Optocouplers
Data Book
1996

TEMIC
Semiconductors

Contents

TEMIC
Semiconductors

Contents (continued)

Optoisolators

Package	Type	Characteristics							
		V_{IO}	CTR I_F=10 mA	$V_{(BRCEO)}$ IC=1 mA	V_{CEsat}	@ I_F	and I_C	t_{on} / t_{off} @ I_C R_L=100 Ω	
		V_{RMS}	%	V	V	mA	mA	μs	mA

6 Pin Optoisolators – with Transistor Output

Package	Type	V_{RMS}	%	V	V	mA	mA	μs	mA
	4N25[2]	3750	100(>20)	>32	<0.5	50	2	4	10
	4N26[2]	3750	100(>20)	>32	<0.5	50	2	4	10
	4N27[2]	3750	100(>10)	>32	<0.5	50	2	4	10
	4N28[2]	3750	100(>10)	>32	<0.5	50	2	4	10
	4N35[2]	3750	150(>100)	>32	<0.3	10	0.5	<10	2
	4N36[2]	3750	150(>100)	>32	<0.3	10	0.5	<10	2
	4N37[2]	3750	150(>100)	>32	<0.3	10	0.5	<10	2
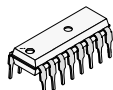
[2] Water-proof construction: Suitable for cleaning process with pure water. For your orders, attach "S" to the order-no. (e.g., 4N25(G)VS)

6 Pin Optoisolators – with Darlington Output

Package	Type	V_{RMS}	%	V	V	mA	mA	μs	mA
	4N32[2]	3750	>500	>55	<1	8	2	50	50
	4N33[2]	3750	>500	>55	<1	8	2	50	50
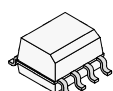
[2] Water-proof construction: Suitable for cleaning process with pure water. For your orders, attach "S" to the order-no. (e.g., 4N25(G)VS)

Multichannel Optoisolators – with Transistor Output

Package	Type	V_{RMS}	%	V	V	mA	mA	μs	mA
	MCT6	2800	>60	>70	<0.3	10	1	6	2
	CNY74–2	2800	50–600 [1]						
	MCT62	2800	>100 [1]						
	K827P	2800	50–600 [1]	>70	<0.3	10	1	6	2
	CNY74-4	2800	50–600 [1]	>70	<0.3	10	1	6	2
	K847P	2800	50–600 [1]	>70	<0.3	10	1	6	2

[1] I_F = 5 mA

Surface Mount Optoisolators – with Transistor Output
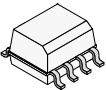
Package	Type	V_{RMS}	%	V	V	mA	mA	μs	mA
	MOC205	2500	40–80	>90	<0.3	10	1	6	5
	MOC206	2500	63–125						
	MOC207	2500	100–200						
	TCMT1020	2500	<40	>90	<0.3	10	1	6	5
	TCMT1021	2500	40–80						
	TCMT1022	2500	63–125						
	TCMT1023	2500	100–200						
	TCMT1024	2500	160–320						
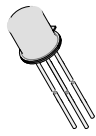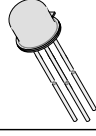
Package	Type	Characteristics							
		V_{IO}	CTR I_F=10 mA	$V_{(BRCEO)}$ IC=1 mA	V_{CEsat}	@ I_F	and I_C	t_{on} / t_{off} @ I_C R_L=100 Ω	
		V_{RMS}	%	V	V	mA	mA	μs	mA

Surface Mount Optoisolators – with Transistor Output

Package	Type	V_{IO} V_{RMS}	CTR %	$V_{(BRCEO)}$ V	V_{CEsat} V	@ I_F mA	and I_C mA	t_{on}/t_{off} μs	@ I_C mA
	MOC211	2500	>20	>90	<0.3	10	1	6	5
	MOC212		>50						
	MOC213		>100						
	MOC215		>20 [1]						
	MOC216		>50 [1]						
	MOC217		>100 [1]						
	TCMT1030	2500	>10 [1]	>90	<0.3	10	1	6	5
	TCMT1031		>20 [1]						
	TCMT1032		>50 [1]						
	TCMT1033		>100 [1]						
	TCMT1034		>200 [1]						
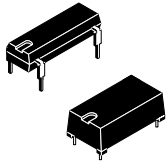
[1] I_F = 1 mA

Metal Can Optoisolators

Package	Type	V_{IO} V_{RMS}	CTR %	$V_{(BRCEO)}$ V	V_{CEsat} V	@ I_F mA	and I_C mA	t_{on}/t_{off} μs	@ I_C mA
	CNY18III	500	25–50	>32	<0.2	10	1	5	5
	CNY18IV	500	40–80	>32	<0.2	10	1	5	5
	CNY18V	500	60–120	>32	<0.2	10	1	5	5
	K120P	800	50 (>25)	>35	<0.3	20	2.5	5	3
	3C91C	1000	100 (>40)	>50	<0.3	20	2.5	10	2
	3C92C	800	100 (>40)	>50	<0.3	20	2.5	6	2

Package	Type	Characteristics							
		V_{IO}	CTR I_F=10 mA	$V_{(BRCEO)}$ IC=1 mA	V_{CEsat}	@ I_F	and I_C	t_{on} / t_{off} @ I_F R_L=100 Ω	
		V_{DC}	%	V	V	mA	mA	μs	mA
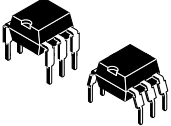
Optoisolators – for Intrinsic Safety Requirements, with Transistor Output

Package	Type	V_{IO} V_{DC}	CTR %	$V_{(BRCEO)}$ V	V_{CEsat} V	@ I_F mA	and I_C mA	t_{on}/t_{off} μs	@ I_F mA
	CNY21Exi Ex-90.C.2106U	10000	80(>50)	>32	<0.3	10	1	5	5
	CNY65Exi Ex-81/2158U	11600	63–125	>32	<0.3	10	1	5	5

Package	Type	Characteristics							
		V_{IO}	CTR	$V_{(BRCEO)}$	V_{CEsat} @	I_F	and I_C	t_{on} / t_{off} @	I_F
			I_F=10 mA	I_C=1 mA				R_L=100 Ω	
		V_{DC}	%	V	V	mA	mA	μs	mA
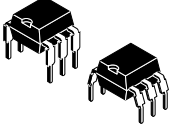
VDE 0884 Approved Optoisolators

Standard Optoisolators – with Transistor Output

Package	Type	V_{DC}	%	V	V	mA	mA	μs	mA
	4N25(G)V[1]	6000	100(>20)	>32	<0.5	50	2	4	10
	4N35(G)V[1]	6000	150(>100)	>70	<0.3	10	0.5	10	2

[1] Water-proof construction: Suitable for cleaning process with pure water. For your orders, attach "S" to the order-no. (e.g., 4N25(G)VS)

No Base Connection

Package	Type	V_{DC}	%	V	V	mA	mA	μs	mA
	TCDT1110(G)	6000	150(>100)	>70	<0.3	10	0.5	10	2
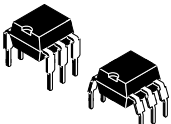
Order "G" devices e.g., TCDT1110(G) with wide spaced 0.4 lead form, for 8 mm PC board spacing safety requirements!

– With CTR Ranking
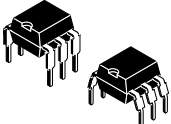
Package	Type	V_{DC}	%	V	V	mA	mA	μs	mA
	CQY80N(G)[1]	6000	90(>50)	>32	<0.3	10	1	9	5
	CNY17(G)-1[1]	6000	40–80	>32	<0.3	10	1	9	5
	CNY17(G)-2[1]	6000	63–125	>32	<0.3	10	1	9	5
	CNY17(G)-3[1]	6000	100–200	>32	<0.3	10	1	9	5

[1] Water-proof construction: Suitable for cleaning process with pure water. For your orders, attach "S" to the order-no., e.g., 4N25(G)VS

No Base Connection

Package	Type	V_{DC}	%	V	V	mA	mA	μs	mA
	TCDT1100(G)	6000	90(>50)	>32	<0.3	10	1	9	5
	TCDT1101(G)	6000	40–80	>32	<0.3	10	1	9	5
	TCDT1102(G)	6000	63–125	>32	<0.3	10	1	9	5
	TCDT1103(G)	6000	100–200	>32	<0.3	10	1	9	5
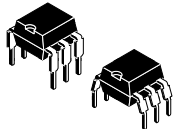
– With CTR Ranking and High Output Voltage

Package	Type	V_{DC}	%	V	V	mA	mA	μs	mA
	CNY75(G)A[1]	6000	63–125	>90	<0.3	10	1	4	10
	CNY75(G)B[1]	6000	100–200	>90	<0.3	10	1	6	10
	CNY75(G)C[1]	6000	160–320	>90	<0.3	10	1	7	10

[1] Water-proof construction: Suitable for cleaning process with pure water. For your orders, attach "S" to the order-no. (e.g., 4N25(G)VS)

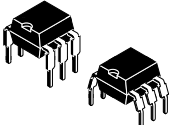| Package	Type	Characteristics							
		V_{IO}	CTR I_F=10 mA	$V_{(BRCEO)}$ IC=1 mA	V_{CEsat}	@	I_F and I_C	t_{on} / t_{off}	@ I_F R_L=100 Ω
		V_{DC}	%	V	V	mA	mA	μs	mA
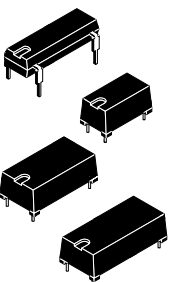
No Base Connection

Package	Type	V_{DC}	%	V	V	mA	mA	μs	mA
	TCDT1120(G)	6000	63	>90	<0.3	10	1	4	10
	TCDT1122(G)	6000	63–125	>90	<0.3	10	1	5	10
	TCDT1123(G)	6000	100–200	>90	<0.3	10	1	6	10
	TCDT1124(G)	6000	160–320	>90	<0.3	10	1	7	10
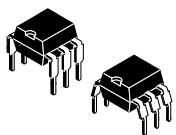
Order "G" devices, e.g., CNY75GA with wide spaced 0.4" lead form, for 8 mm PC board spacing safety requirements!

Optoisolators – for High Isolation Voltages

Package	Type	V_{DC}	%	V	V	mA	mA	μs	mA
	CNY21N	8000	60(>25)	>32	<0.3	10	1	5	5
	CNY64		50–300						
	CNY64A	8000	63–125	>32	<0.3	10	1	5	5
	CNY64B		100–200						
	CNY65		50–300						
	CNY65A	8000	63–125	>32	<0.3	10	1	5	5
	CNY65B		100–200						
	CNY66	8000	50–300	>32	<0.3	10	1	5	5

Package	Type	Characteristics					
		V_{IO} V_{IOTM}	V_{DRM} V	I_{TRMS} mA	I_{FT} mA	V_{TM} V	dv/dt V/μs

Optoisolators – with Triac Driver Output

Package	Type	V_{IO} V_{IOTM}	V_{DRM} V	I_{TRMS} mA	I_{FT} mA	V_{TM} V	dv/dt V/μs
	K3010P(G)		250	100	<15	<3	10
	K3011P(G)				<10		
	K3012P(G)	6000			<5		
	K3020P(G)		500	100	<30	<3	10
	K3021P(G)				<15		
	K3022P(G)				<10		
	K3023P(G)				<5		

Order "G" devices e.g., K3011PG with wide spaced 0.4 " lead form, for 8 mm PC board spacing safety requirements!
[1] VDE 0884 certificate is applied

TEMIC
Semiconductors
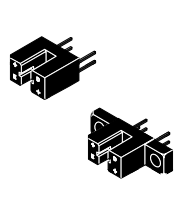
Optical Sensors

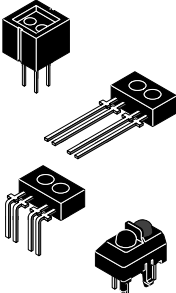| Package	Type	Characteristics						
		I_C	CTR @ I_F		$V_{(BR)CEO}$ @ 1 mA	V_{CEsat} @ I_F and I_C		
		mA	%	mA	V	V	mA	mA

Reflective Optical Sensors

	CNY70							
	TCRT1000	>0.3	>1.5	20	>32	<0.3	20	0.1
	TCRT1010							
	TCRT5000	>0.35	>3.5	10	>32	<0.4	10	0.1
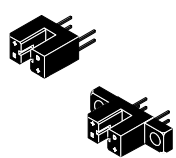
Transmissive Optical Sensors

– with Aperture – with Transistor Output
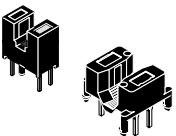
	TCST1103	4(>2)	20(>10)	20	70	3.2	0.6	1
	TCST2103	4(>2)	20(>10)	20	70	3.2	0.6	1
	TCST1202	2(>1)	10(>5)	20	70	3.2	0.4	0.5
	TCST2202	2(>1)	10(>5)	20	70	3.2	0.4	0.5
	TCST1300	0.5(>0.25)	2.5(>1.25)	20	70	3.2	0.2	0.25
	TCST2300	0.5(>0.25)	2.5(>1.25)	20	70	3.2	0.2	0.25

*)TCST2103 /TCST2202 /TCST2300

– without Aperture – with Transistor Output

	TCST1000	0.5(>0.25)	2.5(>1.25)	20	70	3.1	0.8	–
	TCST2000	0.5(>0.25)	2.5(>1.25)	20	70	3.1	0.8	–

Miniature Transmissive Optical Sensors – with Transistor Output
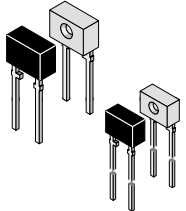
	TCST1230	1(>0.5)	5(>2.5)	20	70	3	0.8	–
	TCST1030	2.5(>1.2)	25(>12)	10	70	3	0.8	–
	TCST5123	5(>2.4)	25(>12)	20	70	2.8	0.8	–

Miniature Optical Encoder – with Transistor Output (Dual Channel)

	TCVT1300	0.6(>0.4)	2(>1.3)	30	70	1.5	0.2	0.2
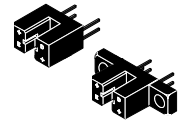
Package	Type	Characteristics						
		I_C	CTR @ I_F		$V_{(BR)CEO}$ @ 1 mA	Gap	Resolution	Aperture
		mA	%	mA	V	mm	mm	mm

Matched Pairs (Emitter and Detector)
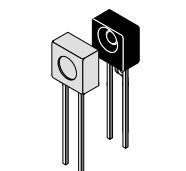
Package	Type	I_C mA	CTR %	I_F mA	$V_{(BR)CEO}$ V	Gap mm	Resolution mm	Aperture mm
	TCZT8012	2(>1)	10(>5)	20	70	<0.4	20	0.1
	TCZT8020	0.5(>0.25)	2.5(>1.25)	20	70	<0.4	20	0.025

Package	Type	Characteristics						
		I_{FT}	t_{on} / t_{off}	t_r / t_f	V_{CC}	Gap	Resolution	Aperture
		mA	μs	μs	V	mm	mm	mm

Transmissive Optical Sensors – with Schmitt Trigger Logic[1]

Package	Type	I_{FT} mA	t_{on}/t_{off} μs	t_r/t_f μs	V_{CC} V	Gap mm	Resolution mm	Aperture mm
	TCSS1100	<10	2	0.03	5	3.2	0.6	1
	TCSS2100	<10	2	0.03	5	3.2	0.6	1

Matched Pairs (Emitter and Detector) – with Schmitt Trigger Logic[1]
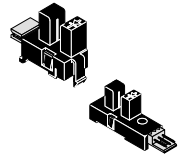
Package	Type	I_{FT} mA	t_{on}/t_{off} μs	t_r/t_f μs	V_{CC} V	Gap mm	Resolution mm	Aperture mm
	TCZS8000	<20	2	0.03	5	–	–	–
	TCZS8100	<10	2	0.03	4.5–16	–	–	–

1) Inverted, open collector output

Optical Sensors with Wires and Connectors

Package	Type	Characteristics						
		I_{FT}	V_{OL}	I_S	V_{CC}	Gap	Resolution	Aperture
		mA	V	mA	V	mm	mm	mm

Transmissive Optical Sensors – with Schmitt Trigger Logic Output

Package	Type	I_{FT} mA	V_{OL} V	I_S mA	V_{CC} V	Gap mm	Resolution mm	Aperture mm
	TCYS5201	–	0.35	30	5	5	0.4	0.5
	TCYS6201	–	0.35	30	5	5	0.4	0.5

TEMIC
Semiconductors

Product Information Card

Optocouplers – Isolators

Market Segment, Recommended TEMIC Devices	Description	Applications
Switchmode power supply CQY80N/ TCDT1101-03 CNY75A-C/ TCDT1121-23 CNY64 or CNY65 for larger creepage distances	On-off external control circuit, feedback circuit, overvoltage detection circuit. Main features: Insulation input-to-output and small transformers are replaced. Key features: Isolation test voltage (std is 3.750 KV RMS) and CTR (ratio output current/ input current). Different models request different CTR rank. Coupler with **no base connection** is very popular because it prevents interferences. Most usable parts: CQY80N/ **TCDT1100** and CNY75/ **TCDT1120** all couplers also available in "G" version. "G" stands for extended creepage distance of 0.4″ lead to lead**.**	Power supply in monitors, computers, copy machines, printers, faxmachines, TV, VCR, medical equipment, washing machines etc.
Control equipment please recommend: 4N35-4N37	Isolation of dc input circuit, isolation of dc output circuit, signal serve motor control circuit. Isolation for signal transfer system for automatic door control, circuit lamp and relay drive circuit.	Programmable controller, numerical control, PPC tele-facsimile, automatic door control, others
Office automation equipment please recommend: CNY64, CNY65	Motor driving power-supply circuit (primary-secondary circuit isolation), high-voltage control circuit of static electric printer, printer driver circuit interface between input and output circuit.	PPC tele-facsmile equipment, printer
Vending machine please recommend: 4N35-4N37	Interface between input and output circuit type selection circuit.	
Household appliance please recommend: CNY64, CNY65 K3010P-K3023P	Audio signal isolation, video signal interface, power-supply circuit, motor control circuit. Triac driver interface between input and output Base amplification circuit of inverter control over-current detection circuit.	TV, electrical sewing machine, microwave oven, warm air heating equipment, air conditioner
Audio equipment see switch-mode power supply	Power supply circuit (primary-secondary circuit isolation)	Compact disc player
Telecommunication please recommend: K3010P-K3023P, 4N35-4N37, 4N32	Isolation for signal transfer system, pulse-dial circuit, ring-detector circuit, loop monitor circuit	Push-button telephone system

Optocouplers – Optical Sensors

Market Segment, Application	Description	Usability
TV, audio please recommend: TCRT1000, 5000, TCST5123, 1030, 1230 TCVT1300	Detection of rotation speed, position pick-up head, home position tape counter, tape-end detection	VCR, VDP, CD player, tape deck
Home electric please recommend: TCRT5000, TCST1103, TCST1300, IR single parts	Scattering reflection light, detection of washing water contaminiation, detection of salt level, mechanical position detection, movement of needle, cloth feeder	Smoke detector. washing machines, dish-washer, health equipment, sewing machines
Automotive please recommend: optical pairs: TCZT8020, TCZT8012, TCZS8100, TCRT1000	Engine speed detection, point-position detection, steering angle detection, detection of door lock	Tachometer, speedometer, steering wheel, door
Control and measure please recommend: TCVT1300, TCRT1000	Speed rotation, motor position, distance detection, mechanical position detection, object sensor	Rotary encoder measuring, devices, robots, electricity meters
Office automation please recommend: TCST1030, 1230, TCST1300, TCRT1000 TCRT5000	Detection of paper, paper position, home position, print timing, detection of paper feeding, detection of paper exhaustion index, write-protect detection, zero tracking detection, detection of scan timing	Copier, printer, typewriter, facsimile, FDD, tape drives, handy, scanner
Others TCST1103, TCRT5000, TCST1300	Detection of coins, detection of paper money, detection of prints, detection of weight, object sensor/ on/ off position, liquid-level detection	Slot machine ticket/ vending machines, validator, film cutter, electronic scales, watertab, liquid, container

TEMIC
Semiconductors

Classification Chart for Opto Isolators

General purpose

4N-Series	Standard Transistor output	4N27/28 CTR>10%	
		4N25/26 CTR>20%	
		4N35–37 CTR>100%	
	Base n.c. Transistor output	TCDT1110 CTR>50%	
	High CTR Darlington output	4N32/33 CTR>500%	
Multichannel	2 Channels Transistor output	American pin connection — CNY74–2 CTR>50–600%	
		American pin connection — MCT6/62 CTR>100%	
		Japanese pin connection — K827P CTR>50–600%	
	4 Channels Transistor output	American pin connection — CNY74–4 CTR>50–600%	
		Japanese pin connection — K847P CTR>50–600%	

1500 V 2800 V 3550 V 3750 V 6000 V

96 11941

Classification Chart for Opto Isolators

VDE-tested devices for e.g., switching power supply

Thickness of isolation > 2mm

use for:
IEC 335 / VDE 700;
safety standard

VDE
0884

Creepage distance
≥8mm

Transistor output

CNY64/65/66
CTR>50%

CNY21N
CTR>25%

base n.c. TCDT110.(G)
CTR>50%

base n.c. TCDT1110(G)
CTR>100%

base n.c. TCDT112.(G)
CTR>63%

4N25(G)V
CTR>20%

4N35(G)V
CTR>100%

CQY80N(G)
CTR>50%

CNY17(G)
CTR>40%

CNY75(G)
CTR>63%

Transistor output

Thickness of
isolation>0.75mm

use for:
IEC 435 / VDE 0805
IEC 380 / VDE 0806

Triac driver

K3010P(G)
V_{DRM}=250V, I_{FT}≤15mA

K3020P(G)
V_{DRM}=500V, I_{FT}≤30mA

Ex

Creepage distance
> 8mm

Thickness of
isolation > 3.3mm

Transistor output

CNY65Exi
CTR 63–125%

CNY21Exi
CTR>50%

PTB-tested device use for:
intrinsic safety

Hermetically-sealed
package JEDEC TO72

Different pin
connections

Transistor output

CNY18
CTR>25%

K120P
CTR>25%

3C91C
CTR>40%

3C92C
CTR>40%

500 V 1000 V 6000 V 8000 V 10000 V 11000 V 15000 V
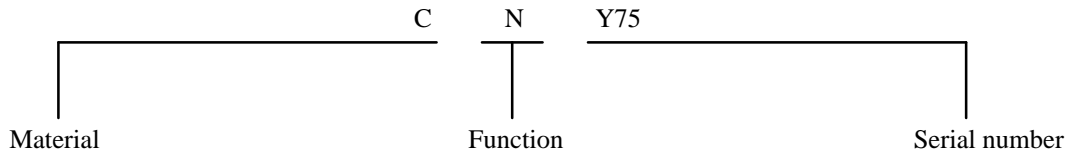
96 11940

TEMIC
Semiconductors

Conventions Used in Presenting Technical Data

Nomenclature for Semiconductor Devices According to Pro Electron

The type number of semiconductor devices consists of two letters followed by **a serial number**

$$C \qquad N \qquad Y75$$

Material   Function   Serial number

The **first letter** gives information about the material used for the active part of the devices.

A   GERMANIUM
(Materials with a band gap of 0.6 – 1.0 eV) [1]

B   SILICON
(Materials with a band gap of 1.0 – 1.3 eV) [1]

C   GALLIUM-ARSENIDE
(Materials with a band gap > 1.3 eV) [1]

R   COMPOUND MATERIALS
(For instance Cadmium-Sulphide)

The **second letter** indicates the circuit function:

A   DIODE: Detection, switching, mixer

B   DIODE: Variable capacitance

C   TRANSISTOR: Low power, audio frequency

D   TRANSISTOR: Power, audio frequency

E   DIODE: Tunnel

F   TRANSISTOR: Low power, high frequency

G   DIODE: Oscillator, miscellaneous

H   DIODE: Magnetic sensitive

K   HALL EFFECT DEVICE:
In an open magnetic circuit.

L   TRANSISTOR: Power, high frequency

M   HALL EFFECT DEVICE:
In a closed magnetic circuit

N   PHOTO COUPLER

P   DIODE: Radiation sensitive

Q   DIODE: Radiation generating

R   THYRlSTOR: Low power

S   TRANSISTOR: Low power, switching

T   THYRISTOR: Power

U   TRANSISTOR: Power, switching

X   DIODE: Multiplier, e.g., varactor, step recovery

Y   DIODE: Rectifying, booster

Z   DIODE: Voltage reference or voltage regulator, transient suppressor diode
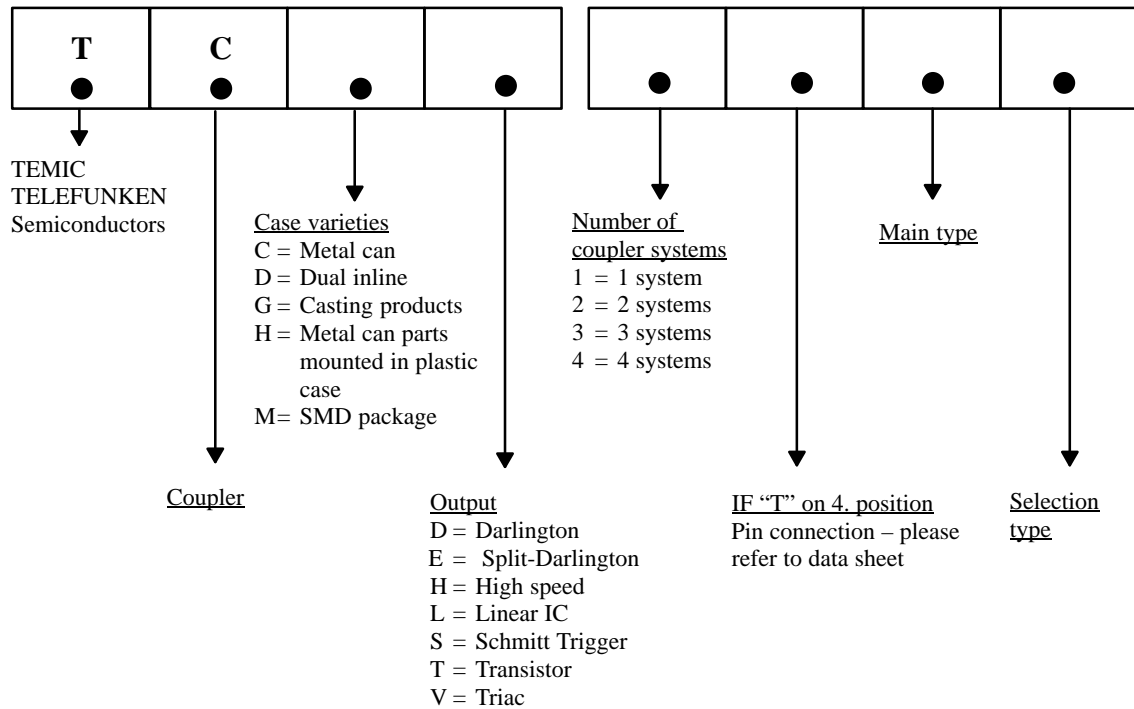
The **serial number** consists of:

- Three figures, running from 100 to 999, for devices primarily intended for consumer equipment.

- One letter (Z, Y, X, etc.) and two figures running from 10 to 99, for devices primarily intended for professional equipment.

A version letter can be used to indicate a deviation of a single characteristic, either electrically or mechanically.
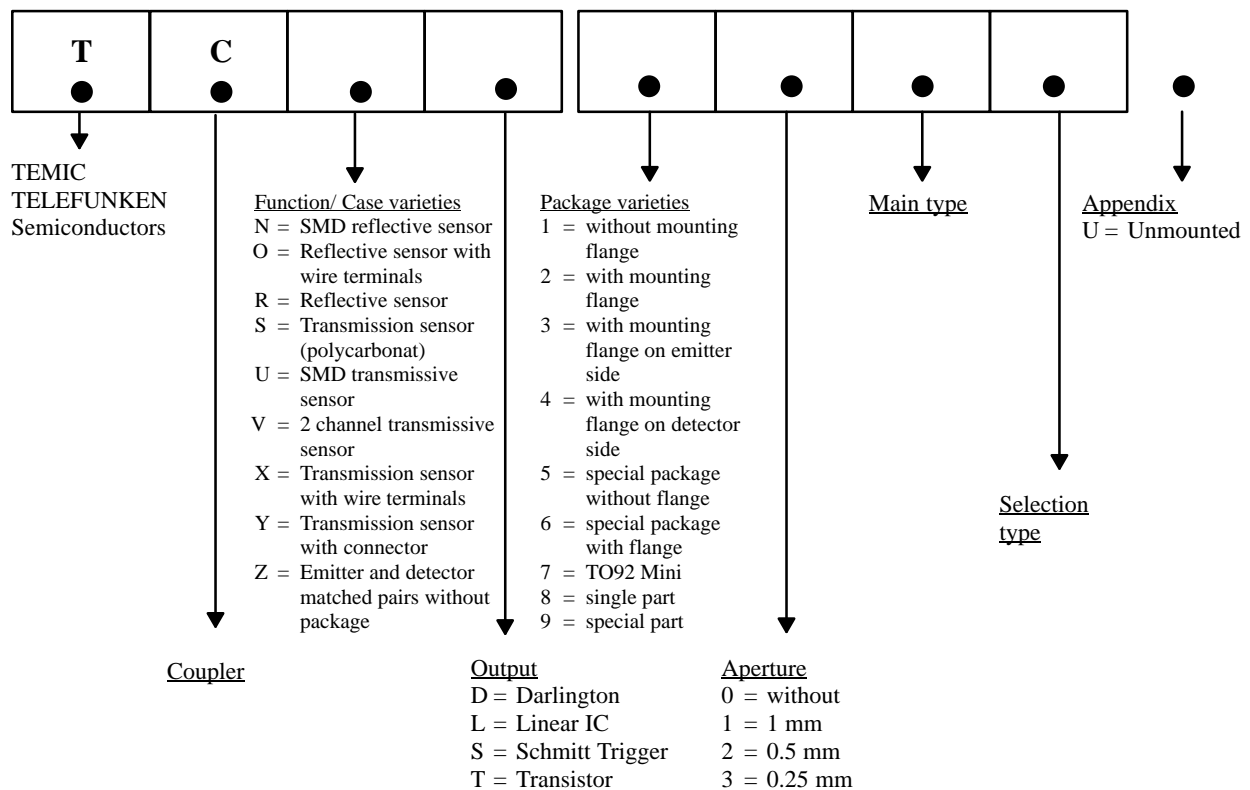
The letter never has a fixed meaning, the only exception being the letter R, which indicates reversed voltage, i.e., collector-to-case.

[1]   The material mentioned are examples

Type Designation Code for Optocouplers

```
┌─────┬─────┬─────┬─────┐   ┌─────┬─────┬─────┬─────┐
│  T  │  C  │     │     │   │     │     │     │     │
│  ●  │  ●  │  ●  │  ●  │   │  ●  │  ●  │  ●  │  ●  │
└─────┴─────┴─────┴─────┘   └─────┴─────┴─────┴─────┘
```

TEMIC
TELEFUNKEN
Semiconductors

Case varieties
C = Metal can
D = Dual inline
G = Casting products
H = Metal can parts
    mounted in plastic
    case
M = SMD package

Number of
coupler systems
1 = 1 system
2 = 2 systems
3 = 3 systems
4 = 4 systems

Main type

Coupler

Output
D = Darlington
E = Split-Darlington
H = High speed
L = Linear IC
S = Schmitt Trigger
T = Transistor
V = Triac

IF "T" on 4. position
Pin connection – please
refer to data sheet

Selection
type

Type Designation Code for Optical Sensors

```
┌─────┬─────┬─────┬─────┐   ┌─────┬─────┬─────┬─────┐
│  T  │  C  │     │     │   │     │     │     │     │   ●
│  ●  │  ●  │  ●  │  ●  │   │  ●  │  ●  │  ●  │  ●  │
└─────┴─────┴─────┴─────┘   └─────┴─────┴─────┴─────┘
```

TEMIC
TELEFUNKEN
Semiconductors

Function/ Case varieties
N = SMD reflective sensor
O = Reflective sensor with
    wire terminals
R = Reflective sensor
S = Transmission sensor
    (polycarbonat)
U = SMD transmissive
    sensor
V = 2 channel transmissive
    sensor
X = Transmission sensor
    with wire terminals
Y = Transmission sensor
    with connector
Z = Emitter and detector
    matched pairs without
    package

Package varieties
1 = without mounting
    flange
2 = with mounting
    flange
3 = with mounting
    flange on emitter
    side
4 = with mounting
    flange on detector
    side
5 = special package
    without flange
6 = special package
    with flange
7 = TO92 Mini
8 = single part
9 = special part

Main type

Appendix
U = Unmounted

Coupler

Output
D = Darlington
L = Linear IC
S = Schmitt Trigger
T = Transistor

Aperture
0 = without
1 = 1 mm
2 = 0.5 mm
3 = 0.25 mm

Selection
type

TEMIC
Semiconductors

Symbols and Terminology – Alphabetically

A
Anode, anode terminal

A
Radiant sensitive area
That area which is radiant-sensitive for a specified range

a
Distance between the emitter (source) and the detector

AQL
Acceptable **Q**uality **L**evel,
see "Qualification and Monitoring"

B
Base, base terminal

C
Capacitance

C
Cathode, cathode terminal

C
Collector, collector terminal

°C
Celsius
Unit of the centigrade scale; can also be used (besides K) to express temperature changes
Symbols: T, ΔT
$T(°C) = T(K)–273$

C_{CEO}
Collector emitter capacitance
Capacitance between the collector and the emitter with open base
Measurement is made by applying reverse voltage between collector and emitter terminals.

C_j
Junction capacitance
Capacitance due to a PN-junction of a diode
It decreases with increasing reverse voltage.

C_k
Coupling capacitance
Capacitance between the emitter and the detector of an opto isolator

CTR
Current **T**ransfer **R**atio
Ratio between output and input current

$$CTR = 100 \frac{I_C}{I_F} \%$$

d
Distance

Δv/Δt cr
Critical rate of rise of off-state voltage ($I_F = 0$)
Highest value of "rate of rise of off-state voltage" which will cause no switching from the off-state to the on-state.

Δv/Δt crq
Critical rate of rise of commutating voltage ($I_F \geq I_{FT}$)
Highest value of "rate of rise of commutating voltage". It will not switch-on the device again until after the voltage has decreased to zero and the trigger current is switched to zero ($I_f \leq I_{FT}$).

E
Emitter, emitter terminal

f
Frequency
Unit: Hz (Hertz)

f_g
Cut-off frequency
The frequency at which the modules of the small signal current transfer ratio has decreased to $\frac{1}{\sqrt{2}}$ of its lowest frequency value.

G_B
Gain bandwidth product
Gain bandwidth product is defined as the product of M times the frequency of measurement, when the diode is biased for maximum of obtainable gain.

h_{FE}
DC current gain

I_B
Base current

I_C
Collector current

I_{CB}
Collector base current

I_{CEO}
Collector dark current, with open base
At radiant sensitive devices with open base and without illumination/radiation ($E = 0$)

I_{CM}
Repetitive peak collector current

I_{CX}
Cross talk current
For reflex-coupled isolators, collector emitter cut-off current with the IR emitter activated, but without reflecting medium

I_{DRM}
Repetitive peak off-state current
The maximum leakage current that may occur under the conditions of V_{DRM}

I_F
Forward current continuous
The current flowing through the diode in direction of lower resistance

I_{FAV}
Average (mean) forward current

I_{FM}
Peak forward current

I_{FSM}
Surge forward current

I_{FT}
Threshold forward current
The minimum current required to switch from the off-state to the on-state

I_H
The minimum current required to maintain the thyristor in the on-state

I_o
DC output current

I_{OH}
High level output current

I_R
Reverse current, leakage current
Current which flows when reverse bias is applied to a semiconductor junction

I_{ro}
Reverse dark current
Reverse dark current which flows through a photoelectric device without radiation/ illumination

I_{Srel}
Relative supply current

I_T
On-state current
The permissible output current under stated conditions

K
Kelvin
The unit of absolute temperature T (also called the Kelvin temperature); also used for temperature changes (formerly °K)

P_{tot}
Total power dissipation

P_v
Power dissipation, general

R_{IO}
Input/ output isolation resistor

R_L
Load resistance

R_{thJA}
Thermal resistance, junction ambient

R_{thJC}
Thermal resistance, junction case

S
Displacement

T
Period (duration)

T
Temperature
0 K = –273.16°C
Unit: K (Kelvin), °C (Celsius)

t
Time

T_{amb}
Ambient temperature
It self-heating is significant:
Temperature of the surrounding air below the device, under conditions of thermal equilibrium.
If self-heating is insignificant:
Air temperature in the immediate surroundings of the device

T_{amb}
Ambient temperature range
As an absolute maximum rating:
The maximum permissible ambient temperature range.

T_{case}
Case temperature
The temperature measured at a specified point on the case of a semiconductor device
Unless otherwise stated, this temperature is given as the temperature of the mounting base for devices with metal can

t_d
Delay time

t_f
Fall time, see figure 17

T_j
Junction temperature
It is the spatial mean value of temperature which the junction has acquired during operation. In the case of phototransistors, it is mainly the temperature of collector junction because its inherent temperature is maximum.

TC
Temperature coefficient
The ratio of the relative change of an electrical quantity to the change in temperature (ΔT) which causes it, under otherwise constant operating conditions.

t_{off}
Turn-off time, see figure 17

t_{on}
Turn-on time, see figure 17

t_p
Pulse duration, see figure 17

t_r
Rise time, see figure 17

t_s
Storage time

T_{sd}
Soldering temperature
Maximum allowable temperature for soldering with specified distance from case and its duration (see table 2)

T_{stg}
Storage temperature range
The temperature range at which the device may be stored or transported without any applied voltage

V_{BEO}
Base-emitter voltage, open collector

$V_{(BR)}$
Breakdown voltage
Reverse voltage at which a small increase in voltage results in a sharp rise of reverse current
It is given in technical data sheets for a specified current.

$V_{(BR)CEO}$
Collector emitter breakdown voltage, open base

$V_{(BR)EBO}$
Emitter base breakdown voltage, open collector

$V_{(BR)ECO}$
Emitter collector breakdown voltage, open base

V_{CBO}
Collector-base voltage, open emitter
Generally, reverse biasing is the voltage applied to any one of two terminals of a transistor in such a way that one of the junction operates in reverse direction, whereas the third terminal (second junction) is specified separately.

V_{CE}
Collector-emitter voltage

V_{CEO}
Collector-emitter voltage, open base ($I_B = 0$)

V_{CEsat}
Collector emitter saturation voltage
Saturation voltage is the dc voltage between collector and emitter for specified (saturation) conditions i.e., I_C and I_F, whereas the operating point is within the saturation region.
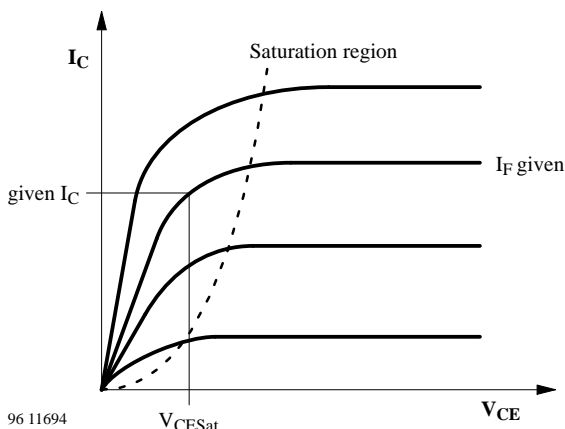

Figure 1.

96 11694

V_{DRM}
Repetitive peak off-state voltage
The maximum allowable instantaneous value of repetitive off-state voltage that may be applied across the triac output

V_{EBO}
Emitter base voltage, open collector

V_{ECO}
Emitter collector voltage, open base

V_F
The voltage across the diode terminals which results from the flow of current in the forward direction

V_{IO}
The voltage between the input terminals and the output terminals

V_{IORM}
The maximum recurring peak (repetitive) voltage value of the optocoupler, characterizing the long-term withstand capability against transient overvoltages

V_{IOTM}
The impulse voltage value of the optocoupler, characterizing the long-term withstand capability against transient overvoltage

V_{IOWM}
The maximum rms. voltage value of the optocoupler, characterizing the long-term withstand capability of its insulation

V_R
Reverse voltage
Voltage drop which results from the flow of reverse current

V_s
Supply voltage

V_{TM}
On-state voltage
The maximum voltage when a thyristor is in the on-state

V_{TMrel}
Relative on-state voltage

$\pm\varphi$
Angle of half sensitivity
The plane angles through which a detector, illuminated by a point source, can be rotated in both directions away from the optical axis, before the electrical output of the device falls to half the maximum value

$\pm\varphi$
Angle of half sensitivity
The plane angles through which an emitter can be rotated in both directions away from the optical axis, before the electrical output of a linear detector facing the emitter falls to half the maximum value

Example for Using Symbols According to DIN 41 785 and IEC 148
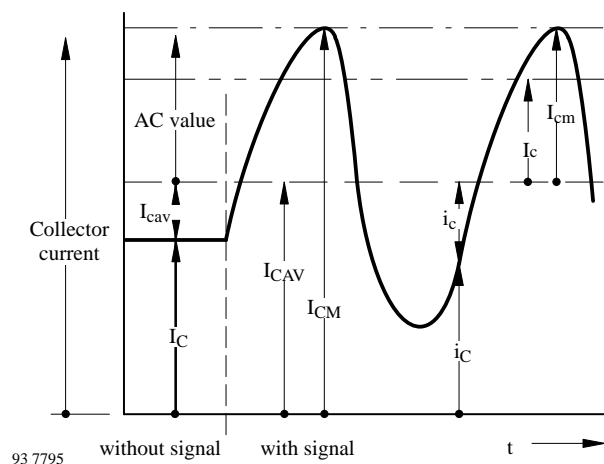
a)   Transistor

93 7795

Figure 2.

I_C	dc value, no signal
I_{CAV}	Average total value
$I_{CM}; I_C$	Maximum total value
I_C	RMS varying component
$I_{CM}; I_C$	Maximum varying component value
i_C	Instantaneous total value
i_C	Instantaneous varying component value

The following relationships are valid:

$$I_{CM} = I_{CAV} + I_{cm}$$

$$i_C = I_{CAV} + i_c$$

b)   Diode

93 7796
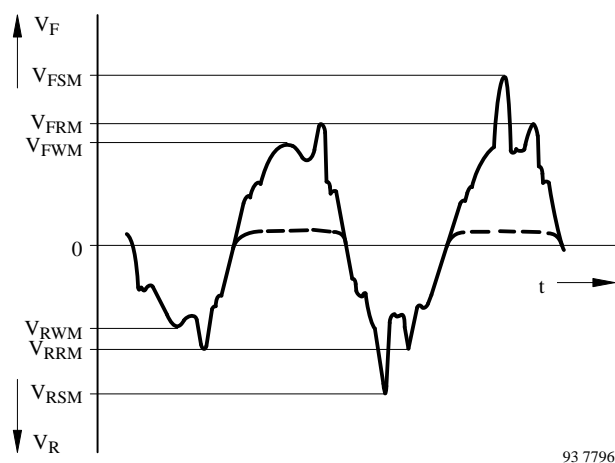
Figure 3.

V_F	Forward voltage
V_R	Reverse voltage
V_{FSM}	Surge forward voltage (non-repetitive)
V_{RSM}	Surge reverse voltage (non-repetitive)
V_{FRM}	Repetitive peak forward voltage
V_{RRM}	Repetitive peak reverse voltage
V_{FWM}	Crest working forward voltage
V_{RWM}	Crest working reverse voltage

TEMIC
Semiconductors

c)   Triac

Figure 4.

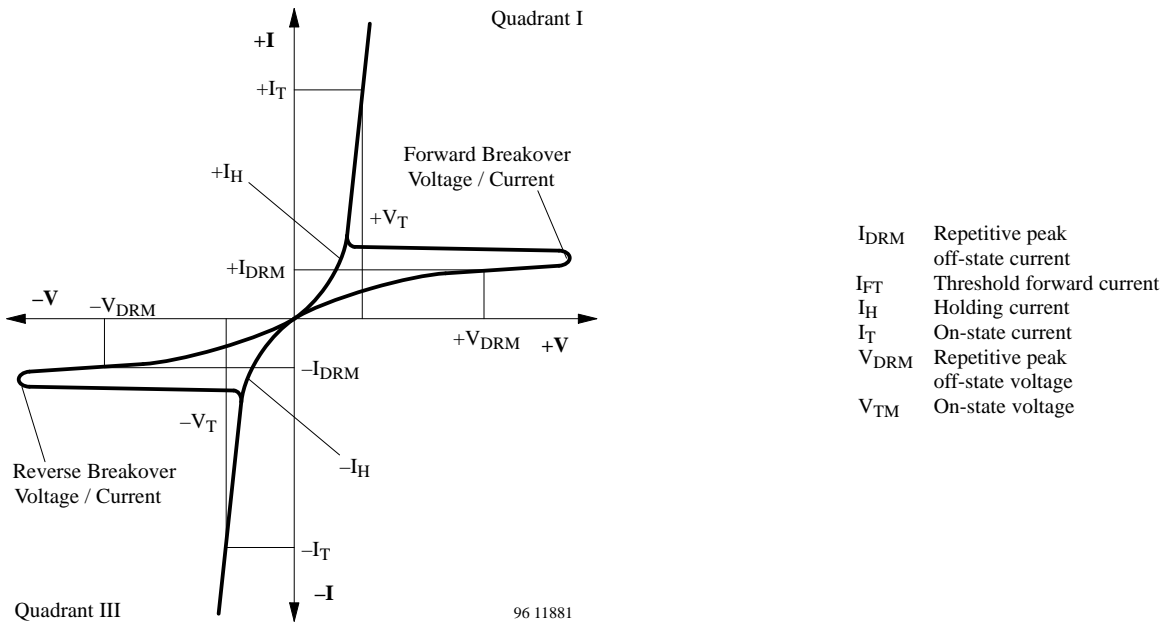|	
I_{DRM}	Repetitive peak off-state current
I_{FT}	Threshold forward current
I_H	Holding current
I_T	On-state current
V_{DRM}	Repetitive peak off-state voltage
V_{TM}	On-state voltage

d)   Designation and symbols of optoelectronic devices are given so far as possible according to DIN 44020 sheet 1 and IEC publication 50 (45).

Data Sheet Structure

Data sheet information is generally presented in the following sequence:

- Description

- Absolute maximum ratings

- Thermal data – thermal resistances

- Optical and electrical characteristics

- Diagrams

- Dimensions (mechanical data)

Description

The following information is provided: Type number, semiconductor materials used, sequence of zones, technology used, device type and, if necessary, construction.

Also, short-form information on special features and the typical applications is given.

Absolute Maximum Ratings

These define maximum permissible operational and environmental conditions. If any one of these conditions is exceeded, it could result in the destruction of the device.

Unless otherwise specified, an ambient temperature of 25 ± 3 °C is assumed for all absolute maximum ratings.

Most absolute ratings are static characteristics; if measured by a pulse method, the associated measurement conditions are stated. Maximum ratings are absolute (i.e., not interdependent).

Any equipment incorporating semiconductor devices must be designed so that even under the most unfavorable operating conditions the specified maximum ratings of the devices used are never exceeded. These ratings could be exceeded because of changes in

- Supply voltage, the properties of other components used in the equipment

- Control settings

- Load conditions

- Drive level

- Environmental conditions and the properties of the devices themselves (i.e., ageing).

Thermal Data – Thermal Resistances

Some thermal data (e.g., junction temperature, storage temperature range, total power dissipation) are given under the heading "Absolute maximum ratings"; (This is because they impose a limit on the application range of the device).

The thermal resistance junction ambient (R_{thJA}) quoted is that which would be measured without artificial cooling, i.e., under worst case conditions.

Temperature coefficients, on the other hand, are listed together with the associated parameters under "Optical and electrical characteristics".

Optical and Electrical Characteristics

Here, the most important operational, optical and electrical characteristics (minimum, typical and maximum values) are listed. The associated test conditions, supplemented with curves and an AQL-value quoted for particularly important parameters (see "Qualification and Monitoring") are also given.

Diagrams

Besides the static (dc) and dynamic (ac) characteristics, a family of curves is given for specified operating conditions. These curves show the typical interpendence of individual characteristics.

Dimensions (Mechanical Data)

This list contains important dimensions and the sequence of connection, supplemented by a circuit diagram. Case outline drawings carry DIN-, JEDEC or commercial designations. Information on the angle of sensitivity or intensity and weight completes the list of mechanical data.

Please Note:

If the dimensional information does not include any tolerances, the following applies:

Lead length and mounting hole dimensions are minimum values. Radiant sensitive (or emitting area respectively) are typical values, all other dimensions are maximum.

Any device accessories must be ordered separately, quoting the order number.

Additional Information

Preliminary specifications

This heading indicates that some information on preleminary specifications may be subject to slight changes.

Not for new developments

This heading indicates that the device concerned should not be used in equipment under development. It is, however, available for present production.
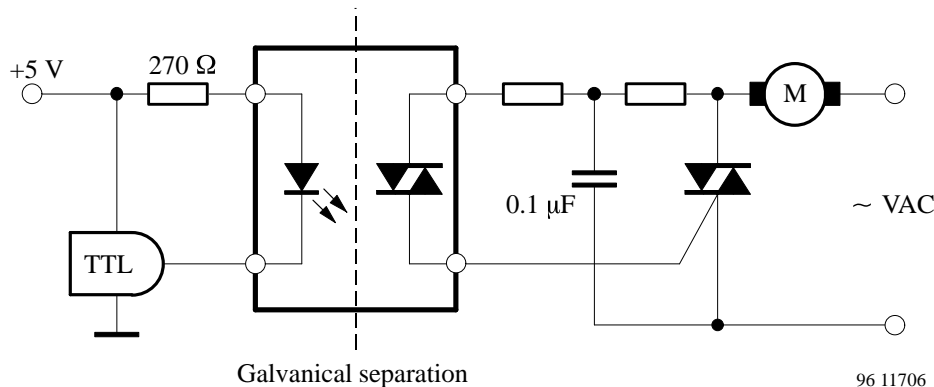
TEMIC
Semiconductors

Figure 5. Basic application of an optocoupler

General Description

Basic Function

In an electrical circuit, an optocoupler ensures total electric isolation, including potential isolation, as in the case of a transformer, for instance.

In practice, this means that the control circuit is located on one side of the optocoupler, i.e., the emitter side, while the load circuit is located on the other side, i.e., the receiver side. Both circuits are electrically isolated by the optocoupler (figure 5). Signals from the control circuit are transmitted optically to the load circuit, and are therefore free of retroactive effects. In most cases, this optical transmission is realized with light beams whose wavelengths span the red to infrared range, depending on the requirements applicable to the optocoupler. The bandwidth of the signal to be transmitted ranges from a dc voltage signal to frequencies in the MHz band. An optocoupler is comparable to a transformer or relay. Besides having smaller dimensions in most cases, the advantages of optocouplers compared to relays are the following: it ensures considerably shorter switching times, no contact bounce, no interference caused by arcs, no mechanical wear and the possibility of adapting a signal, already in the coupler, to the following stage in the circuitry. Thanks to all these advantages, optocouplers are outstandingly suitable for circuits used in microelectronics and also in data processing and telecommunication systems. Optocouplers are used to an increasing extent as safety tested components, e. g., in switchmode power supplies.

Design

An optocoupler has to fulfill 5 essential requirements:

- Good insulation behavior
- High current transfer ratio (CTR)
- Low degradation

- Low coupling capacitance
- No uncontrolled function by field strength influences

These factors are essentially dependent on the design, the materials used and the corresponding chips used for the emitter/receiver.

TEMIC has succeeded in achieving a design with optimized insulation behavior and good transfer characteristics.

TEMIC offers various mechanical designs. The 6-lead DIP package optocoupler is used most widely throughout the world.

Since this design deviates fundamentally from manufacturers' designs, it is necessary to explain its characteristics.

In TEMIC's 6-lead DIP couplers, the emitter and receiver chips are placed side by side. A semi-ellipsoid with best reflection capabilities is fitted over both chips. The entire system is then cast in a plastic material impermeable to the infrared range and of high dielectric strength. The whole system is enveloped in a light-proof plastic compound to ensure that no external influences such as light or dust, etc. will disturb the coupler, see figure 6.

The design offers several advantages in comparison to conventional coupler designs.

The mechanical clearance between the emitter and receiver is 0.75 mm and is thus mechanically stable even under thermal overloads, i.e., the possibility of a short circuit caused by material deformation is excluded. This is important for optocouplers which have to fulfill strict safety requirements (VDE/UL specifications), see VDE0884 Facts and Information.

Thanks to their large clearance these couplers have a very low coupling capacity of 0.2 pF. Couplers with conventional designs, i.e., where the emitter and receiver are fitted "face-to-face" (figure 7), have higher coupling capacitance values by a factor of 1.3 - 2. Attention must be paid to the coupling capacitance in digital circuits in which steep pulse edges are produced which superimpose themselves on the control signal. With a low coupling capacitance, the transmission capabilities of these interference spikes are effectively suppressed between the input and output because a coupler should only transmit the effective signal. This capability of suppressing dynamic interferences is commonly known as "common-mode rejection".
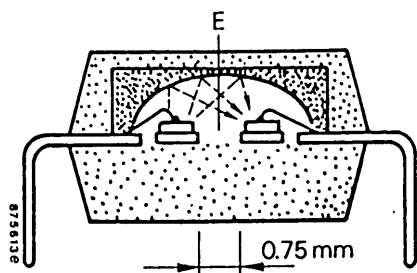

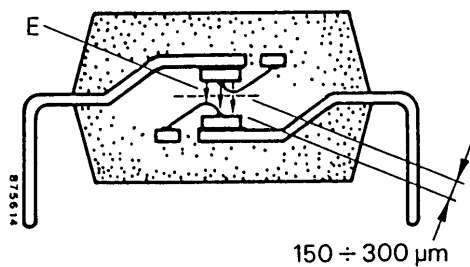Figure 6. Inline emitter and transmitter chip design (e.g., CQY80N)

Figure 7. Face-to-face design

Due to the special design of these couplers, the receiver surface is outside the area of the direct field strength. Field strength is produced when there is a voltage potential between the coupler's input and output. It causes the migration of positive ions to the transistor's surface. Positive ions perform on the base in the same way as a gate voltage applied to an n-channel FET transistor (see figure 8).

If inversions occur on the surface, the phototransistor becomes forward-biased, causing an inadmissible residual collector-emitter current. As a result, controlled functioning of the coupler is no longer guaranteed (figure 8). This effect occurs mainly whenever the receiver is within the field strength potential. The manufacturer should create suitable protective measures in this case. Using TEMIC's optocouplers, such protective measures are not necessary thanks to their perfect design.

The degradation of an optocoupler, i.e., impairment of its CTR over a finite period, depends on two factors. On the one hand, it depends on the emitter element due to its decreasing radiation power while, on the other hand, it depends on ageing or opaqueness of the synthetic resin which must transmit the radiation from the emitter to the receiver. A decrease in the radiation power can be primarily ascribed to thermal stress caused by an external, high ambient temperature and/or high a forward current. In practice, optocouplers are operated with forward current of 1 to 30 mA through the emitting diode. In this range, degradation at an average temperature of 40°C is less than 5% after 1000 h. If we compare this value with the service life requirements applicable to transistors for high grade systems (such as those used in telecommunication system standards), the optocoupler takes a good position with such degradation values. The Deutsche Bundespost, for example, permits a B-drift of no more than 20% for transistors with a maximum testing time of 2000 h. In general, an optocoupler's life time is a period of 150.000 h, i.e, the CTR should not have dropped below 50% of its value at 0 hours during this time (see figure 9).
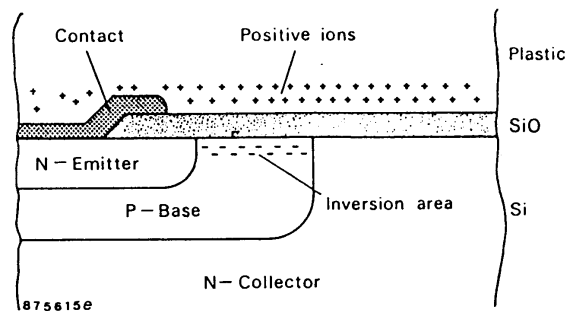

Figure 8. Functions of parasitic field effect transistor as a result of failure (latch-up) in the phototransistor of couplers
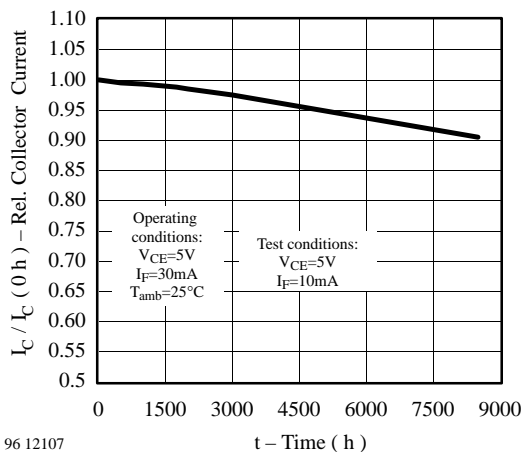
Figure 9. Degradation under typical operating conditions with reference to the CQY80N

Technical Description – Assembly

Emitter

Emitters are manufactured using the most modern Liquid Phase Epitaxy (LPE) process. By using this technology, the number of undesirable flaws in the crystal is reduced. This results in a higher quantum efficiency and thus higher radiation power. Distortions in the crystal are prevented by using mesa technology which leads to lower degradation. A further advantage of the mesa technology is that each individual chip can be tested optically and electrically even on the wafer.

Detector

TEMIC detectors have been developed so that they match perfectly to the emitter. They have low capacitance values, high photosensitivity and are designed for an extremely low saturation voltage.

Silicon nitride passivation protects the surface against possible impurities.

Assembly

The components are fitted onto lead frames by fully automatic equipment using conductive epoxy adhesive. Contacts are established automatically with digital pattern recognition using the well-proven thermosonic technique. In addition to optical and mechanical checks, all couplers are measured at a temperature of 100°C.

Conversion Tables – Optoelectronic General

Table 1. Corresponding radiometric and photometric definitions, symbols and units (DIN 5031, Part 1, 3)

Radiometric Units			Photometric Units			Note
Unit	Symbol	Unit	Unit	Symbol	Unit	
Radiant flux, Radiant power	Φ_e	Watt, W	Luminous flux	Φ_v	lumen, lm	Power
Radiant exitance, Exitance	M_e	W/m^2	Luminous emittance	M_v	lm/m^2	Output power per unit area
(Radiant) intensity	I_c	W/sr	(Luminous) intensity	I_v	Candela, cd, lm/sr	Output power per unit solid angle
Radiant sterance, Radiance	L_e	$\dfrac{W}{sr^*m^2}$	Luminance (Brightness sterance)	L_v	cd/m^2	Output power per unit solid angle and emitting areas
Radiant incidance, Irradiance	E_e	W/m^2	Illuminance	E_v	lm/m^2 Lux, lx	Input power per unit area
Radiant energy	Q_e	Ws	Luminous energy	Q_v	lm s	Power $\times$ time
Irradiation	H_e	Ws/m^2	Illumination	H_v	lm s/m^2	Radiant energy or luminous energy per unit area

Measurement Techniques

Introduction

The characteristics given in the optocoupler's data sheets are verified either by 100% production tests followed by statistic evaluation or by sample tests on typical specimens. Possible tests are the following:

- Measurements on emitter chip

- Measurements on detector chip

- Static measurements on optocoupler

- Measurement of switching characteristics, cut-off frequency and capacitance

- Thermal measurements

The basic circuits used for the most important measurements are shown in the following sections, although these circuits may be modified slightly to cater for special measurement requirements.

Measurements on Emitter Chip

Forward- and Reverse Voltage Measurements

The forward voltage, V_F, is measured either on a curve tracer or statically using the circuit shown in figure 10. A specified forward current (from a constant current source) is passed through the device and the voltage developed across it is measured.

To measure the reverse voltage, V_R, a 100 μA reverse current from a constant current source is applied to the diode (figure 11) and the voltage developed across it is measured on a voltmeter of extremely high input impedance (≥ 10 MΩ).

Measurements on Detector Chip

V_{CEO} and I_{CEO} Measurements

The collector-emitter voltage, V_{CEO}, is measured either on a transistor curve tracer or statically using the circuit shown in figure 12.

The collector dark current, I_{CEO}, must be measured in complete darkness (figure 13). Even ordinary daylight illumination might cause wrong measurement results.
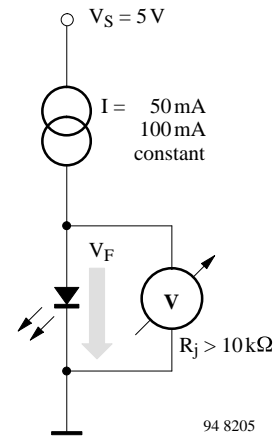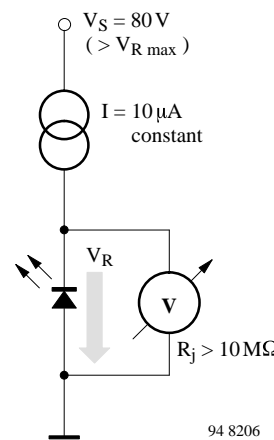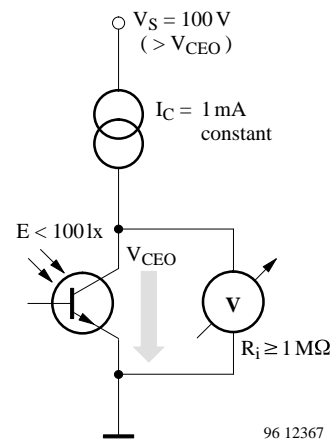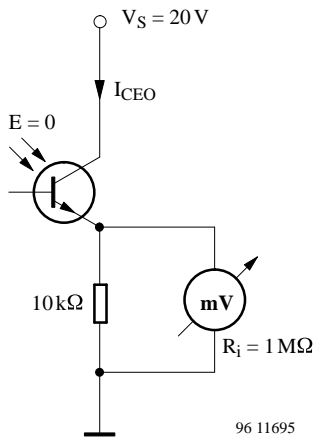

Figure 10.

Figure 11.

Figure 12.

Figure 13.

Figure 14.

Static Measurements

To measure the collector current, I_C (figure 14), a specified forward current, I_F, is applied to the lR diode. Voltage drop is then measured across a low-emitter resistance.

In the case of collector-emitter saturation voltage, V_{CEsat} (figure 15), a forward current, I_F, is applied to the IR diode and a low collector current, I_C, in the phototransistor. V_{CEsat} is then measured across collector and emitter terminals as shown in figure 15.

Figure 15.

Switching Characteristics

Definition

Each electronic device generates a certain delay between input and output signals as well as a certain amount of amplitude distortion. A simplified circuit (figure 16) shows how the input and output signals of optocouplers can be displayed on a dual-trace oscilloscope.

The following switching characteristics can be determined by comparing the timing of the output current waveform to that of the input current waveform (figure 17).
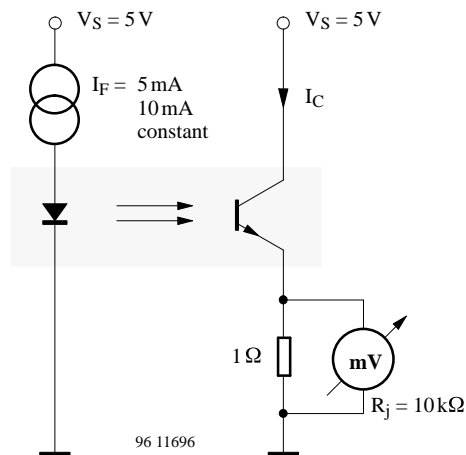
Figure 16.

96 11698

t_p	pulse duration
t_d	delay time
t_r	rise time
t_{on} $(= t_d + t_r)$	turn-on time
t_s	storage time
t_f	fall time
t_{off} $(= t_s + t_f)$	turn-off time
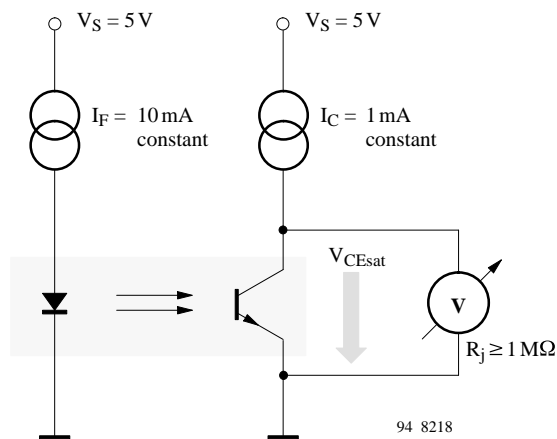
Figure 17.

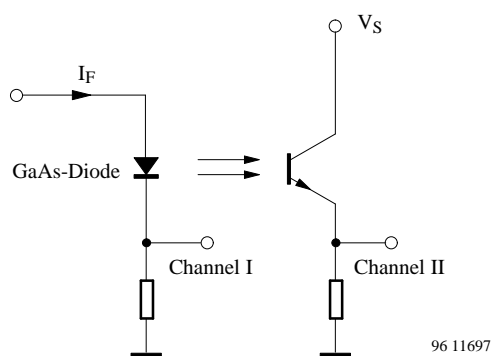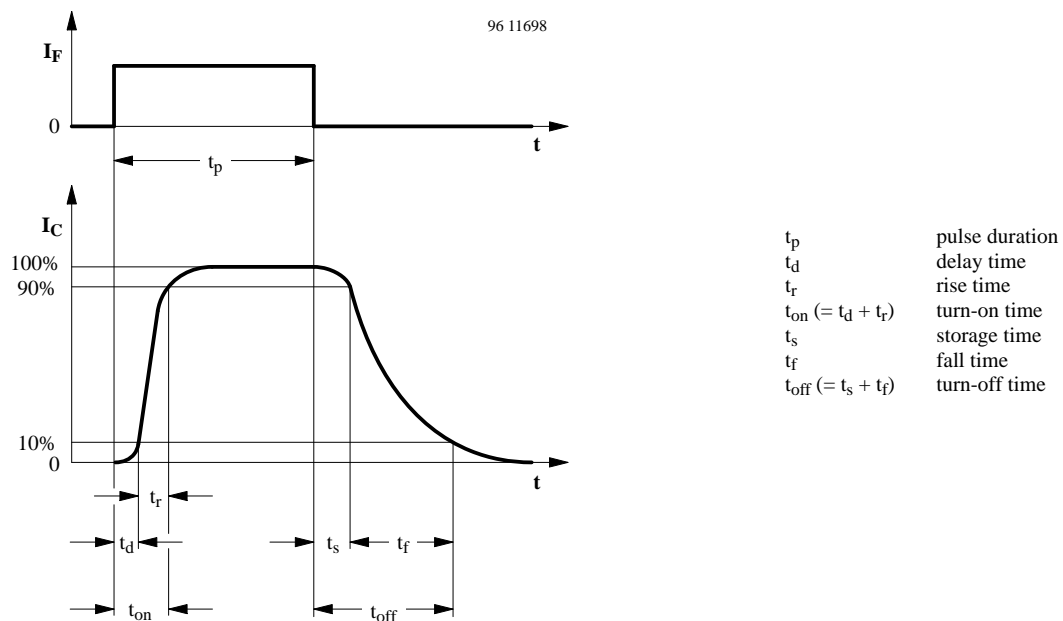## Improvements of Switching Characteristics of Phototransistors and Darlington Photo-transistors

With normal transistors, switching tunes can be reduced if the drive signal level and hence the collector current is increased. Another time reduction (especially in fall time t_f) can be achieved by using a suitable base resistor. However, this can only be done at the expense of a decreasing CTR.

TEMIC
Semiconductors

Taping of SMD Couplers

TEMIC couplers in SMD packages are available in an anti-static 12 mm blister tape (in accordance with DIN IEC 286-3) for automatic component insertion.

The blister tape is a plastic strip with impressed component cavities, covered by a top tape. For orders add "GS12" to the part number, e.g., TCMT1020GS12.
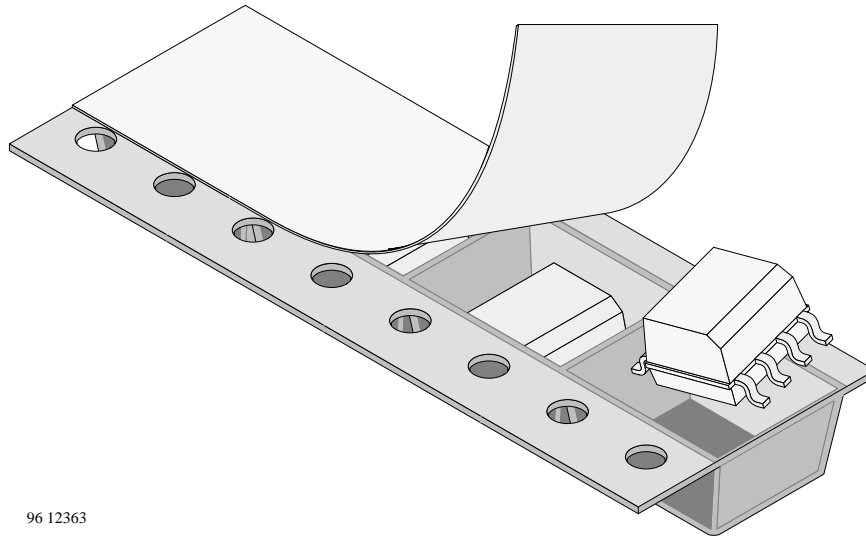
96 12363

Figure 18. Blister tape
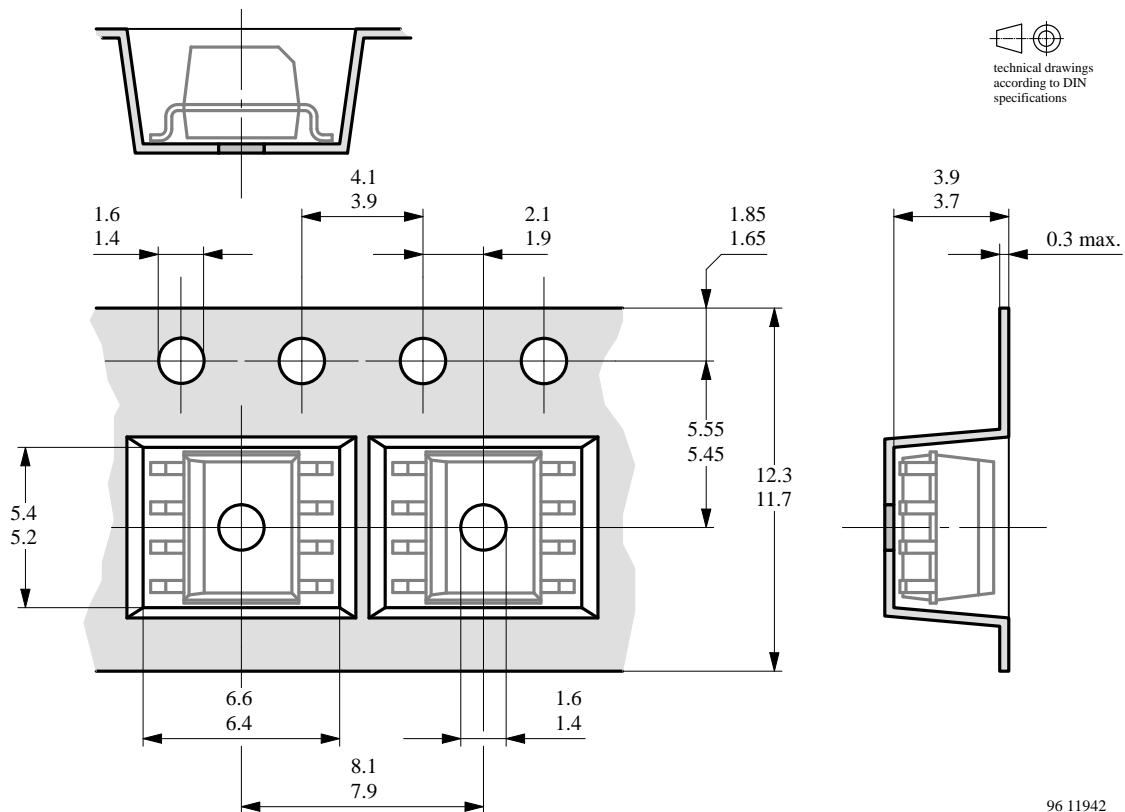
technical drawings
according to DIN
specifications

Figure 19. Tape dimensions in mm

96 11942

Number of Components   Quantity per reel: 2000 pcs   (minimum quantities for order)

Technical Information

Peel test requirement: 50 ± 20 gm
Temperature/ Pressure settings:

	Seal pressure	Real temperature
Wheel pressure	front/ rear	front/ rear
25 – 30 psi	35 psi	145 – 150°C

Production run quantity:

Trailer	Production units	Leader
38 pcs – 300 mm min.	2000 pcs	63 pcs – 500 mm min.

De-reeling direction   94 8158

≥ 160 mm   40 empty compartments   min. 75 empty compartments

Tape leader   Carrier leader   Carrier trailer
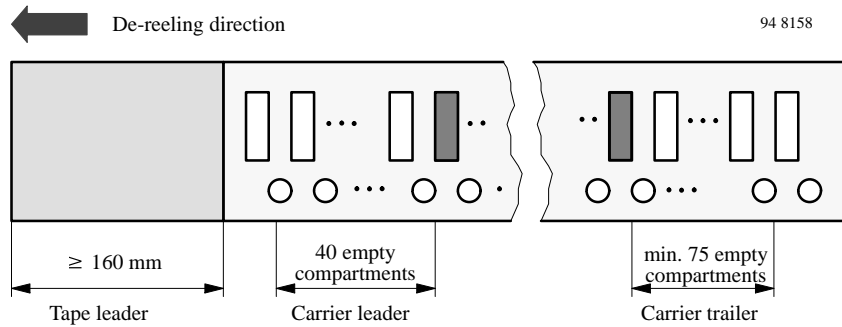
Figure 20. Beginning and end of reel

W₁

34.0
32.0

N

2.5
1.5

21.5
20.5

12.90
12.75

95 10518

W₂

Figure 21. Reel dimensions

TEMIC
Semiconductors
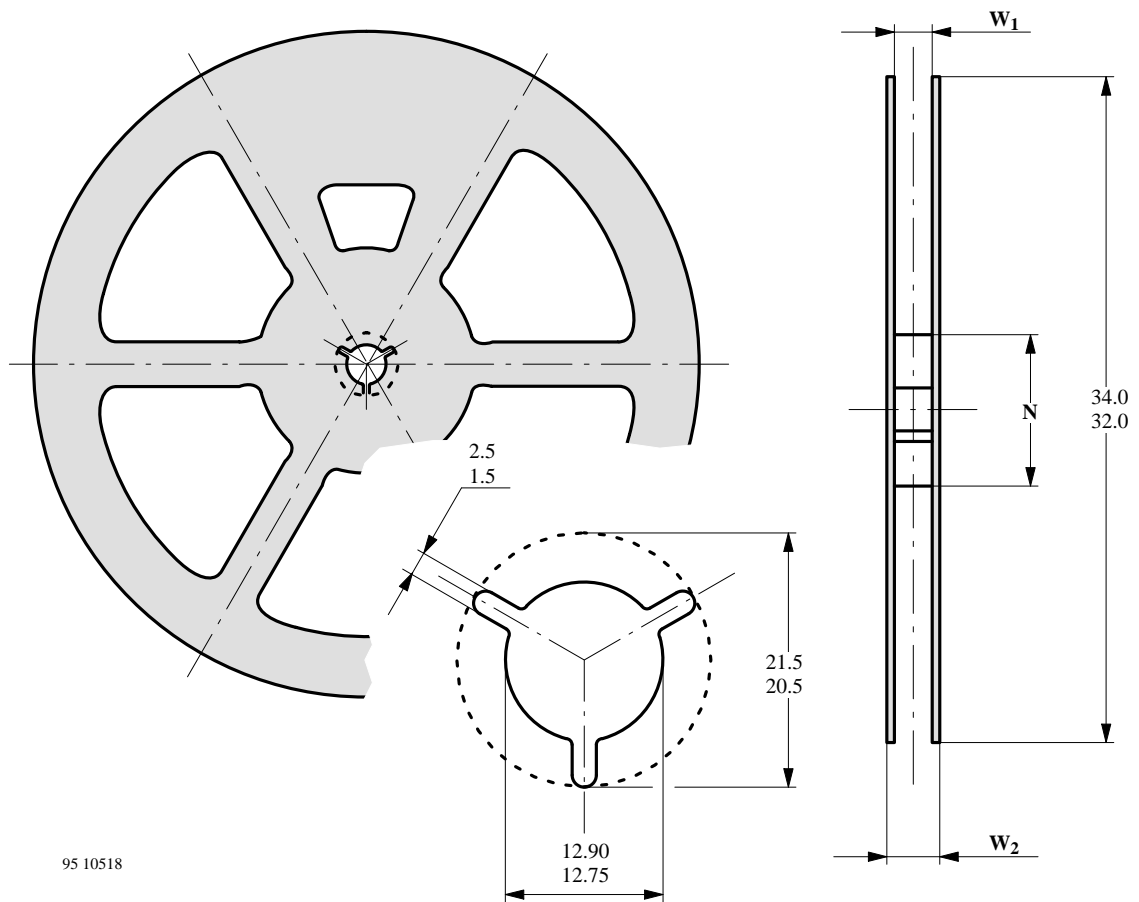
Missing Devices

A maximum of 0.5% of the total number of components per reel may be missing, exclusively missing components at the beginning and at the end of the reel. Maximum of three consecutive components may be missing, provided this gap is followed by six consecutive compartments.
The tape leader is at least 160 mm and is followed by a carrier leader with at least 10 and not more than 20 empty compartments. The tape leader may include the carrier trailer, providing the two are not connected together. The last component is followed by a carrier tape trailer with at least 10 empty compartments and is sealed with cover tape.

Top Tape Removal Force

The removal force lies between 0.1 N and 1.0 N at a removal speed of 5 mm/s.
In order to prevent the components from popping out of the blisters, the top tape must be pulled off at an angle of 180°C with respect to the feed direction.

Ordering Designation

The type designation of the device in SO8 package is given by the appendix number: GS12.

Example: TCMT1020-GS12

Assembly Instructions

General

Optoelectronic semiconductor devices can be mounted in any position.
Connecting wires of less than 0.5 mm diameter may be bent, provided the bend is not less than 1.5 mm from the bottom of the case and no mechanical stress has an affect on it. Connection wires of larger diameters, should not be bent.
If the device is to be mounted near heat-generating components, consideration must be given to the resultant increase in ambient temperature.

Soldering Instructions

Protection against overheating is essential when a device is being soldered. Therefore, the connection wires should be left as long as possible. The time during which the specified maximum permissible device junction temperature is exceeded at the soldering process should be as short as possible (one minute maximum). In the case of plastic encapsulated devices, the maximum permissible soldering temperature is governed by the maximum permissible heat that may be applied to the encapsulant rather than by the maximum permissible junction temperature.
The maximum soldering iron (or solder bath) temperatures are given in table 2. During soldering, no forces must be transmitted from the pins to the case (e.g., by spreading the pins).

Table 2. Maximum soldering temperatures

	Iron Soldering			Wave or Reflow Soldering		
	Iron Temperature	Distance of the Soldering Position from the Lower Edge of the Case	Maximum Allowable Soldering Time	Soldering Temperature see temperature/time profiles	Distance of the Soldering Position from the Lower Edge of the Case	Maximum Allowable Soldering Time
Devices in metal case	$\leqq 245°C$ $\leqq 245°C$ $\leqq 350°C$	$\geqq 1.5$ mm $\geqq 5.0$ mm $\geqq 5.0$ mm	5 s 10 s 5 s	245°C 300°C	$\geqq 1.5$ mm $\geqq 5.0$ mm	5 s 3 s
Devices in plastic case ≥ 3 mm	$\leqq 260°C$ $\leqq 300°C$	$\geqq 2.0$ mm $\geqq 5.0$ mm	5 s 3 s	235°C 260°C	$\geqq 2.0$ mm $\geqq 2.0$ mm	8 s 5 s
Devices in plastic case <3 mm	$\leqq 300°C$	$\geqq 5.0$ mm	3 s	260°C	$\geqq 2.0$ mm	3 s

Soldering Methods

There are several methods for soldering devices onto the substrate. The following list is not complete.

(a)   Soldering in the vapor phase

Soldering in saturated vapor is also known as condensation soldering. This soldering process is used as a batch system (dual vapor system) or as a continuous single vapor system. Both systems may also include a pre-heating of the assemblies to prevent high temperature shock and other undesired effects.

(b)   Infrared soldering

By using infrared (IR) reflow soldering, the heating is contact-free and the energy for heating the assembly is derived from direct infrared radiation and from convection.

The heating rate in an IR furnace depends on the absorption coefficients of the material surfaces and on the ratio of component's mass to an As-irradiated surface.

The temperature of parts in an IR furnace, with a mixture of radiation and convection, cannot be determined in advance. Temperature measurement may be performed by measuring the temperature of a certain component while it is being transported through the furnace.

The temperatures of small components, soldered together with larger ones, may rise up to 280°C.

Influencing parameters on the internal temperature of the component are as follows:

- Time and power
- Mass of the component
- Size of the component
- Size of the printed circuit board
- Absorption coefficient of the surfaces
- Packing density
- Wavelength spectrum of the radiation source
- Ratio of radiated and convected energy

Temperature/time profiles of the entire process and the influencing parameters are given in figure 26.

(c)   Wave soldering

In wave soldering one or more continuously replenished waves of molten solder are generated, while the substrates to be soldered are moved in one direction across the crest of the wave.

Temperature/time profiles of the entire process are given in figure 26.

(d)   Iron soldering

This process cannot be carried out in a controlled situation. It should therefore not be used in applications where reliability is important. There is no SMD classification for this process.

(e)   Laser soldering

This is an excess heating soldering method. The energy absorbed may heat the device to a much higher temperature than desired. There is no SMD classification for this process at the moment.

(f)   Resistance soldering

This is a soldering method which uses temperature-controlled tools (thermodes) for making solder joints. There is no SMD classification for this process at the moment.
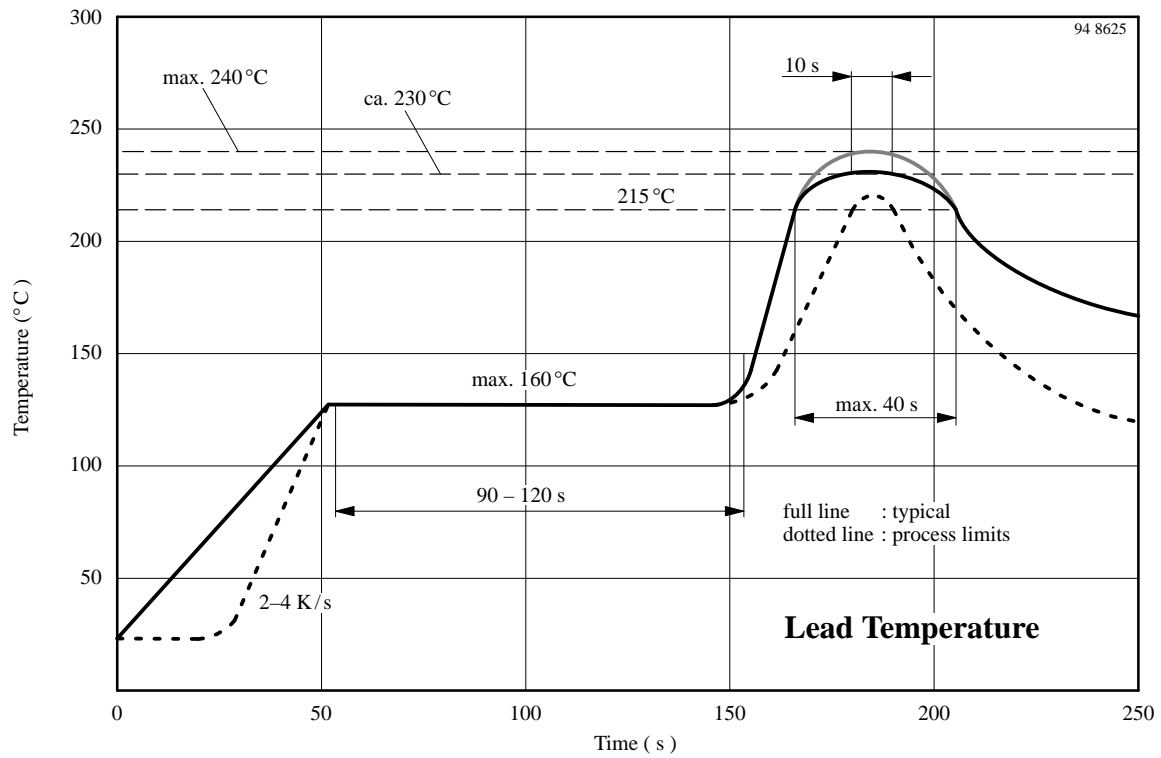
Temperature-Time Profiles

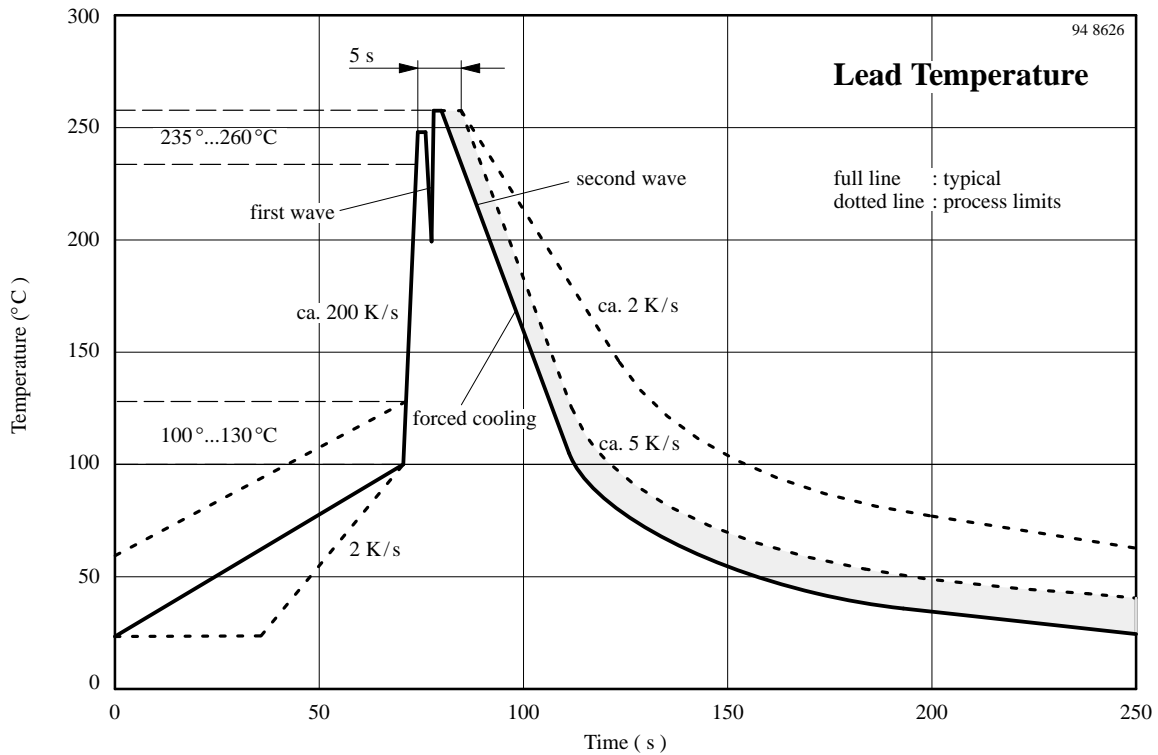Figure 22. Infrared reflow soldering optodevices (SMD package)

Figure 23. Wave soldering double wave optodevices

Heat Removal

The heat generated in the semiconductor junction(s) must be moved to the ambient. In the case of low-power devices, the natural heat conductive path between case and surrounding air is usually adequate for this purpose.

In the case of medium-power devices, however, heat conduction may have to be improved by the use of star- or flag-shaped heat dissipators which increase the heat radiating surface.

The heat generated in the junction is conveyed to the case or header by conduction rather than convection; a measure of the effectiveness of heat conduction is the inner thermal resistance or thermal resistance junction case, R_{thJC}, whose value is given by the construction of the device.

Any heat transfer from the case to the surrounding air involves radiation convection and conduction, the effectiveness of transfer being expressed in terms of an R_{thCA} value, i.e., the case ambient thermal resistance. The total thermal resistance, junction ambient is therefore:

$$R_{thJA} = R_{thJC} + R_{thCA}$$

The total maximum power dissipation, P_{totmax}, of a semiconductor device can be expressed as follows:

$$P_{totmax} = \frac{T_{jmax} - T_{amb}}{R_{thJA}} = \frac{T_{jmax} - T_{amb}}{R_{thJC} + R_{thCA}}$$

where:

T_{jmax} the maximum allowable junction temperature

T_{amb} the highest ambient temperature likely to be reached under the most unfavourable conditions

R_{thJC} the thermal resistance, junction case

R_{thJA} the thermal resistance, junction ambient

R_{thCA} the thermal resistance, case ambient, depends on cooling conditions. If a heat dissipator or sink is used, then R_{thCA} depends on the thermal contact between case and heat sink, heat propagation conditions in the sink and the rate at which heat is transferred to the surrounding air.

Therefore, the maximum allowable total power dissipation for a given semiconductor device can be influenced only by changing T_{amb} and R_{thCA}. The value of R_{thCA} could be obtained either from the data of heat sink suppliers or through direct measurements.

In the case of cooling plates as heat sinks, the approach outlines in figures 25 and 26 can be used as guidelines. The curves shown in both figures 25 and 26 give the thermal resistance R_{thCA} of square plates of aluminium with edge length, a, and with different thicknesses. The

case of the device should be mounted directly onto the cooling plate.

The edge length, α, derived from figures 25 and 26 in order to obtain a given R_{thCA} value, must be multiplied with α and β:

$$\alpha' = \alpha \times \beta \times \alpha$$

where

$\alpha = 1.00$ for vertical arrangement

$\alpha = 1.15$ for horizontal arrangement

$\beta = 1.00$ for bright surface

$\beta = 0.85$ for dull black surface

Example

For an IR emitter with $T_{jmax} = 100°C$ and $R_{thJC} = 100$ K/W, calculate the edge length for a 2 mm thick aluminium square sheet having a dull black surface ($\beta = 0.85$) and vertical arrangement ($\alpha = 1$), $T_{amb} = 70°C$ and $P_{tot\,max} = 200$ mW.

$$P_{tot\,max} = \frac{T_{jmax} - T_{amb}}{R_{thJC} + R_{thCA}}$$

$$R_{thCA} = \frac{T_{jmax} - T_{amb}}{P_{tot\,max}} - R_{thJC}$$

$$R_{thCA} = \frac{100°C - 70°C}{0.2\ W} - 100\ K/W$$

$$R_{thCA} = \frac{30}{0.2} - 100\ K/W$$

$$R_{thCA} = 50\ K/W$$

$$\Delta T = T_{case} - T_{amb}$$

can be calculated from the relationship :

$$P_{tot\,max} = \frac{T_{jmax} - T_{amb}}{R_{thJC} + R_{thCA}} = \frac{T_{case} - T_{amb}}{R_{thCA}}$$

$$\Delta T = T_{case} - T_{amb} = \frac{R_{thCA} \times (T_{jmax} - T_{amb})}{R_{thJC} + R_{thCA}}$$

$$\Delta T = \frac{50\ K/W \times (100°C - 70°C)}{100\ K/W + 50\ K/W}$$

$$\Delta T = \frac{50\ K/W \times 30°C}{150\ K/W}$$

$$\Delta T = 10°C = 10\ K$$

94 7834

Figure 24.

94 7835
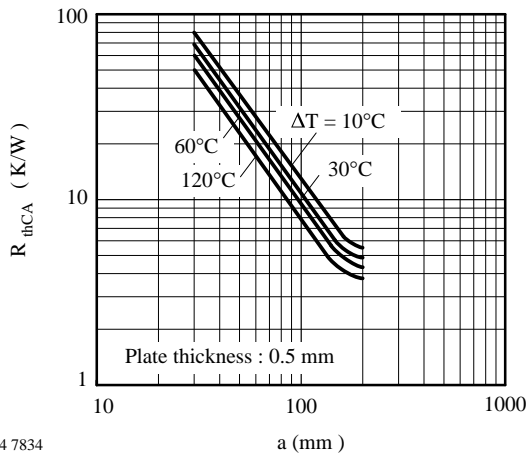
Figure 25.

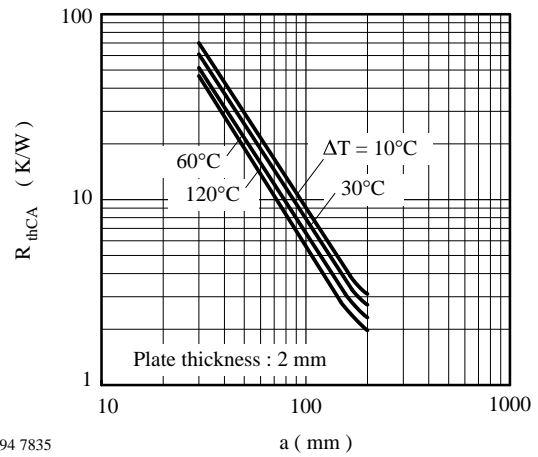With $R_{thCA} = 50$ k/W and $\Delta T = 10°C$, a plate of 2 mm thickness has an edge length $\alpha = 28$ mm.

However, equipment life and reliability have to be taken into consideration and therefore a larger sink would normally be used to avoid operating the devices continuously at their maximum permissible junction temperature.

Handling Instructions

Protection against Electrostatic Damage

Although electrostatic breakdown is most often associated with IC semiconductor devices, optoelectronic devices are also prone to such a breakdown. Miniaturized and highly integrated components are particularly sensitive.

Sensitivity

Breakdown Voltages

Typical electrostatic voltages in the working environment can easily reach several thousand volts, well above the level required to cause a breakdown. As market requirements are moving towards greater miniaturization, lower power consumption, and higher speeds, optoelectronic devices are becoming more integrated and delicate. This means that they are becoming increasingly sensitive to electrostatic effects.

Device Breakdown

Electrostatic discharge events are often imperceptible. This might cause the following problems.

Delay Failure

Electrostatic discharge may damage the device or change its characteristics without causing immediate failure. The device may pass inspection, move into the market, then fail during its initial period of use.

Difficulty in Identifying Discharge Site

Human beings generally cannot perceive electrostatic discharges of less than 3000 V, while semiconductor devices can sustain damage from electrostatic voltages as low as 100 V. It is often very difficult to locate the process at which electrostatic problems occur.

Basic Countermeasures

Optoelectronic devices must be protected from static electricity at all stages of processing. Each device must be protected from the time it is received until the time it has been incorporated into a finished assembly. Each processing stage should incorporate the following measures.

Suppression of Electrostatic Generation

Keep relative humidity at 50 to 70% (if humidity is above 70%, morning dew may cause condensation).

Remove materials which might cause electrostatic generation (such as synthetic resins) from your workplace. Check the appropriateness of floor mats, clothing (uniforms, sweaters, shoes), parts trays, etc.

Use electrostatically safe equipment and machinery.

Removal of Electrostatic Charges

Connect conductors (metals, etc.) to ground, using dedicated grounding lines. To prevent dangerous shocks and damaging discharge surges, insert a resistance of 800 kΩ between conductor and grounding line.

Connect conveyors, solder baths, measuring machines, and other equipment to ground, using dedicated, grounding lines.

Use ionic blowers to neutralize electrostatic charges on insulators. Blowers pass charged air over the targeted object, neutralizing the existing charge. They are useful for discharging insulators or other objects that cannot be effectively grounded.

Human Electrostatic

The human body readily picks up electrostatic charges, and there is always some risk that human operators may cause electrostatic damages to the semiconductor devices they handle. The following counter measures are essential.

Anti-Static Wrist Straps

All people who come into direct contact with semiconductors should wear anti-static wrist straps, i.e., those in charges of parts supply and people involved in mounting, board assembly and repair.

Be sure to insert a resistance of 800 kΩ to 1 MΩ into the straps. The resistance protects against electrical shocks and prevents instantaneous and potentially damaging discharges from charged semiconductor devices.

Be sure that the straps are placed directly next to the skin, placing them over gloves, uniforms or other clothing reduces their effectiveness.

Antistatic Mats, Uniforms and Shoes

The use of anti-static mats and shoes is effective in places where use of a wrist strap is inconvenient (for example, when placing boards into returnable boxes). To prevent static caused by friction with clothing, personnel should wear anti-static uniforms, gloves, sleeves aprons, finger covers, or cotton apparel.

Protection during Inspection, Mounting and Assembly

The personnel has to ensure that hands do not come into direct contact with leads. Avoid non-conductive finger covers. Cover the work desk with grounded anti-static mats.

Storage and Transport

Always use conductive foams, tubes, bags, reels or trays when storing or transporting semiconductor devices.

TEMIC
Semiconductors

Mounting Precautions

Installation

Installation on PWB

When mounting a device on PWB whose pin-hole pitch does not match the lead pin pitch of the device, reform the device pins appropriately so that the internal chip is not subjected to physical stress.

Installation Using a Device Holder

Emitters and detectors are often mounted using a holder. When using this method, make sure that there is no gap between the holder and device.

Installation Using Screws

When lead soldering is not adequate to securely retain a photointerrupter, it may be retained with screws.

The tightening torque should not exceed 6 kg/cm^3. An excessive tightening torque may deform the holder, which results in poor alignment of the optical axes and degrades performance.

Lead Forming

Lead pins should be formed before soldering. Do not apply forming stress to lead pins during or after soldering. For light emitters or detectors with lead frames, lead pins should be formed just beneath the stand-off cut section. For optocouplers or optosensors using dual-in-line packages, lead pins should be formed below the bent section so that forming stress does not affect the inside of the device. Stress to the resin may result in disconnection.

When forming lead pins, do not bend the same portion repeatedly, otherwise the pins may break.

Cleaning

General

Optoelectronic devices are particularly sensitive with regard to cleaning solvents. The Montreal Protocol for environmental protection calls for a complete ban on the use of chlorofluorocarbons. Therefore, the most harmless chemicals for optoelectronic devices should be used for environmental reasons. The best solution is to use a modem reflow paste or solder composition which does not require a cleaning procedure. No cleaning is required when the fluxes are guaranteed to be non-corrosive and of high, stable resistivity.

Cleaning Procedures

Certain kinds of cleaning solvents can dissolve or penetrate the transparent resins which are used in some types of sensors. Even black molding components used in standard isolators are frequently penetrated between the mold compound and lead frame. Inappropriate solvents may also remove the marking printed on a device. It is therefore essential to take care when choosing solvents to remove flux.

Cleaning is not required if the flux in the solder material is non-aggressive and any residues are guaranteed to be non corrosive an longterm stable of high resistivity.

In cleaning procedures using wet solvents only high purity Ethyl and Isopropyl alcohol are recommended. The S-series of DIL isolators is also suited for cleaning in high purity water.

In each case, the devices are immersed in the liquid for typically 3 min. and afterwards immediately dried for at least 15 minutes at 50°C in dry air.

In table 3, appropriate cleaning procedures for various product lines are summarized.

Table 3. Appropriate cleaning procedures for several product lines

Cleaning Procedure		Product Lines			
Solvent	Procedure	DIL-Coupler		Sensors	High Voltage Couplers
		System "A"	System "S"		
—	No cleaning of solder materials	○	○	○	○
Ethylalcohol	Immersion + drying	○	○	○	○
Isopropylalcohol	Immersion + drying	○	○	○	○
Water	Immersion + drying	—[1]	○	○	—

○   acceptable
—   not acceptable
[1]   acceptable only if transistor base is not connected to the outside

Precautions

Intensified cleaning methods such as ultrasonic cleaning, steam cleaning, and brushing can cause damage to opto-electronic devices. They are generally not recommended.

Ultrasonic cleaning (unless well controlled) can damage the devices due to its mechanical vibrations.

Using high-intensity ultrasonic cleaning, the process might:

a.   Promote dissolution or crack the package surface and thus affect the performance of e.g., the sensors

b.   Promote separation of the lead frame and resin and thus reduce humidity resistance.

c.   Promote the breakage of band wires

This method should only be used after extensive trials have been run to ensure that problems do not occur.

Brushing can scratch package surfaces. Moreover, it can remove printed markings.

Special care should be taken to use only high purity or chemically well-controlled solvents. Especially chloride ions from flux or solvents that remain in the package are a high risk for the long-time stability of any electronic device. These as well as other promote corrosion on the chip which can interrupt all bond connections to the outside leads.

Quality Information

TEMIC's Continuous Improvement Activities

- Quality training for ALL personnel including production, development, marketing and sales departments

- Zero defect mindset

- Permanent quality improvement process

- Total Quality Management (TQM)

- TEMIC's Quality Policy established by the Management Board

- Quality system certified per ISO 9001 on July 12, 1993 (Commercial Quality System)

- Quality system formerly approved per AQAP-1 (Military Quality System)

TEMIC Tools for Continuous Improvement

- TEMIC qualifies materials, processes and process changes.

- TEMIC uses Process FMEA (Failure Mode and Effects Analysis) for all processes. Process and machine capability as well as Gage R&R (Repeatability & Reproducibility) are proven.

- TEMIC's internal qualifications correspond to IEC 68–2 and MIL STD 883.

- TEMIC periodically requalifies device types (Short Term Monitoring, Long Term Monitoring).

- TEMIC uses SPC for significant production parameters. SPC is performed by trained operators.

- TEMIC's Burn-In of selected device types.

- TEMIC's 100% testing of final products.

- TEMIC's lot release is carried out via sampling. Sampling acceptance criterion is always c = 0.

TEMIC's Quality Policy

Our goal is to achieve total customer satisfaction
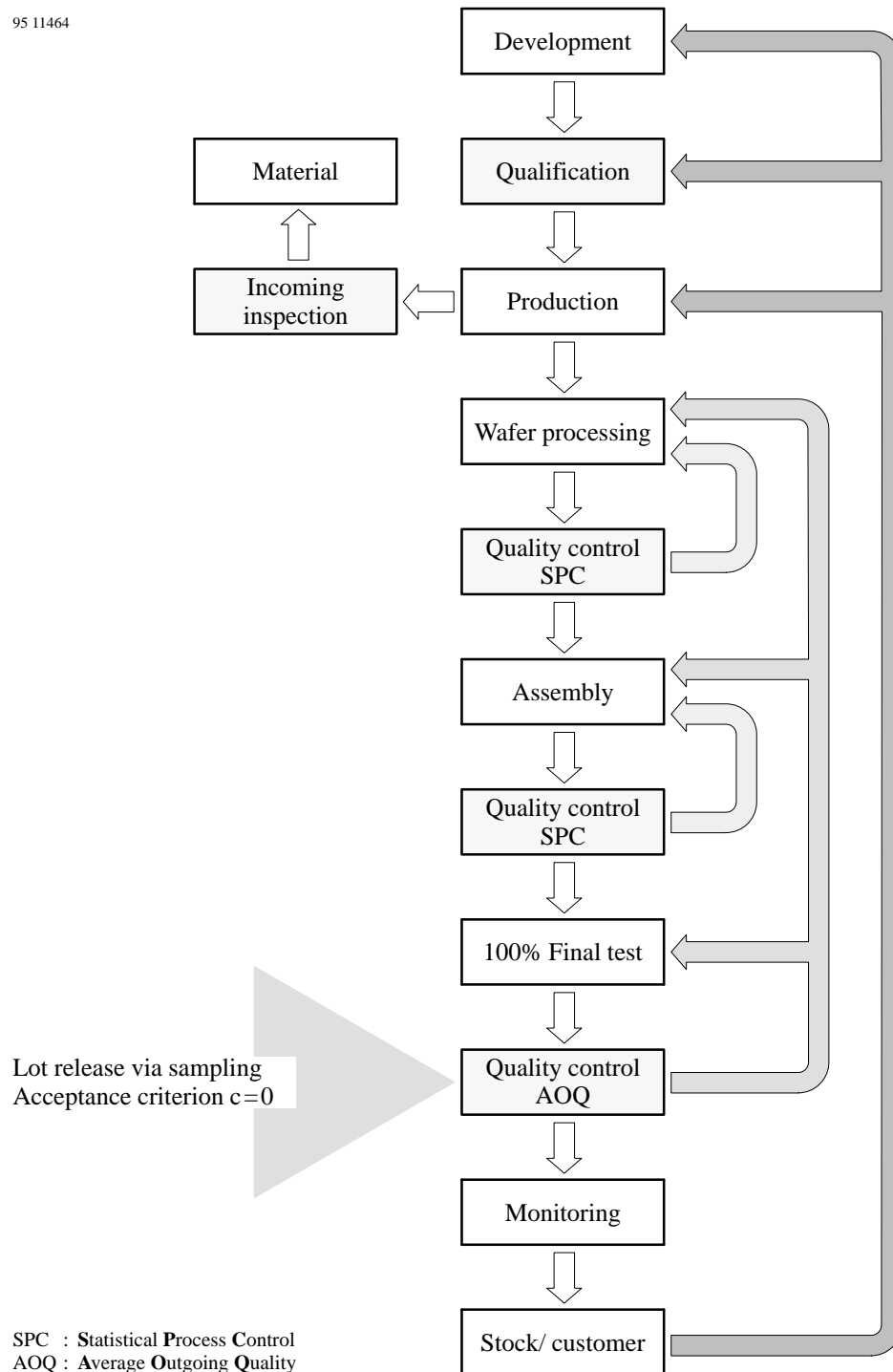
through everything we do.

Therefore, the quality of our products and services
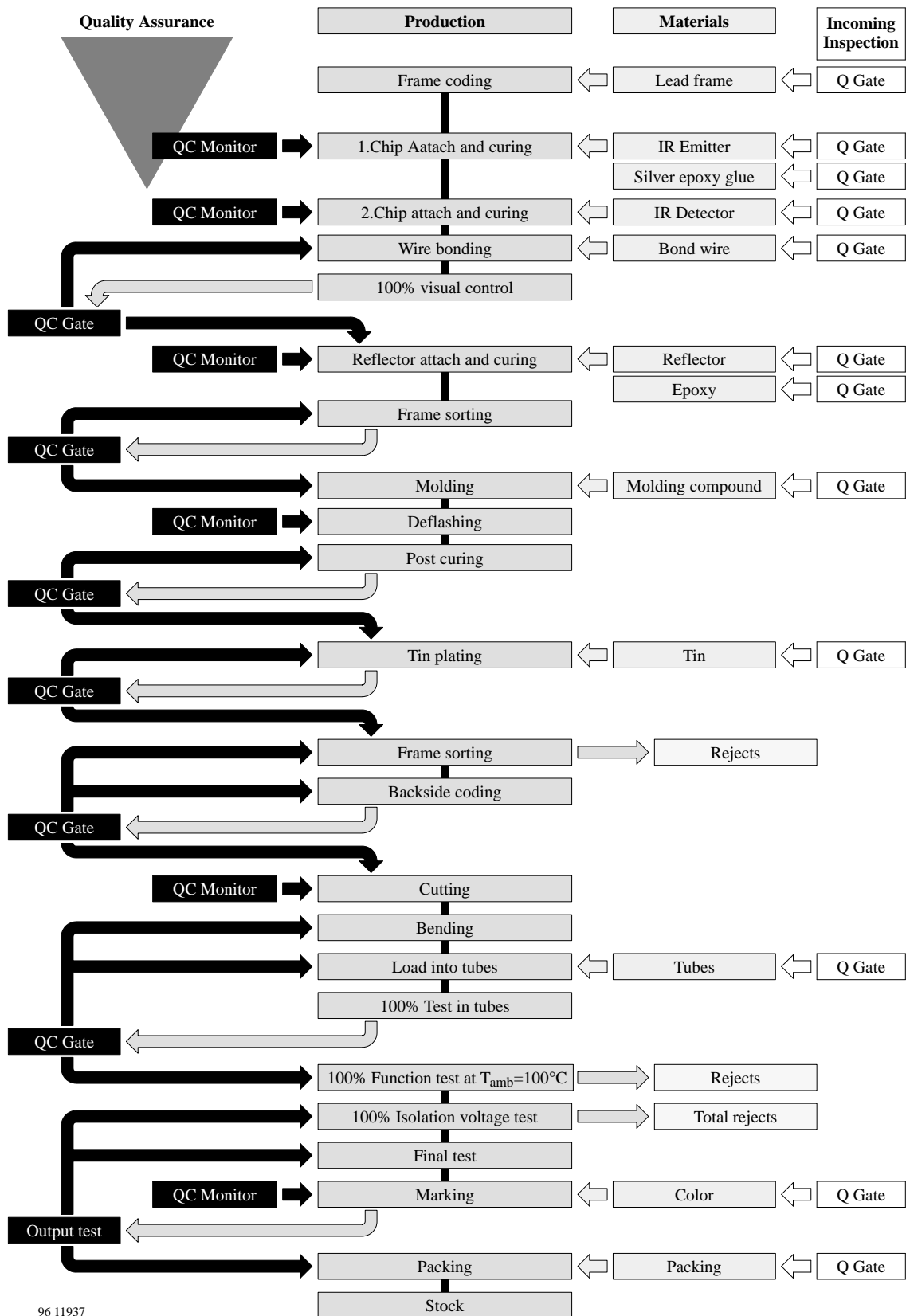
is our number one priority.

Quality comes first!

All of us at TEMIC are part of the process of

continuous improvement.

General Quality Flow Chart Diagram

95 11464

```
                                          Development  ◄──────┐
                                              │               │
                                              ▼               │
              Material          Qualification ◄───────────────┤
                 ▲                    │                       │
                 │                    ▼                       │
              Incoming  ◄──────  Production ◄─────────────────┤
             inspection              │                        │
                                     ▼                        │
                              Wafer processing ◄──────┐       │
                                     │                │       │
                                     ▼                │       │
                              Quality control ────────┤       │
                                  SPC                 │       │
                                     │                │       │
                                     ▼                │       │
                               Assembly ◄─────────────┤       │
                                     │                │       │
                                     ▼                │       │
                              Quality control ────────┘       │
                                  SPC                         │
                                     │                        │
                                     ▼                        │
                              100% Final test ◄───────────────┤
                                     │                        │
                                     ▼                        │
   Lot release via sampling   Quality control ────────────────┤
   Acceptance criterion c=0       AOQ                         │
                                     │                        │
                                     ▼                        │
                               Monitoring                     │
                                     │                        │
                                     ▼                        │
                              Stock/ customer ────────────────┘
```

SPC : **S**tatistical **P**rocess **C**ontrol
AOQ : **A**verage **O**utgoing **Q**uality

TEMIC
Semiconductors

Process Flow Charts

Quality Assurance	Production	Materials	Incoming Inspection
	Frame coding	Lead frame	Q Gate
QC Monitor	1.Chip Aatach and curing	IR Emitter	Q Gate
		Silver epoxy glue	Q Gate
QC Monitor	2.Chip attach and curing	IR Detector	Q Gate
	Wire bonding	Bond wire	Q Gate
	100% visual control		
QC Gate			
QC Monitor	Reflector attach and curing	Reflector	Q Gate
		Epoxy	Q Gate
	Frame sorting		
QC Gate			
	Molding	Molding compound	Q Gate
QC Monitor	Deflashing		
	Post curing		
QC Gate			
	Tin plating	Tin	Q Gate
QC Gate			
	Frame sorting	Rejects	
	Backside coding		
QC Gate			
QC Monitor	Cutting		
	Bending		
	Load into tubes	Tubes	Q Gate
	100% Test in tubes		
QC Gate			
	100% Function test at $T_{amb}=100°C$	Rejects	
	100% Isolation voltage test	Total rejects	
	Final test		
QC Monitor	Marking	Color	Q Gate
Output test			
	Packing	Packing	Q Gate
	Stock		

96 11937

Assembly Flow Chart for Standard Opto-Coupler

Frame	Diced Wafer		
	FG		
Frame Preparation	1st Optical	AQL	R
	Die Attach	SPC	
	Visual	AQL	R
	Wire Bond	SPC Pull Test Shear Test Rip/Peel Test	
	2nd Optical	AQL	R
	Reflector Load Heatstake /Casting	SPC	
	Visual	AQL	R
	Molding		
	Tin Plating		
	Visual	AQL	R
	Cutting	Monitor	
	Marking	Monitor	
	3rd Optical	AQL	R
	Burn–In		
	Electrical Test 100%	Sample Test AQL 0.065	
	Prepacking (Box)	SPC	
	Visual	AQL	R
	Final Packing Barcoding		
	CBW		

96 11938

Qualification and Release

New wafer processes, packages and device types are qualified according to the internal TEMIC Semiconductors specification QSA 3000.

QSA 3000 consists of five parts (see figure 27).

Wafer process release: The wafer process release is the fundamental release/qualification for the various technologies used by TEMIC Semiconductors. Leading device types are defined fo various technologies. Three wafer lots of these types are subjected to an extensive qualification procedure and are used to represent this technology. A positive result will release the technology.

Package release: The package release is the fundamental release/ qualification for the different packages used. Package groups are defined (see figure 27).

Critical packages are selected: two assembly lots are subjected to the qualification procedure representing that package group. A positive result will release all similar packages.

Device type release: The device type released is the release of individual designs.

Monitoring: Monitoring serves both as the continuous monitoring of the production and as a source of data for calculation of early failures (early failure rate: EFR).

Product or process changes are released via ECN (**E**ngineering **C**hange **N**ote). This includes proving process capability and meeting the quality requirements.

Test procedures utilized are IEC 68–2–... and MIL–STD–883 D respectively.
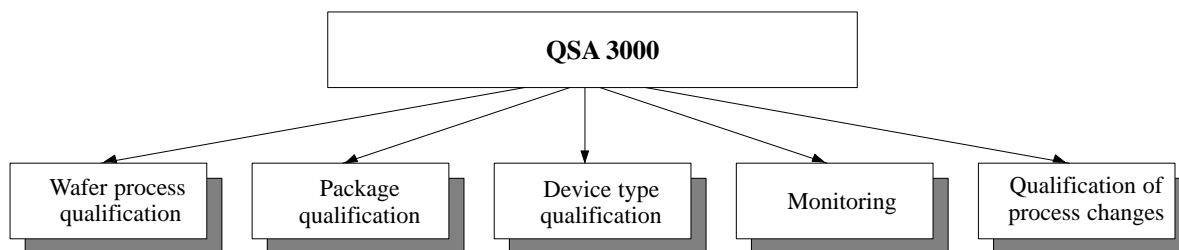
Figure 26. Structure of QSA 3000

Statistical Methods for Prevention

To manufacture high-quality products, it is not sufficient controlling the product at the end of the production process.

Quality has to be 'designed-in' during process- and product development. In addition to that, the 'designing-in' must also be ensured during production flow. Both will be achieved by means of appropriate measurements and tools.

- Statistical Process Control (SPC)
- R&R– (Repeatability and Reproducibility) tests
- Up– Time Control (UTC)
- Failure Mode and Effect Analysis (FMEA)
- Design Of Experiments (DOE)
- Quality Function Deployment (QFD)

TEMIC Semiconductors has been using SPC as a tool in production since 1990/91.

By using SPC, deviations from the process control goals are quickly established. This allows control of the processes before the process parameters run out of specified limits. To assure control of the processes, each process step is observed and supervised by trained personnel. Results are documented.

Process capabilities are measured and expressed by the process capability index (C_{pk}).

Validation of the process capability is required for new processes before they are released for production.

Before using new equipment and new gauges in production, machine capability (C_{mk} = machine capability index) or R&R (Repeatability & Reproducibility) is used to validate the equipment's fitness for use.

Up–Time is recorded by an Up–Time Control (UTC) system. This data determines the intervals for preventive maintenance, which is the basis for the maintenance plan.

A process–FMEA is performed for all processes (FMEA = Failure Mode and Effect Analysis). In addition, a design– or product– FMEA is used for critical products or to meet agreed customer requirements.

Design of Experiments (DOE) is a tool for the statistical design of experiments and is used for optimization of processes. Systems (processes, products and procedures) are analyzed and optimized by using designed experiments.

A significant advantage compared to conventional methods is the efficient perfomance of experiments with minimum effort by determining the most important inputs for optimizing the system.

As a part of the continuous improvement process, all TEMIC Semiconductors' employees are trained in using new statistical methods and procedures.

Reliability

The requirements concerning quality and reliability of products are always increasing. It is not sufficient to only deliver fault–free parts. In addition, it must be ensured that the delivered goods serve their purpose safely and failure free, i.e., reliably. From the delivery of the device and up to its use in a final product, there are some occasions where the device or the final product may fail despite testing and outgoing inspection.

In principle, this sequence is valid for all components of a product.

For these reasons, the negative consequences of a failure, which become more serious and expensive the later they occur, are obvious. The manufacturer is therefore interested in supplying products with the lowest possible

- AOQ (Average Outgoing Quality) value
- EFR (Early Failure Rate) value
- LFR (Long-term Failure Rate) value

Average Outgoing Quality (AOQ)

All outgoing products are sampled after 100% testing. This is known as "Average Outgoing Quality" (AOQ). The results of this inspection are recorded in ppm (parts per million) using the method defined in JEDEC 16.

Early Failure Rate (EFR)

EFR is an estimate (in ppm) of the number of early failures related to the number of devices used. Early failures are normally those which occur within the first 300 to 1000 hours. Essentially, this period of time covers the guarantee period of the finished unit. Low EFR values are therefore very important to the device user. The early life failure rate is heavily influenced by complexity. Consequently, 'designing-in' of better quality during the development and design phase, as well as optimized process control during manufacturing, significantly reduces the EFR value. Normally, the early failure rate should not be significantly higher than the random failure rate. EFR is given in ppm (parts per million).

Long-Term Failure Rate (LFR)

LFR shows the failure rate during the operational period of the devices. This period is of particular interest to the manufacturer of the final product. Based on the LFR value, estimations concerning long-term failure rate, reliability and a device's or module's usage life may be derived. The usage life time is normally the period of constant failure rate. All failures occuring during this period are random.

Within this period the failure rate is:

$$\lambda = \frac{\text{Sum of failures}}{\sum (\text{Quantity} \times \text{Time to failure})} \; \frac{1}{\text{hours}}$$

The measure of λ is FIT (Failures In Time = number of failures in 10^9 device hours).

Example

A sample of 500 semiconductor devices is tested in a operating life test (dynamic electric operation). The devices operate for a period of 10,000 hours.

Failures: 1 failure after 1000 h
               1 failure after 2000 h

The failure rate may be calculated from this sample by

$$\lambda = \frac{2}{1 \times 1000 + 1 \times 2000 + 498 \times 10000} \; \frac{1}{h}$$

$$\lambda = \frac{2}{4983000} \; \frac{1}{h} \; = 4.01 \times 10^{-7} \frac{1}{h}$$

This is a λ-value of 400 FIT, or this sample has a failure rate of 0.04% / 1000 h on average.

95 11401
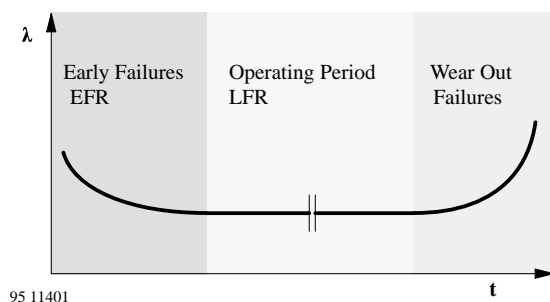
Figure 27. Bath tub curve

Confidence Level

The failure rate λ calculated from the sample is an estimate of the unknown failure rate of the lot.

The interval of the failure rate (confidence interval) may be calculated, depending on the confidence level and sample size.

The following is valid:

- The larger the sample size, the narrower the confidence interval.

- The lower the confidence level of the statement, the narrower the confidence interval.

The confidence level applicable to the failure rate of the whole lot when using the estimated value of λ is derived from the x^2-distribution. In practice, only the upper limit of the confidence interval (the maximum average failure rate) is used.

Therefore:

$$\lambda_{max} = \frac{x^2/2 \; (r; P_A)}{n \times t} \; \text{in} \; \frac{1}{h}$$

$$LFR = \frac{x^2/2 \; (r; P_A)}{n \times t} \; \times 1 \times 10^9 \; \text{in [FIT]}$$

r: Number of failures

P_A: Confidence level

n: Sample size

t: Time in hours

$n \times t$:   Device hours

The $x^2/2$ for λ are taken from table 4.

For the above example from table 4:
$x^2/2$ (r=2; P_A=60%) = 3.08
$n \times t = 4983000$ h

$$\lambda_{max} = \frac{3.08}{4983000} \; = 6.18 \times 10^{-7} \frac{1}{h}$$

This means that the failure rate of the lot does not exceed 0.0618% / 1000 h (618 FIT) with a probability of 60%.

If a confidence level of 90% is chosen from the table 5:
$x^2/2$ (r=2; P_A=90%) = 5.3

$$\lambda_{max} = \frac{5.3}{4983000} \; = 1.06 \times 10^{-6} \frac{1}{h}$$

This means that the failure rate of the lot does not exceed 0.106% / 1000 h (1060 FIT) with a probability of 90%.

Operating Life Tests

Number of devices tested: n   = 50

Number of failures
(positive qualification):   c   = 0

Test time: t   = 2000 hours

Confidence level: P_A = 60%

$\varkappa^2/2\ (0;\ 60\%)\ 0.93$

$$\lambda_{max} = \frac{0.93}{50 \times 2000} = 9.3 \times 10^{-6} \frac{1}{h}$$

This means, that the failure rate of the lot does not exceed 0.93% / 1000 h (9300 FIT) with a probability of 60%.

This example demonstrates that it is only possible to verify LFR values of 9300 FIT with a confidence level of 60% in a normal qualification tests (50 devices, 2000 h).

To obtain LFR values which meet today's requirements (< 50 FIT), the following conditions have to be fulfilled:

- Very long test periods

- Large quantities of devices

- Accelerated testing (e.g., higher temperature)

Table 4.

Number of Failures	Confidence Level			
	50%	60%	90%	95%
0	0.60	0.93	2.31	2.96
1	1.68	2.00	3.89	4.67
2	2.67	3.08	5.30	6.21
3	3.67	4.17	6.70	7.69
4	4.67	5.24	8.00	9.09
5	5.67	6.25	9.25	10.42
6	6.67	7.27	10.55	11.76
7	7.67	8.33	11.75	13.16
8	8.67	9.35	13.00	14.30
9	9.67	10.42	14.20	15.63
10	10.67	11.42	15.40	16.95

Mean Time to Failure (MTTF)

For systems which can not be repaired and whose devices must be changed, e.g., semiconductors, the following is valid:

$$MTTF = \frac{1}{\lambda}$$

MTTF is the average fault-free operating period per a monitored (time) unit.

Accelerating Stress Tests

Innovation cycles in the field of semiconductors are becoming shorter and shorter. This means that products must be brought to the market quicker. At the same time,

expectations concerning the quality and reliability of the products have become higher.

Manufacturers of semiconductors must therefore assure long operating periods with high reliability but in a short time. Sample stress testing is the most commonly used way of assuring this.

The rule of Arrhenius describes this temperature-dependent change of the failure rate.

$$\lambda(T_2) = \lambda(T_1) \times e^{\left[\frac{E_A}{k} \times \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]}$$

Boltzmann's constant
$$k = 8.63 \times 10^{-5}\ eV/K$$

Activation energy
$$E_A\ in\ eV$$

Junction temperature real operation
$$T_1\ in\ Kelvin$$

Junction temperature stress test
$$T_2\ in\ Kelvin$$

Failure rate real operation
$$\lambda\ (T_1)$$

Failure rate stress test
$$\lambda\ (T_2)$$

The acceleration factor is described by the exponential function as being:

$$AF = \frac{\lambda(T_2)}{\lambda(T_1)} = e^{\left[\frac{E_A}{k} \times \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]}$$

Example

The following conditions apply to an operating life stress test:

Environmental temperature during stress test
$$T_A = 125°C$$

Power dissipation of the device
$$P_V = 250\ mW$$

Thermal resistance junction/environment
$$R_{thJA} = 100\ K/W$$

The system temperature/junction temperature results from:

$$T_J = T_A + R_{thJA} \times P_V$$

$$T_J = 125°C + 100\ K/W \times 250\ mW$$

$$T_J = 150°C$$

Operation in the field at an ambient temperature of 100°C and at an average power dissipation of 100 mW is utilized. This results in a junction temperature in operation of $T_J = 110°C$. The activation energy used for bipolar technologies is $E_A = 0.7\ eV$.

The resulting acceleration factor is:

$$AF = \frac{\lambda(423K)}{\lambda(383K)} = e^{\left[\frac{E_A}{k} \times \left(\frac{1}{383K} - \frac{1}{423K}\right)\right]}$$

$$AF \approx 7.4$$

This signifies that, regarding this example, the failure rate is lower by a factor of 7.4 compared to the stress test.

Other accelerating stress tests may be:

- Humidity (except displays type TDS.)
  $T_A = 85°C$
  $RH = 85\%$

- Temperature cycling
  Temperature interval as specified

The tests are carried out according to the requirements of appropriate IEC–standards (see also chapter 'Qualification and Release').

Activation Energy

There are some conditions which need to be fulfilled in order to use Arrhenius' method:

- The validity of Arrhenius' rule has to be verified.

- 'Failure-specific' activation energies must be determined.

These conditions may be verified by a series of tests. Today, this procedure is generally accepted and used as a basis for estimating operating life. The values of activation energies can be determined by experiments for different failure mechanisms.

Values often used for different device groups are:

Opto components	0.7 eV
Bipolar ICs	0.7 eV
MOS ICs	0.6 eV
Transistors	0.7 eV
Diodes	0.7 eV

By using this method, it is possible to provide long–term predictions for the actual operation of semiconductors even with relatively short test periods.
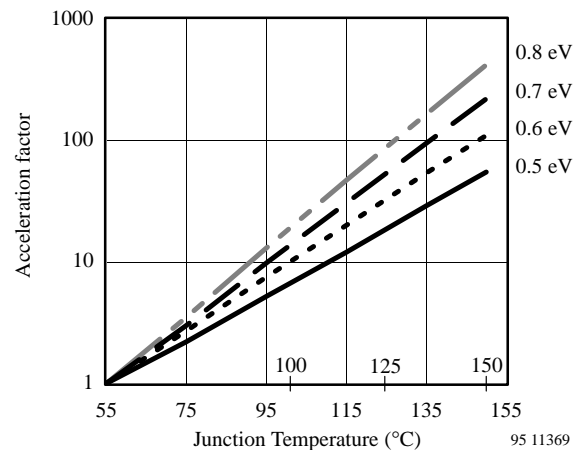

Figure 28. Acceleration factor for different activation energies normalized to $T_j = 55°C$

Safety

Reliability and Safety

All semiconductor devices have the potential of failing or degrading in ways that could impair the proper operation of safety systems. Well-known circuit techniques are available to protect against and minimize the effects of such occurrences. Examples of these techniques include redundant design, self-checking systems and other fail-safe techniques. Fault analysis of systems relating to safety is recommended. Environmental factors should be analyzed in all circuit designs, particularly in safety-related applications.

If the system analysis indicates the need for the highest degree of reliability in the component used, it is recommended that TEMIC be contacted for a customized reliability program.

Toxicity

Although gallium arsenide and gallium aluminium arsenide are both arsenic compounds, under normal use conditions they should be considered relatively benign. Both materials are listed by the 1980 NIOH 'Toxicology of Materials' with LD_{50} values (Lethal Dosis, probability 50%) comparable to common table salt.

Accidental electrical or mechanical damage to the devices should not affect the toxic hazard, so the units can be applied, handled, etc. as any other semiconductor device. Although the chips are small, chemically stable and protected by the device package, conditions that could break these crystalline compounds down into elements or other compounds should be avoided.

Optocouplers in Switching Power Supplies

The following chapters should give a full understanding on how to use optocouplers which provide protection against electric shock for designs.

Safety standards for optocouplers are intended to prevent injury or damage due to electric shock

Two levels of electrical interface are normally used:

Reinforced, or safe insulation is required in an optocoupler interface between a hazardous voltage circuit (like an ac line) and a touchable **S**afety **E**xtra **L**ow **V**oltage (SELV) circuit.

Basic insulation is required in an optocoupler interface between a hazardous voltage circuit and a non-touchable **E**xtra **L**ow **V**oltage (ELV) circuit.

The most widely used insulation for optocouplers in switch-mode power supply is reinforced insulation (class II). The following information enables the designer to understand the safety aspects, the basic concept of the VDE 0884 and the design requirements for applications.

VDE 0884 - Facts and Information

Optocouplers for line-voltage separation must have several national standards. The most accepted standards are:

- UL/ CSA for America
- BSI for Great Britain
- SETI, SEMKO, NEMKO, DEMKO for Nordic countries (Europe)
- VDE for Germany

Today, most manufacturers operate on a global scale. It is therefore mandatory to perform all approvals.

The VDE 0884 is now becoming a major safety standard in the world, partly due to German experts having a long record of experience in this field. It is therefore worthwhile understanding some requirements and methods of the VDE 0884.

At the moment there are two drafts which are being circulated to set the VDE 0884 to an international IEC standard.

The IEC 47 (CO) 1042 describes the terms and definitions − IEC 47 (CO) 1175 the test procedure, while the test method itself is already incorporated in IEC 747-5.

If design engineers work with TEMIC optocouplers, they will find some terms and definitions in the data sheets which relate to VDE 0884. These will now be explained:

Rated isolation voltages:

V_{IO} is the voltage between the input terminals and the output terminals.

Note: All voltages are peak voltages!

- V_{IOWM} is a maximum rms. voltage value of the optocouplers assigned by TEMIC. This characterizes the long term withstand capability of its insulation.

- V_{IORM} is a maximum recurring peak (repetitive) voltage value of the optocoupler assigned by TEMIC. This characterizes the long-term withstand capability against recurring peak voltages.

- V_{IOTM} is an impulse voltage value of the optocoupler assigned by TEMIC. This characterizes the long-term withstand capability against transient over voltages.

Isolation test voltage for routine tests is at factor 1.875 higher than the specified V_{IOWM}/ V_{IORM} (peak).

A partial discharge test is a different test method to the normal isolation voltage test. This method is more sensitive and will not damage the isolation behavior of the optocoupler like other test methods probably do.

The VDE 0884 therefore does not require a minimum thickness through insulation. The philosophy is that a mechanical distance only does not give you an indication of the safety reliability of the coupler. It is more recommendable to check the total construction together with the assembling performance. The **partial discharge test method** can monitor this more reliably.

The following tests must be done to guarantee this safety requirement.

100% test (piece by piece) for one second at a voltage level of specified V_{IOWM}/V_{IORM} (peak) multiplied by 1.875 − test criteria is partial discharge less than 5 pico coulomb.

A lotwise test at V_{IOTM} for 10 seconds and at a voltage level of specified V_{IOWM}/ V_{IORM} (peak) multiplied by 1.5 for 1 minute − test criteria is partial discharge less than 5 pico coulomb.

Design example:

The line ac voltage is 380 V rms. Your application class is III (DIN/VDE 0110 Part 1/1.89). According to table 5, you must calculate with a maximum line voltage of 600 V and a transient over voltage of 6000 V.

Table 5. Recommended transient overvoltages related to ac/ dc line voltage (peak values)

V_{IOWM}/V_{IORM} up to	Appl. Class I	Appl. Class II	Appl. Class III	Appl. Class IV
50 V	350 V	500 V	800 V	1500 V
100 V	500.V	800.V	1500.V	2500.V
150 V	800 V	1500 V	2500 V	4000 V
300 V	1500 V	2500 V	400 V	600 V
600.V	2500 V	4000 V	6000 V	800 V
1000 V	4000 V	6000 V	8000 V	1200 V

Now select the CNY75 from our TEMIC coupler program. The next voltage step of 380 V is 600 V (V_{IOWM}).The test voltages are 1600 V for the CNY75 for the routine test and 6000 V/ 1300 V for the sample test.

The VDE 0884 together with the isolation test voltages also require very high isolation resistance, tested at an ambient temperature of 100°C.

Apart from these tests for the running production, the VDE Testing and Approvals Institute also investigates the total construction of the optocoupler. The VDE 0884 requires life tests in a very special sequence; 5 lots for 5 different subgroups are tested.

The sequence for the main group is as follows:

- Cycle test

- Vibration

- Shock

- Dry heat

- Accelerated damp heat

- Low temperature storage (normally –55°C)

- Damp heat steady state

- Final measurements.

Finally there is another chapter concerning the safety ratings. This is described in VDE 0884.

The maximum safety ratings are the electrical, thermal and mechanical conditions that exceed the absolute maximum ratings for normal operations. The philosophy is that optocouplers must withstand a certain exceeding of the input current, output power dissipation, and temperature for at least a weekend. The test time is actually 72 hours. This is a simulated space of time where failures may occur.

It is the designer's task to create his design inside of the maximum safety ratings.

Optocouplers − approved to the VDE 0884 − must consequently pass all tests undertaken. This then enables you to go ahead and start your design.

Layout Design Rules

The previous chapter described the important safety requirements for the optocoupler itself; but the knowledge of the creepage distance and clearance path is also important for the design engineer if the coupler is to be mounted onto the circuit board. Although several different creepage distances referring to different safety standards, like the IEC 65 for TV or the IEC 950 for office equipment, computer, data equipment etc. are requested, there is one distance which meanwhile dominates switching power supplies: This is the 8 mm spacing requirement between the two circuits: The hazardous input voltage (ac 240 power-line voltage) and the safety low voltage.

This 8 mm spacing is related to the 250 V power line and defines the shortest distance between the conductive parts (either from the input to the output leads) along the case of the optocoupler, or across the surface of the print board between the solder eyes of the optocoupler input/ output leads, as shown in figure 29. The normal distance input to output leads of an optocoupler is 0.3". This is too tight for the 8 mm requirement. The designer now has two options: He can provide a slit in the board, but then the airgap is still lower; or he can use the "G" optocoupler from TEMIC. "G" stands for a wide-spaced lead form of 0.4" and obtains the 8 mm creepage, clearance distance. The type designation for this type of "G" coupler is, for example: CNY75G.

The spacing requirements of the 8 mm must also be taken into consideration for the layout of the board.

Figures 30 and 31 provide examples for your layout.

The creepage distance is also related to the resistance of the tracking creepage current stability. The plastic material of the optocoupler itself and the material of the board must provide a specified creeping-current resistance.

The behavior of this resistance is tested with special test methods described in the IEC 112. The term is "CTI" (**C**omparative **T**racking **I**ndex).

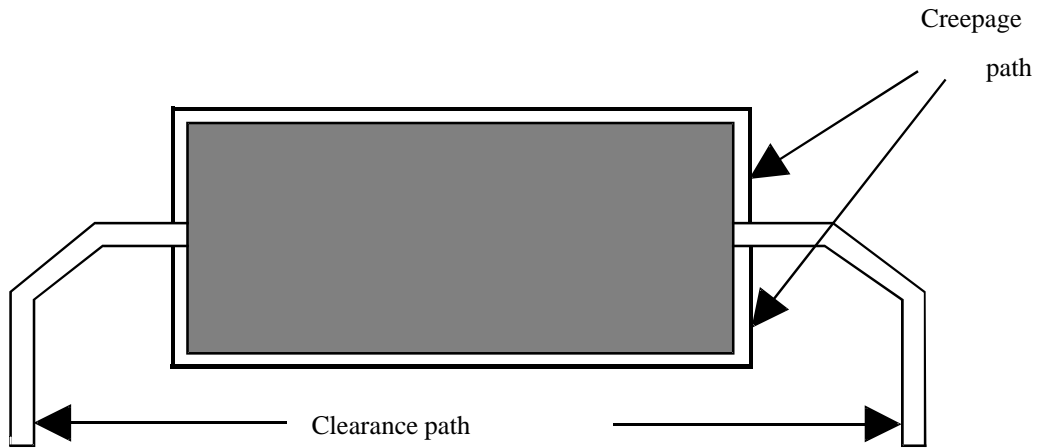The VDE 0884 requires a minimum of a CTI of 175. All TEMIC optocouplers have a CTI of 275.

Figure 29. Isolation creepage/ clearance path

(The creepage path is the shortest distance between conductive parts along the surface of the isolation material. The clearance path is the shortest distance between conductive parts.)
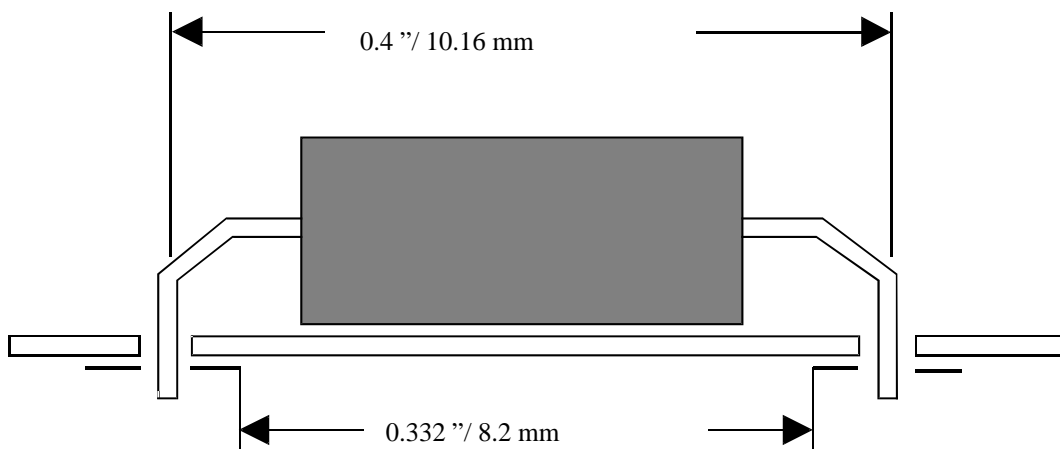
Figure 30. Optocoupler mounting on a board (side view)
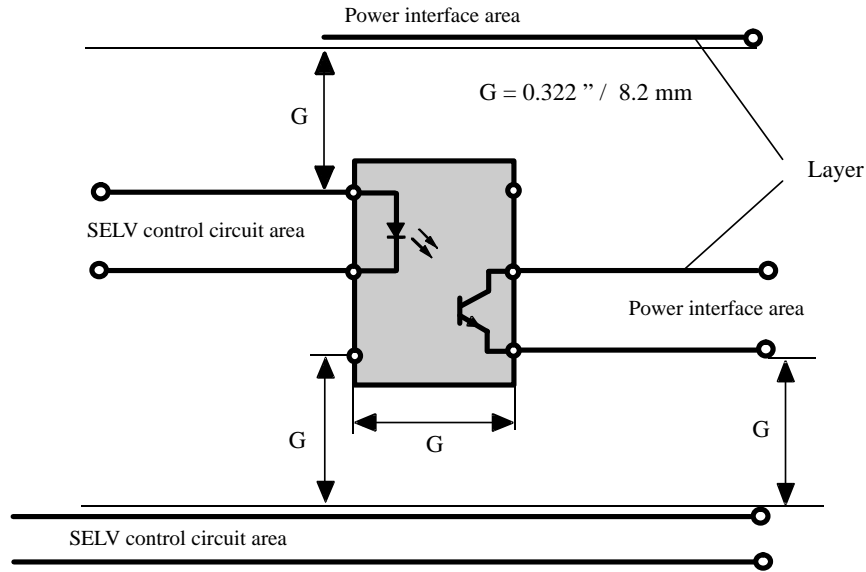
Figure 31. "Top view of optocoupler mounting on a board"
(clearance on PC board: 0.322 / 8.2 mm, creepage path on PC board is 0.322 / 8.2 mm)

Not only the solder eyes of the coupler itself on the board must have the 8 mm distance,
but also all layers located between the SELV areas and the power interface areas.

TEMIC Optocoupler Program

Construction

An optocoupler is comparable with a transformer or a mechanical relay; but its advantages are smaller dimensions, shorter switching time, no contact bounces, no interference caused by arcs and the possibility of adapting a signal already in the coupler for the following stage of the circuit.

This combination together with the safety aspects provides outstanding advantages for use in power supplies. Safety factors in particular depend on the design, construction and selected materials. TEMIC optocouplers are designed with a coplanar lead frame, where the die are mounted side by side. A semi-ellipsoid with even better reflection capabilities is fitted over each dice. The entire system is then casted in a plastic material impermeable to the infrared range and of high di-electric strength. The whole system is now molded with a special mold compound to ensure that no external influences such as light or dust etc. interfere with the functioning of the coupler (see figure 32). This design has several advantages: The "thickness through insulation", the clearance (internally) between the input and the output side is fixed at 0.75 mm and is thus mechanically stable even under thermal overloads, i.e., the possibility of a short circuit caused by material deformation is excluded. Deviations of this distance during the production process are also excluded. These two features are the specific

reasons why TEMIC optocouplers are well-accepted by manufacturers of power supplies.
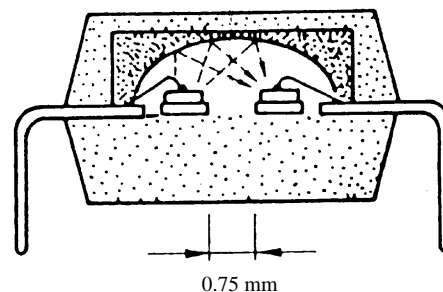

Figure 32. Cut through of a TEMIC optocoupler
(thickness through insulation)

Overview

The information given in this brochure enables the designer to select the right optocoupler for his application. The previous chapters focused only on safety aspects. Apart from this there are other characteristics for the optocoupler. Table 6 enables the designer to select the optocoupler to suit his own needs. This selection should be done using the most important characteristics like CTR (**C**urrent **T**ransfer **R**atio) and devices with or without base connection. The designer may ask for our data sheets for detailed information.
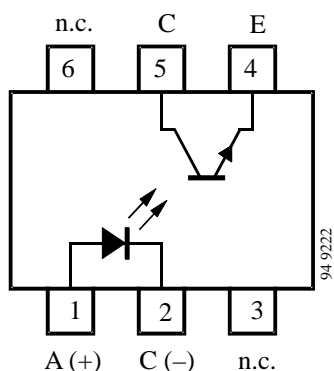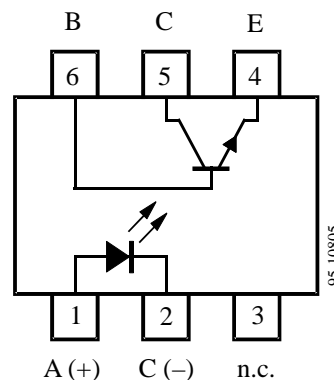
Figure 33. Without base connection

Figure 34. With base connection

6–PIN STD Isolators

Table 6. Devices offering (VDE 0884-tested)

CTR IC/ IF	$V_{CE} > 32$ V Ungrouped CTR		$V_{CE} > 32$ V Grouped CTR		$V_{CE} > 90$ V Grouped CTR	
Base Connection	With	Without	With	Without	With	Without
> 20%	4N25(G)V					
> 50%			CQY80N(G)	TCDT1100(G)		TCDT1120(G)
> 100%	4N35(G)V	TCDT1110(G)				
40 – 80%			CNY17(G)–1	TCDT1101(G)		
63 – 125%			CNY17(G)–2	TCDT1102(G)	CNY75(G)A	TCDT1122(G)
100 – 200%			CNY17(G)–3	TCDT1103(G)	CNY75(G)B	TCDT1123(G)
160 – 320%					CNY75(G)C	TCDT1124(G)

G = wide space 0.4" lead form, for 8 mm PC board spacing requirements

TEMIC
Semiconductors
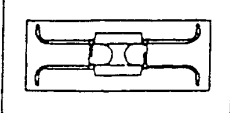
Appendix

Approvals List

As mentioned before, as long there is no equivalent IEC–standard to the VDE 0884, optocouplers must still fulfill all other national safety standards. The copies of documents present all certificates the designer needs for worldwide acceptance of his power supply (see ANT018). All the approvals below are most important. If the designer needs any others, he must be aware that there are many agreements between national institutes, e.g., UL for USA is also accepted by CSA/Canada.

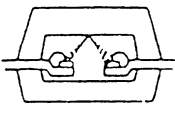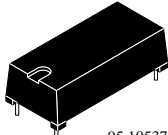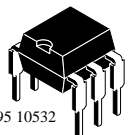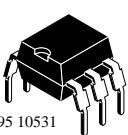TEMIC divides optocouplers into "coupling systems". Each coupling system represents the same technology, materials etc. The coupling systems are indicated with capital letters and each coupler is marked with this coupling system indicator letter. The certificates at least also refer to the systems and list all subtypes to the related coupling system. The user is able to find his selected coupler on the certificate.

Certified Optocouplers for Switching Power Supplies

		Coupling System G, H, I, K	Coupling System A, C, S
0884 (VDE symbol)	German standard VDE 0884 File no. System S: 70753 System A: 68301 System G: 70902 System H: 70977 System J: 70977 System K: 70977	CNY64 CNY65 CNY66 CNY12N	CQY80N CQY80NG CNY17(G)1–3 CNY75(G)A–C TCDT1101(G)A–C TCDT1101(G)–1103(G) TCDT1110(G) TCDT1120–1124(G)
(UL symbol)	American (USA) Test institute UL 1577 File no. E76222	CNY64 CNY65 CNY66 CNY21N	4N25(G)V 4N35(G)V
(SETI symbol)	Nordic approvals (SETI)	CNY64 CNY65 CNY21N	K3010P(G)–K3012P(G) K3020P(G)–K3023P(G)
(BSi symbol)	British Std BS415 BS7002	CNY65	
Internal stucture		95 10537	
Case (examples)		95 10537	95 10532 95 10531

Application of Optoelectronic Reflex Sensors
TCRT1000, TCRT5000, TCRT9000, CNY70

TEMIC optoelectronic sensors contain infrared-emitting diodes as a radiation source and phototransistors as detectors.

Typical applications include:

- Copying machines

- Video recorders

- Proximity switch

- Vending machines

- Printers

- Object counters

- Industrial control

Special features:

- Compact design

- Operation range 0 to 20 mm

- High sensitivity

- Low dark current

- Minimized crosstalk

- Ambient light protected

- Cut-off frequency up to 40 kHz

- High quality level, ISO 9000

- Automated high-volume production

These sensors present the quality of perfected products. The components are based on TEMIC's many year's experience as one of Europe's largest producers of optoelectronic components.

TEMIC
Semiconductors

Drawings of the Sensors
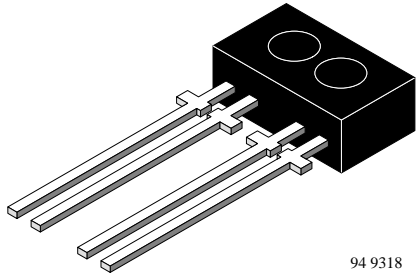
94 9318

TCRT1000

94 9442

TCRT5000

94 9320

TCRT9000

94 9320

CNY70

Optoelectronic Sensors

In many applications, optoelectronic transmitters and receivers are used in pairs and linked together optically. Manufacturers fabricate them in suitable forms. They are available for a wide range of applications as ready-to-use components known as couplers, transmissive sensors (or interrupters), reflex couplers and reflex sensors. Increased automation in industry in particular has heightened the demand for these components and stimulated the development of new types.

General Principles

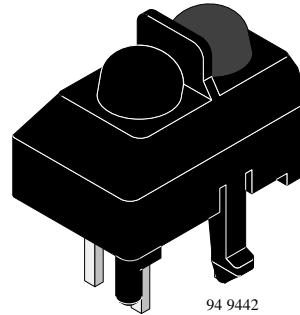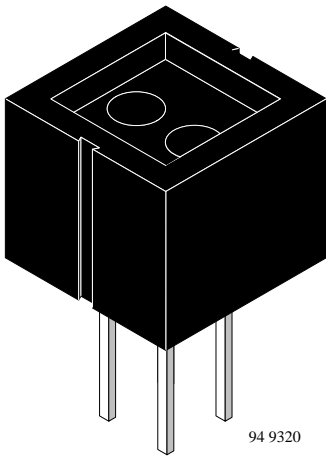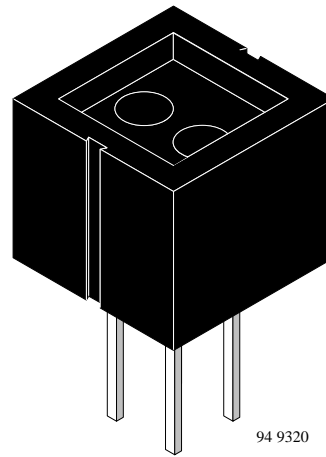The operating principles of reflex sensors are similar to those of transmissive sensors. Basically, the light emitted by the transmitter is influenced by an object or a medium on its way to the detector. The change in the light signal caused by the interaction with the object then produces a change in the electrical signal in the optoelectronic receiver.

The main difference between reflex couplers and transmissive sensors is in the relative position of the transmitter and detector with respect to each other. In the case of the transmissive sensor, the receiver is opposite the transmitter in the same optical axis, giving a direct light coupling between the two. In the case of the reflex sensor, the detector is positioned next to the transmitter, avoiding a direct light coupling.

The transmissive sensor is used in most applications for small distances and narrow objects. The reflex sensor, however, is used for a wide range of distances as well as for materials and objects of different shapes. It sizes by virtue of its open design.

In the following chapters, we will deal with reflex sensors − placing particular emphasis on their practical use. The components TCRT1000, TCRT5000, TCRT9000 and CNY70 are used as examples. However, references made to these components and their use apply to all sensors of a similar design.

The reflex sensors TCRT1000, TCRT5000, TCRT9000 and CNY70 contain IR-emitting diodes as transmitters and phototransistors as receivers. The transmitters emit radiation of a wavelength of 950 nm. The spectral sensi-

tivity of the phototransistors are optimized for this wavelength.

There are no focusing elements in the sensors described, though lenses are incorporated inside the TCRT5000 in both active parts (emitter and detector). The angular characteristics of both are divergent. This is necessary to realize a position-independent function for easy practical use with different reflecting objects.

In the case of TCRT5000, the concentration of the beam pattern to an angle of 16° for the emitter and 30° for the detector, respectively, results in operation on an increased range with optimized resolution. The emitting and acceptance angles in the other reflex sensors are about 45°. This is an advantage in short distance operation. The best local resolution is with the reflex sensor TCRT9000.

The main difference between the sensor types is the mechanical outline (as shown in the figures, see page before), resulting in various electrical parameters and optical properties. A specialization for certain appli-cations is necessary. Measurements and statements on the data of the reflex sensors are made relative to a reference surface with defined properties and precisely known reflecting properties. This reference medium is the diffusely reflecting Kodak neutral card, also known as grey card (KODAK neutral test card; KODAK publi-cation No. Q-13, CAT 1527654). It is also used here as the reference medium for all details. The reflection factor of the white side of the card is 90% and that of the grey side is 18%.

Table 7 shows the measured reflection of a number of materials which are important for the practical use of sensors. The values of the collector current given are relative and correspond to the reflection of the various surfaces with regard to the sensor's receiver. They were measured at a transmitter current of $I_F = 20$ mA and at a distance of the maximum light coupling. These values apply exactly to the TCRT9000, but are also valid for the other reflex sensors. The 'black-on-white paper' section stands out in table 7. Although all surfaces appear black to the 'naked eye', the black surfaces emit quite different reflections at a wavelength of 950 nm. It is particularly important to account for this fact when using reflex sensors. The reflection of the various body surfaces in the infrared range can deviate significantly from that in the visible range.

TEMIC
Semiconductors

Table 7. Relative collector current (or coupling factor) of the reflex sensor TCRT9000 for reflection on various materials. Reference is the white side of the Kodak neutral card. The sensor is positioned perpendicular with respect to the surface. The wavelength is 950 nm.

Kodak neutral card	
White side (reference medium)	**100%**
Gray side	20%
Paper	
Typewriting paper	94%
Drawing card, white (Schoeller Durex)	100%
Card, light gray	67%
Envelope (beige)	100%
Packing card (light brown)	84%
Newspaper paper	97%
Pergament paper	30-42%
Black on white typewriting paper	
Drawing ink (Higgins, Pelikan, Rotring)	4-6%
Foil ink (Rotring)	50%
Fiber-tip pen (Edding 400)	10%
Fiber-tip pen, black (Stabilo)	76%
Photocopy	7%
Plotter pen	
HP fiber–tip pen (0.3 mm)	84%
Black 24 needle printer (EPSON LQ-500)	28%
Ink (Pelikan)	100%
Pencil, HB	26%

Plastics, glass	
White PVC	90%
Gray PVC	11%
Blue, green, yellow, red PVC	40-80%
White polyethylene	90%
White polystyrene	120%
Gray partinax	9%
Fiber glass board material	
Without copper coating	12-19%
With copper coating on the reverse side	30%
Glass, 1 mm thick	9%
Plexiglass, 1 mm thick	10%
Metals	
Aluminum, bright	110%
Aluminum, black anodized	60%
Cast aluminum, matt	45%
Copper, matt (not oxidized)	110%
Brass, bright	160%
Gold plating, matt	150%
Textiles	
White cotton	110%
Black velvet	1.5%

Parameters and Practical Use of the Reflex Sensors

A reflex sensor is used in order to receive a reflected signal from an object. This signal gives information on the position, movement, size or condition (e.g., coding) of the object in question. The parameter that describes the function of the optical coupling precisely is the so-called optical transfer function (OT) of the sensor. It is the ratio of the received to the emitted radiant power.

$$OT = \frac{\Phi_r}{\Phi_e}$$

Additional parameters of the sensor, such as operating range, the resolution of optical distance of the object, the sensitivity and the switching point in the case of local changes in the reflection, are directly related to this optical transfer function.

In the case of reflex sensors with phototransistors as receivers, the ratio I_c/I_F (the ratio of collector current I_c to the forward current I_F) of the diode emitter is preferred to the optical transfer function. As with optocouplers, I_c/I_F is generally known as the coupling factor, k. The following approximate relationship exists between k and OT:

$$k = I_c/ I_F = [(S \times B)/h] \times \Phi_r/\Phi_e$$

where B is the current amplification, $S = I_b/\Phi_r$ (phototransistor's spectral sensitivity), and $h = I_F/\Phi_e$ (proportionality factor between I_F and Φ_e of the transmitter).

In figures 35 and 36, the curves of the radiant intensity, I_e, of the transmitter to the forward current, I_F, and the sensitivity of the detector to the irradiance, E_e, are shown respectively. The gradients of both are equal to unity slope.

This represents a measure of the deviation of the curves from the ideal linearity of the parameters. There is a good proportionality between I_e and I_F and between I_c and E_e where the curves are parallel to the unity gradient.

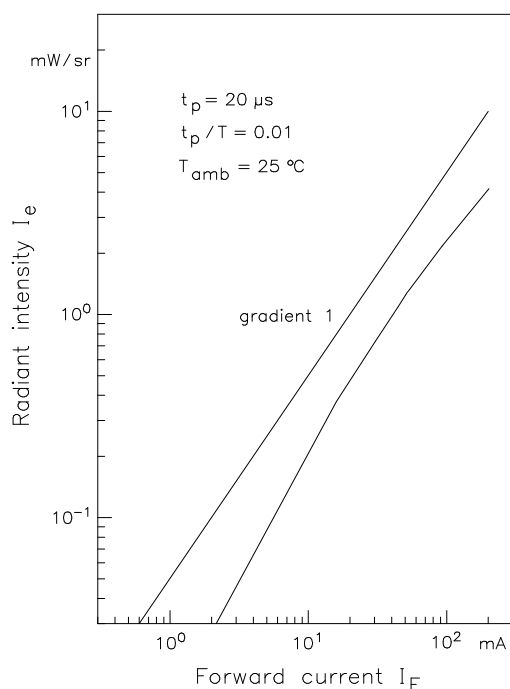Greater proportionality improves the relationship between the coupling factor, k, and the optical transfer function.

Figure 35. Radiant intensity, $I_e = f(I_F)$, of the IR transmitter
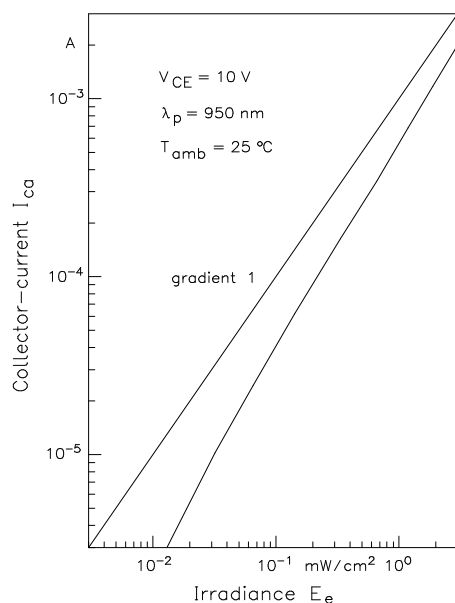
Figure 36. Sensitivity of the reflex sensors' detector

Coupling Factor, k

In the case of reflex couplers, the specification of the coupling factor is only useful by a defined reflection and distance. Its value is given as a percentage and refers here to the diffuse reflection (90%) of the white side of Kodak neutral card at the distance of the maximum light coupling. Apart from the transmitter current, I_F, and the temperature, the coupling factor also depends on the distance from the reflecting surface and the frequency − that is, the speed of reflection change.

For all reflex sensors, the curve of the coupling factor as a function of the transmitter current, I_F, has a flat maximum at approximately 30 mA (figure 37). As shown in the figure, the curve of the coupling factor follows that of the current amplification, B, of the phototransistor. The influence of temperature on the coupling factor is relatively small and changes approximately –10% in the range of –10 to +70°C (figure 38). This fairly favorable temperature compensation is attributable to the opposing temperature coefficient of the IR diode and the phototransistor.

The maximum speed of a reflection change that is detectable by the sensor as a signal is dependent either on the switching times or the threshold frequency, f_c, of the component. The threshold frequency and the switching times of the reflex sensors TCRT1000, TCRT5000, TCRT9000 and CNY70 are determined by the slowest component in the system − in this case the phototransistor. As usual, the threshold frequency, f_c, is defined as the frequency at which the value of the coupling factor has fallen by 3 dB (approximately 30%) of its initial value. As the frequency increases, $f > f_c$, the coupling factor decreases.

Figure 37. Coupling factor $k = f(IF)$ of the reflex sensors
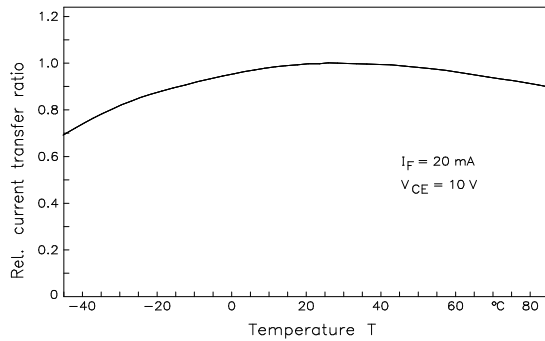
Figure 38. Change of the coupling factor, k,
with temperature, T

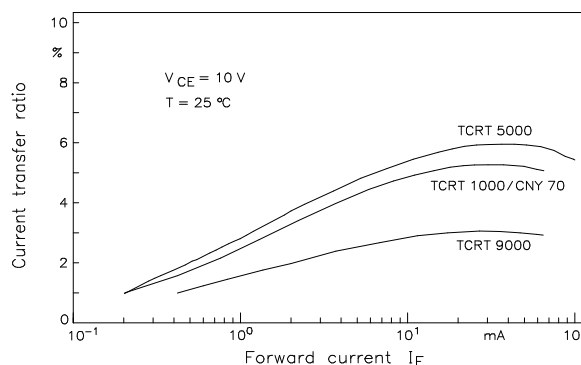As a consequence, the reflection change is no longer easily identified.

Figure 39 illustrates the change of the cut-off frequency at collector emitter voltages of 5, 10 and 20 V and various load resistances. Higher voltages and low load resistances significantly increase the cut-off frequency.

The cut-off frequencies of all TEMIC reflex sensors are high enough (with 30 to 50 kHz) to recognize extremely fast mechanical events.

In practice, it is not recommended to use a large load resistance to obtain a large signal, dependent on the speed of the reflection change. Instead, the opposite effect takes place, since the signal amplitude is markedly reduced by the decrease in the cut-off frequency. In practice, the better approach is to use the given data of the application (such as the type of mechanical movement or the number of markings on the reflective medium). With these given data, the maximum speed at which the reflection changes can be determined, thus allowing the maximum frequency occurring to be calculated. The maximum permissible load resistance can then be selected for this frequency from the diagram f_c as a function of the load resistance, R_L.

Working Diagram

The dependence of the phototransistor collector current on the distance, A, of the reflecting medium is shown in figures 40 and 41 for the reflex sensors TCRT1000 and TCRT9000 respectively.

The data were recorded for the Kodak neutral card with 90% diffuse reflection serving as the reflecting surface, arranged perpendicular to the sensor. The distance, A, was measured from the surface of the reflex sensor.

The emitter current, I_F, was held constant during the measurement. Therefore, this curve also shows the course of the coupling factor and the optical transfer function over distance. It is called the working diagram of the reflex sensor.

The working diagrams of all sensors (figure 40) shows a maximum at a certain distance, A_O. Here the optical coupling is the strongest. For larger distances, the collector current falls in accordance with the square law. When the amplitude, I, has fallen not more than 50% of its maximum value, the operation range is at its optimum.
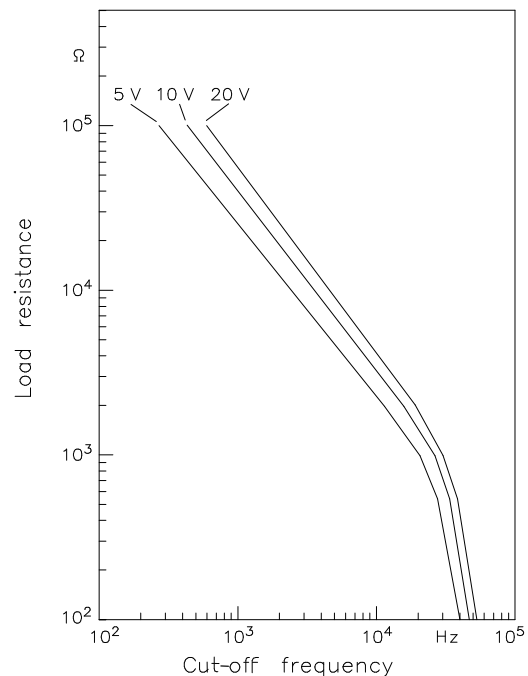
Figure 39. Cut-off frequency, f_c

a) TCRT5000

b) TCRT9000
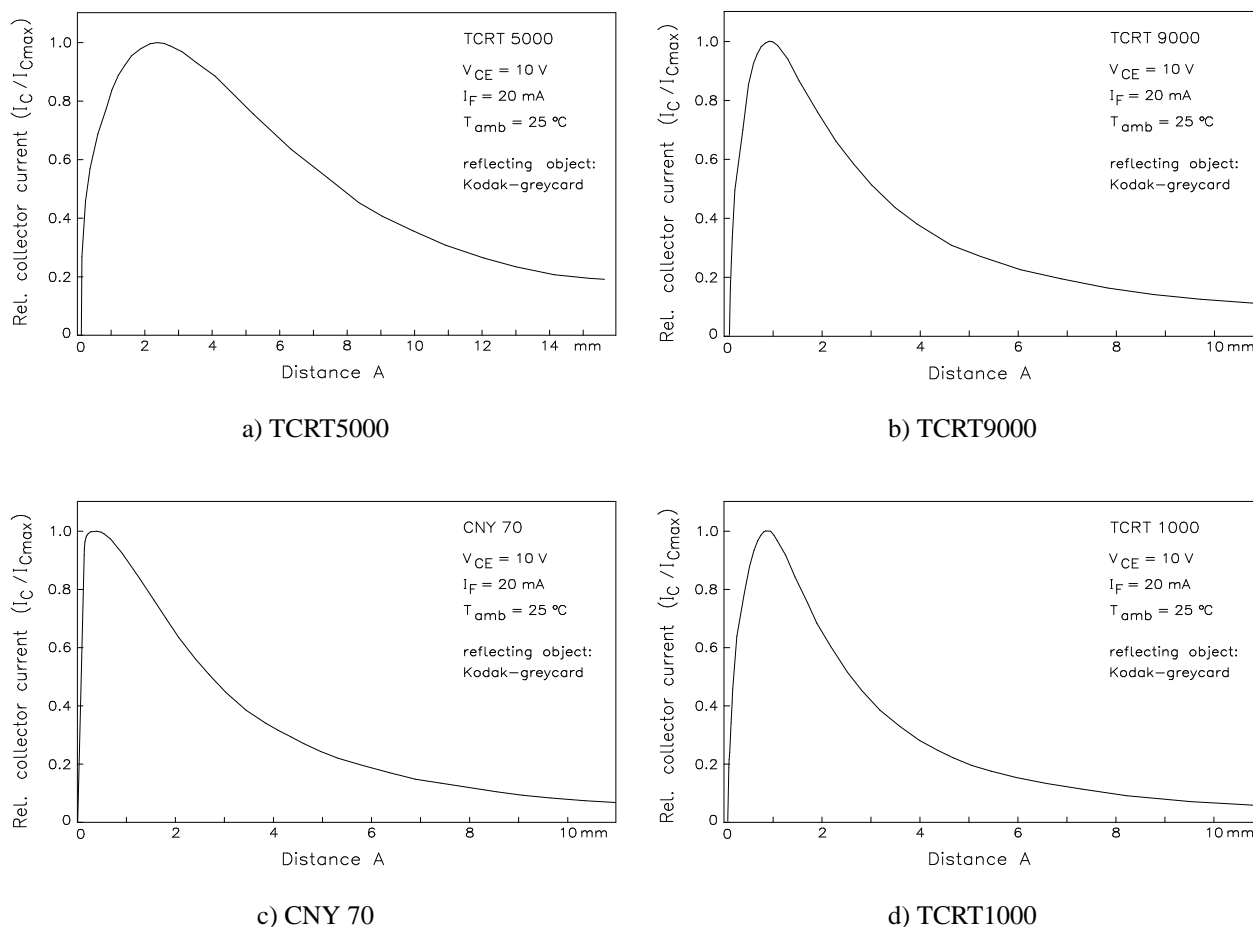
c) CNY 70

d) TCRT1000

Figure 40. Working diagram of reflex sensors TCRT5000, CNY70, TCRT9000 and TCRT1000

Resolution, Trip Point

The behavior of the sensors with respect to abrupt changes in the reflection over a displacement path is determined by two parameters: the resolution and the trip point.

If a reflex sensor is guided over a reflecting surface with a reflection surge, the radiation reflected back to the detector changes gradually, not abruptly. This is depicted in figure 41a. The surface, g, seen jointly by the transmitter and detector, determines the radiation received by the sensor. During the movement, this surface is gradually covered by the dark reflection range. In accordance with the curve of the radiation detected, the change in collector current is not abrupt, but undergoes a wide, gradual transition from the higher to the lower value

As illustrated in figure 41b, the collector current falls to the value I_{c2}, which corresponds to the reflection of the dark range, not at the point X_o, but at the points $X_o + X_{d/2}$, displaced by $X_{d/2}$.

The displacement of the signal corresponds to an uncertainty when recording the position of the reflection change, and it determines the resolution and the trip point of the sensor.

The trip point is the position at which the sensor has completely recorded the light/ dark transition, that is, the range between the points $X_o + X_{d/2}$ and $X_o - X_{d/2}$ around X_o. The displacement, X_d, therefore, corresponds to the width or the tolerance of the trip point. In practice, the section lying between 10 and 90% of the difference $I_c = I_{c1} - I_{c2}$ is taken as X_d. This corresponds to the rise time of the generated signal since there is both movement and speed. Analogous to switching time, displacement, X_d, is described as a switching distance.

TEMIC
Semiconductors

The resolution is the sensor's capability to recognize small structures. Figure 42 illustrates the example of the curve of the reflection and current signal for a black line measuring d in width on a light background (e.g., on a sheet of paper). The line has two light/ dark transitions − the switching distance $X_{d/2}$ is, therefore, effective twice.
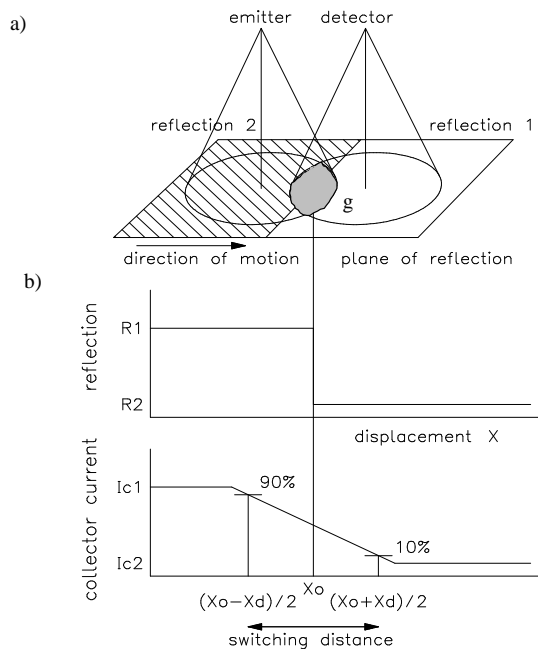
Figure 41. Abrupt reflection change with associated I_c curve
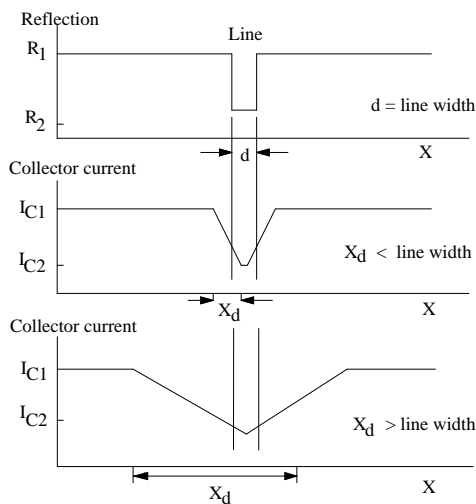
Figure 42. Reflection of a line of width d and corresponding curve of the collector current I_c

The line is clearly recognized as long as the line width is $d \geq X_d$. If the width is less than $\geq X_d$, the collector current change, $I_{c1} - I_{c2}$, that is the processable signal, becomes increasingly small and recognition increasingly uncertain. The switching distance − or better its inverse − can therefore be taken as a resolution of the sensor.

The switching distance, X_d, is predominantly dependent on the mechanical/ optical design of the sensor and the distance to the reflecting surface. It is also influenced by the relative position of the transmitter/ detector axis.

Figure 43 shows the dependence of the switching distance, X_d, on the distance A with the sensors placed in two different positions with respect to the separation line of the light/ dark transition.

The curves marked position 1 in the diagrams correspond to the first position. The transmitter/ detector axis of the sensor was perpendicular to the separation line of the transition. In the second position (curve 2), the transmitter/ detector axis was parallel to the transition.

In the first position (1) all reflex sensors have a better resolution (smaller switching distances) than in position 2. The device showing the best resolution is TCRT9000. It can recognize lines smaller than half a millimeter at a distance below 0.5 mm.

It should be remarked that the diagram of TCRT5000 is scaled up to 10 cm. It shows best resolution between 2 and 10 cm.

All sensors show the peculiarity that the maximum resolution is not at the point of maximum light coupling, A_o, but at shorter distances.

In many cases, a reflex sensor is used to detect an object that moves at a distance in front of a background, such as a sheet of paper, a band or a plate. In contrast to the examples examined above, the distances of the object surface and background from the sensor vary.

Since the radiation received by the sensor's detector depends greatly on the distance, the case may arise when the difference between the radiation reflected by the object on the background is completely equalized by the distance despite varying reflectance factors. Even if the sensor has sufficient resolution, it will no longer supply a processable signal due to the low reflection difference. In such applications it is necessary to examine whether there is a sufficient contrast. This is performed with the help of the working diagram of the sensor and the reflectance factors of the materials.

a) TCRT5000

c) TCRT1000
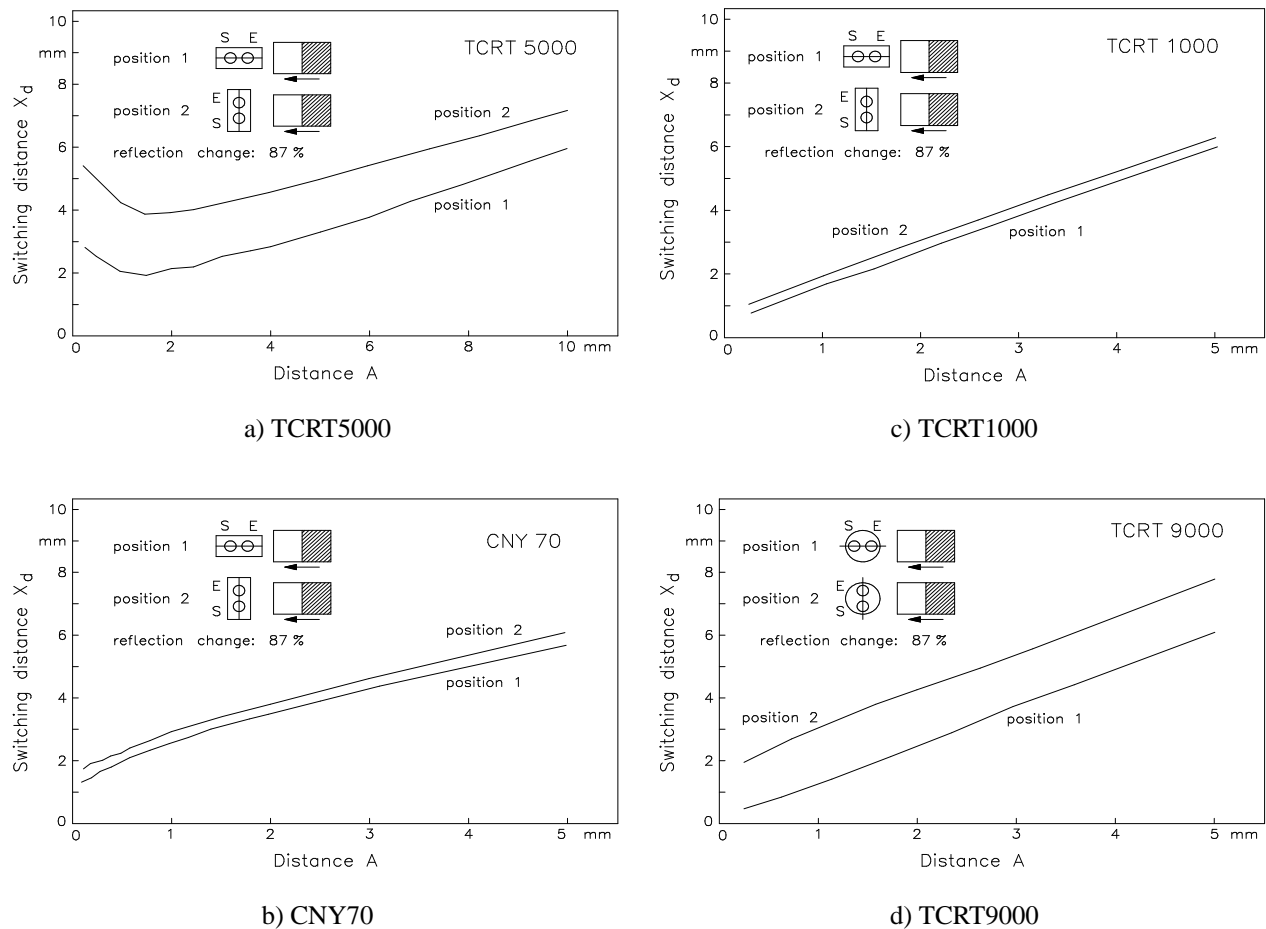
b) CNY70

d) TCRT9000

Figure 43. The switching distance as a function of the distance A for the reflex sensors TCRT5000, CNY70, TCRT1000 and TCRT9000

Sensitivity, Dark Current and Crosstalk

The lowest photoelectric current that can be processed as a useful signal in the sensor's detector determines the weakest usable reflection and defines the sensitivity of the reflex sensor. This is determined by two parameters − the dark current of the phototransistor and the crosstalk.

The phototransistor as receiver exhibits a small dark current, I_{CEO}, of a few nA at 25°C. However, it is dependent on the applied collector-emitter voltage, V_{CE}, and to a much greater extent on the temperature, T (see figure 44). The crosstalk between the transmitter and detector of the reflex sensor is given with the current, I_{cx}. I_{cx} is the collector current of the photoelectric transistor measured at normal IR transmitter operating conditions without a reflecting medium.
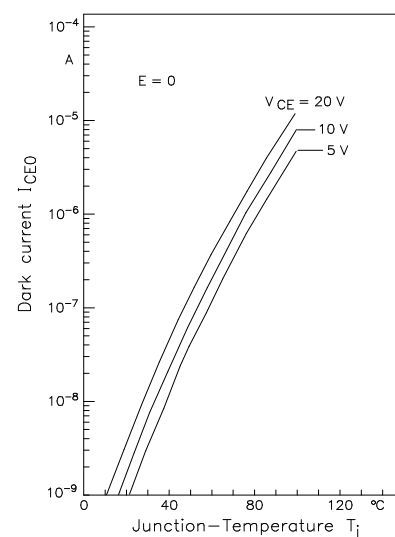
Figure 44. Temperature-dependence of the collector dark current

It is ensured that no (ambient) light falls onto the photoelectric transistor. This determines how far it is possible to guarantee avoiding a direct optical connection between the transmitter and detector of the sensor.

At $I_F = 20$ mA, the current I_{cx} is approximately 50 nA for the TCRT9000 and 15 nA for the CNY70, TCRT1000 and TCRT5000.

I_{cx} can also be manifested dynamically. In this case, the origin of the crosstalk is electrical rather than optical.

For design and optical reasons, the transmitter and detector are mounted very close to each other.

Electrical interference signals can be generated in the detector when the transmitter is operated with a pulsed or modulated signal. The transfer capability of the interference increases strongly with the frequency. Steep pulse edges in the transmitter's current are particularly effective here since they possess a large portion of high frequencies. For all TEMIC sensors, the ac crosstalk, I_{cxac}, does not become effective until frequencies of 4 MHz upwards with a transmission of approximately 3 dB between the transmitter and detector.

The dark current and the dc- and ac crosstalk form the overall collector fault current, I_{cf}. It must be observed that the dc-crosstalk current, I_{cxdc}, also contains the dark current, I_{CEO}, of the phototransistor.

$$I_{cf} = I_{cxdc} + I_{cxac}$$

This current determines the sensitivity of the reflex sensor. The collector current caused by a reflection change should always be at least twice as high as the fault current so that a processable signal can be reliably identified by the sensor.

Ambient Light

Ambient light is another feature that can impair the sensitivity and, in some circumstances, the entire function of the reflex sensor. However, this is not an artifact of the component, but an application specific characteristic.

The effect of ambient light falling directly on the detector is always very troublesome. Weak steady light reduces the sensor's sensitivity. Strong steady light can, depending on the dimensioning (R_L, V_C), saturate the photoelectric transistor. The sensor is 'blind' in this condition. It can no longer recognize any reflection change. Chopped ambient light gives rise to incorrect signals and feigns non-existent reflection changes.

Indirect ambient light, that is ambient light falling onto the reflecting objects, mainly reduces the contrast between the object and background or the feature and surroundings. The interference caused by ambient light is predominantly determined by the various reflection properties of the material which in turn are dependent on the wavelength.

If the ambient light has wavelengths for which the ratio of the reflection factors of the object and background is the same or similar, its influence on the sensor's function is small. Its effect can be ignored for intensities that are not excessively large. On the other hand, the object/ background reflection factors can differ from each other in such a way that, for example, the background reflects the ambient light much more than the object. In this case, the contrast disappears and the object cannot be detected. It is also possible that an uninteresting object or feature is detected by the sensor because it reflects the ambient light much more than its surroundings.

In practice, ambient light stems most frequently from filament, fluorescent or energysaving lamps. Table 8 gives a few approximate values of the irradiance of these sources. The values apply to a distance of approximately 50 cm, the spectral range to a distance of 850 to 1050 nm. The values of table 8 are only intended as guidelines for estimating the expected ambient radiation.

In practical applications, it is generally rather difficult to determine the ambient light and its effects precisely. Therefore, an attempt to keep its influence to a minimum is made from the outset by using a suitable mechanical design and optical filters. The detectors of the sensors are equipped with optical filters to block such visible light. Furthermore, the mechanical design of these components is such that it is not possible for ambient light to fall directly or sideways onto the detector for object distances of up to 2 mm.

If the ambient light source is known and is relatively weak, in most cases it is enough to estimate the expected power of this light on the irradiated area and to consider the result when dimensioning the circuit.

AC operation of the reflex sensors offers the most effective protection against ambient light. Pulsed operation is also helpful in some cases.

Compared with dc operation, the advantages are greater transmitter power and at the same time significantly greater protection against faults. The only disadvantage is the greater circuit complexity, which is necessary in this case. The circuit in figure 48 is an example of operation with chopped light.

Table 8. Examples for the irradiance of ambient light sources

Light source (at 50 cm distance)	Irradiance E_e ($\mu W/cm^2$) 850 to 1050 nm		Frequency (Hz)
	Steady light	AC light (peak value)	
Filament lamp (60 W)	500		
Fluorescent lamp OSRAM (65 W)	25	30	100
Economy lamp OSRAM DULUX (11 W)	14	16	100

Application Examples, Circuits

The most important characteristics of the TEMIC reflex sensors are summarized in table 9. The task of this table is to give a quick comparison of data for choosing the right sensor for a given application.

Application Example with Dimensioning

With a simple application example, the dimensioning of the reflex sensor can be shown in the basic circuit with the aid of the component data and considering the boundary conditions of the application.

The reflex sensor TCRT9000 is used for speed control. An aluminum disk with radial strips as markings fitted to the motor shaft forms the re–flecting object and is located approximately 3 mm in front of the sensor. The sensor signal is sent to a logic gate for further processing.

Dimensioning is based on dc operation, due to the simplified circuitry.

The optimum transmitter current. I_F, for dc operation is between 20 and 40 mA. I_F = 20 mA is selected in this case.

As shown in figure 37, the coupling factor is at its maximum. In addition, the degradation (i.e., the reduction of the transmitted IR output with aging) is minimum for currents under 40 mA (< 10% for 10000 h) and the self heating is low due to the power loss (approximately 50 mW at 40 mA).
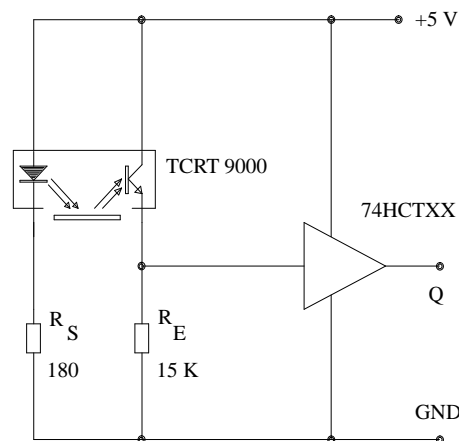
Figure 45. Reflex sensor - basic circuit

Table 9.

Parameter	Symbol	Reflex Sensor Type			
		CNY70	TCRT1000	TCRT5000	TCRT9000
Distance of optimum coupling	A_0	0.3 mm	1 mm	2 mm	1 mm
Distance of best resolution	A_r	0.2 mm	0.8 mm	1.5 mm	0.5 mm
Coupling factor	k	5%	5%	6%	3%
Switching distance (min.)	x_d	1.5 mm	0.7 mm	1.9 mm	0.5 mm
Optimum working distance	X_{or}	0.2 to 3 mm	0.4 to 2.2 mm	0.2 to 6.5 mm	0.4 to 3 mm
Operating range	A_{or}	9 mm	8 mm	> 20 mm	12 mm

Table 10.

Application Data	
Aluminum disk	Diameter 50 mm, distance from the sensor 3 mm, markings printed on the aluminum
Markings	8 radial black stripes and 8 spacings, the width of the stripes and spacings in front of the sensor is approximately = 4 mm (in a diameter of 20 mm)
Motor speed	1000 to 3000 rpm
Temperature range	10 to 60°C
Ambient light	60 W fluorescent lamp, approximate distance 2 m
Power supply	5 V ± 5%
Position of the sensor	Position 1, sensor/ detector connecting line perpendicular to the strips

Special attention must also be made to the downstream logic gate. Only components with a low input offset current may be used. In the case of the TTL gate and the LS-TTL gate, the I_{LH} current can be applied to the sensor output in the low condition. At –1.6 mA or –400 µA, this is above the signal current of the sensor. A transistor or an operational amplifier should be connected at the output of the sensor when TTL or LS-TTL components are used. A gate from the 74HCTxx family is used.

According to the data sheet, its fault current I_{LH} is approximately 1 µA.

The expected collector current for the minimum and maximum reflection is now estimated.

According to the working diagram in figure 40c, it follows that when A = 3 mm

$$I_c = 0.5 \times I_{cmax}$$

I_{cmax} is determined from the coupling factor, k, for $I_F = 20$ mA.

$$I_{cmax} = k \times I_F$$

At $I_F = 20$ mA, the typical value

$$k = 2.8\%$$

is obtained for k from figure 37.

However, this value applies to the Kodak neutral card or the reference surface. The coupling factor has a different value for the surfaces used (typewriting paper and black-fiber tip pen). The valid value for these material surfaces can be found in table 7:

$$k_1 = 94\% \times k = 2.63\% \text{ for typing paper and}$$

$$k_2 = 10\% \times k = 0.28\% \text{ for black-tip pen}$$
$$\text{(Edding)}$$

Therefore: $I_{c1} = 0.5 \times k_1 \times I_F = 263$ µA
              $I_{c2} = 0.5 \times k_2 \times I_F = 28$ µA

Temperature and aging reduce the collector current. They are therefore important to I_{c1} and are subtracted from it.

Figure 38 shows a change in the collector current of approximately 10% for 70°C. Another 10% is deducted from I_{c1} for aging

$$I_{c1} = 263 \text{ µA} – (20\% \times 263 \text{ µA}) = 210 \text{ µA}$$

The fault current I_{cf} (from crosstalk and collector dark current) increases the signal current and is added to I_{c2}. Crosstalk with only a few nA for the TCRT9000 is ignored. However, the dark current can increase up to 1 µA at a temperature of 70°C and should be taken into account.

In addition, 1 µA, the fault current of the 74HCTxx gate, is also added

$$I_{c2} = 30 \text{ µA}$$

The effect of the indirect incident ambient light can most easily be seen by comparing the radiant powers produced by the ambient light and the sensor's transmitter on 1 mm^2 of the reflecting surface. The ambient light is then taken into account as a percentage in accordance with the ratio of the powers.

From table 8:

$$E_e (0.5 \text{ m}) = 40 \text{ µW/ cm}^2 \text{ (dc + ac/ 2)}$$
$$E_e (2 \text{ m}) = E_e(0.5 \text{ m}) \times (0.5/ 2)^2$$

(Square of the distance law)

$$E_e (2 \text{ m}) = 2.5 \text{ µW/ cm}^2$$
$$\phi_{sf} = 0.025 \text{ µW}$$

The radiant power ($\Phi_{sf} = 0.025$ µW) therefore falls on 1 mm^2.

When $I_F = 20$ mA, the sensor's transmitter has the radiant intensity:

$$I_e = \frac{\Phi_e}{\Omega} = 0.5 \text{ W/sr}$$

(see figure 35)

The solid angle for 1 mm^2 surface at a distance of 3 mm is

$$\Omega = \frac{1 \text{ mm}^2}{(3 \text{ mm})^2} = \frac{1}{9} \text{sr}$$

It therefore follows for the radiant power that:

$$\Phi_e = I_e \times \Omega = 55.5 \text{ mW}$$

The power of 0.025 µW produced by the ambient light is therefore negligibly low compared with the corresponding power (approximately 55 µW) of the transmitter.

The currents I_{c1}, I_{c2} would result in full reflecting surfaces, that is, if the sensor's visual field only measures white or black typing paper. However, this is not the case. The reflecting surfaces exist in the form of stripes.

The signal can be markedly reduced by the limited resolution of the sensor if the stripes are narrow. The suitable stripe width for a given distance should therefore be selected from figure 43. In this case, the minimum permissible stripe width is approximately 3.8 mm for a distance of 3 mm (position 1, figure 43d). The markings measuring 4 mm in width were expediently selected in this case. For this width, a signal reduction of about 20% can be permitted with relatively great certainty, so that 10% of the difference ($I_{c1} - I_{c2}$) can be subtracted from I_{c1} and added to I_{c2}.

$$I_{c1} = 210 \text{ µA} - 18 \text{ µA} = 192 \text{ µA}$$
$$I_{c2} = 30 \text{ µA} + 18 \text{ µA} = 48 \text{ µA}$$

The suitable load resistance, R_E, at the emitter of the photo-transistor is then determined from the low and high levels 0.8 V and 2.0 V for the 74HCTxx gate.

$$R_E < 0.8 \text{ V}/ I_{c2} \text{ and } R_E > 2.0 \text{ V}/ I_{c1},$$
i.e., $\quad$ 10.2 kΩ $< R_E <$ 16.7 kΩ
$\qquad$ 12 kΩ is selected for R_E

The corresponding levels for determining R_E must be used if a Schmitt trigger of the 74HCTxx family is employed.

The frequency limit of the reflex sensor is then determined with $R_E = 12$ kΩ and compared with the maximum operating frequency in order to check whether signal damping attributable to the frequency that can occur.

Figure 39 shows for $V_s = 5$ V and $R_E = 12$ kΩ approximately, for the TCRT9000, $f_c = 1.5$ kHz.

Sixteen black/ white stripes appear in front of the sensor in each revolution. This produces a maximum signal frequency of approximately 400 Hz for the maximum speed of 3000 rpm up to 50 rps. This is significantly less than the f_c of the sensor, which means there is no risk of signal damping.

In the circuit in figure 45, a resistor, R_c, can be used on the collector of the photoelectric transistor instead of R_E. In this case, an inverted signal and somewhat modified dimensioning results. The current I_{c1} now determines the low signal level and the current I_{c2} the high. The voltages ($V_s - 2$ V) and ($V_s - 0.8$ V) and not the high level and low

level 2 V and 0.8 V, are now decisive for determining the resistance, R_c.

Circuits with Reflex Sensors

The couple factor of the reflex sensors is relatively small. Even in the case of good reflecting surfaces, it is less than 10%. Therefore, the photocurrents are in practice only in the region of a few µA. As this is not enough to process the signals any further, an additional amplifier is necessary at the sensor output. Figure 46 shows two simple circuits with sensors and follow-up operational amplifiers.

The circuit in figure 46b is a transimpedance which offers in addition to the amplification the advantage of a higher cut-off frequency for the whole layout.

Two similar amplification circuits incorporating transistors are shown in figure 47.

The circuit in figure 48 is a simple example for operating the reflex sensors with chopped light. It uses a pulse generator constructed with a timer IC. This pulse generator operates with the pulse duty factor of approximately 1. The frequency is set to approximately 22 kHz. On the receiver side, a conventional LC resonance circuit ($f_o = 22$ kHz) filters the fundamental wave out of the received pulses and delievers it to an operational amplifier via the capacitor, C_k. The LC resonance circuit simultaneously represents the photo transistor's load resistance. For direct current, the photo transistor's load resistance is very low − in this case approximately 0.4, which means that the photo transistor is practically shorted for dc ambient light.

At resonance frequencies below 5 kHz, the necessary coils and capacitors for the oscillator become unwieldy and expensive. Therefore, active filters, made up with operational amplifiers or transistors, are more suitable (figures 49 and 50). It is not possible to obtain the quality characteristics of passive filters. In addition to that, the load resistance on the emitter of the photo transistor has remarkably higher values than the dc resistance of a coil. On the other hand, the construction with active filters is more compact and cheaper. The smaller the resonance frequency becomes, the greater the advantages of active filters compared to LC resonant circuits.

In some cases, reflex sensors are used to count steps or objects, while at the same time recognition of a change in the direction of rotation (= movement direction) is necessary. The circuit shown in figure 51 is suitable for such applications. The circuit is composed of two independent channels with reflex sensors. The sensor signals are formed via the Schmitt trigger into TTL impulses with step slopes, which are supplied to the pulse inputs of the binary counter 74LS393. The outputs of the 74LS393 are coupled to the reset inputs. This is made in such a way that

the first output, whose condition changes from 'low' to 'high', sets the directly connected counter. In this way, the counter of the other channel is deleted and blocked. The outputs of the active counter can be displaced or connected to more electronics for evaluation.

It should be mentioned that such a circuit is only suited to evenly distributed objects and constant movements. If this is not the case, the channels must be close to each other, so that the movement of both sensors are collected successively. The circuit also works perfectly if the last mentioned condition is fulfilled. Figure 52 shows a pulse circuit combining analog with digital components and offering the possibility of temporary storage of the signal delivered by the reflex sensor. A timer IC is used as the pulse generator.

The negative pulse at the timer's output triggers the clock input of the 74HCT74 flip-flop and, at the same time, the reflex sensor's transmitter via a driver transistor. The flip-flop can be positively triggered, so that the condition of the data input at this point can be received as the edge of the pulse rises. This then remains stored until the next rising edge.

The reflex sensor is therefore only active for the duration of the negative pulse and can only detect reflection changes within this time period. During the time of negative impulses, electrical and optical interferences are suppressed. A sample and hold circuit can also be employed instead of the flip-flop. This is switched on via an analog switch at the sensor output as the pulse rises.
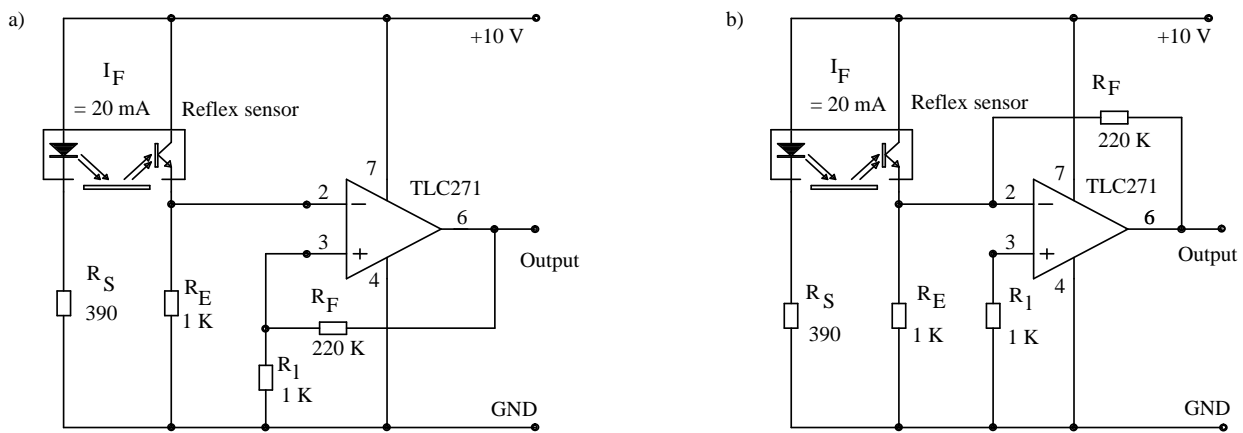
Figure 46. Circuits with operational amplifier
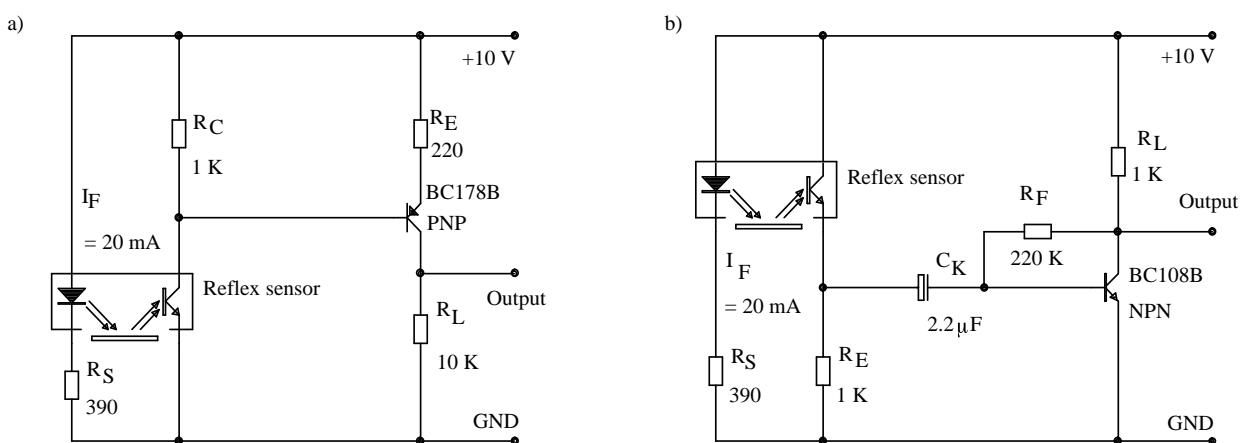
Figure 47. Circuits with transistor amplifier
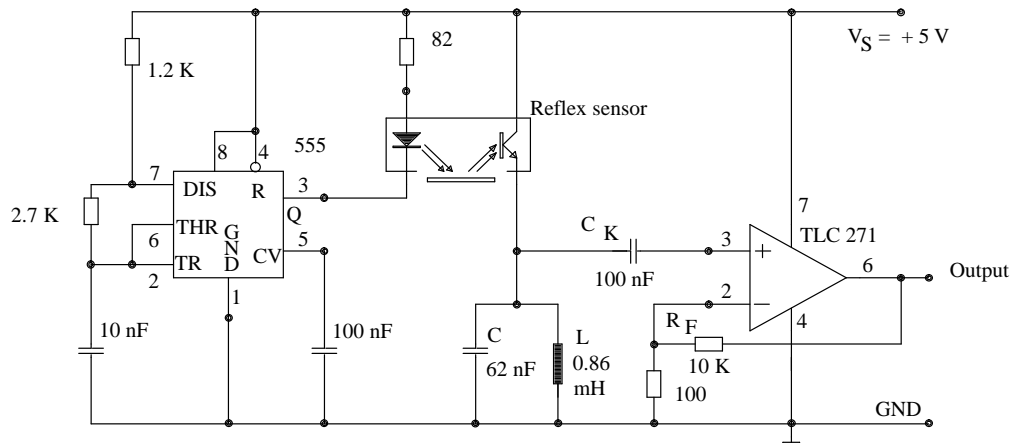
Figure 48. AC operation with oscillating circuit to suppress ambient light
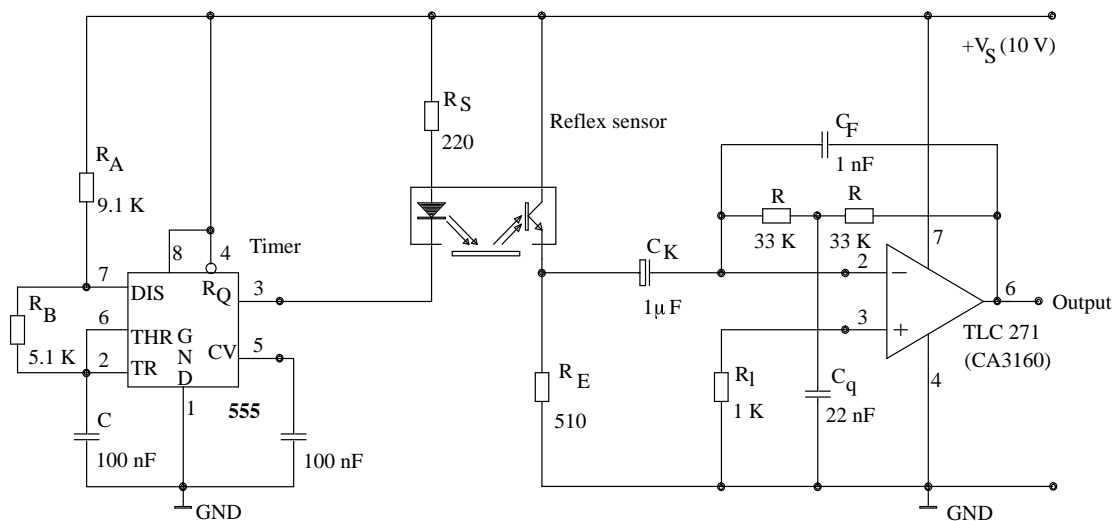
Timer dimensions:

t_p (pulse width) $= 0.8\,RC = 400\,\mu s$

T (period) $= 0.8\,(R_A + R_B) \times C = 1\,ms$

Active filter :

$$C = \sqrt{C_f \times C_q} \qquad Q = \sqrt{\frac{C_q}{C_f}}$$

$$f_o = 1/(6.28 \times C \times R) \qquad V_{uo} = \frac{2\,R}{R_E} \times Q^2$$

Figure 49. AC operation with active filter made up of an operational amplifier, circuit and dimensions
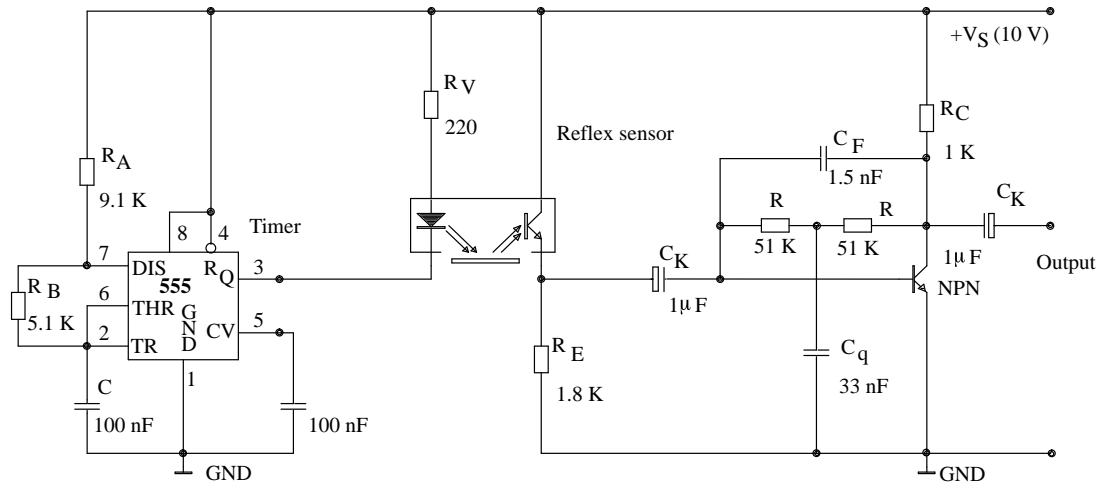
Timer dimensions: t_p (pulse width) $= 0.8\, RC = 400\ \mu s$
T (period) $= 0.8\,(R_A + R_B) \times C = 1\ ms$

Active filter : $C = \sqrt{C_f \times C_q}$ $Q = \sqrt{\dfrac{C_q}{C_f}}$

$f_o = 1/(6.28 \times C \times R)$ $V_{uo} = \dfrac{2\,R}{R_E} \times Q^2$

Figure 50. AC operation with transistor amplifier as active filter
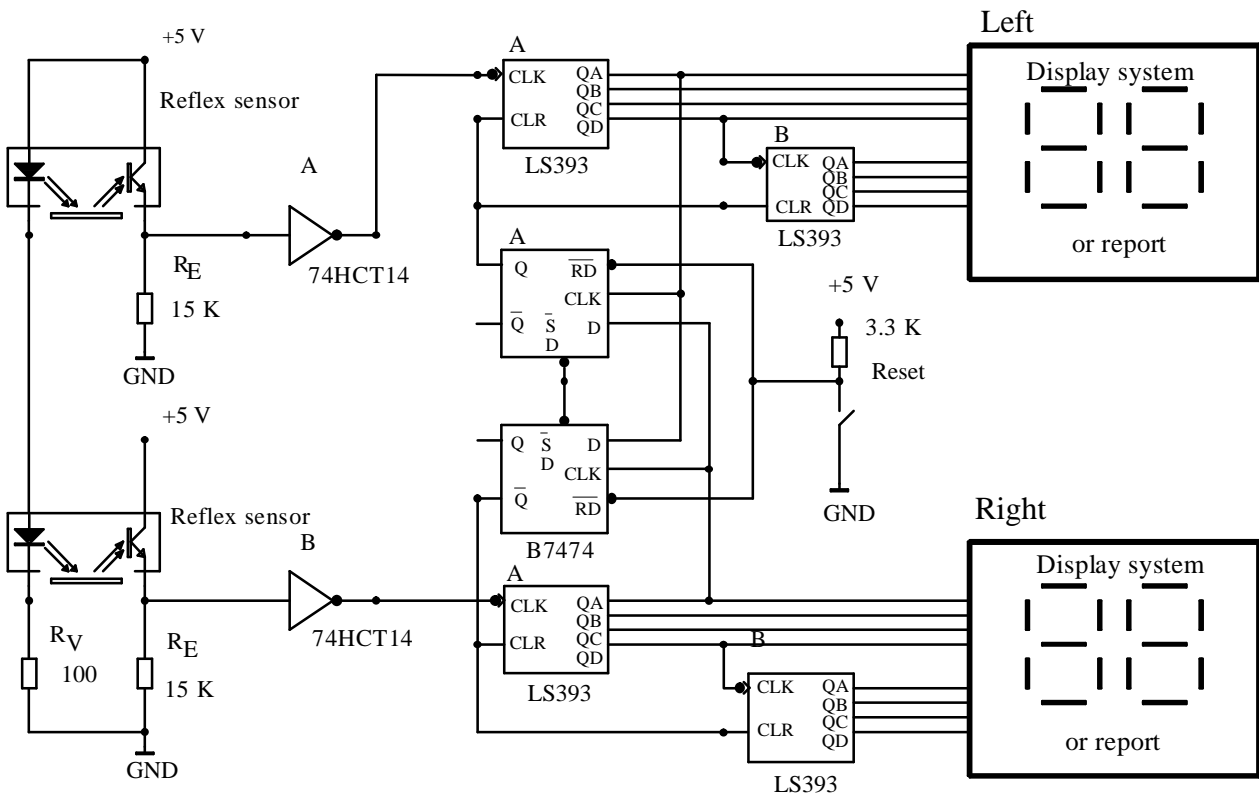
Figure 51. Circuit for objects count and recognition of movement direction
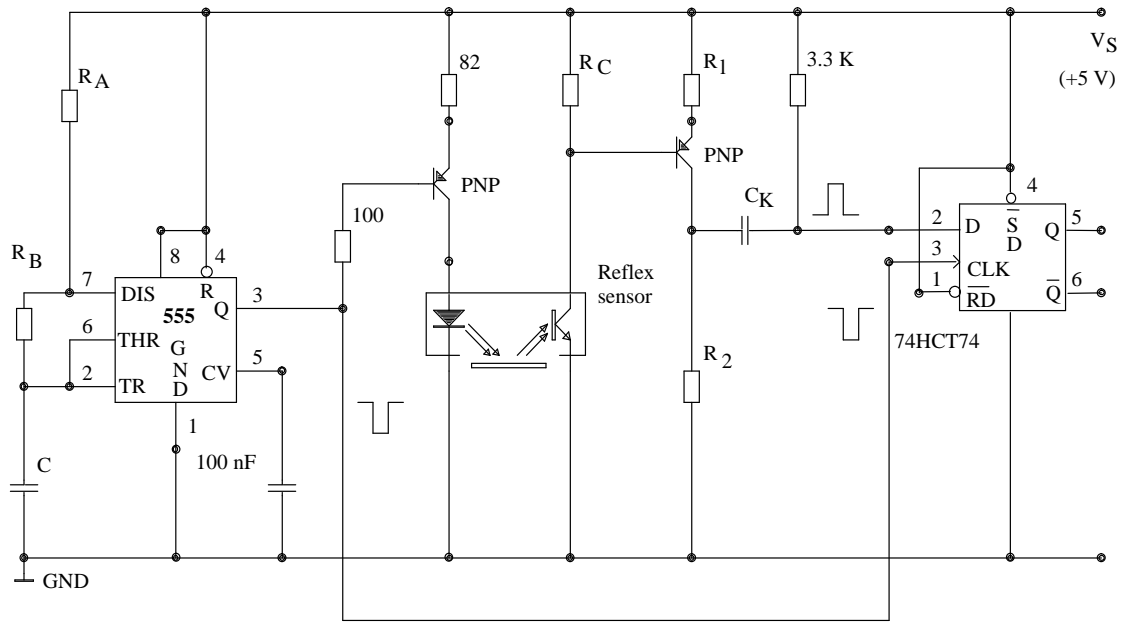
Figure 52. Pulse circuit with buffer storage

TEMIC
Semiconductors

Cross Reference List Opto

Competition–Type	Competitor	Device	TFK–Device	Code	Prio
Isolators					
3C63B	Hafo	Isolator	CNY66	A	3
3C63C	Hafo	Isolator	CNY66	A	3
3C91B	Hafo	Isolator	CNY18	B,E	3
3C91C	Hafo	Isolator	CNY18	B,E	3
3C92B	Hafo	Isolator	CNY18	B,E	3
3C92C	Hafo	Isolator	CNY18	B,E	3
3N243	Optek	Isolator	K120P	A	3
3N244	Optek	Isolator	K120P	A	3
3N245	Optek	Isolator	K120P	B	3
3N281	Texas	Isolator	K120P	B	3
4N25, 25A	Various Suppliers	Isolator	4N25	A	3
4N26	Various Suppliers	Isolator	4N26	A	3
4N27	Various Suppliers	Isolator	4N27	A	3
4N28	Various Suppliers	Isolator	4N28	A	3
4N29	Various Suppliers	Isolator	4N32	A	3
4N29A	Various Suppliers	Isolator	4N32	A	3
4N30	Various Suppliers	Isolator	4N32	B	3
4N31	Various Suppliers	Isolator	4N32	B	3
4N32	Various Suppliers	Isolator	4N32	A	3
4N33	Various Suppliers	Isolator	4N33	A	3
4N35	Various Suppliers	Isolator	4N35	A	3
4N37	Various Suppliers	Isolator	4N37	A	3
4N38	Various Suppliers	Isolator	4N38	A	3
4N38A	Various Suppliers	Isolator	4N38A	A	3
CLA7	Clairex	Isolator	CNY64	E	3
CLA7AA	Clairex	Isolator	CNY64	E	3
CNX21	QTC	Isolator	CNY21N	A, C	3
CNX35	QTC	Isolator	CQY80N	A	3
CNX36	QTC	Isolator	CNY75B	A	3
CNX38	QTC	Isolator	CNY75B	A	3
CNX82	Motorola	Isolator	TCDT1100	A	3
CNX83	Motorola	Isolator	CQY80N	A	3
CNY17A	QTC	Isolator	CNY17–1	A	3
CNY17B	QTC	Isolator	CNY17–2	A	3
CNY17C	QTC	Isolator	CNY17–3	A	3
CNY17D	QTC	Isolator	CNY75C	A	3
CNY17–1	Various Suppliers	Isolator	CNY17–1	A	3
CNY17–2	Various Suppliers	Isolator	CNY17–2	A	3
CNY17–3	Various Suppliers	Isolator	CNY17–3	A	3
CNY17–4	Various Suppliers	Isolator	CNY75C	A	3
CNY17–F1	Various Suppliers	Isolator	TCDT1101	A	3
CNY17–F2	Various Suppliers	Isolator	TCDT1102	A	3

Competition–Type	Competitor	Device	TFK–Device	Code	Prio
CNY17–F3	Various Suppliers	Isolator	TCDT1103	A	3
CNY17–F4	Various Suppliers	Isolator	TCDT1124	A	3
CNY47	QTC	Isolator	4N25	B	3
CNY47A	QTC	Isolator	4N25	B	3
CNY48	QTC	Isolator	4N32	B	3
CNY51	QTC	Isolator	CNY75B	A	3
CNY57	QTC	Isolator	CNY17–1	A	3
CNY57A	QTC	Isolator	CQY80N	A	3
CNY62	QTC	Isolator	CNY21N	B, C	3
CNY63	QTC	Isolator	CNY21N	B, C	3
CNY65	QTC	Isolator	CNY65	A	3
CNY75A	QTC	Isolator	CNY75A	A	3
CNY75B	QTC	Isolator	CNY75B	A	3
CNY75C	QTC	Isolator	CNY75C	A	3
GEPS2001	QTC	Isolator	CNY80N	A	3
GFH600–1	QTC	Isolator	CNY75A	A	3
GFH600–2	QTC	Isolator	CNY75B	A	3
GFH600–3	QTC	Isolator	CNY75C	A	3
H11A5	QTC	Isolator	4N28	B	3
H11A5100	QTC	Isolator	4N35	A	3
H11A520	QTC	Isolator	CQY80N	B	3
H11A550	QTC	Isolator	CQY80N	B	3
H11A1	QTC	Isolator	CQY80N	A	3
H11A2	QTC	Isolator	4N26	A	3
H11A3	QTC	Isolator	4N25	A	3
H11A4	QTC	Isolator	4N27	A	3
H11AV1	QTC	Isolator	CNY64	B, E	3
H11AV2	QTC	Isolator	CNY64	B, E	3
H11AV3	QTC	Isolator	CNY64	B, E	3
H11B1	QTC	Isolator	4N32	A	3
H11B2	QTC	Isolator	4N32	A	3
H11B3	QTC	Isolator	4N32	A	3
H11J1	QTC	Isolator	K3010P	B	3
H11J2	QTC	Isolator	K3010P	A	3
H11J3	QTC	Isolator	K3010P	B	3
H11J4	QTC	Isolator	K3010P	A	3
H11J5	QTC	Isolator	K3010P	A	3
H11L1	QTC	Isolator	TCDS1001	A	3
H11L2	QTC	Isolator	TCDS1001	A	3
H.24A1	QTC	Isolator	CNY64	B, E	3
H.24A2	QTC	Isolator	CNY64	B, E	3
IL–1	Siemens	Isolator	4N25	A	3
IL–100	Siemens	Isolator	TCDS1001	D, E	3
IL–101	Siemens	Isolator	TCDS1001	D, E	3
IL–201	Siemens	Isolator	CNY75A	B	3

TEMIC
Semiconductors

Competition–Type	Competitor	Device	TFK–Device	Code	Prio
IL–202	Siemens	Isolator	CNY75B	B	3
IL–250	Siemens	Isolator	CNY71	B	3
IL–5	Siemens	Isolator	CQY80NG	A	3
IL–74	Siemens	Isolator	4N27	A	3
IL–CT6	Siemens	Isolator	MCT6	A	3
ILCA2–30	Siemens	Isolator	4N32	A	3
ILD–1	Siemens	Isolator	CNY74–2	A	3
ILD–74	Siemens	Isolator	CNY74–2	A	3
ILQ–1	Siemens	Isolator	CNY74–4	A	3
ILQ–74	Siemens	Isolator	CNY74–4	A	3
MCA230	QTC	Isolator	4N32	A	3
MCA230	QTC	Isolator	4N32	B	3
MCA231	QTC	Isolator	4N32	A	3
MCA231	QTC	Isolator	4N32	B	3
MCP3009	QTC	Isolator	K3010P	A	3
MCP3010	QTC	Isolator	K3010P	A	3
MCP3011	QTC	Isolator	K3011P	A	3
MCP3020	QTC	Isolator	K3020P	A	3
MCP3021	QTC	Isolator	K3021P	A	3
MCP3022	QTC	Isolator	K3022P	A	3
MCT2	QTC	Isolator	4N26	A	3
MCT2E	QTC	Isolator	4N25	A	3
MCT210	QTC	Isolator	4N35	B	3
MCT210	QTC	Isolator	4N35	A	3
MCT2200	QTC	Isolator	CQY80N	B	3
MCT2201	QTC	Isolator	CNY75B	A	3
MCT2202	QTC	Isolator	CNY75A	A	3
MCT26	QTC	Isolator	4N26	A	3
MCT26	QTC	Isolator	4N26	A	3
MCT270	QTC	Isolator	CQY80N	A	3
MCT271	QTC	Isolator	CNY17–1	A	3
MCT272	QTC	Isolator	CNY75 A	B	3
MCT273	QTC	Isolator	CNY75B	B	3
MCT274	QTC	Isolator	CNY75C	B	3
MCT275	QTC	Isolator	CNY75B	B	3
MCT276	QTC	Isolator	CNY17–1	A	3
MCT277	QTC	Isolator	4N36	A	3
MCT3	QTC	Isolator	4N28	A	3
MCT4	QTC	Isolator	K120P	A	3
MCT6	QTC	Isolator	CNY74–2	A	3
MCT66	QTC	Isolator	CNY74–2	A	3
MOC1005	Motorola	Isolator	CNY75A	B	3
MOC1006	Motorola	Isolator	CNY75A	B	3
MOC119	Motorola	Isolator	4N32	B	3
MOC205	Motorola	Isolator	TCMT1021	A	3

Competition–Type	Competitor	Device	TFK–Device	Code	Prio
MOC206	Motorola	Isolator	TCMT1022	A	3
MOC207	Motorola	Isolator	TCMT1023	A	3
MOC215	Motorola	Isolator	TCMT1031	A	3
MOC216	Motorola	Isolator	TCMT1032	A	3
MOC217	Motorola	Isolator	TCMT1033	A	3
MOC221	Motorola	Isolator	TCMT1033	A	3
MOC222	Motorola	Isolator	TCMT1034	A	3
MOC223	Motorola	Isolator	TCMT1034	B	3
MOC3009	Motorola	Isolator	K3010P	A	3
MOC3010	Motorola	Isolator	K3010P	A	3
MOC3011	Motorola	Isolator	K3011P	A	3
MOC3012	Motorola	Isolator	K3012P	A	3
MOC3020	Motorola	Isolator	K3020P	A	3
MOC3021	Motorola	Isolator	K3021P	A	3
MOC3022	Motorola	Isolator	K3022P	A	3
MOC3023	Motorola	Isolator	K3023P	A	3
MOC5005	Motorola	Isolator	TCDS1001	A	3
MOC5006	Motorola	Isolator	TCDS1001	A	3
MOC5007	Motorola	Isolator	TCDS1001	A	3
MOC5008	Motorola	Isolator	TCDS1001	A	3
MOC5009	Motorola	Isolator	TCDS1001	A	3
MOC8101	Motorola	Isolator	TCDT1101	A	3
MOC8102	Motorola	Isolator	TCDT1102	B	3
MOC8103	Motorola	Isolator	TCDT1103	B	3
MOC8104	Motorola	Isolator	TCDT1124	B	3
MOC8112	Motorola	Isolator	TCDT1100	A	3
MOC8113	Motorola	Isolator	TCDT1110	A	3
OPI110	Optek	Isolator	CNY21N	E	3
OPI113	Optek	Isolator	CNY65	D, E	3
OPI120	Optek	Isolator	CNY66	E	3
OPI123	Optek	Isolator	CNY66	D, E	3
OPI1264A	Optek	Isolator	CNY21N	E	3
OPI1264B	Optek	Isolator	CNY65	E	3
OPI1264C	Optek	Isolator	CNY65	B, E	3
OPI140	Optek	Isolator	K120P	B	3
OPI2100	Optek	Isolator	CNY75C	A	3
OPI2150	Optek	Isolator	4N27	A	3
OPI2151	Optek	Isolator	4N27	A	3
OPI2152	Optek	Isolator	4N26	A	3
OPI2153	Optek	Isolator	CQY80N	A	3
OPI2154	Optek	Isolator	4N27	A	3
OPI2155	Optek	Isolator	4N26	A	3
OPI2250	Optek	Isolator	4N26	A	3
OPI2251	Optek	Isolator	4N26	A	3
OPI2252	Optek	Isolator	4N25	A	3

TEMIC
Semiconductors

Competition–Type	Competitor	Device	TFK–Device	Code	Prio
OPI2253	Optek	Isolator	CQY80N	A	3
OPI2254	Optek	Isolator	4N26	A	3
OPI2255	Optek	Isolator	4N25	A	3
OPI2500	Optek	Isolator	CNY71	A	3
OPI3009	Optek	Isolator	K3010P	A	3
OPI3010	Optek	Isolator	K3010P	A	3
OPI3011	Optek	Isolator	K3011P	A	3
OPI3012	Optek	Isolator	K3012P	A	3
OPI3020	Optex	Isolator	K3020P	A	3
OPI3021	Optek	Isolator	K3021P	A	3
OPI3022	Optek	Isolator	K3022P	A	3
OPI3023	Optek	Isolator	K3023P	A	3
OPI3150	Optek	Isolator	4N33	A	3
OPI3151	Optek	Isolator	4N33	B	3
OPI3153	Optek	Isolator	4N33	A	3
OPI3250	Optek	Isolator	4N33	A	3
OPI3251	Optek	Isolator	4N32	B	3
OPI3253	Optek	Isolator	4N32	A	3
OPI7002	Optek	Isolator	CNY64	E	3
OPI7010	Optek	Isolator	CNY64	B, E	3
PC508	Sharp	Isolator	CNY65	D, E	3
PC613	Sharp	Isolator	CNY75	A	3
PC627	Sharp	Isolator	K827P	A	3
PC713U	Sharp	Isolator	CNY75A	A	3
PC733	Sharp	Isolator	CNY71	A	3
PC827U	Sharp	Isolator	K827P	A	3
PC829	Sharp	Isolator	CNY74–2	A	3
PC847U	Sharp	Isolator	K827P	A	3
PS2001A	NEC	Isolator	CQY80N	A	3
PS2001B	NEC	Isolator	CQY80N	A	3
PS2003A	NEC	Isolator	CQY80N	A	3
PS2003B	NEC	Isolator	4N25	A	3
PS2004A	NEC	Isolator	4N32	D	3
PS2004B	NEC	Isolator	4N32	B	3
PS2005A	NEC	Isolator	CQY80N	A	3
PS2005B	NEC	Isolator	4N25	A	3
PS2010	NEC	Isolator	4N25	A	3
PS2011	NEC	Isolator	CQY80N	A	3
PS2013	NEC	Isolator	CQY80N	B	3
PS2014	NEC	Isolator	4N32	B	3
PS2015	NEC	Isolator	CQY80N	A	3
PS2021	NEC	Isolator	CQY80N	A	3
PS2022	NEC	Isolator	4N32	B	3
PS2401A–2	NEC	Isolator	K827P	B	3
PS2401A–4	NEC	Isolator	K827P	B	3

Competition–Type	Competitor	Device	TFK–Device	Code	Prio
SFH600–0	Siemens	Isolator	CNY17–1	A	3
SFH600–1	Siemens	Isolator	CNY17–2	A	3
SFH600–2	Siemens	Isolator	CNY17–3	A	3
SFH600–3	Siemens	Isolator	CNY75C	A	3
SFH601–1	Siemens	Isolator	CNY17–1	D	3
SFH601–2	Siemens	Isolator	CNY75A	A	3
SFH601–3	Siemens	Isolator	CNY75B	A	3
SFH601–4	Siemens	Isolator	CNY75C	A	3
TIL111	Texas	Isolator	4N27	A	3
TIL112	Texas	Isolator	4N27	A	3
TIL113	Texas	Isolator	4N33	A	3
TIL114	Texas	Isolator	4N25	A	3
TIL115	Texas	Isolator	4N26	A	3
TIL116	Texas	Isolator	4N25	A	3
TIL117	Texas	Isolator	CQY80N	A	3
TIL120	Texas	Isolator	K120P	A	3
TIL121	Texas	Isolator	K120P	B	3
TIL124	Texas	Isolator	CQY80N	B	3
TIL125	Texas	Isolator	CQY80N	B	3
TIL126	Texas	Isolator	CQY80N	B	3
TIL127	Texas	Isolator	4N32	B	3
TIL153	Texas	Isolator	4N26	B	3
TIL154	Texas	Isolator	4N25	B	3
TIL155	Texas	Isolator	CQY80N	A	3
TIL156	Texas	Isolator	4N32	B	3
TLP3051	Toshiba	Isolator	K3052P	A	3
TLP3052	Toshiba	Isolator	K3051P	A	3
TLP504–A	Toshiba	Isolator	K827P	A	3
TLP521–2	Toshiba	Isolator	K827P	A	3
TLP521–4	Toshiba	Isolator	K827P	A	3
TLP531–A	Toshiba	Isolator	CQY80N	A	3
TLP531–BL	Toshiba	Isolator	CNY75C	B	3
TLP531–GB	Toshiba	Isolator	CNY75B	A	3
TLP531–GR	Toshiba	Isolator	CNY75B	A	3
TLP531–Y	Toshiba	Isolator	CNY75A	A	3
TLP531–YG	Toshiba	Isolator	CQY80N	A	3
TLP533	Toshiba	Isolator	CQY80N	B	3
TLP535	Toshiba	Isolator	CQY80N	A	3
TLP571	Toshiba	Isolator	4N32	B	3
TLP595	Toshiba	Isolator	TCDT1900	B	3
Sensors					
CNY28	QTC	Sensor	TCST2103	A	4
EE–SMR1–1	Omron	Sensor	TCRT9050	A	4
EE–SMR3–1	Omron	Sensor	TCRT9000	A	4
EE–SX1025	Omron	Sensor	TCST1230	A	4

TELEFUNKEN Semiconductors
06.96

TEMIC
Semiconductors

Competition–Type	Competitor	Device	TFK–Device	Code	Prio
GP1A05	Sharp	Sensor	TCSS6201	A	4
GP1A21	Sharp	Sensor	TCYS5201	A	4
GP1S01	Sharp	Sensor	TCST2103	B, C	4
GP1S01F	Sharp	Sensor	TCST2103	B, C	4
GP1S02	Sharp	Sensor	TCST2103	B, C	4
GP1S04	Sharp	Sensor	TCST1103	A, C	4
H21A1	QTC	Sensor	TCST2103	A	4
H21A2	QTC	Sensor	TCST2103	A	4
H21A4	QTC	Sensor	TCST2103	A	4
H21A5	QTC	Sensor	TCST2103	A	4
H21L	QTC	Sensor	TCSS2100	B	4
H22A1	QTC	Sensor	TCST1103	A	4
H22A2	QTC	Sensor	TCST1103	A	4
H22A4	QTC	Sensor	TCST1103	A	4
H22A5	QTC	Sensor	TCST1103	A	4
H22L	QTC	Sensor	TCSS1100	B	4
HOA0870–055	Honeywell	Sensor	TCST1103	C	4
HOA0870–251	Honeywell	Sensor	TCST2300	C	4
HOA0870–255	Honeywell	Sensor	TCST2103	C	4
HOA0871–051	Honeywell	Sensor	TCST1103	C	4
HOA0871–255	Honeywell	Sensor	TCST2103	B, C	4
HOA0872–051	Honeywell	Sensor	TCST1300	C	4
HOA0872–055	Honeywell	Sensor	TCST1103	B, C	4
HOA0872–251	Honeywell	Sensor	TCST2300	C	4
HOA0872–255	Honeywell	Sensor	TCST2103	C	4
HOA1397–1	Honeywell	Sensor	CNY70	B, C	4
HOA1397–2	Honeywell	Sensor	CNY70	B, C	4
HOA1872–11	Honeywell	Sensor	TCST1103	C	4
HOA1872–12	Honeywell	Sensor	TCST1103	C	4
HOA1873–11	Honeywell	Sensor	TCST2103	C	4
HOA1873–12	Honeywell	Sensor	TCST2103	C	4
HOA1879–15	Honeywell	Sensor	TCST2300	B, C	4
MOC7811	Motorola	Sensor	TCST2103	A	4
MOC7812	Motorola	Sensor	TCST2103	A	4
MOC7821	Motorola	Sensor	TCST1103	A	4
MOC7822	Motorola	Sensor	TCST1103	A	4
MST8	QTC	Sensor	TCST2000	E	4
MST81	QTC	Sensor	TCST2000	E	4
OPB706A	Optek	Sensor	CNY70	C	4
OPB706B	Optek	Sensor	CNY70	C	4
OPB706C	Optek	Sensor	CNY70	C	4
OPB710	Optek	Sensor	TCSS2100	A, C	4
OPB804	Optek	Sensor	TCST1000	B, E	4
OPB813	Optek	Sensor	TCST2000	B	4
OPB813S10	Optek	Sensor	TCST2103	E	4

Competition–Type	Competitor	Device	TFK–Device	Code	Prio
OPB814	Optek	Sensor	TCST1103	B, E	4
OPB815	Optek	Sensor	TCST2103	B, E	4
OPB816	Optek	Sensor	TCST2000	B	4
OPB817	Optek	Sensor	TCST2103	B, E	4
OPB870N55	Optek	Sensor	TCST1103	C	4
OPB870T51	Optek	Sensor	TCST2300	C	4
OPB870T55	Optek	Sensor	TCST2103	C	4
OPB871N51	Optek	Sensor	TCST1300	B, C	4
OPB871N55	Optek	Sensor	TCST1103	B, C	4
OPB871T51	Optek	Sensor	TCST2300	B, C	4
OPB871T55	Optek	Sensor	TCST2103	B, C	4
OPB872N51	Optek	Sensor	TCST1300	C	4
OPB872N55	Optek	Sensor	TCST1103	C	4
OPB872T51	Optek	Sensor	TCST2300	C	4
OPB872T55	Optek	Sensor	TCST2103	C	4
OPB875N55	Optek	Sensor	TCST1000	C	4
OPB875T55	Optek	Sensor	TCST2000	C	4
OPB971P55	Optek	Sensor	TCSS1100	A, C	4
OPB973N55	Optek	Sensor	TCSS1100	A, C	4
OPB973T55	Optek	Sensor	TCSS2100	A, C	4
OPD819S10	Optek	Sensor	TCST2300	B, E	4
OPD823A	Optek	Sensor	TCST2103	B, C	4
OPD824B	Optek	Sensor	TCST2103	B, C	4
OPD847	Optek	Sensor	TCST1103	B, E	4
OPD848	Optek	Sensor	TCST1103	B, E	4
OPD870N51	Optek	Sensor	TCST1300	C	4
TIL147	Texas	Sensor	TCST1103	D, E	4
TIL148	Texas	Sensor	TCST1103	D, E	4
TIL143	Texas	Sensor	TCST2000	D, E	4
TIL144	Texas	Sensor	TCST2000	D, E	4
TLP1001	Toshiba	Sensor	TCSS2100	B	4
TLP800	Toshiba	Sensor	TCST2103	B, C	4
TLP801	Toshiba	Sensor	TCST1103	B, C	4
TLP804	Toshiba	Sensor	TCST1202	B, C	4
TLP908	Toshiba	Sensor	TCRT1000	E	4
TLP908(LB)	Toshiba	Sensor	TCRT1010	E	4