time constants (particularly in short circuit operation) the actual pulse shape of the short circuit current that deviates from an ideal square pulse has to be noted. See diagram.





Relative spectral sensitivity
$S_{rel} = f(\lambda)$

2.3. Silicon photodiodes

These photodiodes have a PN junction poled by a reversed bias. The capacitance which decreases with a growing reverse voltage reduces the switching times. The PN junction is of easy access to the light. Without illumination a very small reverse current flows, the so-called dark current. Light falling onto the surrounding of the PN junction generates charge carrier pairs there that lead to an increase of the reverse current. This photocurrent is proportional to the illuminance. Therefore, photodiodes are particularly well suited for quantitative light measurements. The planar technique has 2 essential advantages: The dark currents are considerably smaller than for comparable photo electric components in non-planar technique. This leads to a reduction of the current noise and thus to a decisive improvement of the signal/noise ratio.

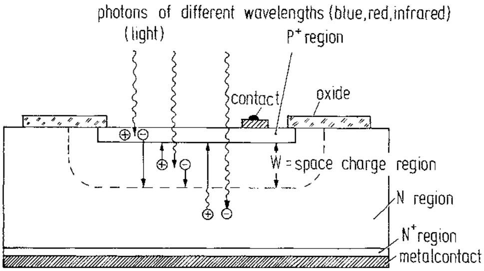


Figure 1

Figure 1 shows the basic design of a photodiode. The limit of the space charge region is indicated by a dashed line.

Without illumination only a small dark current I_D flows through the PN junction as a result of thermally generated carriers.

With light, additional charge carrier pairs (hole electron pairs) are generated in the P and N region by the radiation quantum (internal photo effect). Carriers originating in the space charge region are immediately extracted because of the electrical field present there, i.e. the holes in the P and the electrons in the N direction. Carriers from the remaining field must first diffuse into the space charge region in order to be separated there. If holes and electrons recombine before, they do not contribute to the photocurrent.

Thus, the photocurrent I_P is a combination of the drift current of the space charge region and the diffusion current of the P and N area.

I_P is proportional to the incident radiation intensity. Since I_D is very small for diodes, it can be neglected in the equation $I_P = I_P + I_D$. Subsequently one gets a linear correlation between I_P and the incident radiation intensity over a very wide range.

Diodes with a small space charge width are termed PN diodes, diodes with a large space charge width PIN diodes.

PN diodes have the diffusion current as dominating part of the photocurrent whereas it is the drift current in the case of PIN diodes.

As the capacitance of the space charge width W is inversely proportional, the PIN diode is characterized by a smaller capacitance than a PN diode of identical surface. The capacitance of (most of) the diodes reads:

$$C_D \sim \sqrt{\frac{N}{V}}$$

The less the doping N of the basic material and the higher the applied voltage V, the lower the capacitance.

Fig. 2 shows the capacitance as function of the voltage for a PIN diode, e.g. BPY 12.

Junction capacitance as a function of reverse voltage $C = f(V_R)$

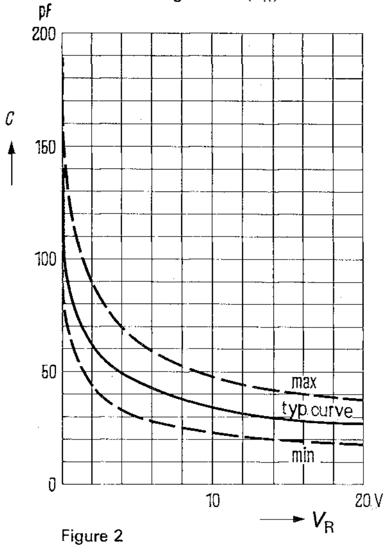


Figure 2

2.4. Mounting instructions for silicon voltaic cells and photodiodes,
open design without casing

As silicon is an inherently brittle material, the photoelectronic component should be shielded from pressure or tension. Contact points are particularly endangered. Should tension come to bear on the solid wire leads which, for technological reasons, are alloyed to a very thin P layer it should only be parallel to the surface and must not exceed 200 p (pond). Leads may only be bent 3 mm off the outer edge of the photoelectric component. Photoelectric components can be cemented onto metallic or plastic supports but the expansion coefficient of the material has to be taken into consideration to prevent mechanical strain between support and photoelectric component at change of temperature. An epoxy resin is to be used to cement or encapsulate the photoelectric component. It has to be colourless and should not grow darker with time. After curing, the epoxy resin must not have any gas occlusions (filter effect). The epoxy resin EPICOTE 162[1] together with the hardener LAROMIN-C 260[2] are particularly suited for the encapsulation of photoelectric components. 100 weight parts EPICOTE 162, 38 weight parts LAROMIN-C 260 are to be mixed well and remain workable for about 30 minutes. After that period of time the epoxy becomes viscid. All material to be encapsulated has to be dry, dust- and grease-free. Should bubbles form after the encapsulation it is advisable to raise the curing process temperature to 100°C for a short time. It makes the bubbles come to the surface and burst. The normal curing temperature lies between 60 and 80°C. The curing time is 1 hour, it lessens with higher temperature. When working with epoxy great care should be taken that neither the resin nor the hardener touches the skin. The quickly binding glue SICOMET 85[3] proves adequate to cement open-design Si diodes or photovoltaic cells. The light sensitive surface of the photovoltaic cell is coated with a protective lacquer and should not be contaminated while cementing.

1) Registered trademark (Shell Chemical)
2) Registered trademark (BASF)
3) Registered trademark (Sichel-Werke, Hannover)

2.5. Silicon phototransistors

The introduction of the planar technique allows to produce phototransistors of small dimensions. They are used as photoelectric detectors in control and regulating devices. The photoelectric transistors are excellently suited as receivers for incandescent lamp light, as their maximal photosensitivity lies near the infrared limit of the light wave spectrum.

In its mode of operation a photoelectric transistor corresponds to that of a photodiode with built-in amplifier. It has a 100 to 500 times higher photosensitivity than a comparable photoelectric diode.

The photoelectric transistor is preferably operated in an emitter circuit and acts similar to an AF transistor.

Unilluminated only a small collector-emitter leakage current flows. It amounts to approximately $I_d = B \cdot I_{CBO}$, B standing for the current amplification and I_{CBO} for the reverse current of the base diode.

At illumination the reverse current of the base diode I_{CBO} increases by the photocurrent I_P'. Thus, one receives for the photocurrent $I_P \sim B\ (I_{CBO} + I_P')$.

Consequently, the photocurrent of a transistor is a function of the photocurrent I_P' of the base diode and the current amplification B. As B cannot be increased indefinitely, an as high as possible photosensitivity of the base diode is aimed at.

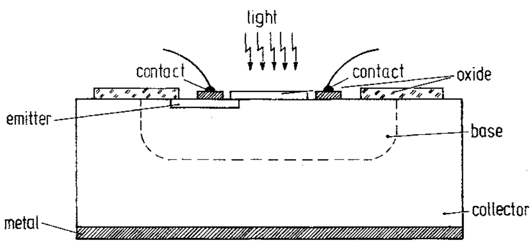


Figure 3

Figure 3 shows the design of a phototransistor. The emitter and base leads are affixed laterally to make the base diode most easily accessible to light. The large collector zone ensures that the most possible radiation quanta are absorbed there and will contribute to the photocurrent.

Contrary to a photodiode, a linear interconnection between the incident radiation intensity and the photocurrent I_P exists only in a small region, since the current gain B depends on the current. Figure 4 shows typical current voltage characteristics of a phototransistor.

Since the reverse current I_{CBO} of the base diode is amplified in the same way as the photocurrent I_P, the signal/noise ratio of the phototransistor is the same as that of the photodiode.

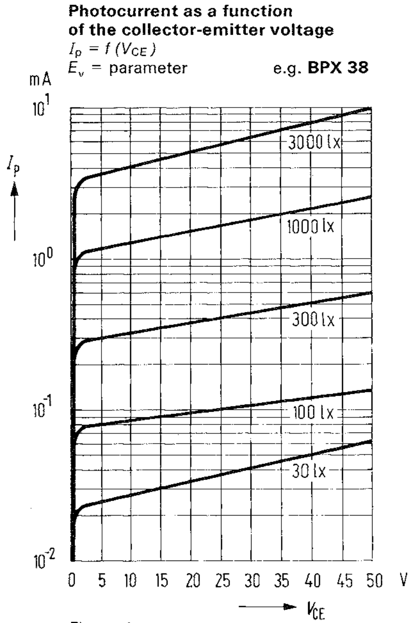


Figure 4

For the versatile applications, special type phototransistors are available. BPY 62, BPX 43, BP 101 and BP 102 requiring no lens on the receiver side are suitable for general applications.

BPY 62 is outstanding for a higher cut off frequency, BPX 43 for a higher photo-sensitivity.

In case the application demands a lens on the detector side, this requirement is met by BPX 38. The flat window of this phototransistor makes a precise reproduction of the focal spot on the photosensitive surface of the transmitter system possible. On account of the larger system surface, the adjustment and alignment of the transistor case to the light emitter causes less difficulties.

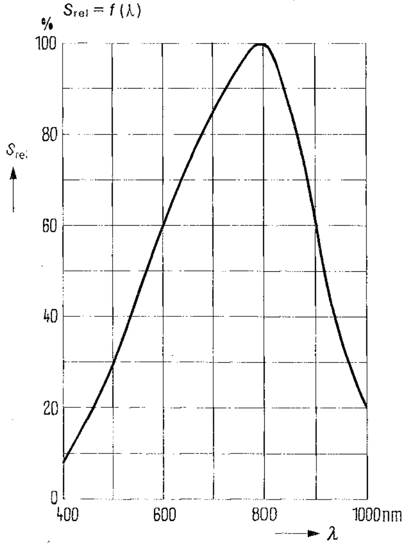
At the types mentioned, the user may preset the operating point of the phototransistor by wiring the base leads. The rapidity of response may thus be increased and the photo-sensitivity reduced. A fixed bias can reverse the phototransistor. Coincidence circuits can be realized by scanning this bias.

The phototransistor BPY 61 meets the requirement for high packing density. It is enclosed in a miniature glass case of 13 mm x 2.1 mm Ø and its photosensitivity is by the factor 500 to 1000 higher than small-surface silicon photovoltaic cells. Also the BPX 62 in micro ceramic case is provided for use on PC boards at minimum space requirements. The tolerance range of the light sensitivity is subdivided into four sensitivity groups. There is no base contact. Light is the controlling element which produces a correspondingly high collector current via the emitter-base path of the transmitter system, multiplied by the factor of the current gain. The rise and fall times depend on the illuminance and decrease with rising intensity.

Main applications are scanning of binary coded discs, films and punched cards.

Under limited mounting conditions the following amplifier must often be connected by relatively long leads. There is only little danger of interference pick-up since a sufficiently large signal to noise ratio is ensured by high photoelectric currents.

Relative spectral sensitivity
$S_{rel} = f(\lambda)$



2.6. Photoresistors

Photoresistors are passive photoelectric components. They consist of cadmium sulphide or cadmium selenide or a mixture of these two materials and have a high spectral sensitivity for light wavelengths from ultraviolet to the near infrared. Electrically they are ohmic resistors, their resistance degree being determined by the illuminance.

Photoresistors are bipolar and can therefore be used in dc and ac circuits.

A change in the resistance degree as a function of the illuminance causes a moment of inertia. The response times are some milliseconds. The temperature coefficient of a photoresistor is low and decreases with rising illuminance.

2.7. Light emitting diodes (IRED/LED)[1] and semiconducting indicators

Definition

Light emitting diodes are semiconductor diodes emitting electromagnetic radiation when operated in forward direction. The wavelength of the emitted radiation depends on the semiconductor material used and its doping. GaAsP LEDs (gallium arsenide phosphide LEDs) emit red light, GaP LEDs (gallium phosphide-LEDs) emit green, yellow light, respectively, and GaAs diodes (gallium arsenide IRED) emit in the infrared region of the spectrum.

The main applications result from these facts. Diodes emitting in the visible spectral region are used as signal lamps or indicators whereas GaAs diodes are employed as a radiation source in light barrier arrangements.

Displays are used to represent numerical or alpha-numerical symbols. The symbols are produced in one level which results in a wide viewing angle. Special data sheets are available on LED semiconductor displays.

IRED, LED and displays have the following advantages:

- long life (appr. 10^5 hrs half life)
- they are shock and vibration resistant
- they are circuit compatible
- the emitted light can easily be modulated
- their designs permit a high packing density.

[1] LED = Light emitting diode
IRED = Infrared emitting diode

2.7.1. Design and mode of operation

Light emitting diodes are operated in forward direction. At flow of current freely moving electrons penetrate through the PN junction into the P-space where they recombine with the holes present there. At this process, energy is released in form of radiation.

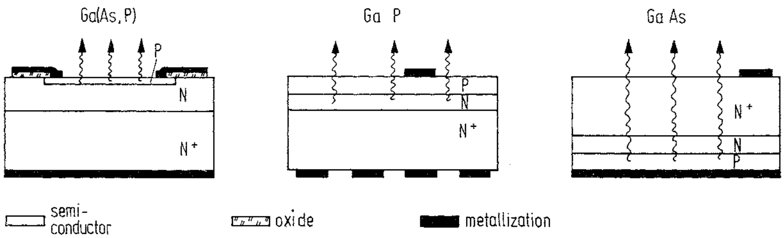


Figure 5

Figure 5 shows as diagram three types of light emitting diode systems. GaAsP diodes manufactured in planar-technology have their PN junction 2–4 μ under the semiconductor surface. The light is produced in the thin P region and leaves the crystal through the near surface. All light propagating into the interior of the crystal is absorbed. The GaP and GaAs LEDs are epitaxial diodes with an approximately 20–50 μm P layer, where the radiation is produced.

The absorption of these materials is very low. Therefore, the GaAs IRED LEDs are mounted with the P side to the metal support for better heat dissipation.

LEDs emitting in the visible range are offered as full-plastic versions. The single diodes (such as LD 41, LD 30, LD 57, LD 37 etc.) are intended for installation in front panels. The arrays LD 46, LD 47, LD 48 are suitable for versatile applications. The arrays of these types, consisting of 1 to 10 individual diodes, can be arranged indefinitely. They are suitable for use in complex indication systems such as scales and large displays.

GaAs IREDs are enclosed in plastic cases (array series LD 26) or in hermetically sealed glass-metal ones (CQY 17, CQY 18, CQY 77, CQY 78). The radiation characteristics are essential for the user. When using the light emitting diodes in arrangements without an optical lens as for instance in a reading-head for punched tapes, the apex angle of the radiation should be small. This is the case with LD 26 and CQY 77. In connection with optical lens systems those types are preferred where radiation leaves through a flat window (CQY 18, CQY 78).

In a 7-segment display 7 LEDs are mounted on a metal support and are red plastic encapsulated. The red colouring is meant to improve the contrast. Larger ones (up to 60 mm height) can be realized with the LD 46 array series as numerical or alpha-numerical display. The displays can be triggered as well in static as in time division multiplex-operation ($f > 100$ Hz because then free of flickering) by a BCD seven segment decoder/driver circuit. For displays with several digits the time division multiplex process usually proves more economic. Only one decoder is used for all figures which, like the digits, are driven by a clock generator. A latch holds the input signal until new information is received (Fig. 6).

Block diagram of the multiplex driving of n-digit LED displays

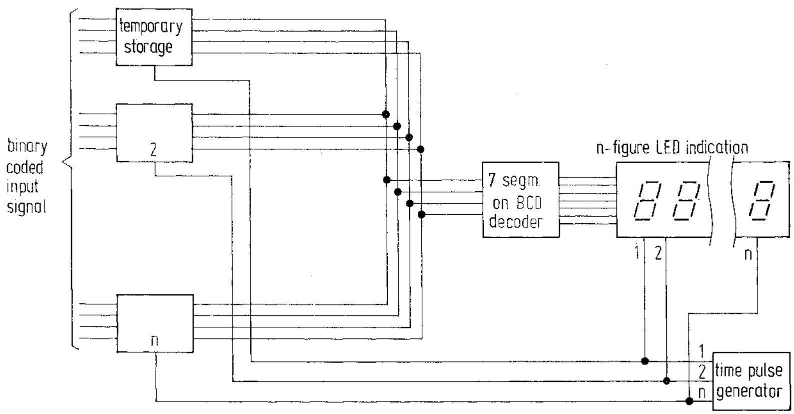


Figure 6

2.7.2. Electrical-optical characteristics

The emitted radiation (luminous intensity respectively) changes lineary with the forward current in the normal operation range as far as diodes and displays are concerned. If the forward current is very high, the curve asymptotically approaches a threshold value. This is caused by a strong heating of the semiconductor system. The linearity range can be widened by switching from static to pulse operation. Non-linearity also turns-up at small forward currents. It is caused by excess current not contributing to the radiation and cannot be influenced by the customer.

Radiant power as function of the forward current

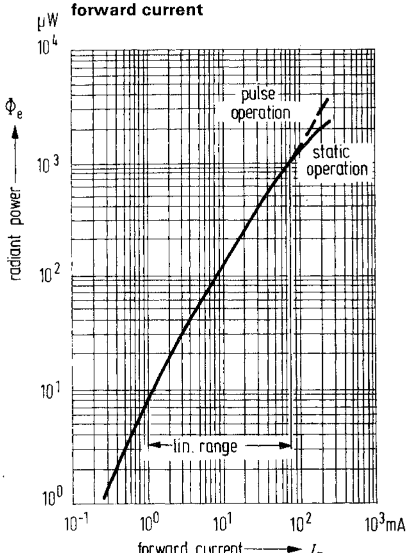


Figure 7

At constant current, the radiant intensity, luminous intensity respectively, decreases with rising temperature. The temperature coefficient is −0.7% per degree for GaAs, −0.8% per degree for GaAsP, and −0.3% per degree for GaP. This is negligible for many applications. If the temperature dependence proves disturbing it can widely be eliminated by compensation circuits.

The radiant power emitted by LEDs declines with increasing length of operation ("aging"). A "life" of components was introduced to describe the degree of degradation. It is defined as the time after which the radiant power has fallen to half the value. In case of CW operation the life is approximately 10^5 hours. This applies to an ambient temperature T_{amb} = 25°C and a forward current I_F = 100 mA (CQY 17, CQY 18, CQY 77, CQY 78) respectively I_F = 50 mA (LD 26 series and visible LED).

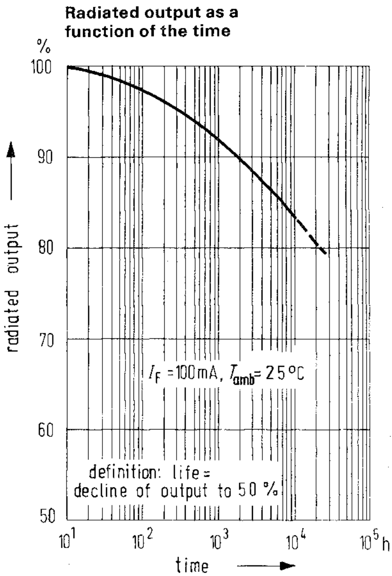


Figure 8

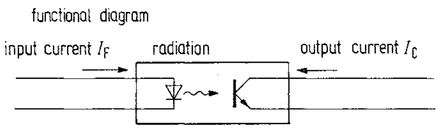
2.8 Optoelectronic couplers

Definition

Couplers are optoelectronic components for the transmission of signals at electrical input-output separation. They are also termed optoelectronic isolators.

Design and mode of application

The information is transmitted optically. The electrical signal is converted into an optical one by an emitter in the components, passed on optically and reconverted into an electrical signal by a detector. A gallium arsenide infrared light emitting diode serves as emitter and a silicon phototransistor as detector. At forward current flux the infrared emitting diode generates a radiation of about 950 nm wavelength on the input side of the component. This radiation is fed to the phototransistor via a light conducting medium. The transistor current depends on the striking radiant power. Potential differences up to a few kV may exist between the input and output, depending upon the type of component.



Basic circuit

As shown in the above diagram the current transmission is effected by connecting the output to the emitter and collector of the transistor. Often also the base is connected. This permits more variations in the wiring technique. On the one hand, charge carriers can be shunt off from the base via a resistor by which the cut-off frequency of the transistor is increased, though at the expense of the transmission factor. On the other side, the transistor with its normal transistor functions can be incorporated in the secondary circuit.

The essential characteristics

of optoelectronic couplers are their current transmission ratio and the insulation voltage.

The insulation voltage depends on the type. At the TO 18 like CNY 18 it amounts to 500 V, at the DIL 6 coupler CNY 17 to 2.5 kV.

The transmission ratio is the relation between output and input current and is stated in percents. Practical values lie between 20 and 300%. Its rating depends on the radiant power of the light emitting diode, the quality of light transmission and the static current transfer ratio of the transistor. Latter usually amounts to a few hundred.

Since both, the light emitting diode and the phototransistor are temperature dependent, the transmission ratio of the coupler is so too. At low temperatures, it is determined by the positive temperature coefficient of the transmitter, at higher temperatures the negative coefficient of the LED prevails. At first, the transmission ratio of the coupler increases with the temperature, then passes through a maximum between 0 and 50°C and declines afterwards.

Couplers are well suited for transmission of both digital and analog signals. In analog operation a certain non-linearity between input and output current has to be taken into consideration which, however, is negligible in case of small signals.

2.9. Measuring technique of optoelectronic semiconductor devices

Optoelectronic semiconductor devices, photovoltaic cells, photodiodes, phototransistors etc. are special versions of standard semiconductor devices which were developed in view of their particular field of application. Their measuring technique includes and is based on the conventional and well-known one of diodes and transistors. It is supplemented by a special optoelectronic measuring technique. Irrespective of the fact whether the objects to be measured are radiation sensitive (detectors) or radiation emitting (emitters) components or a combination of both (e.g. optoelectronic couplers), the measuring system radiator/receiver remains the same, only the object to be measured changes its place. The essential difference to the standard measuring method lies in the broadband of the measuring system and the pronounced spectral characteristics of emitters and detectors as well as in the problem of an exact description of these characteristics and their reproducibility in order to achieve coinciding results at any time and in any place. This requires the observation of the following instructions.

Radiation sensitive components (detectors)

Radiation-sensitive semiconductor devices serve to convert radiation energy into electrical one. Radiation energy can be offered to the component in manifold forms, depending on the source of radiation. For measuring purposes only such radiation sources can be taken into consideration which, in their spectral energy distribution, can easily be covered and are reproducible, i.e. thermic radiation sources like the tungsten filament lamp, which at least in the wavelength range here of interest comes very close to the black body and monochromatic light sources that means those emitting radiation of only one wavelength or at least of a very narrow wavelength range, above all light emitting diodes and a combination of whatever emitters with narrow band filters. Because of its high energy, the tungsten filament lamp is mainly used for measuring the radiation sensitivity when set to a "colour temperature" of 2856 K, corresponding to standard light A as per IEC 306-1 part 1 and DIN 5033 while light emitting diodes are primarily employed for cut-off frequency and switching time measurements as they can be modulated or pulsed up to high frequencies. At this instance, we want to draw your attention to the following. The definition "colour temperature" (see table 2.9.1) shows that basically, this statement is only very limited useful for the optoelectronic measuring technique, quasi only as auxiliary. But unfortunately the term has come to stay. In practice the lamps are not calibrated to colour temperature but to "relative temperature in the visible range", mostly to a green-red relation. An extension to a red-green-infrared relation and thus an approach to the, for our measuring technique solely correct, "distribution temperature" in the wavelength range 350 nm to 1200 nm, or even better 300 nm to 1800 nm, is worth aspiring after. This still meets with objections on the part of lamp manufacturers to extend their calibration equipment and the relative small quantity of lamps required.

The tungsten filament lamps used for measuring purposes have to be set to a relative spectral energy distribution that corresponds to that of the black body at a temperature of normally 2856 K at least in the wavelength range 350 nm to 1200 nm, and have to be operated under very stable conditions. It is necessary to have the lamp operated with constant current, the deviation from the rated value must be kept less than ±0.1%. This requirement seems to be very high, but one has to consider that a deviation of the lamp current by 0.1% brings about a change of the radiant intensity by 0.7% and, of the colour temperature, by 2 K. Naturally, the lamp can also be operated with constant voltage but this is hard to realize in practice because of the inevitable and varying contact resistances in the lamp socket, therefore an operation with constant current is to be preferred.

A lamp voltage check at the same time permits a control of the lamp with regard to a change in its characteristics for example by evaporating of coiled filament material which would point to the fact that the lamp is no longer suitable for measuring purposes and has either to be replaced or calibrated anew. This check is mainly recommended for the "standard lamps" which are standard for colour temperature, radiant and/or luminous intensityy.

For general measuring purposes, serial measurements in particular, the standard lamps gauged by the PTB or the manufacturer are usually not used because of the calibration costs. Therefore, the service lamps are set to the given ratings by a comparison with these standard lamps. The procedure is as follows:

Setting of colour temperature

The standard lamp is set to current and/or voltage according to the material test certificate. So as to obtain exact and reproducible values, the coil filament of the lamp has to be adjusted precisely to vertical with a tolerance of $\pm 1°$. After a heating period of approximately 30 minutes the photocurrent of a linear receiver, usually the short-circuit current of a photoelectric device, is measured behind a narrow-band filter with a transmission wavelength of approximately 500 nm, 900 nm respectively. Care should be taken that the filters have no further pass band. The relation of these 2 measured values characterizes the spectral energy distribution of the black body at the given temperature. Now, the lamp current of the lamp to be calibrated is changed until the ratio of the photocurrent measured behind the 2 filters coincides with that measured before at the standard lamp. Thus the service lamp has the same colour temperature (or to be more precise, ratio temperature) as the standard lamp. It should be mentioned here that the lamp has to be calibrated in the case in which it will be operated later on since different heat conditions and reflexions in the case may lead to considerable changes in the radiation characteristics of the lamp.

Adjustment of the distance from the incandescent coiled filament for a given irradiance E_e, illuminance E_v, respectively

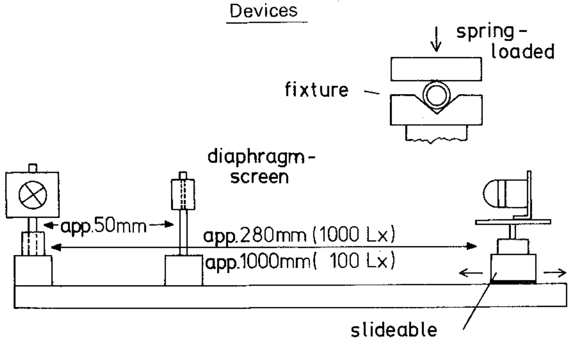
The material test certificate of the standard lamp usually states the radiant intensity (I_e) the luminous intensity (I_v), respectively, for the direction vertical to the coiled filament. At a sufficiently large spacing from the coiled filament, at least ten times the maximal filament dimension, we have $E = I/R^2$ from which one can calculate the spacing for the desired value of E according to $R = \sqrt{I/E}$. Now, the photocurrent of the photovoltaic cell is measured at this distance from the coiled filament of the standard lamp and then, by means of the voltaic cell, the distance to the service lamp at which the same photocurrent flows is set. In case a sufficiently precise luxmeter (e.g. Osram Centra-V (λ) Si photovoltaic cell) or a power meter of an adequate bandwidth is available the adjustment can, of course, be done by them. When irradiance measuring instruments are used one has to take into consideration that, in general, it is impossible to cover the entire range of the spectral energy distribution of the (black) emitter because, for example, of the installation of the thermocoupler behind a quartz-window. Consequently the measured irradiance E_e is too low compared to the black body. As a result the object is measured at too high an irradiance when E_e has been adjusted by this instrument (shortened spacing from body) although the object itself is insensitive to the spectral range filtered off in the radiant intensity meter. This can lead to differences in the photo current up to 20%. When stating the irradiance it is necessary to indicate the measuring instrument used in order to compare the measuring results (spectral sensitivity curve, window material, etc) and, for the colour temperature of the emitter, the correction factor related to the black body.

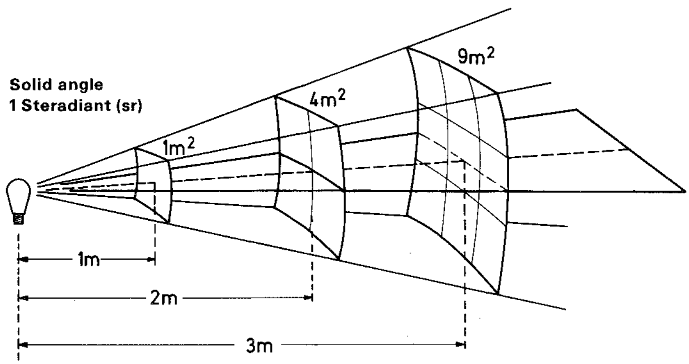
The radiant intensities given in this book were measured with the Hewlett-Packard Radiant Flux Meter hp 8334A with option 013.

At the moment the PTB and/or lamp manufacturers gauge standard lamps only at colour and/or ratio temperature in the visible range. Caused by the structure of standard lamp, in particular by uneven temperature distribution over the coiled filament (heat dissipation by suspension), these gaugings do not even for lamps of the same type guarantee the same shape of spectral energy distribution in the infrared where the components to be measured usually have their maximum. Depending on type of lamp this is expressed in differences of the photocurrent of some % up to more than 10% under same measuring conditions, i.e. E_V = 100 lx and T_F = 2856 K. Lamps with filament or double filament show this particularly strong. Merely the new version Wi 41G of Osram with its detached coiled filament is an exception. The scattering from lamp to lamp is only some per mills as measurements of a large quantity of lamps proved and it can therefore be recommended as standard lamp in connection with semiconductor photoelectric components.

For photosensitivity measurements (photocurrent or photovoltage) the components to be measured are placed at the position predetermined for the specific irradiance and there they are held in such way that the radiant sensitive surface of the semiconductor chip is vertical to the direction of light. Cylindric components such as in TO 18, TO 5 or similar plastic cases are put up so that the case axis will coincide with the direction of radiation. This is of prime importance for components with a highly focusing lens. A holder with a sliding socket for the terminal wires proved useful (see figure 9).

I_p Test Assembly for Photoelectric Devices





$$E = \frac{I}{R^2} = \frac{\Phi}{F}$$

F = **Space penetrated by light flux Φ**

Figure 9

When measuring the short-circuit current I_K of a voltaic cell care has to be taken that the internal resistance of the measuring instrument used is small enough compared to the internal resistance of the photovoltaic cell. The same applies to measuring the open circuit, the internal resistance of the measuring instrument is large compared to the internal resistance of the photovoltaic cell. Fig. 10 shows this connection for the photovoltaic cell BPY 11 for E_v = 100 lx.

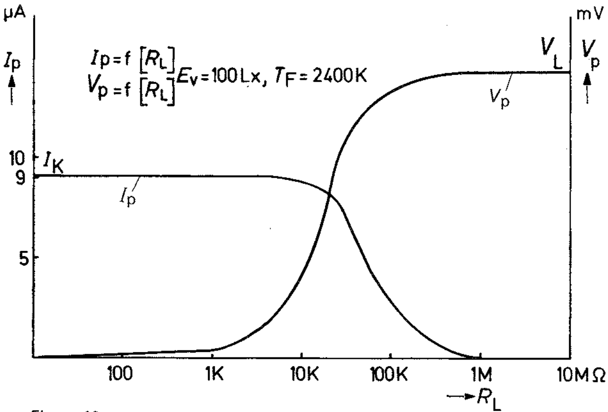


Figure 10

Measuring of switching times

The switching times are measured oscillographically by a set-up as shown in the below circuit diagram (fig. 11) by means of a pulsed infrared emitting GaAs diode as measuring source and a double-beam oscillograph. The switching times of the GaAs must, of course, be small compared to the switching times of the component to be measured.

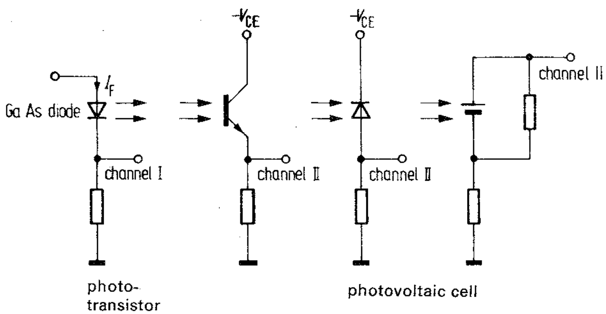
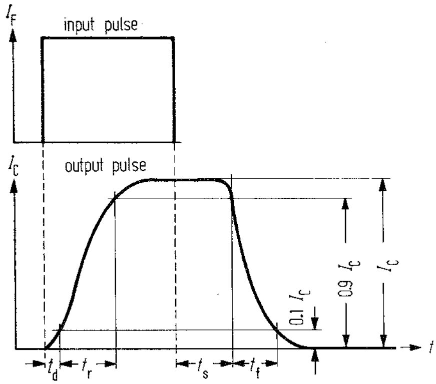


Figure 11

Switching times

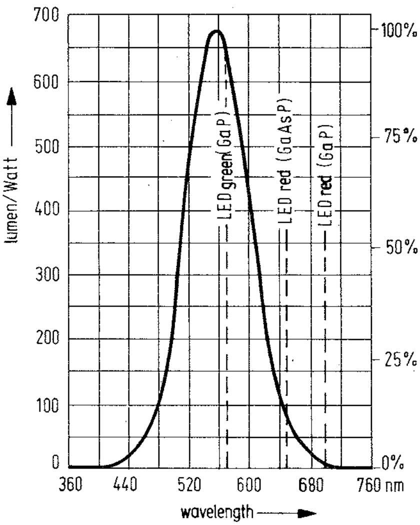
Delay time	t_d
Rise time	t_r
Turn-on time	t_{on} $(= t_d + t_r)$
Storage time	t_s
Fall time	t_f
Turn-off time	t_{off} $(= t_s + t_f)$



Radiation emitting components (emitters)
Radiation in the visible range – LED – (light emitting diodes)

The luminous intensity is measured in the direction of the case axes by a detector with $V(\lambda)$ characteristics and a calibration in candela (foot-lambert). Attention has to be paid that the adjustment to the $V(\lambda)$-curve (fig. 12) is also sufficiently exact in the wavelength range of the LED. Though most meters of this kind have an integral coincidence with $V(\lambda)$ up to a few percents, but at the slopes, particularly around 700 nm, deviate strongly from the $V(\lambda)$ shape.

Sensitivity curve of the human eye
$[V(\lambda)]$



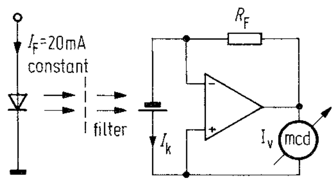
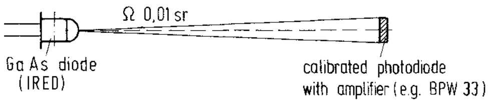


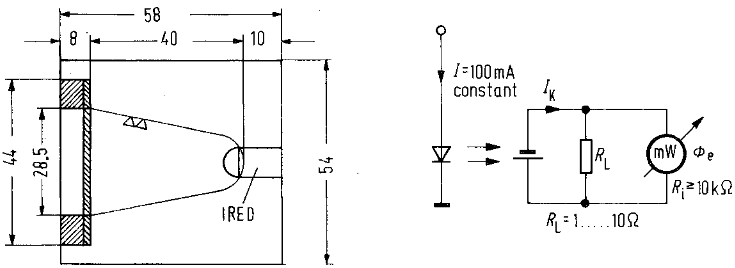
Figure 12

Radiation in the infrared range – IRED – (infrared emitting diodes)

The radiant intensity I_e in the direction of the case axis should be measured by a wavelength independent detector (thermocouple element) but low sensitivity, inertia and temperature sensitivity cause difficulties. For this reason, one usually measures with a correspondingly calibrated photovoltaic cell. In such case, the spectral sensitivity curve of the photovoltaic cell has to be considered and the measuring result corrected with regard to the deviations in the emitted wavelength of the radiator to be measured (for example IRED with different production technology). If the total radiation of the component shall be measured, the IRED has to be fitted in a parabolic like reflector to ensure that all radiation emitted by the component reaches the photovoltaic cell that forms the end of the parabola. Figure 13 shows the outline of such a measuring parabola. As for the rest, the same requirements apply as for radiant intensity measurements.



Calibrated photodiode with amplifier (for example BPW 33)

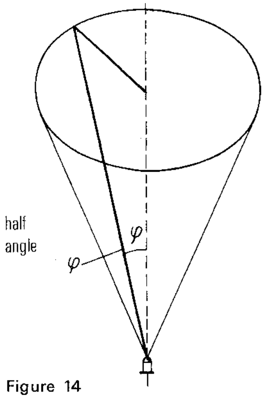


Large surface photovoltaic cell

Figure 13

In cases where IRED emitting diodes are used in connection with mirrors or lenses, for example in light barriers it can proof useful to state the radiant power (radiation capacity) Φ_e defined in a cone with the half viewing angle φ, respectively the curve $\Phi_e = f(\varphi)$ – (Fig. 14)

Radiation cone as a fuction of the half angle φ



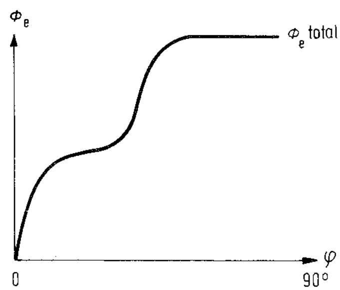
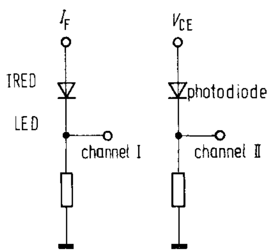


Figure 14

Measuring of switching times

For measuring of switching times the same applies as for the radiant sensitive components except that now a photodiode serves as detector and its switching time must be small compared to that of the IRED or LED to be measured.



Optoelectronic couplers

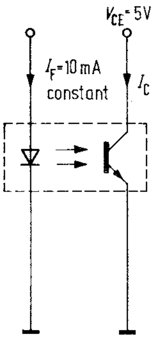
Optoelectronic couplers isolate electrically the input and output of two circuits with different voltage potentials. The potential differences that can safely be separated in the sense of VDE regulations depend not only on the characteristics of the coupler but also on the type of circuit and the environmental conditions at the time of operation.

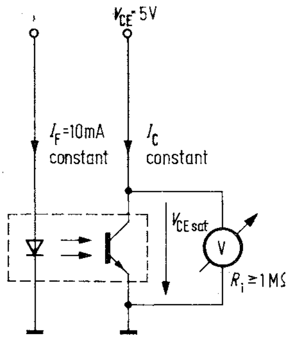
Up to now no definite DIN standards or VDE regulations have been established for couplers but the Deutsche Elektrotechnische Kommission (DKE/VK 631.6) is working at it. As basis for the use of couplers the regulations VDE 0110 and VDE 0160 as well as VDE 0303/ DIN 53480 can be consulted besides the decision VDE-69 [ETZ-b, volume 26 (1974) H 22] on which in all probability the DIN standards now being worked on will rest.

To determine the permissible nominal insulation test voltage for a specific application, the component manufacturer can state the ratings of the insulation test voltage, the air gap and leakage path, latter in respect of the insulation characteristics of the packaging material used (KC value according to VDE 6303/DIN 53480) from which parameter the nominal insulation test voltage can be derived on hand of the tables VDE 0110/0160.

Measuring optoelectronic couplers

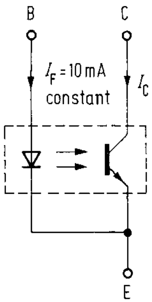
Apart from measuring the static parameter of GaAs IR and Si phototransistors (or Si photodiodes) the coupling factor is of prime importance. Its gauging corresponds to that of the current amplification at the transistor only that in this case I_F (analogous I_B) and V_{CE} are operated under constant current source while I_C is gauged.





The analogy with the transistor goes so far that, except of course for the isolation characteristics, one can gauge couplers at the plotter oscilloscope like transistors with extreme low current amplification.

In this case the anode of the GaAs IRED is the base ($I_F \triangleq I_B$), cathode and emitter of the phototransistor are commonly connected with the emitter terminal, whereas the collector of the phototransistor is connected with the collector terminal of the plotter oscilloscope.



Switching times

For optocouplers the same applies as for radiation sensitive components with the modification that the IRED emitting diode is fixed in the component (see figure 11).

2.9.1. Terms of temperature for optical radiations

Serial No.	Term	Symbol	Relation to Planckian Radiation	Definition	Application	Notes
Temperature that may be allied to any optical radiation						
1	Radiance temperature	T_s	Equality of the spectral radiance of a selected wavelength	The spectral radiance of any wavelength of a radiation to be denoted may be correlated with that Planckian temperature at which it has the same radiance at the same wavelength. Pyrometry formula (Acc. to Wien): $\frac{1}{T_s} = \frac{1}{T} - \frac{\lambda}{c_2} \ln(\varepsilon \cdot r)$	Pyrometry	Visual pyrometry usually operates with an effective wavelength of about 650 nm. In general, the radiance temperature depends on the wavelength. It is always lower than the real temperature.
Temperatures that may be allied only to optical radiations having certain characteristics						
2	Colour temperature	T_f	Equality of colour	When a radiation has a colour equalling that of a Planckian radiation the temperature of the latter is the colour temperature of the radiation to be denoted.	Colour measurements	In general, T_f may not be used to draw any conclusion as to spectral distribution. In case of mere temperature radiations T_f usually equals approx. T_v in the visible region.
3	Correlated colour temperature	T_n	As large a colour similarity as possible	When radiation has a colour not equalling that of a Planckian radiation but-assessed acc. to sensation-comes close to it, the temperature of the closest. Planckian radiation is the correlated colour temperature of the radiation to be denoted.	Colour measurements	In general, T_n may not be used to draw any conclusion as to spectral distribution. The statement of the correlated colour temperature only makes sense if the colour of the radiation to be denoted is less than about 10 . . . 15 thresholds of sensation away from the Planckian curve shape. If the colour difference approaches zero T_n switches to T_f.
4	Distribution temperature	T_v	Equality of the relative spectral radiation distribution between λ_1 and λ_2	If radiation in a wavelength region to be stated has a spectral distribution between λ_1 and λ_2 which is proportional to a Planckian radiation distribution the temperature of the latter is the distribution temperature of the radiation to be denoted.	Spectral measurements	If the range of spectral proportionality covers the visible T_f equals T_v. As there are no radiation sources which strictly meet the spectral proportionality condition over a long wavelength range, in practice deviations of up to a few per cent are allowed so that, for instance, $T_f \approx T_v$ applies to a tungsten radiation in the wavelength range of about 400 to 750 nm.
5	Ratio temperature	T_r	Equality of the radiation quotient of two selected wavelengths	When the quotient Q of the radiation of two (close) wavelengths (ranges) λ_1 and λ_2 of a radiation to be denoted equals the corresponding quotient of a Planckian radiation, the temperature of the latter is the ratio temperature of the radiation to be denoted. Q between 0 ($\Delta T = 0$) and $\lambda_2^4 : \lambda_1^4$ ($\Delta T = \infty$) with $\lambda_1 < \lambda_2$.	"Blue/Red" measurements	In general T_r may **not** be used to draw any conclusion as to the spectral distribution. In case of mere temperature radiation T_r between λ_1 and λ_2 is usually approximately T_v if the spacing between the two wavelengths is within reasonable bounds.

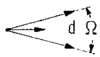
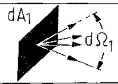
DIN 5496, DIN 5033, DIN 5031.
International Dictionary of Light Engineering, 3rd Ed. 1970, publ. by CIE and IEC.

In case of a grey body characterized by a total emissivity independent of wavelength $\varepsilon(\lambda)$ = constant, the numerical values of several temperatures will coincide with the real temperature $T = T_w = T_r = T_f = T_n = T_v$ (exception: $T_s < T$).

2.9.2. Radiation and light measurements

No		Radiometric terms: Term	Symbol	Unit	Relation	Simplified definition	Spectr. radiometric terms: Term	Symbol	Unit	Photometric terms: Term	Symbol	Unit
1		Radiant power	Φ_e, P	W		Radiant power is the total power given in the form of radiation	Spectral radiant power distribution	$\Phi_{e\lambda}$	$\frac{W}{nm}$	Luminous flux	Φ_v	lm Lumen

Emitter

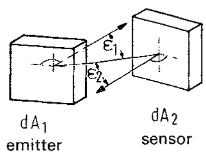
2		Radiant intensity	I_e	$\frac{W}{sr}$	$I_e = \frac{d\Phi_e}{d\Omega_1}$	Radiant intensity is radiant power per solid angle	Spectral radiant intensity distribution	$I_{e\lambda}$	$\frac{W}{sr\ nm}$	Luminous intensity	I_v	$\frac{lm}{sr} = cd$ Candela
3		Radiance	L_e	$\frac{W}{m^2\ sr}$	$L_e = \frac{d^2\Phi_e}{dA_1 \cdot d\Omega_1}$	Radiance is radiant power per area and solid angle	Spectral radiance distribution	$L_{e\lambda}$	$\frac{W}{cm^2\ sr\ nm}$	Luminance	L_v	$\frac{cd}{cm^2} = sb$ stilb

Sensor

4		Irradiance	E_e	$\frac{W}{m^2}$	$E_e = \frac{d\Phi_e}{dA_2}$	Irradiance is incident radiant power per (sensor) surface	Spectral irradiance distribution	$E_{e\lambda}$	$\frac{W}{m^2\ nm}$	Illuminance	E_v	$\frac{lm}{m^2} = lx$ lux

Indices "e" (= energetic) and "v" (= visual) may be omitted unless danger of confusion DIN 1301, DIN 1304, DIN 5031, DIN 5496

International Dictionary of Light Engineering, 3rd Ed. publ. by CIE and IEC



Photometric Basic Law

$$d^2\Phi = L\,\frac{dA_1 \cdot \cos\varepsilon_1 \cdot dA_2 \cdot \cos\varepsilon_2}{r^2}\,\Omega_0$$

Inverse Square Law

$E = \frac{I}{r^2} \cos\varepsilon_2\,\Omega_0$ (r should be 10 times the max. spacing of emitter-sensor to keep error below 1%).

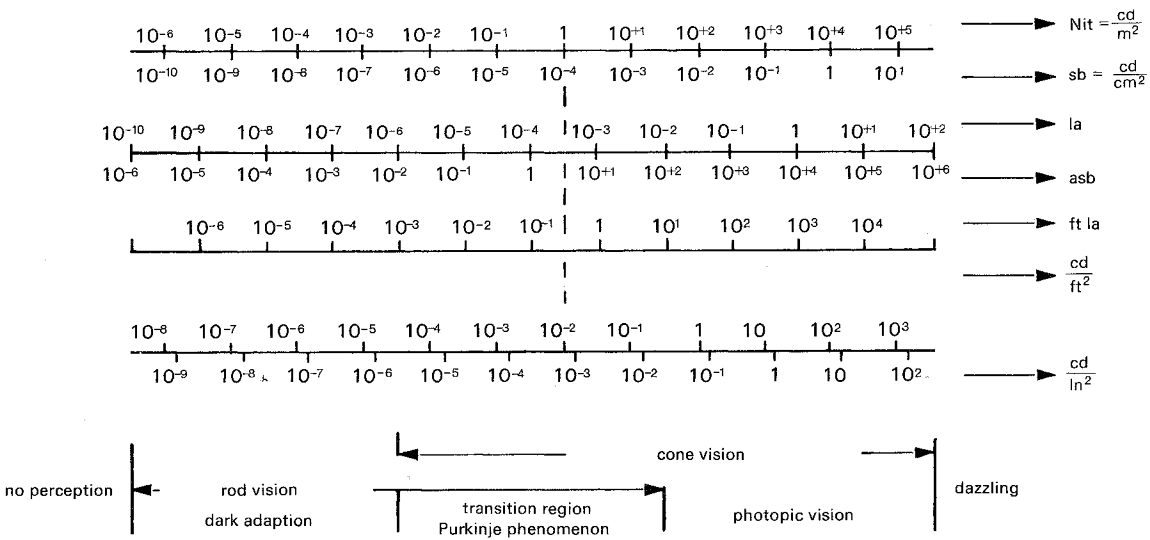
dA_1 = element of area of emitter
dA_2 = element of area of sensor
ε_1 = angle of radiation
ε_2 = angle of irradiation
= spacing emitter-sensor
Ω_0 = 1 sr

2.9.3. Radiation characteristics

Denotation	Symbol	Meas. quant.	Abbr.	Definition
Quantity of radiation	Q	Joule Wattsecond	J Ws	quantity of radiation through a surface
Radiant power	Φ	Watt	W	quantity of radiation Q per second through a surface
Point source of radiation	–	–	–	. . . is a source viewed from such a great distance R that all rays seem to emanate from one point. When b max. linear expansion of source: $R \geqq b$ (example: sun for observer on earth).
Solid angle (For figure see "General")	Ω	sterad	sr	$\Omega = \frac{A_1}{R_1^2} = \frac{A_2}{R_2^2} = \frac{A_3}{R_3^2} = \frac{A}{R^2}$; the radiant power Φ [W] of a point source is constant in solid angle. (Prerequisite: homogenous, undamping medium.) $\Omega = 1$ is $A = R^2$ so that Ω hemisphere = $\Omega_0 = 2\pi$ sr; Ω full sphere = $\Omega_0 = 4\pi$ sr
Radiant intensity	I	$\frac{\text{Watt}}{\text{sterad}}$	$\frac{\text{W}}{\text{sr}}$	is the solid angle density of the radiant power $\left(\frac{d\Phi}{d\Omega}\right)$. I of one source generally varies depending upon viewing direction. I only defined when $R \geqq b$;
Total radiant power of a source	Φ_{tot}	Watt	W	$\Phi_{tot} = \int_0^{4\pi} I \, d\Omega$
Irradiance (For figure see "General")	E –	$\frac{\text{Watt}}{\text{meter}^2}$	$\frac{\text{W}}{\text{m}^2}$	. . . is the surface density of the radiant power (spherical surface) for a point source. $E = \frac{d\Phi}{dA}$; $dA = R^2 \, d\Omega$ $E = \frac{d\Phi}{d\Omega \, R^2} = \frac{I}{R^2}$; $I = ER^2$
Radiance (For figure see "General")	L	$\frac{\text{Watt}}{\text{m}^2 \text{ sterad}}$	$\frac{\text{W}}{\text{m}^2 \text{ sr}}$	. . . is the radiant intensity referred to the radiant surface viewed by the observer. (Surface projection $A_p = A \cos \varepsilon$ when ε is the angle by which the radiant surface is rotated against the connecting line to viewer. $L = \frac{I}{A_p} = \frac{I}{A \cos \varepsilon}$). Important optical quantity. 1) In an undamped beam path L is maintained and cannot be increased by any optical measure. 2) The human eye sees differences in radiance as differences in brightness.
Sensitivity of detector	$S = \frac{i}{E}$	$\frac{\text{ampere}}{\text{irradiance}}$	$\frac{\text{A}}{E}$	electrical quantity (current, voltage or resistance) in relation to irradiance

2.9.4. Luminance conversion factors units

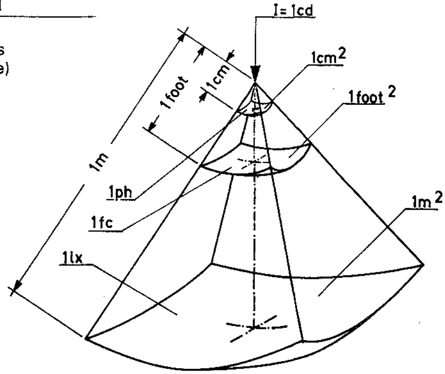
Unit		sb	cd/m2	cd/ft2	cd/in2	asb	L	mL	ftL
1	Stilb = cd/cm2 = sb	1	10^4	929	6.45	31400	3.14	3140	2920
1	cd/m2 = Nit = nt	10^{-4}	1	9.29×10^{-2}	6.45×10^{-4}	3.14	3.14×10^{-4}	0.314	0.292
1	cd/ft2	1.076×10^{-3}	10.76	1	6.94×10^{-3}	33.8	3.38×10^{-3}	3.38	3.14
1	cd/in2	0.155	1550	144	1	4870	0.487	487	452
1	Apostilb = asb	3.18×10^{-5}	0.318	2.96×10^{-2}	2.05×10^{-4}	1	10^{-4}	0.1	0.29×10^{-2}
1	Lambert = L or la	0.318	3183	296	2.05	10^4	1	10^3	929
1	mL or mla	3.18×10^{-4}	3.18	0.296	2.05×10^{-3}	10	10^{-3}	1	0.929
1 1 1 1	footlambert = equivalent footcandle = apparent footcandle = ftL or ftla	3.43×10^{-4}	3.43	0.318	2.21×10^{-3}	10.76	1.076×10^{-3}	1.076	1



2.9.5. Illuminance units and conversion factors

Unit	lx	mlx	ph	fc
Lux = lx	1	10^{-3}	10^{-4}	9.29×10^{-2}
Millilux = mlx	10^{-3}	1	10^{-7}	9.29×10^{-5}
Phot = ph	10^{4}	10^{7}	1	929
Footcandle = fc*	10.76	10760	1.076×10^{-3}	1

* Note: equivalent footcandle or apparent footcandle equals footlambert (luminance) not footcandle (illuminance)



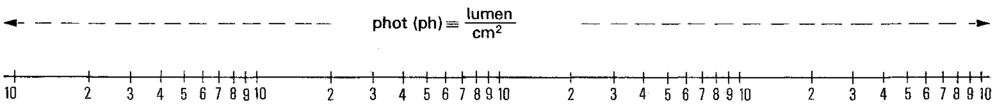
Luminous flux Φ per second per sterad (sr) 1 lumen (lm)

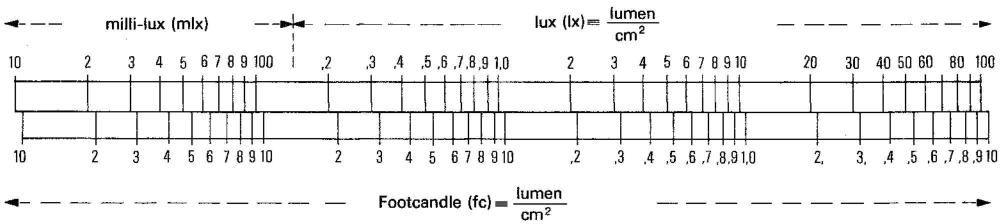
space angle $\Omega = \frac{A}{R^2} = 1$ sterad $= 1$ sr

1 foot ≙ 0.305 m

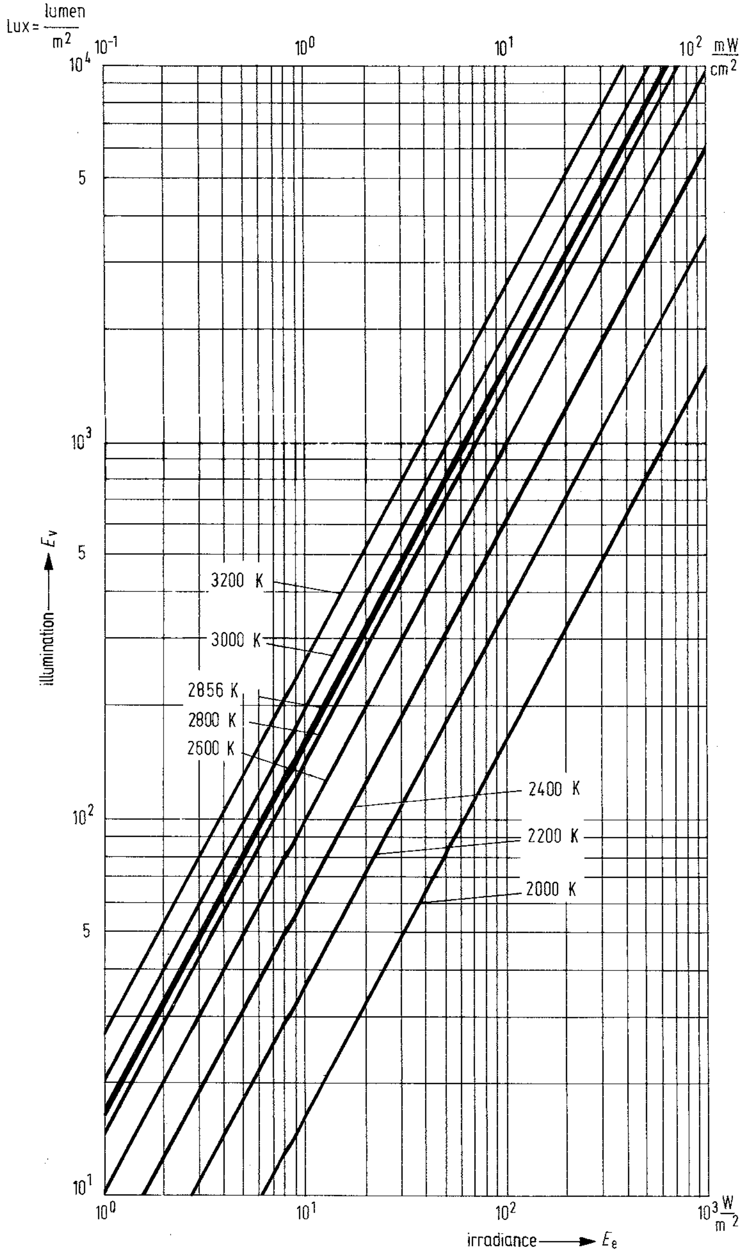
1 full sphere $= 4\pi \cdot$ sr

illuminance

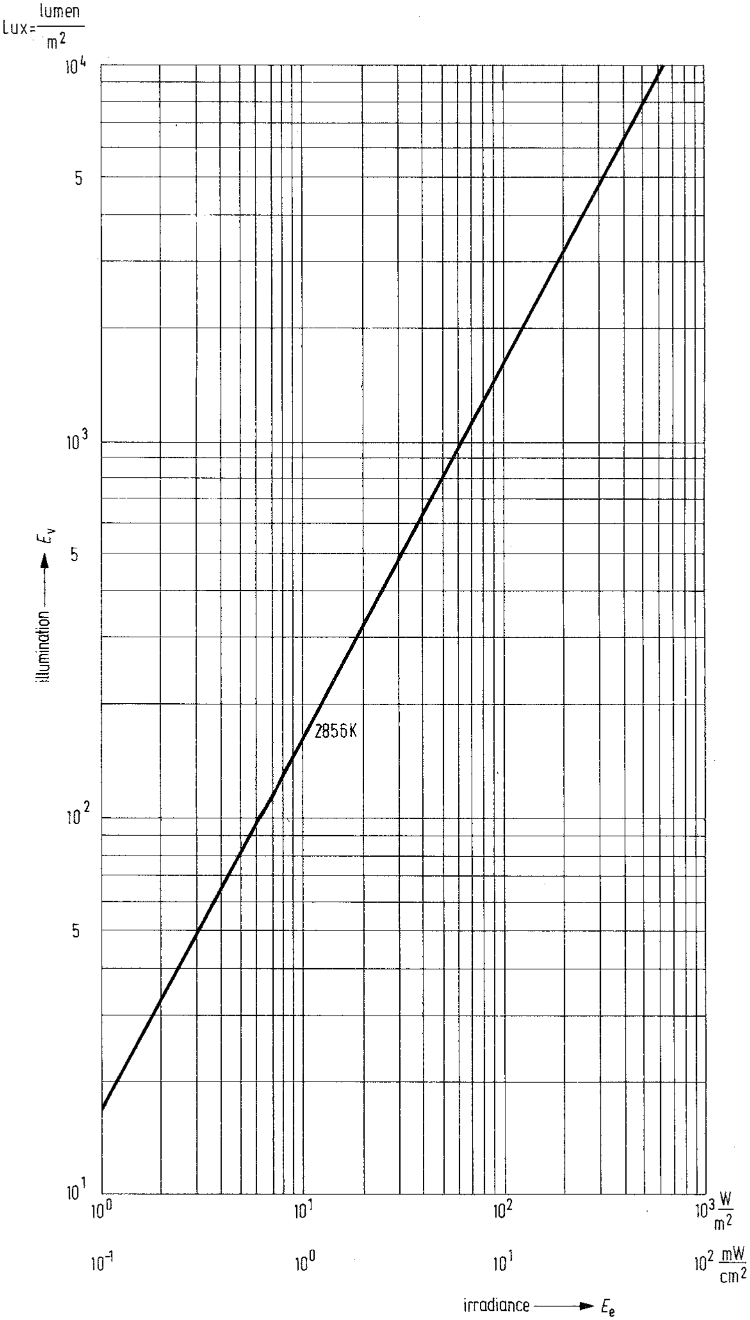




Conversion of E_v (lx) into E_e (W/m² or mW/cm²) referred to the radiation of a black radiator

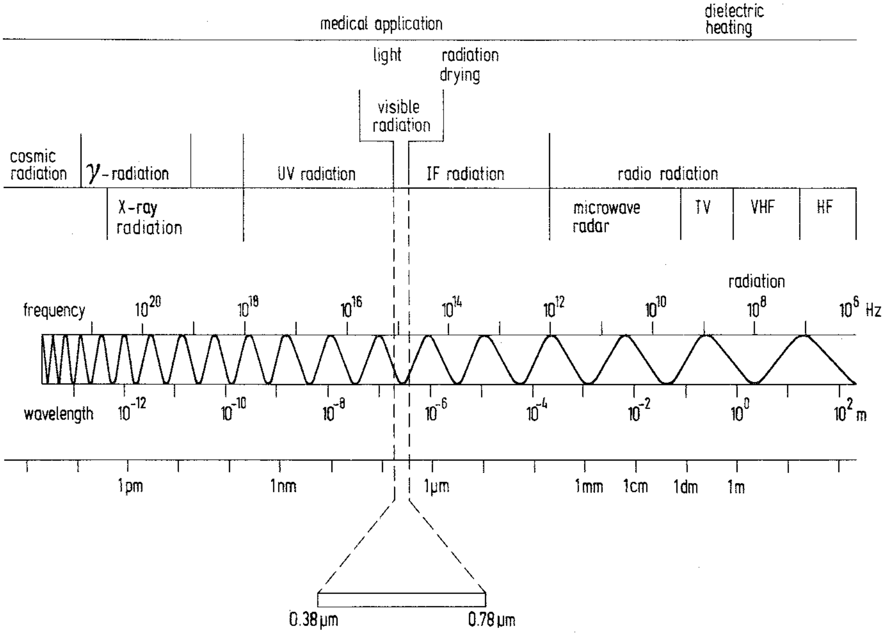


Conversion of E_v (lx) into E_e (W/m² or mW/cm²) referred to the radiation of a black radiator

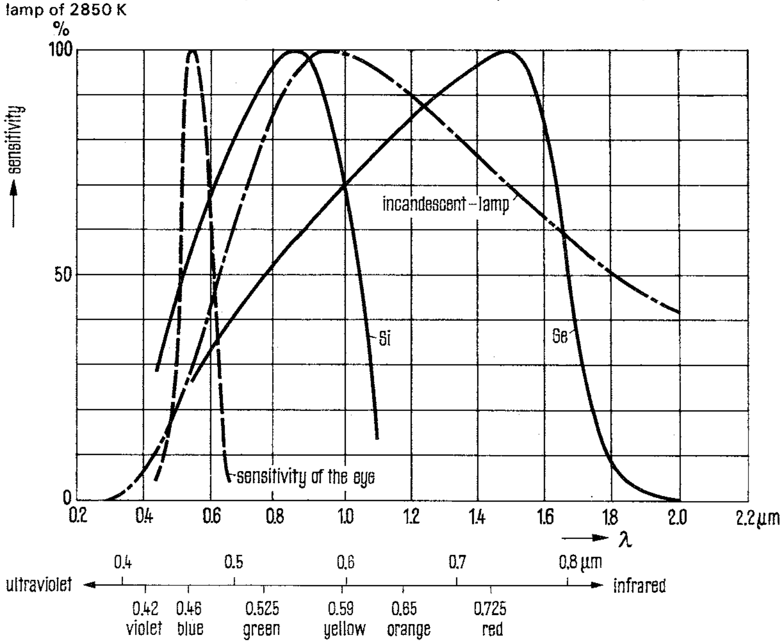


2.9.6 Electromagnetic radiation – ranges of frequency and wavelength

Ranges of frequency and wavelength of the various types of electromagnetic radiation energy and position of the area of visible radiation plus spectrum of light radiation.

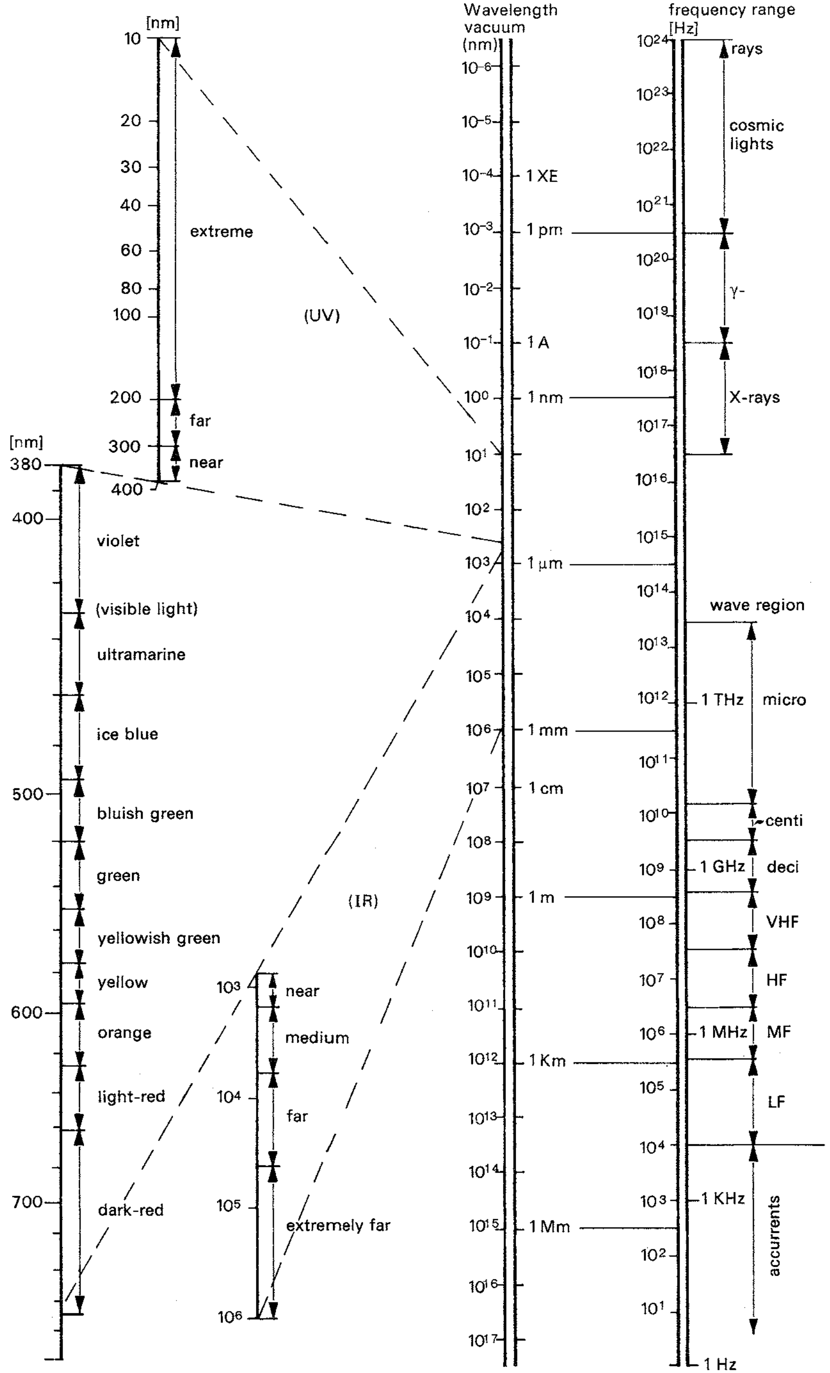


Relative sensitivity of various photosensitive receivers in comparison with the spectral emission of an incandescent lamp of 2850 K



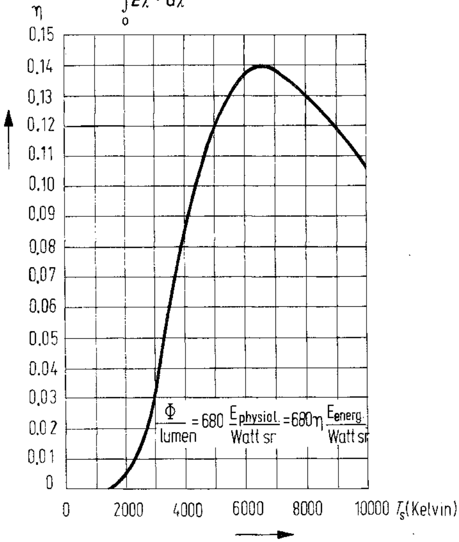
This graph generally applies to all photoelectric devices made of germanium and silicon

Electromagnetic radiation

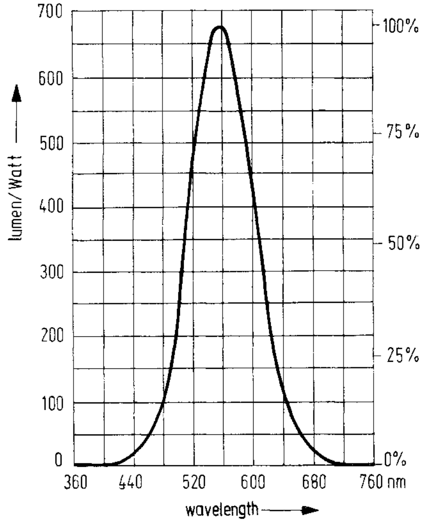


Visual efficiency of the total radiation of the black body as a function of temperature

$$\eta = \frac{\int_0^\infty V\lambda \cdot E\lambda \cdot d\lambda}{\int_0^\infty E\lambda \cdot d\lambda}$$

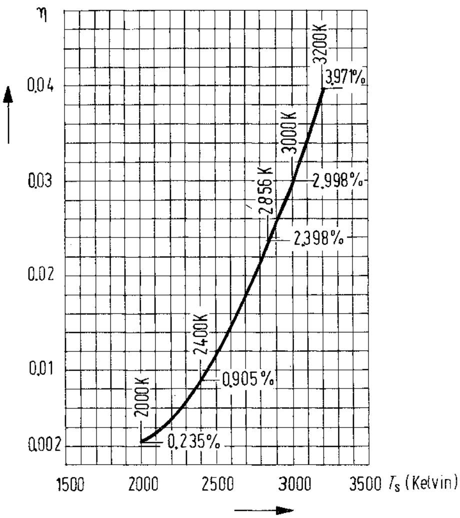


Sensitivity curve of the human eye ($V\lambda$ = luminosity factor for photopic vision)



Section of above curve

$$\eta = \frac{\int_0^\infty V\lambda \cdot E\lambda \cdot d\lambda}{\int_0^\infty E\lambda \cdot d\lambda}$$



2. 10. Quality definition

To designate the delivery quality, the following specifications are given:

1. Maximum and minimum values of the characteristics

2. AQL value (Acceptable Quality Level)

A delivered lot, the defect percentage of which is equal to or less than the percentage given in AQL-value shall be accepted with greater probability (usually 90%) due to sampling tests.

For the various defects (for definitions see para. 3) the AQL values listed in the table apply, unless otherwise specified. The identical sampling inspection plans DIN 40 080 or ABC-STD 105 serve as basis for the attribute test.

3. Definition of defects (the tentative norm DIN 40 080 was considered)

For each group of defects covered by an AQL value, only the number of defective devices (with one or several defective characteristics in this group) is considered.

Total (critical) defect

In case of such a defect the functional use of the device is considerably impaired or impossible.

Examples:

Broken leads or case, wrong or missing type designation, rough cracks and porous spots, open contacts or short circuits as well as essential deviation from characteristics.

Major defect

Such defect noticeably affects the usability of the device. If the specified limits of the characteristics with * are exceeded, it is considered as a major defect.

Minor defect

Such defects impair only slightly the usability of the device

Examples:

Deviation from dynamic and optic characteristics provided there is no particular importance for main application; insignificant excess of temperature, slight case damage, poorly legible type designation.

Classification of defects	Single AQL	Summary AQL
1. Defective case or connection		
a) total defect	0.25	0.25
b) major defect	0.25	
2. Defective electrical or optical characteristics		
a) total defect	0.25	0.25
b) major defect	0.65	2.50
c) minor defect	2.50	–

2.11. Mounting and soldering instructions

1. Mounting

The component can be mounted in any position. Bending of the leads is allowed up to a distance of 1.5 mm from the case provided the diameter of the leads does not exceed 0.5 mm. While bending the leads no mechanical forces must be applied to the case. Leads with a diameter larger than 0.55 mm should not be bent.

If the device is to be mounted near heat generating components, the increased ambient temperature has to be considered in the calculation of the junction temperature.

2. Soldering

Care has to be taken that the component is not overloaded thermically when soldered in. The maximum junction temperature may only be exceeded for a very short time (max. 1 minute).

The following maximum soldering temperatures and times are permissible:

(Compare DIN 40 046, Sheet 18)

	Iron soldering (with 3 mm nozzle)			Dip soldering		
	Iron temperature	Soldering distance from the case	Maximum soldering time	Soldering temperature	Soldering distance from the case	
Metal or glass case	300°C	≧ 1.5 mm	5 s	235°C 260°C	≧ 1.5 mm ≧ 1.5 mm	5 s 3 s
Plastic case	300°C	≧ 2 mm	3 s	235°C 260°C	≧ 2 mm ≧ 2 mm	3 s 3 s