TSOP1x IR Detector Photomodules

TELEFUNKEN Semiconductors
08.97

Table of Contents

General Information

Introduction

Infrared remote controls have become a standard part of home entertainment equipment. Nearly all functions of sat receivers, TV sets, VCRs, hi-fi audio receivers and compact disk players are remote controlled.

Without exception, the signals have been transmitted up until now with an optical carrier in the near infrared with a wavelength between 840 nm and 960 nm. Infrared headphones, interpreter transmission systems in conference rooms, optical computer links and optoelectronic keys also work in this wavelength range.

Remote-control receivers must be extremely sensitive and should not react to interference from other infrared emitters. The systems must also not disturb each other.

Generally, interference between remote-control systems can be avoided by addressing the different units with a special code. The aim is to integrate the control of different units into one.

For the developer of remote-control systems, it is an essential task to avoid interference by omni-present optical and electromagnetic radiation sources. Therefore, certain specifications must be made for the receiver photomodule and with regards to their properties in the application.

The system developer has a substantial influence on the performance of the system by choosing a suitable transmission code. The procedure in evaluating all incoming signals (either disturbing or useful ones) contributes significantly to the optimization of the system.

This design guide gives some necessary background information for the system developer to optimize the operation of photomodules. The physical boundary conditions which can have an influence on the performance of the receiver photomodules are also described.

The IR remote-control photomodules within this design guide are complete front ends, including photo pin diode, AGC amplifier, bandpass and demodulator.

TEMIC has been a major supplier of infrared communication devices for more than twenty years and offers the safety of a perfected product. The components are based on the many years' experience of one of the most advanced infrared receiver manufacturer.

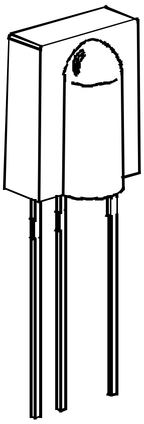
Typical applications

- TV sets
- Video recorders
- Sat receivers
- DVD (**D**igital **V**ersatile **D**isk)
- Slide projectors
- Hi-fi components
- Data communication

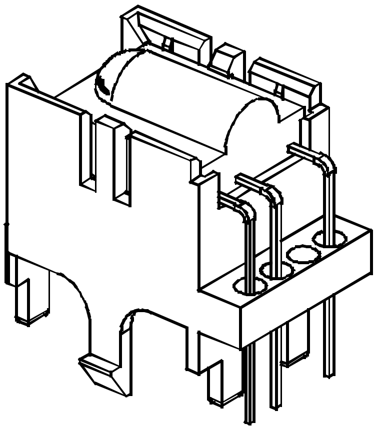
Special features

- Compact outline
- Available for carrier frequencies of 27 kHz up to 62 kHz
- No external components necessary
- Output microcomputer-compatible
- High sensitivity for large transmitting range (120 ft/ 35 m)
- Maximum interference safety against optical and electrical disturbances
- High quality level ISO 9001
- Automated large-volume production

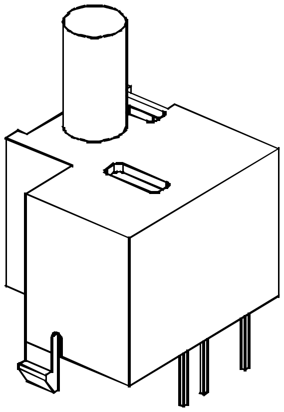
Available Types and Packages



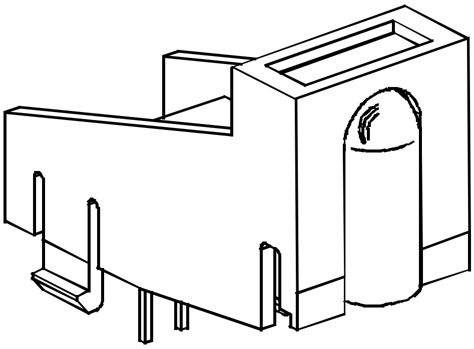
TSOP1..SS – standard side view



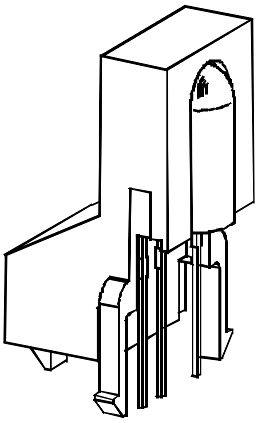
TSOP1..TB – standard top view



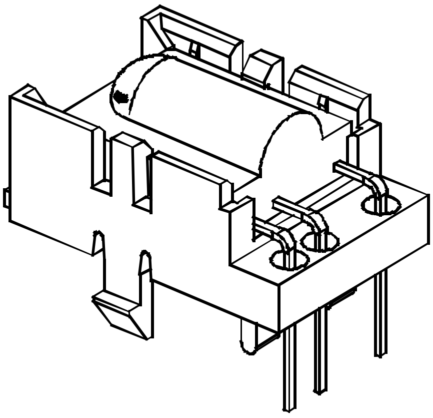
TSOP1..YB – top view
with transparent holder and light guide



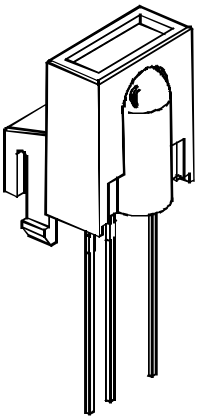
TSOP1..W



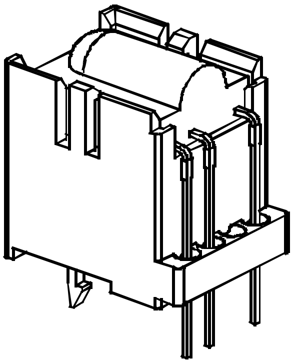
TSOP1..XG – side view with holder



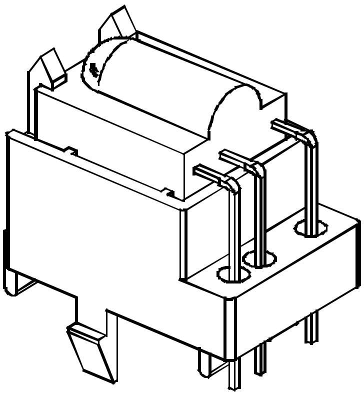
TSOP1..UU – top view
with very flat holder



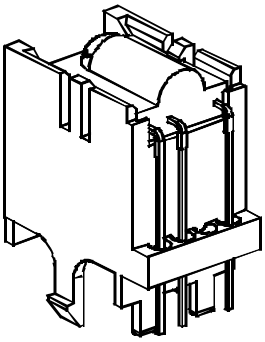
TSOP1..KS – side view with holder



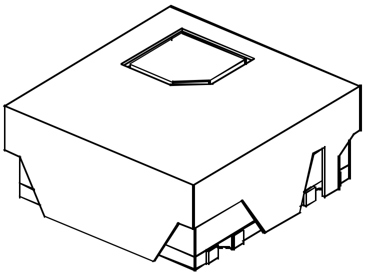
TSOP1..R



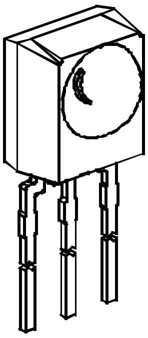
TSOP1..CB – top view
with flat holder



TSOP1..G



TSOP – SMD case

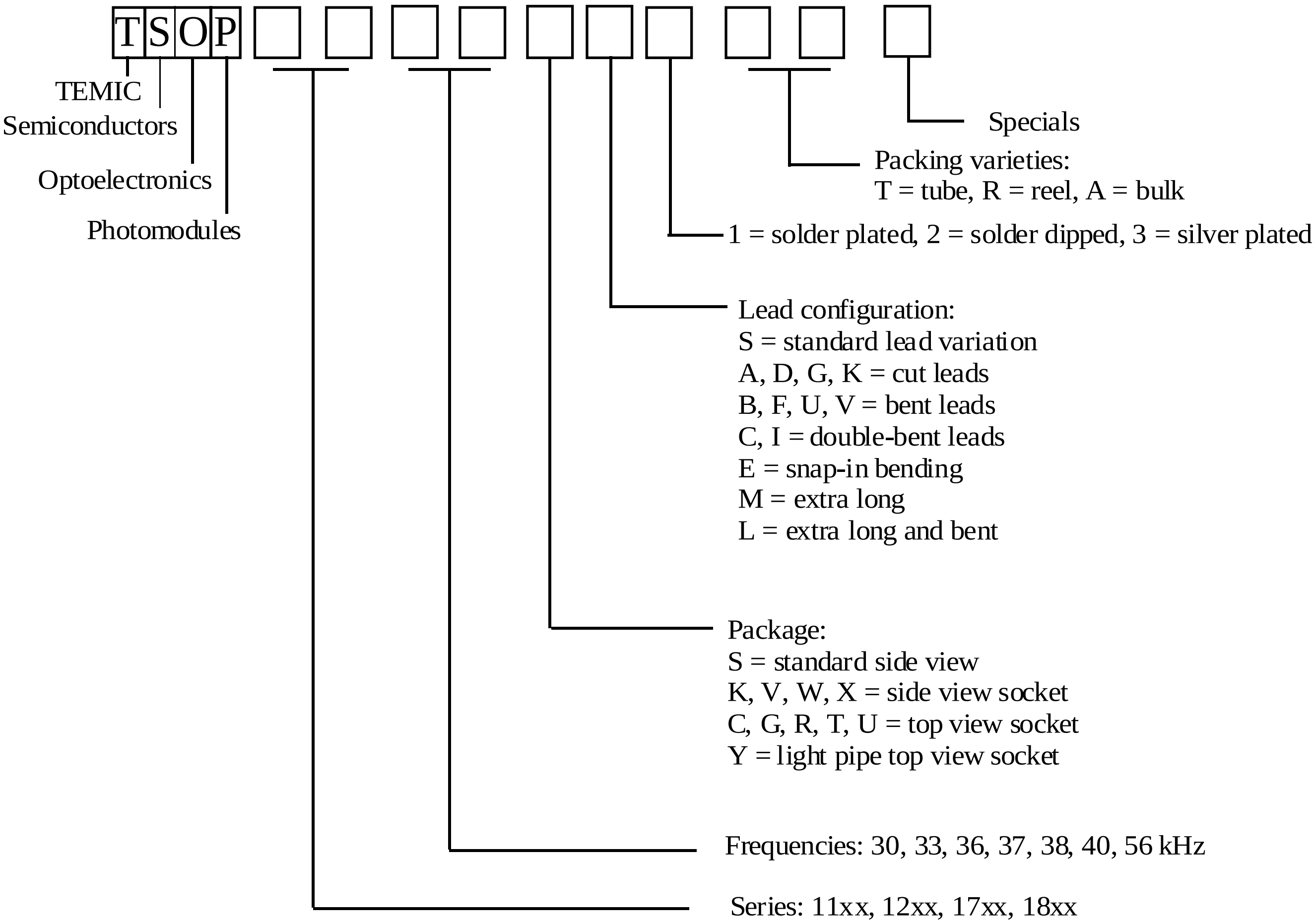


TSOP18..S – small size
standard side view

Type Series	Typical Application	Application Examples
TSOP11..	Short bursts and high data rate	Continuous data transmission; RECS 80 code
TSOP12..	For use in disturbed ambient	RC 5-, NEC code
TSOP17..	Standard applications	RC 5-, NEC code
TSOP18..	Small-size photomodule	RECS 80-, RC 5-, NEC code

TEMIC Type Designation Code

The key to understanding the type name of the TSOP series:



TEMIC Semiconductors

Optoelectronics

Photomodules

Specials

Packing varieties:
T = tube, R = reel, A = bulk

1 = solder plated, 2 = solder dipped, 3 = silver plated

Lead configuration:
S = standard lead variation
A, D, G, K = cut leads
B, F, U, V = bent leads
C, I = double-bent leads
E = snap-in bending
M = extra long
L = extra long and bent

Package:
S = standard side view
K, V, W, X = side view socket
C, G, R, T, U = top view socket
Y = light pipe top view socket

Frequencies: 30, 33, 36, 37, 38, 40, 56 kHz

Series: 11xx, 12xx, 17xx, 18xx

Example: TSOP1736SS2 = Standard receiver with 36 kHz carrier frequency, active low output, side-view package and with tin-plated leads

Free-Space Data Transmission in the Near Infrared

Data transmission in free space places a high interference immunity on the photomodules. The receiver unit (waiting to receive signals) is loaded with different optical and electromagnetic disturbances, omni-present in the ambient or generated by the electrical appliance itself. All optical sources with an emission spectrum in the receiving bandwidth (830 nm - 1100 nm) of the detector can be considered as disturbing sources. Possible sources for electrical interferences are all modulated power signals in the operating frequency range as found especially in deflecting currents in TV sets with their harmonics. Another potential source for disturbances are energy-saving fluorescent lamps.

Optical Sources of Interference

In the visible, remote-control receivers are totally insensitive because they are equipped with an optical cut-off filter at a wavelength of, e.g. 830 nm. Therefore, only radiation with longer wavelengths are detected. Special measures in the design and technology of TEMIC devices ensure that sensitivity above 950 nm drops as sharply as possible.

The silicon photo detector receives in this way a limited spectrum originating from the common broadband "white" light sources which are emitted in the visible and infrared, respectively. For the assessment of visible radiation, mostly the quantity illuminance (measured in Lux = Lumen/ m^2) instead of the quantity irradiance (measured in Watt/ m^2) is used. However, the quantity illuminance is absolutely unsuitable for the description of infrared radiation because the part of radiation with wavelengths longer than 780 nm is generally not assessed. This will be described later more detailed.

Generally, the question of the photo current generated in a remote-control receiver by a defined illumination arises. This can not be answered without knowing the spectral distribution of the source.

Various Radiation Sources in Filtered Silicon Detector Diodes

The spectral distribution of a radiant source is very varied and is dependent on the mechanism of radiation generation. The spectral emission curve of a thermal radiator such as, e.g., an incandescent (tungsten) lamp is very broadband and is described very well by Planck's radiation law.

The spectral emission of fluorescent lamps is rather complicated. In the infrared only, little radiation is emitted. The spectral emission is a combination of the relative broadband emission of the luminescent phosphor, the emitted mercury lines and the lines emitted from the gas filling the tubes. For assessment of the disturbing influences of these sources, consideration has to be given to the various time constants (milliseconds) of the activated luminescent materials. Direct emission on the other hand is modulated to the current, passing through the lamp with all high-frequency parts on it. Therefore, one part of the emitted spectrum is to be considered as a low-frequency source while the other must be regarded as a broadband disturbing source with high-frequency parts.

In the main, the sun can be seen as a thermal radiator which is influenced by atmospheric absorption.

Silicon photo diodes with integrated cut-off filters are used in IR data transmission systems such as the remote-control appliance. The spectral responsitivity of the diode in the received band is near 100% quantum efficiency. For the lower wavelength cut-off, the edge is at about 820 nm to 900 nm, depending on the wavelength of the emitters. The long wavelength cut-off and wavelength dependent decrease of the sensitivity at longer wavelengths is given by the spectral absorption of the silicon and the thickness of the active volume (in pin diodes the wafer thickness). The response to different light sources can be numerically calculated with this kind of detector model. For the calculation, a thermal radiator with a temperature of 5900 K was chosen as an equivalent to the solar spectrum (see figure 1) for direct and global radiation under AM2 conditions.

This radiator is compared with a standard illuminant A radiator (T = 2856 K) which is approximately equivalent to a common tungsten incandescent lamp. In figure 2, the spectral density of the emission of both sources are shown as a function of the wavelength normalized to equal photometrically weighted outputs. Additionally, the sensitivity of the human eye V(λ) and of a filtered silicon detector (similar to TEMIC BPV23NF) is shown. It can easily be seen that the radiation from the sun-equivalent source contains much less radiation than the tungsten lamp in the sensitive wavelength range of the silicon detector diode.

These facts can also be numerically evaluated with regard to the expected photo current of the detector diode resulting in the data given in table 1. The irradiance and illuminance necessary to generate a photo current $I_{ra} = 100\ \mu A$ are listed for the filtered silicon detector diode with an effective area of 8 mm^2.

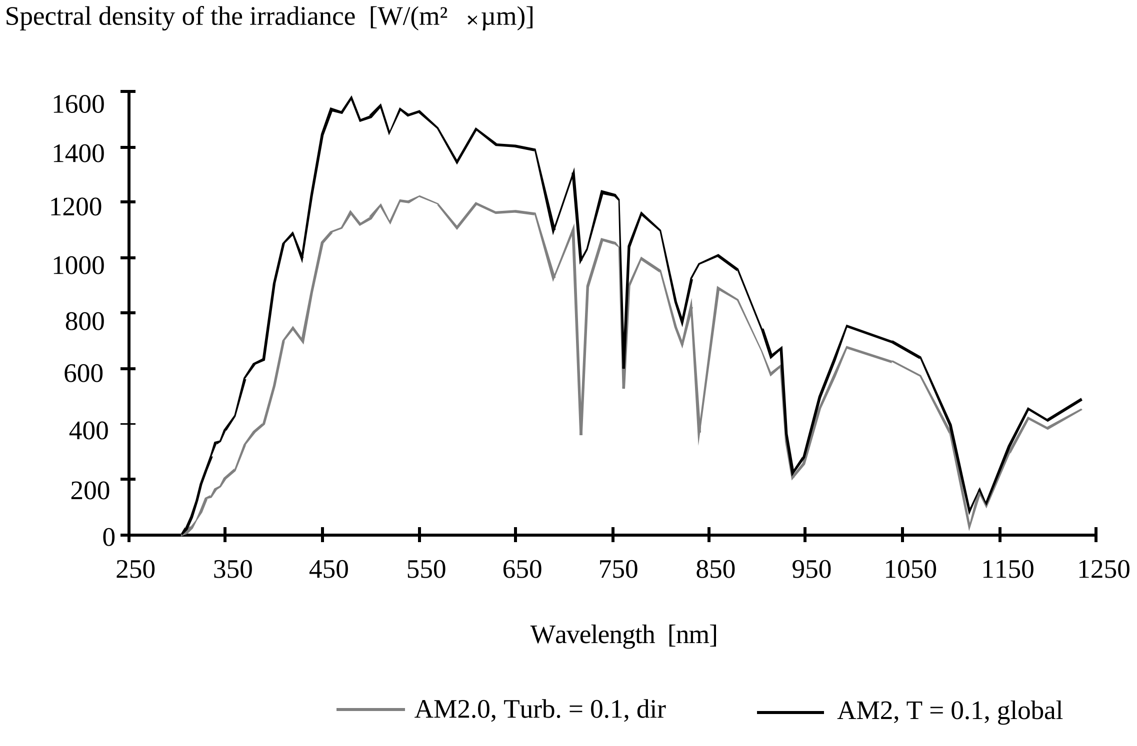


Figure 1. Spectral distribution of the solar spectrum

Of course, an irradiance could be assigned to the thermal radiation. However, this is not very effective in our consideration because it cannot describe a result in terms of, e.g., a photo current (the total irradiance is the integrated quantity over the wavelength from zero to infinity). The illuminance resulting from the radiation of an infrared emitter is per definition zero. The result is of significance in that drastically different illuminances of radiation sources necessary for the generation of equal photo currents. The efficiency of the sunlight as a disturbing source (photometrically weighted, same illuminance) is a factor of 6 smaller than that of an incandescent lamp. In this calculation, the atmospheric absorption of water is not taken into account (see figure 1 – AM2 is equivalent to the solar irradiance on late afternoon, vertical axis: Spectral density of the irradiance as a function of the wave-length). This additional damping is increased with decreased azimuth. This should be considered when calculating the photo currents of detectors in the ambient as, e.g., remote-control detectors in cars. An equivalent mathematical correct weighting of the real sunlight (see figure 2) is mathematically no problem but it makes no sense because its spectral distribution changes during the day and is dependent on weather conditions.

Weighting is carried out by the human eye [function V/(λ)] and by a filtered silicon detector. The amplitudes are normalized to give, photometrically weighted, the same illuminance. The human eye will see both sources as equal 'brightness'.

Table 1. Filtered silicon detector diode (area A = 8 mm^2, sensitivity equivalent to figure 2)

Source	**Wave-length**	**Irradi-ance**	**Illumi-nance**
IRED	950 nm	18 W/ m^2	-
Thermal radiator	T = 5900 K equivalent to sun	–	14700 Lux
Thermal radiator	T = 2856 K standard illuminant A	–	2500 Lux

The necessary irradiation or illumination to generate a photo current of I_{ra} is 100 µA.

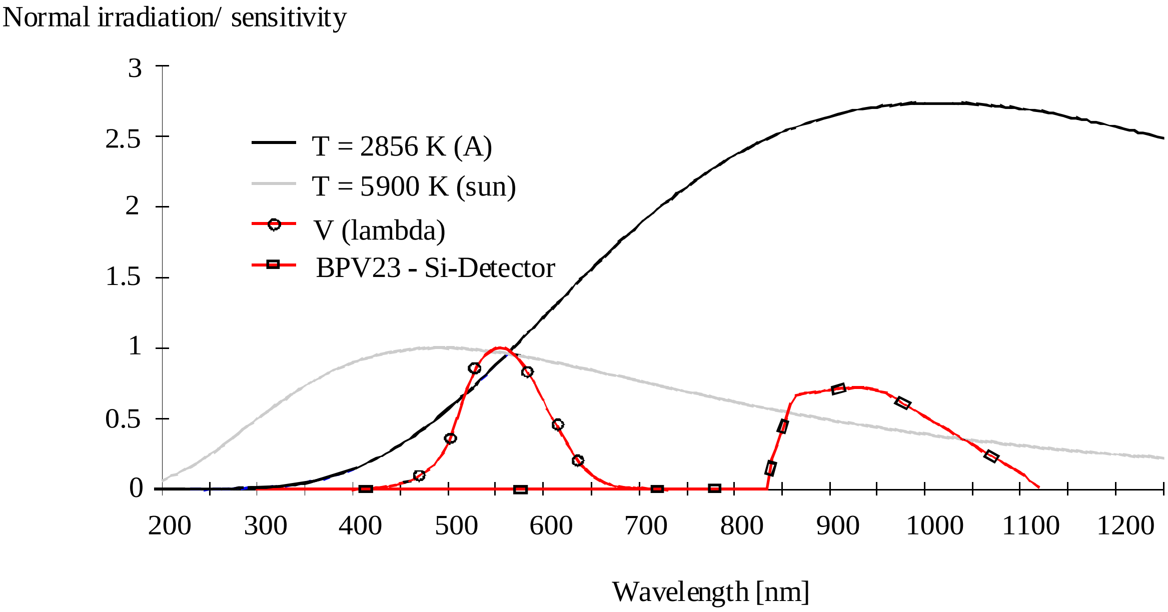


Figure 2. Blackbody radiation with various color temperatures

Application Hints

In this sub-chapter, recommendations for the design of a front panel for, e.g., a TV or a VCR device is given.

Usually, the front panels of home devices are black, and the optical window in front of the IR receiver should also be black. That means that a plastic material is needed which is transmissive for the infrared signals but not transparent for visible light. The diagram in figure 3 shows an example of the spectral transmittance of such a plastic material (Bayer Makrolon color 45/601).

The cut-off wavelength should be between 700 and 850 nm in order to appear black and in order not to absorb signal energy.

There is a loss of power in every front panel of about 8% due to reflection (4% at each side). On the one hand, the thickness of the panel should be kept small, as there is an additional loss of energy in the plastic material. On the other hand, the thickness of the plastic or the color mixture should not be too small in order to avoid that one can see inside the device. In contrast to other products which have a metal can shielding, the TEMIC TSOP receiver has an advantageous black package which prevents that it is visible behind the front panel.

The relation between the necessary thickness and the optical transmittance is given by:

$$\tau(\lambda) = (1 - \rho) \times e^{[-\alpha(\lambda)\times d]}$$

$\tau(\lambda)$ = Spectral transmittance
ρ = Constant factor for reflection loss (about 0.08)
e = 2.718282
$\alpha(\lambda)$ = Coefficient of plastic material (about 0.03 mm^{-1} at 950 nm in the example above)
d = Thickness of front panel

There are several plastic materials with such a spectral behavior. Some examples of Polycarbonate are given here:

Makrolon 2805; color #: 45-601
(blue - black); supplier: Bayer

Makrolon 2805: color #: 45-401
(green - black); supplier: Bayer

Lexan 21125, 21051, 21127;
supplier: General Electric

Supplier's addresses: see appendix

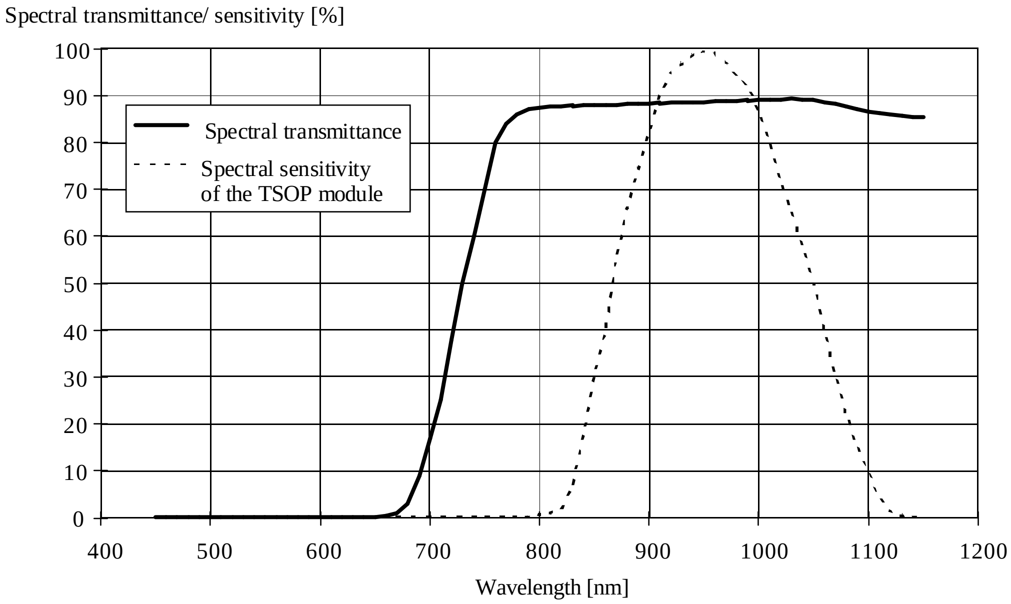


Figure 3. Spectral transmittance and spectral sensitivity of TSOP modules

Transmission Range

The transmission range in free-space transmission systems is defined by a series of different parameters. Fundamental data are the properties of the transmitter and receiver units. Additionally, the ambient can influence the transmission characteristics by disturbing optical or, when arising, electromagnetic radiation.

A critical point is the comparability of calculations and measurements of the transmission range. Calculating transmission ranges in the simplest case assumes a square-law relationship between distance d and irradiance E_e. With a given intensity I_e, the result is

$$E_e = I_e / d^2$$

With known responsitivity of the receiver photomodule and known intensity of the transmitter, the transmission range can be read from figure 4 where the relationship is implemented. As a typical threshold of the receiver sensitivity for safe operation, a value of 0.3 mW/m^2 is taken for the necessary irradiance in figure 4. This is equivalent to the typical specified value of the TSOP series. The maximum sensitivity threshold is specified at 0.5 mW/ cm^2. The typical intensity values of selected emitters are listed in table 2.

Operating, e.g., a TSAL6200 emitter at 1.0 A pulsed-forward current leads to an intensity of 500 mW/ sr. These data result (in combination with the TEMIC receiver photomodules) in a theoretical transmission range of 41 m (see figure 4).

The interdependence between transmission range and irradiance at the location of the receiver is shown in figure 5. The necessary irradiance for safe reception using TEMIC receiver photomodules is also shown.

In practice, it is difficult to realize the quadratic relationship between irradiance and transmission distance.

In general, a smaller decrease in sensitivity is observed due to reflection of walls and floors. This means that the example calculated here is the worst case and in reality better transmission ranges are attained.

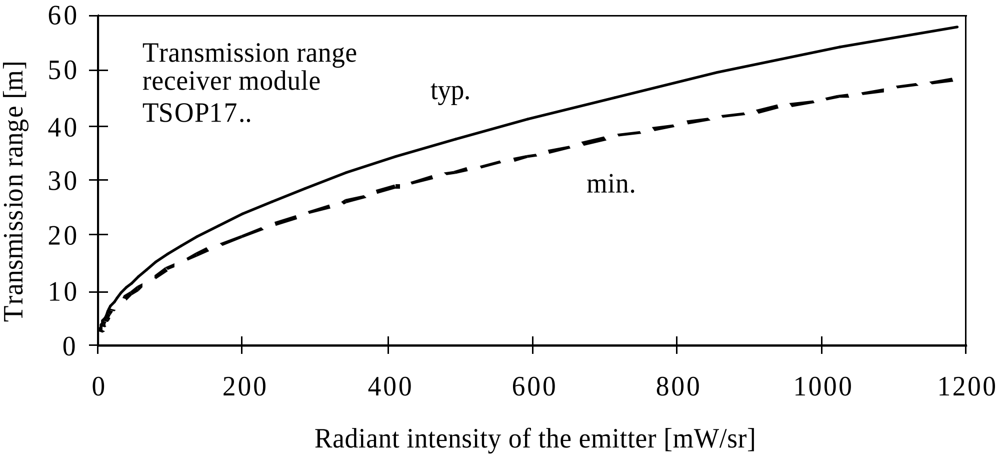


Figure 4. Maximum transmission range in free space with receiver photomodules TSOP17.. as a function of the radiant intensity of the emitter

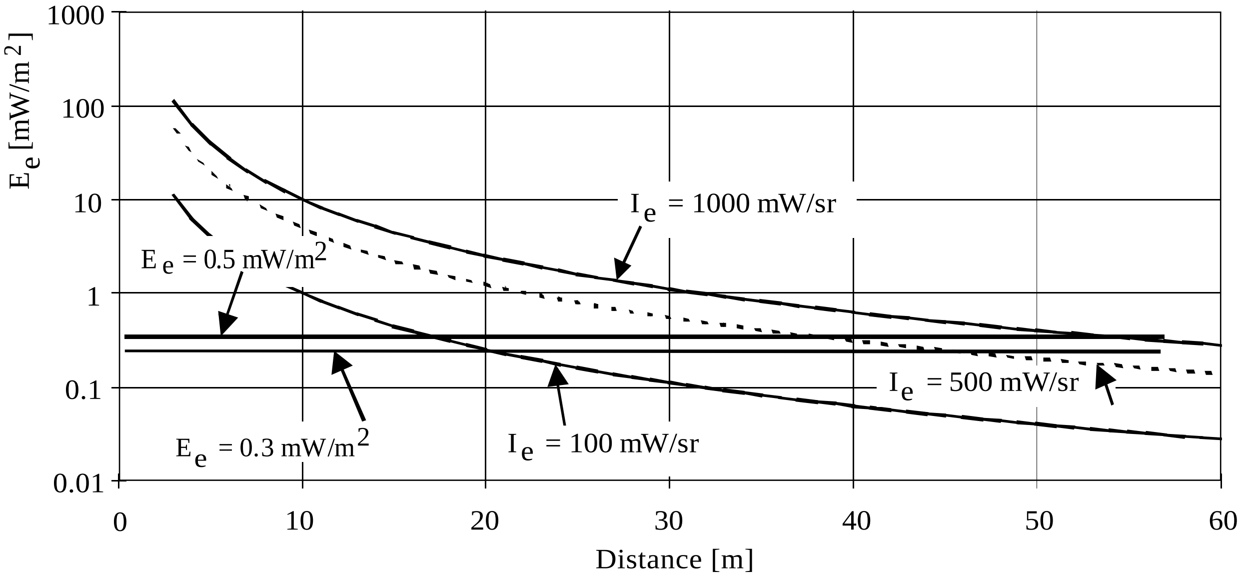


Figure 5. Irradiance E_e as a function of the distance
(parameters are the radiant intensities of the emitters)

Table 2. Emitters for remote-control appliances

Emitter	Technology	Wavelength [nm]	Radiant Flux I_f = 100 mA	Radiant Intensity I_f = 100 mA	Radiant Intensity I_f = 1.5 A	Emission Angle
			mW Typ.	**mW/ sr Typ.**	**mW/ sr Typ.**	
TSIP4401	GaAlAs	950	22	25	300	± 20°
TSIL6400	GaAlAs	950	25	25	–	± 17°
TSIP7601	GaAlAs	950	25	20	260	± 30°
TSUS4300	GaAs	950	13	18	160	± 16°
TSAL6200	GaAlAs	950	33	60	–	± 16°
TSUS5202	GaAs	950	15	30	280	± 15°
TSUS5402	GaAs	950	15	30	190	± 22°

The levels for indoor optical powers can be estimated by using other approximations. In this case, it is assumed that the whole inner surface of a room is irradiated with the emission of the source. To irradiate the whole surface of a square room (e.g. area = 30 m^2, height = 2.5 m) with an overall irradiance of E_e = 0.5 mW/ m^2, an emitted radiant flux of 60 mW is necessary (surface = 120 m^2, 100% efficiency). With 80% reflection loss, about 300 mW emitted radiation will be sufficient for safe reception in the whole room. 300 mW is a value which can be achieved with an emitter TSAL6200 operating at a peak-forward current of 1.0 A. Under these conditions, no direct path between emitter and receiver is supposed, but radiation after at least one reflection will reach the detector (direct reception will obey the square law, see table 2).

Comparison of remote-control systems is often performed in long corridors. Such measurements cannot be transferred at all from one corridor to the other because of different reflectivity properties of walls etc. In a corridor, the function of the irradiance does not obey the square of the distance law. The behavior in a corridor can be described by the function:

$$E_e = I_e \times \left(\frac{a}{d^2} + \frac{b}{d} + \frac{c}{\sqrt{d}} \right)$$

The values of a, b and c must be individually determined for each corridor.

The corridor, for example, where the system measurements are performed at TEMIC, is described in a range from 1 m to 70 m by the parameters

$$a = 0.93,\ b = 0.074,\ c = -0.0072.$$

This relationship is exactly valid for the given emitter only. By changing the emission angle or wavelength, the reflectivity of the corridor also changes and with it the values of the coefficients.

The Languages of Data Transmission Systems

In most remote-control transmission systems, only small data rates are transmitted to control the functions of home entertainment equipment. A vital pre-requisite is the safety of transmission where an incorrect interpretation of the transmitted code is not permissible. Unintelligible signals must be ignored. Usually, commands are repeated until the remote-controlled device reacts as desired. The operator can directly observe the result of pressing a key by visual feedback.

The commands can be transmitted by variation of the coding of the optical carrier. Some methods of modulation have been established. Nowadays, only the digital transmission of words is used where the word length can vary which means one word can include a different number of bits.

The three commonly used representations of a bit in remote-control systems (see figure 6) are described in the following paragraphs.

The TEMIC receiver photomodule series is developed and optimized for the use in carrier frequency transmission. Special types for different operating frequencies are available in the range from 30 kHz to 60 kHz. Standard types are available for the frequencies 30 kHz, 33 kHz, 36 kHz, 36,7 kHz, 38 kHz, 40 kHz and 56 kHz. Other frequencies in this range can be realized on request.

The so-called flash-mode signals without carrier frequency cannot be received with the TEMIC photomodules.

The data words to be transmitted consist of a defined number of bits. Word lengths and coding method are defined in the transmission standards. Several transmission standards are now accepted worldwide. Some of them are described in the following paragraphs.

In European equipment, the most commonly used standards are the RC 5 code and the RECS 80 code. Another popular transmission language is the NEC code (Far East).

In addition, many important consumer electronic product manufacturers have their own company standard regarding the transmission code.

The RC 5 Code

In the RC 5 standard, a bi-phase coding is applied (see figure 7). The carrier frequency is fixed at 36 kHz. Similar transmission standards are used in the frequency range between 30 kHz and 56 kHz.

The transmission of a word begins with two start bits, followed by a toggle bit. The toggle bit changes its value at each key operation. With this change, an interruption of the transmission link can be distinguished from a multiple key pressing. The five address bits address the device to be controlled. The command bits contain the information to be transmitted.

Each bit in a data word consists of a burst of 32 pulses with a repetition rate of 36 kHz. The equivalent times are shown in the pulse diagrams.

For the RC 5 code, TEMIC recommends the TSOP1236-, the TSOP1736- or the TSOP1836 series.

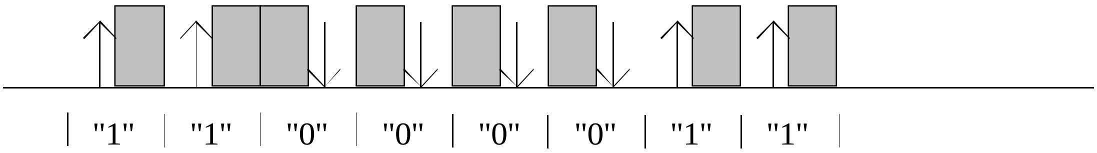


Figure 6a. Bi-phase coding
(a rising edge within a time window is equivalent to a "1", a falling edge represents a "0")

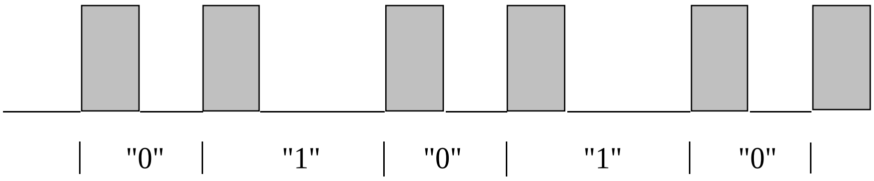


Figure 6b. Pulse-distance modulation

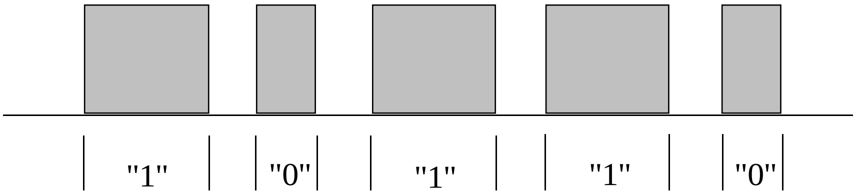


Figure 6c. Pulse-length code

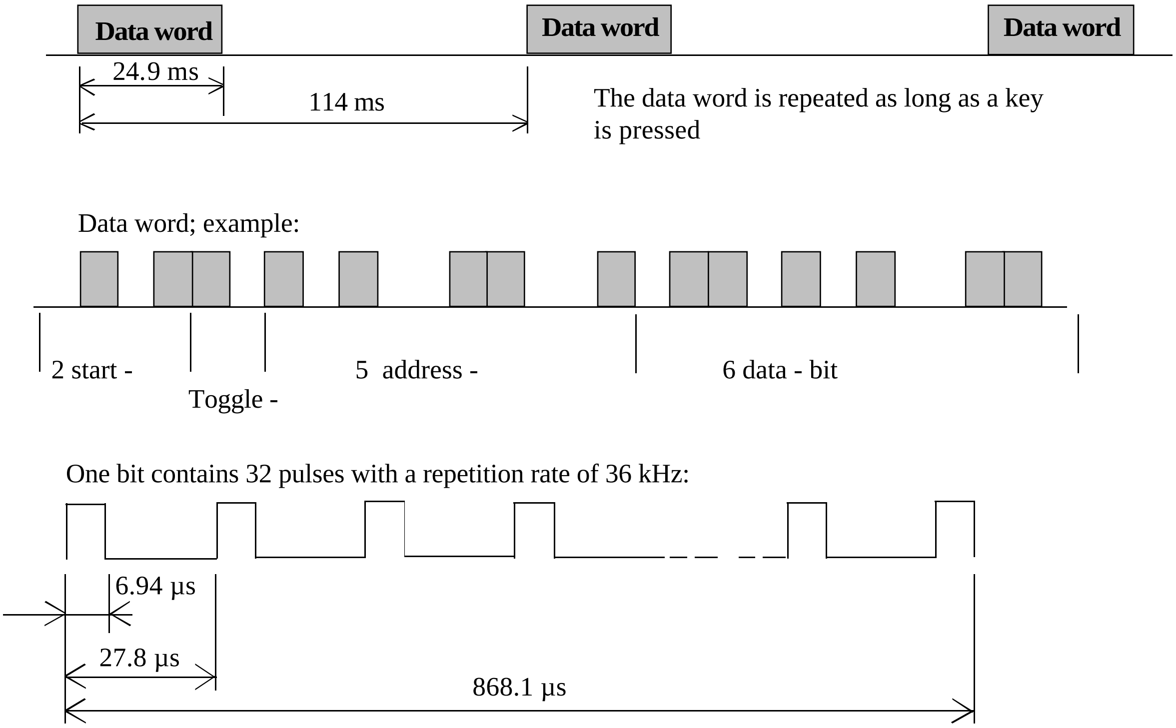


Figure 7. RC 5 transmission code

The RECS 80 Code

With a length of 70 ms, the data word in the RECS 80 code is nearly three times as long as that in the RC 5 code. The RECS 80 code operates with a digital pulse-distance modulation. As in the RC 5 code, toggle, address and command bits are used. Sometimes, a flash mode is found in combination with the RECS 80 code where single pulses of infrared radiation are transmitted instead of bursts. A carrier frequency of 400 kHz is also used instead of the common carrier in the range between 30 and 56 kHz. TEMIC's IR receiver series TSOP11.. and TSOP18.. are optimized for the RECS 80 code with these carrier frequencies.

TSOP photomodules are not suited for receiving flash mode or 400-kHz signals.

However, a combination of a TEMIC pin photo diode (e.g. BPV23NF) with the integrated circuit U2506B is recommended for transmission in the 400-kHz band.

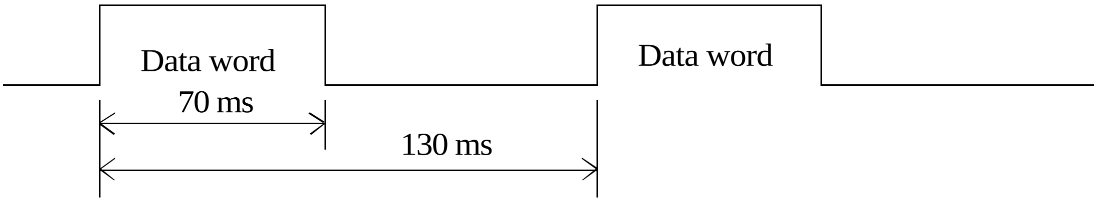


Figure 8a. RECS 80 pulse-distance modulation
(the single bits are pulse-distance coded; see figures 6c and 8b)

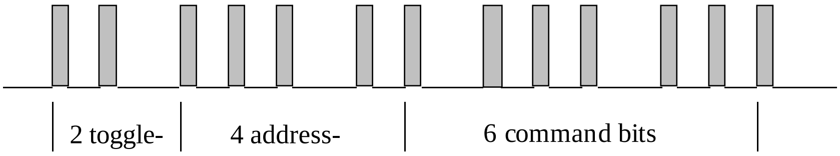


Figure 8b. Pulse-distance modulation
(example of a data word, the pulse distance for a "1" is about 7.5 ms, for a "0" about 5 ms)

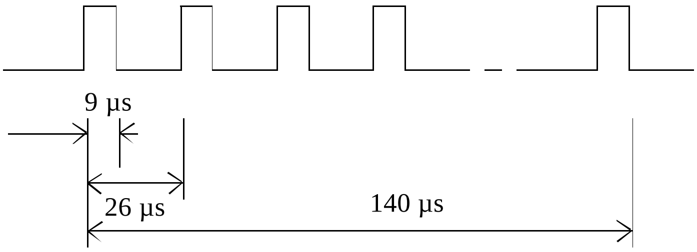


Figure 8c. Pulse-distance modulation

The NEC Code

The NEC code also works with bursts of a defined carrier frequency. Therefore, TSOP12.., TSOP17.. and TSOP18.. receiver photomodules operate optimally in this system.

The NEC code starts the transmission using a so-called leader code, a burst of a length of 9 ms, followed by the data word after a pause of 4.5 ms. This leader code is responsible for leveling the internal control loops in the receiver modules.

As long as a key is pressed, only the leader code is repeatedly transmitted, followed by a single bit. A specialty of this code is the property of constant word length in connection with a pulse-distance modulation. Both address and command bit are transmitted twice, first as the normal byte followed by the inverted byte. This is shown in figure 9. The burst defining a bit contains 22 pulses each of a length of 8.77 µs with a period of 26.3 µs. A "0" is represented by a pulse distance of 1.125 ms, the "1" with 2.25 ms, respectively. 8 address bits are used to identify the device to be controlled. A further 8 bits are used for the transmission of the command. As mentioned above, the words are always followed, without a pause, by the inverted words, e.g., the transmission of the address "00110111" and the command "00011010" is performed by sending the word:
"00110111'11001000'00011010'11100101".

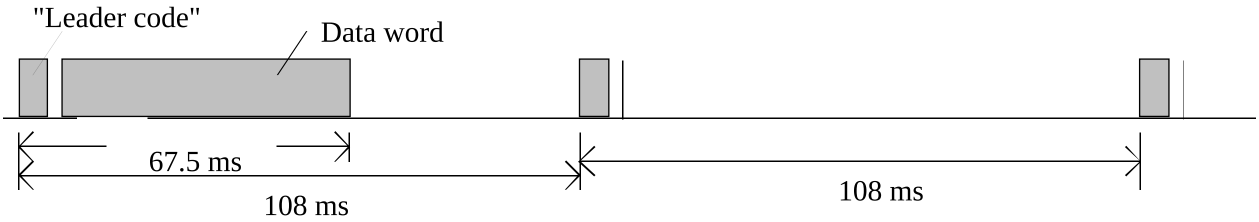


Figure 9a. NEC transmission code
(the leader code followed by a single bit is transmitted as long as a key is pressed)

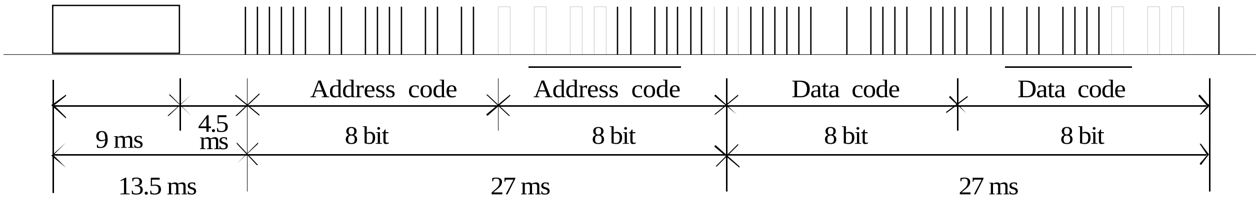


Figure 9b. NEC transmission code
(data word from figure 8a)

Description of the Detector Photomodules Series

The integrated circuits of the TEMIC receiver photomodules are produced using TEMIC bipolar technology.

By design, the following features are defined:

- High immunity against modulated and unmodulated ambient light, also against **C**urrent **W**ave (CW) sources
- Minimum of external circuitry
- Low power consumption
- Timing and output levels are microcomputer-compatible

The function of the TEMIC receiver photomodules can be described using the block diagram in figure 10. The incident infrared radiation bursts generate an equivalent photo current in the photo PIN diode. The DC part is separated in the bias block, and the AC part is passed to a transimpedance amplifier followed by an automatic gain-control amplifier and an integrated bandpass filter.

The final evaluation is performed by a comparator, an integrator and a Schmitt Trigger stage.

The blocks "Automatic Gain Control" and "Automatic Threshold Control" are responsible for the dynamic control of the working points as well as the threshold levels to suppress the influences of the ambient light and other disturbing radiation sources.

Input stage: The input stage provides the necessary bias voltage for the detector diode. The block "bias" (figure 10) additionally separates DC- and low-frequency parts from the useful signal of the photo current. The low frequency including DC current work on a low-impedance load in the block "bias". The AC signals are fed to the transimpedance amplifier.

The block "bias" reacts to the photodiode as a variable frequency-dependent load resistance similar to an LC resonant circuit with a low equivalent resistance for low-frequency signals and a high resistance of some 100 kΩ at the operating frequency. The currents at the operating frequency are converted by the transimpedance amplifier (low input impedance <10 kΩ) to a voltage at the input of the **C**ontrolled **G**ain **A**mplifier (CGA).

Controlled Gain Amplifier CGA: The CGA amplifier generates most of the voltage gain of the whole circuitry whereby the amplification is controlled by the **A**utomatic **G**ain **C**ontrol (AGC) block. The gain variation of this amplifier is about 60 dB.

Bandpass filter: The bandpass filter is tuned during the production process. Due to the small outline of the receiver type TSOP18.., its carrier frequency is adjusted on the IC. The center frequency of other TEMIC receiver types is adapted by an internal resistor during assembly. Due to the selectivity of this filter, the signal-to-noise ratio is improved. The figure of merit of the filter in the TSOP12..- and TSOP17.. series is approximately ten. The figure of merit in the TSOP11..- and TSOP18.. series is seven.

Automatic Gain Control (AGC): The AGC stage ensures that the receiver photomodule is immune to disturbances. It adapts to the existing noise- or disturbance level by changing the gain of the amplifier. The time constant of this AGC is chosen to be sufficient large in order to avoid a considerable sensitivity decrease during transmission. The AGC does not react to the useful signal but reduces the sensitivity in case of disturbances. The AGC has to distinguish between useful and disturbance signals. The intelligent AGC of the TSOP18.. detects if the radiation has a correlation to the power-line frequency (all kind of fluorescent lamps). Of course, the AGC also evaluates the noise caused by DC light sources. The AGCs of the other TEMIC photomodules evaluate the duty cycle of the signal over a long time period. Thus, the AGC is able to suppress the noise of DC light sources (tungsten lamp or sunlight) and of CW light sources (fluorescent lamps) if these disturbances are applied longer than 300 ms approximately. As the duty cycle of a typical remote-control signal is low (see previous chapter), the sensitivity in case of such a signal is not affected by the AGC. The exact duty-cycle limitations for each TEMIC photomodule series are given in the following chapter. The capacitor C_R in the block diagram represents the long-time constant of the AGC. This capacitor is not necessary for the TSOP18...

Automatic Threshold Control (ATC): The Automatic Threshold Control is shifting the comparator level for signal evaluation. The comparator stage is just as sensitive as necessary to avoid unexpected output pulses at the output. The ATC raises the threshold for signal evaluation to an optimized working point to assure the best signal-to-noise ratio for the received signal. The comparator level is shifted up to half of the actual signal value within a few µs. Between the single bursts of the transmission telegram, the threshold slides back towards the initial value with a time constant of t = 15 ms until the next burst adjusts the threshold level again. This time constant is suitable for the most common transmission codes. Using this method, it can be efficiently avoided that disturbance pulses are detected as falsely transmitted signals during the transmission of an information block.

Integrator and Schmitt Trigger: The integrator is triggered when the signal reaches the above mentioned comparator threshold. The integration time necessary to control the output via the Schmitt Trigger is 6 cycles the carrier frequency for the TSOP11..- and the TSOP18.. series. The TSOP12- and TSOP17 series need an integration time (minimum burst length) of about 10 cycles.

The integrator prevents the feed-through of short disturbances to the output. Integrator and Schmitt Trigger are designed so to have a good correlation between the optical burst length at the input and the output pulse width.

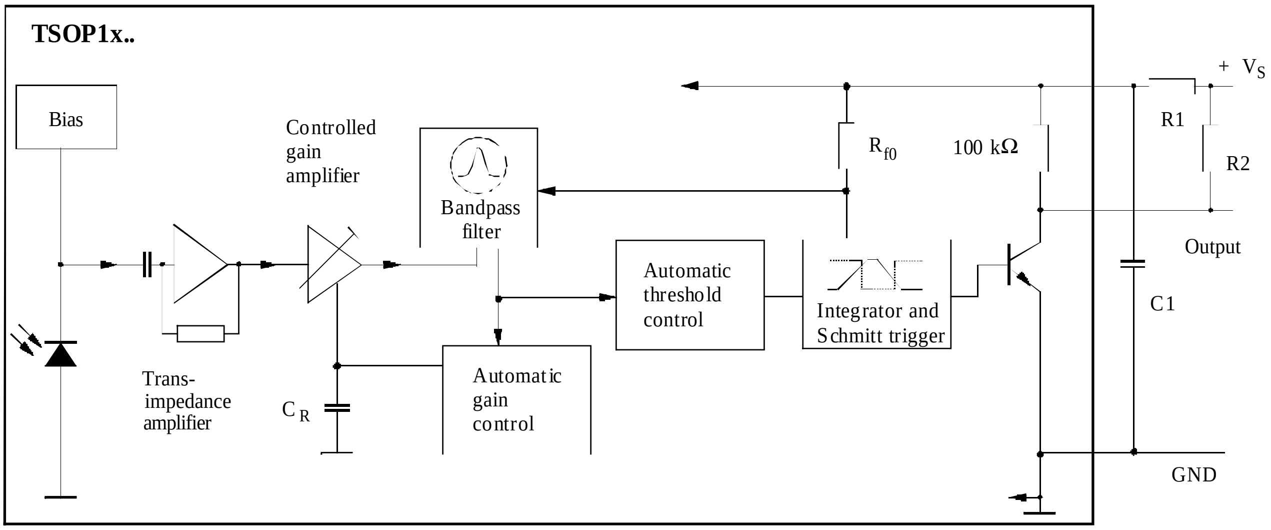


Figure 10. Block diagram of the TEMIC receiver photomodules

Behavior Under Operational Conditions

Influence of the ATC: In quiescent mode, i.e. no signal on the receiver photomodule, the circuit is controlled to its most sensitive working point. This point is determined by the magnitude of the input noise which should not cause any signal at the output. However, due to the statistical distribution of the input noise, single pulses occurring at the output cannot always be avoided. This does not present any problem for the signal processor following the photomodule as long as the likelihood of noise-generated pulses is small.

During transmission, the control loops are set to those working points which guarantee the best signal-to-noise ratio. When using transmission codes with burst intervals of $t_{rep} > 15$ ms within the telegram, the threshold runs down during the pauses to the noise-controlled level. This mode of operation should be avoided because it is impossible to adjust the noise-optimized working point. The likelihood of noise or background radiation-generated output signals will increase. If this cannot be avoided, the signal processor soft-ware must tolerate or compensate such errors to prevent extended reaction. However, the likelihood of such unexpected output pulses is by design of the AGC's working point very low. In quiescent mode, there is normally less than one unexpected output pulse each minute.

Influence of the AGC: The AGC adapts the threshold level to the external disturbance sources, e.g., incandescent light, fluorescent light, sunlight and all kind of RF- and optical CW signals. The AGC circuit can distinguish between useful signals and disturbances as long as the transmission maintains the duty cycle condition of each type (see next chapter). The ATC is adjusting to the remote-control signal, the AGC, however, to the disturbance level only.

The conditions must also be observed when transmitting larger amounts of data as in special TV applications where long transmission blocks are used for service adjustments of the equipment. In this so-called factory mode, the duty cycle is increased to a maximum tolerable value and a sensitivity loss is acceptable.

When this limit condition of the AGC is exceeded, the sensitivity of the receiver photomodule decreases continuously, but only to a level where unexpected output pulses are almost impossible. At each burst, the capacitor C_R inside the TSOP receiver (see figure 10) is charged, leading to an increase of the voltage controlling the CGA (Controlled Gain Amplifier). The capacitor voltage may decay within the time window of a gap between two bursts.

Normally, the gain of the CGA remains at a constant level. During the first two ms of a burst, the charge current is low in order to ensure that the gain remains high if a key on the remote control is pressed for a long time. This is valid for all transmission codes. If a burst is longer than 2 ms or a continuous disturbance signal is applied, the value of the charge current increases.

To recapitulate, the duty cycle and the burst length are the two criteria how the AGC of TSOP11.., TSOP12.. and TSOP17.. detects if a signal is a disturbance. The remote-control signal has short bursts and a low duty cycle. For the TSOP12.. series, the relation of charge current to discharge current is 3:1. Thus, the TSOP12.. is able to suppress effectively all kinds of fluorescent lamps, even if they are strongly modulated. Regarding the TSOP11.. and TSOP17.. series, this relation is 1:1 for the AGC capacitor.

The AGC of the TSOP18.. is not controlled by the duty cycle of the signal. As typical remote-control signals have a telegram pause longer than 25 ms (see figure 11), the AGC can recognize whether the signal is coming from a remote-control- or a different source. Disturbance light sources, however, do not have such a gap. In addition, the amplitude and the radiated frequency of all kinds of fluorescent lamps are modulated synchronously to the power-line frequency which is 50 or 60 Hz. Therefore, the maximum amplitude of the disturbance signal is repeated at least every 20 ms. The AGC reduces the sensitivity of the receiver to a level where no disturbance output pulses can occur. Thus, the remote-control transmission code should have a data-telegram pause of at least 25 ms in order to assure proper operation of the TSOP18.. receiver. Almost all transmission codes provide this time gap and can therefor be successfully received by the TSOP18.. The TSOP18..'s AGC adjustment is very slow. A sensitivity change of 6 dB (factor 2) takes about 800 ms, the total dynamic range is 50 dB. That means that a short transmission distance of about 1 m (-50 dB) is still possible, even if the data telegram's gaps are not longer than 25 ms.

Influence of the Integrator

The integrator stage needs a minimum burst length until the output is switched. Therefore, the integrator can suppress disturbances such as short bursts or spikes. An optimum function in the application of the receiver photomodules is achieved by using burst lengths representing one bit not shorter than the special integration time of the series. The gap between two bursts must also exceed a minimum time period (recovery time of the integrator). The various timing requirements for the TEMIC photomodule series are given in the next chapter.

Features and Restrictions

To enable correct functioning of the remote-control system, the most suitable type of the TEMIC photomodule series has to be chosen regarding the criteria of the transmission code (duty cycle, burst length, gap length) and its decoding method. The duty cycle is defined in the example given in figure 11.

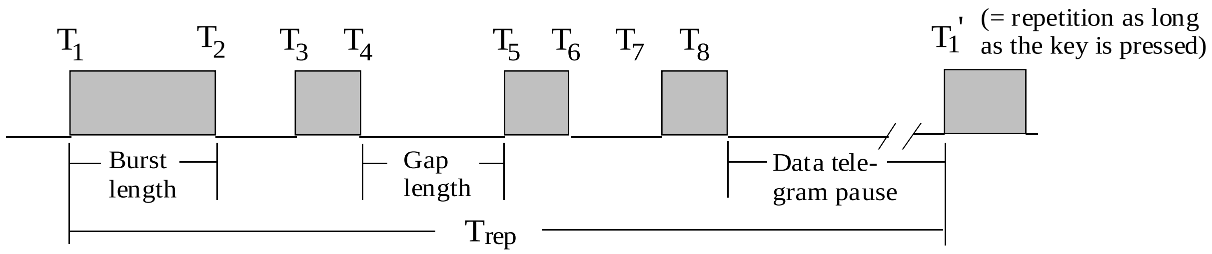
Table 3. Timing requirements for the various photomodule series

	Maximum Duty Cycle	**Minimum Burst Length**	**Minimum Gap Length**	**Timing Tolerance of Output Pulses**
TSOP11..	$N/(18 + 1.1 \times N)$	$6/f_O$	$10/f_O$	$-4/f_O + 6/f_O$
TSOP12..	$N/(25 + 1.1 \times N)$	$10/f_O$	$10/f_O$	$-6/f_O + 6/f_O$
TSOP17..	$N/(22 + 1.1 \times N)$	$10/f_O$	$10/f_O$	$-6/f_O + 6/f_O$
TSOP18..		$6/f_O$	$10/f_O$	$-4/f_O + 6/f_O$

f_O = Carrier frequency of transmission, N = Number of periods in a burst

Table 4. Timing requirements; example
(typical transmission code with 22 periods in a burst at 38 kHz)

	Maximum Duty Cycle	**Minimum Burst Length**	**Minimum Gap Length**	**Timing Tolerance of Output Pulses**
TSOP11..	0.52	160 µs	260 µs	–100 µs + 160 µs
TSOP12..	0.45	260 µs	260 µs	–160 µs + 160 µs
TSOP17..	0.47	260 µs	260 µs	–160 µs + 160 µs
TSOP18..		160 µs	260 µs	–100 µs + 160 µs



The duty cycle is defined as $\frac{(T2 - T1) + (T4 - T3) + (T6 - T5) + (T8 - T7)}{T_{rep}}$

Figure 11. Timing values in a common transmission telegram

Duty Cycle

If a data-transmission language uses different burst lengths (N), the calculation can be done with an average burst length. As the long-time control reacts very slowly, examinations of the duty cycle should be carried during a long interval time (about 300 ms). The duty cycle may be higher than the limit which is mentioned here for a short amount of time without a loss of sensitivity (< 100 ms). The TSOP18.. series has no duty-cycle limitation. However, the length of the data telegram pause (see figure 11) should be longer than 25 ms.

Operating Conditions

Measurement Procedure and Test Circuit

The definition of the sensitivity of a digitally switching receiver front end is a problem. When increasing the irradiance from zero on the receiver photomodule at a certain level, the output starts to react statistically to the input signal. The pulse lengths at the output are not a mirror of the envelope of the input signal. With increased signal strength, the likelihood of correct recognition is increased and the pulse lengths are a reproduction of the input envelope.

To obtain defined conditions for the measurement, an error tolerance is fixed for the delay and pulse-length deviations of the output signal.

Table 5. Time windows for signal evaluation

	Delay of Leading Edge	**Timing Toler. with Output Pulse Width**
TSOP11..	$3/f_o < t_d < 9/f_o$	$-4/f_o$ $+6/f_o$
TSOP12..	$7/f_o < t_d < 15/f_o$	$-6/f_o$ $+6/f_o$
TSOP17..	$7/f_o < t_d < 15/f_o$	$-6/f_o$ $+6/f_o$
TSOP18..	$3/f_o < t_d < 9/f_o$	$-4/f_o$ $+6/f_o$

Definition: The threshold sensitivity is that irradiance, at which the measured values of delay and output pulse length all are inside the tolerated band.

Sensitivity in Dark Ambient

A remark is necessary before the definition and the measurement of this parameter are described: When comparing different transmission systems, the measured sensitivity in a dark ambient is the parameter mostly measured first although this condition is hardly present in the real application. The typical application of entertainment electronics is in a light ambient, e.g., a television receiver is rarely operated in total darkness because the light from the screen will illuminate the ambient. Therefore, the TEMIC photomodule series are optimized for operation in a disturbed and light ambient.

The sensitivity threshold in dark ambient is measured using the definition in the chapter "Measurement Procedure and Test Circuit". The sensitivity is discussed from an optical point of view in the chapter "Sensitivity".

The output pulse length in response to an input burst is drawn the data sheet. The phenomenon described in the chapter "Measurement Procedure and Test Circuit", the dependence of the output pulse length on the input signal, can be demonstrated here. At an irradiance of about 0.2 mW/m^2, short pulses arrive at the output. With the irradiation increased to 0.35 mW/m^2, the output signal length typically reaches the length of the input burst length. This length has not changed more than that inside the small tolerance field defined already up to an irradiation of 100 W/m^2. This means, an overdriving or dynamic of nearly six orders of magnitude is allowed. A TV remote control with a built-in TEMIC photomodule operates typically in a distance range of 1 cm (direct contact, distance given by front plate) to more than 35 m.

Disturbing Optical Radiation

The built-in control circuits and loops adjust the sensitivity threshold to the most sensitive working point at the existing background illumination and other radiation from optical and electrical sources. These sources can be incandescent lamps, standard fluorescent lamps, and in particular energy-saving electronic fluorescent lamps. The photo current generated in the internal detector diode induces a current noise which limits the sensitivity with background unmodulated light. The light of incandescent lamps is almost unmodulated or exhibits only a small modulation depth. Gas discharge lamps are strongly modulated with the operating current and are therefore more critical sources in respect to disturbances.

Behavior in Electromagnetic Fields

A most unpleasant ambient with regard to electromagnetic sources is the inside of television receivers. The horizontal deflection operates at a frequency of 15625 Hz (625 × 25) or 15750 Hz (525 × 30). The harmonics with 31250 Hz or 31500 Hz are directly on or in the neighborhood of the remote-control carrier frequencies. With a standard selectivity, the interference cannot be suppressed electrically at a reasonable cost. An excellent suppression of disturbances is achieved by constructive measures in the design such as, e.g., the right position of the detector chip inside the package, very short wire connections, the shielding of the chip and an internal shield in the package. Here, the advantages of the compact package compared to printed circuit boards can be demonstrated. At applied field strengths of 700 V/ m at the rated carrier frequency, the sensitivity is only reduced by a factor of two, equivalent to a loss of transmission range of about 30%.

Influence of Disturbed V_S

The receiver photomodule should operate with a stable supply voltage to prevent a sensitivity decrease. This decrease depends on the amplitude and the frequency of the disturbance. As mentioned above, disturbances from the harmonics of deflection currents in TV sets are in the remote-control band. As the deflection currents are high, an interaction with the power supply voltage is possible. There is also a possibility of interference with emitted RF signals, in particular with subharmonics of the operating frequency when using switchmode power supplies. In the data sheet, the relation between sensitivity and power-supply disturbances is shown for 100 Hz, 1 kHz, 10 kHz and for the rated center.

In the block diagram (figure 10), two resistors (R1, R2) and one capacitor are given as additional external components in the application circuit. These external components are optional and depend on the quality of the power supply conditions and the demands of the circuit that follows. R2 is the optional load resistor which can operate if necessary in parallel to the internal 100 kΩ load. The minimum resistance of R2 is 10 kΩ. In the specification, the filter combination R1/ C1 with C1 = 4.7 µF and R1 = 330 Ω is recommended to suppress disturbances on the power line. The parts can be omitted when no disturbances are expected.

The influence of the power line disturbances on the function of the device can be taken from the presentation of the threshold sensitivity vs. the amplitude of the disturbance (at center operating frequency) on the power line (see the enclosed data sheet). In the application, the R1/ C1 combination should be optimized, also regarding the commercial point of view and, if possible, omitted. In test circuits, this combination always should be implemented to obtain correct measurements.

Angular Dependence

Remote-control applications require a large angular opening of the detector to enable the detection of scattered radiation. The lens arrangement, referring to the same chip area, results in a gain of 2, whereas the angle characteristic approximates to the $\cos^2$ law. Larger central sensitivity can be realized at a reduced angular opening.

Typical Circuitry

In the chapters before, the internal circuitry, the function and the usual operation of the photomodule were described. In the following, a few hints are given on standard circuits and evaluation processes.

At present, two evaluation methods are pursued: Either special circuits are used to evaluate the remote-control recordings (see "Typical Application Circuit") or the evaluation is left for execution by the equipment (see "Recommendations for Evaluation").

Typical Application Circuit

Various manufactures offer circuits for decoding remote-control signals. The circuitry in figure 12 incorporates MARC4 4-bit micro-controllers. For technical details, please order the according MARC4 data sheet.

There are also TEMIC ICs available which can be used for remote control of simple equipments such as lights, windows, garage doors, fans etc. An example for a simple remote-control circuit is shown in figure 13. The U6050B (figure 13a) is an encoder with 8 keys, the U6052B (figure 13b) is operating as a decoder and is able to drive 8 relays.

Another application for TEMIC photomodules is a sensitive far-distance light barrier. An example for a simple reflex sensor circuit is shown in figure 14.

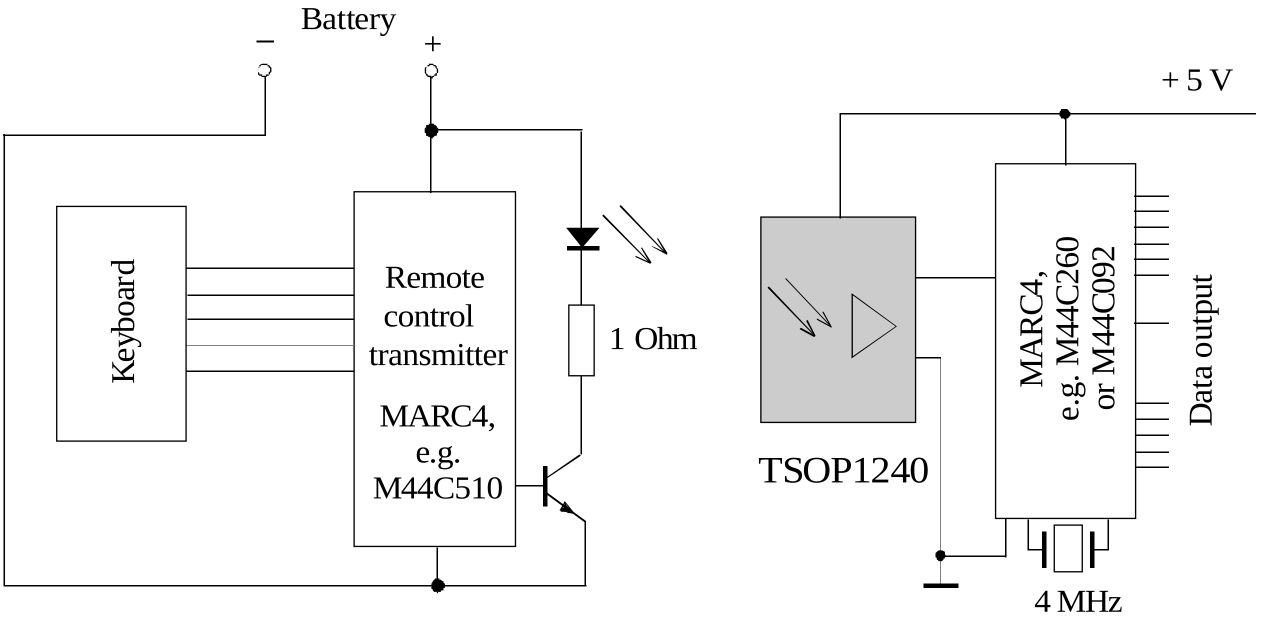


Figure 12. Circuit for decoding remote-control signals

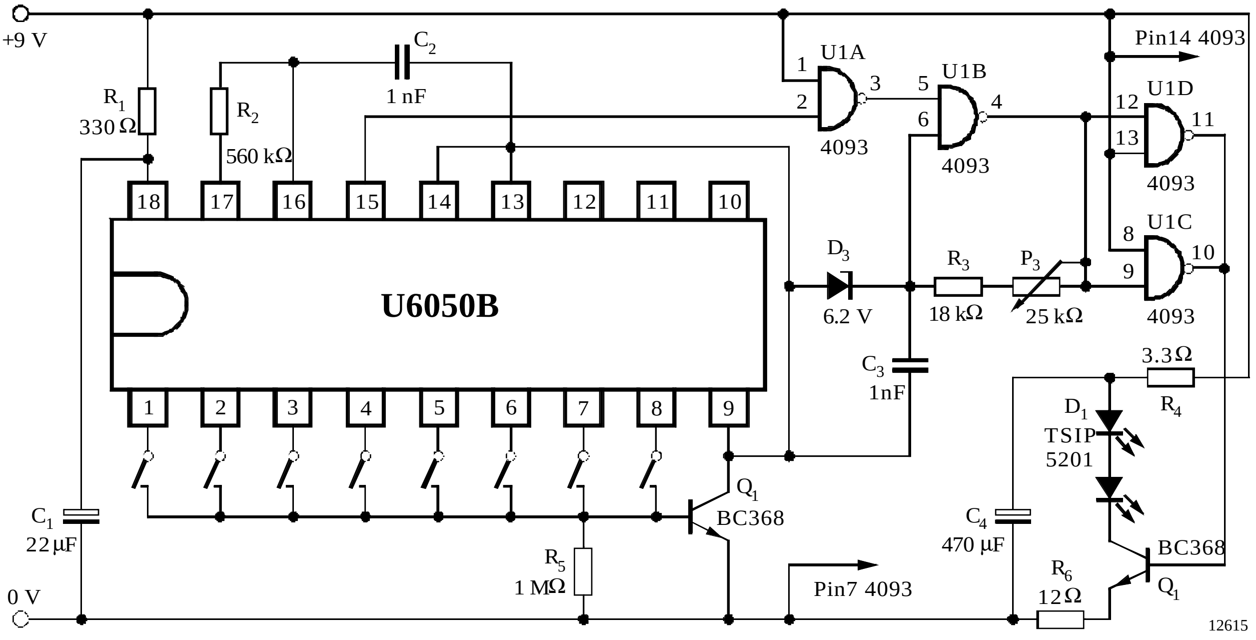


Figure 13a. Simple remote-control circuit – transmitter

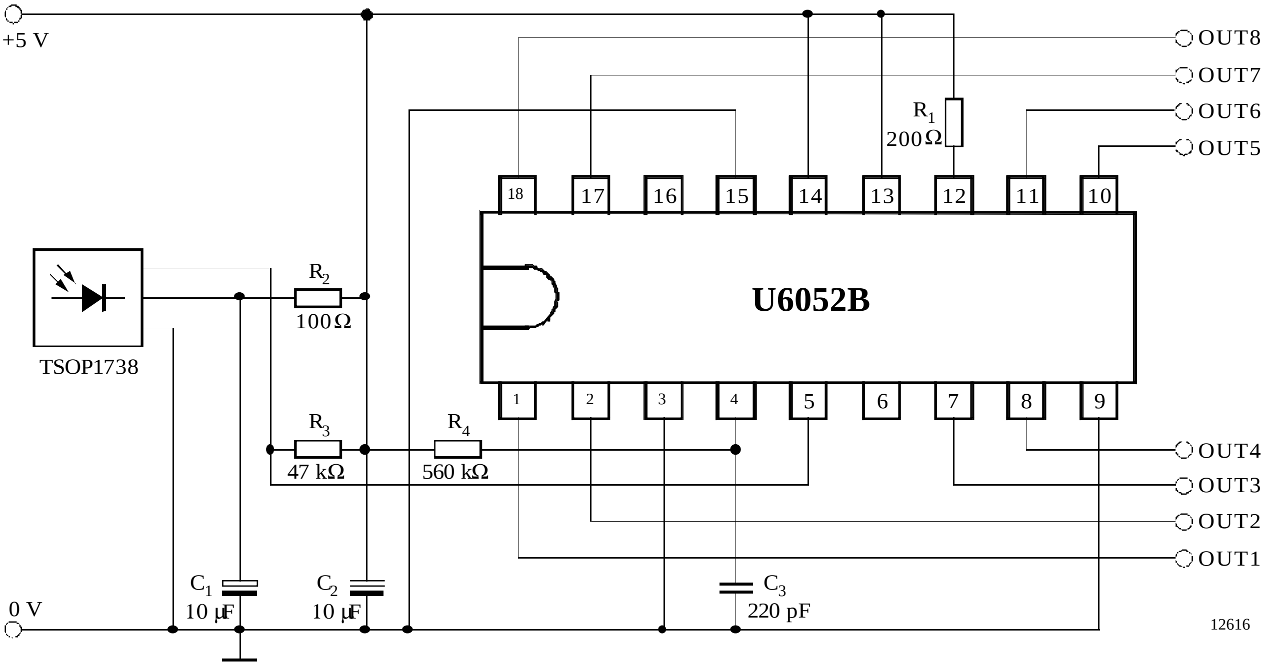


Figure 13b. Simple remote-control circuit – receiver

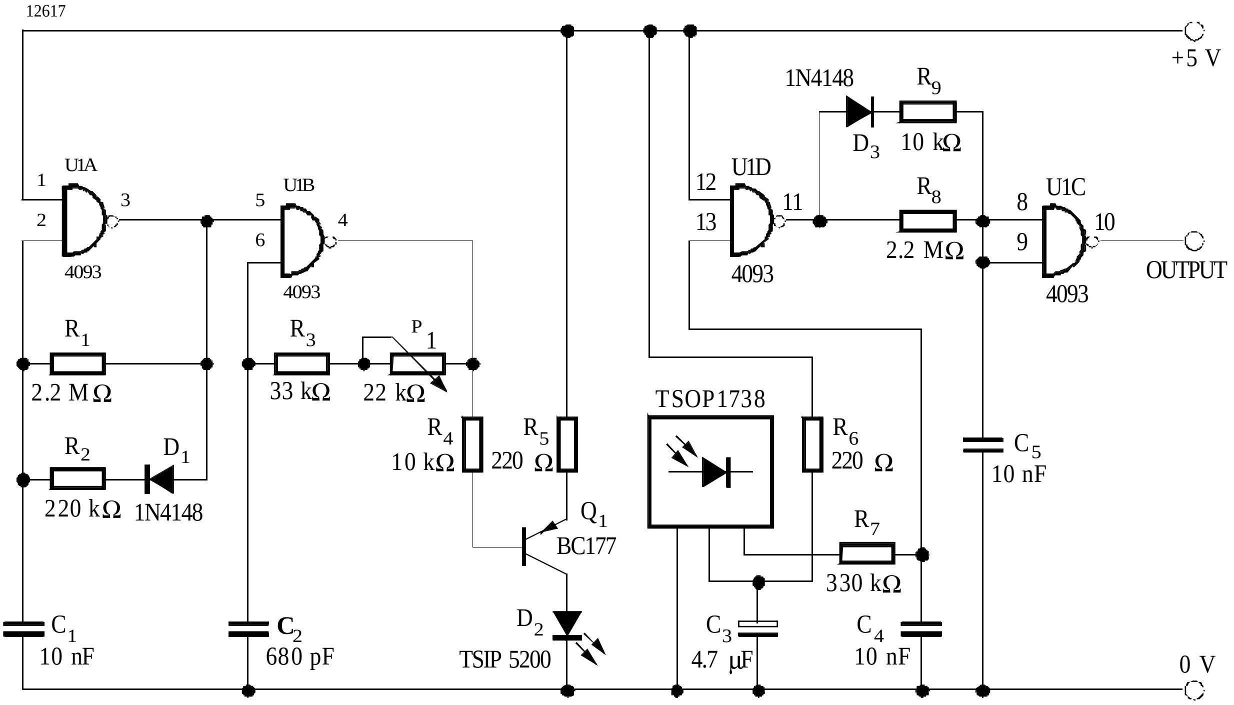


Figure 14. Sensor circuit with TEMIC photomodules

Recommendations for Evaluation

A transmitted telegram consists of pulses which reach the photomodule as optical signals. The output signal of the TEMIC photomodules presents an almost exact reproduction of the envelope of this signal. If the input signal is large enough, the delay times for the rise- and decay flanks will be the same. The amplification control has reduced the sensitivity of the photomodule to a level where disturbances are not registered. In such a case, the first incoming flank causes an interrupt, and the time to the following flanks is measured. This method, however, runs the danger that disturbances are accepted as signals and consequently wrong interpretations are the results. Disturbances are most likely when dealing with weak signals and should be suppressed by the software accordingly.

For example, one method used is to examine the record after an interrupt has occurred in a predetermined time window to see which type of flank of the logic signal was present (increasing or decreasing). In addition, it is possible to evaluate the pulse length with the corresponding second flank of a pulse to qualify and re-iterate the information obtained first. All these functions mentioned above are incorporated in the processor software to ensure proper transmission even over long distances.

To ease the burden on the processor during the serial acceptance of the data, a plausibility test should be performed on the signals which already entered. If the test shows that the pulse sequence is non-sensible, the entered data word must be rejected.

Table 6. Comparison of various manufacturer's photomodules under differing ambient conditions

	Distance in Dark Ambient	**Directivity**	**EMI Immunity**	**DC Light Disturbance**	**Fluorescent Light Disturbance**
TEMIC TSOP17..	21 m	horiz.+/-45°; vert. +52°/-65°	E: 1000 V/m; M: sufficient	12 m	10 m
TEMIC TSOP18..	22 m	+/-45°	E: 800 V/m; M: sufficient	12 m	10 m
Supplier 1	21 m	+/-48°	E: 700 V/m; M: sufficient	11 m noise pulses	12 m
Supplier 2	23 m	+/-50°	E: 600 V/m; M: sufficient	8m	18 m
Supplier 3	16 m	horiz.+/-44°; vert.+/-52°	E: 10000 V/m; M: not sufficient in TV	5 m	10 m
Supplier 4	16 m	horiz.+/-48°; vert.+/-40°	E: 10000 V/m; M: not sufficient in TV	5 m	10 m
Supplier 5	15 m	+/-41°	E: 300 V/m; M: sufficient	3 m	11 m
Supplier 6	18 m	+/-47°	E: 200 V/m; M: sufficient	8 m	11 m

Test conditions:

Distance: transmitter with an intensity of $I_e = 100$ mW/sr

Directivity: angle of half transmission distance

EMI immunity: "M" means magnetic field disturbance; "E" means electrical field disturbance

DC light disturbance: 5000 Lux sun light or 1000 Lux from incandescent bulb;
"noise pulses" means unexpected output pulses due to noise

Fluorescent light disturbance: Osram Dulux EL20W is 1 m in front of the photomodule

As there are many different kind of lamps, comparison is difficult.
Between most of the lamps there is no big difference regarding the modules. Powerful lamps, however, with a frequency close to the carrier frequency of the signal will benefit most by TEMIC's photomodules.

Appendix

Comparison Test

Table 6 shows the results of tests carried out in TEMIC laboratories on TSOP photomodules and other manufacturers’ versions. The sensitivity threshold was determined with 600 bursts, the burst interval with 10 ms, the burst length with 30 pulses (duty cycle 1:1 at the nominal frequency). The criteria for reaching the sensitivity threshold is that 598 from 600 pulses with a time tolerance of ±160 µs must be recognized. The threshold was determined at various environmental conditions that may occur in the remote-control ambient.

Please note: The TSOP series is specified for ambient temperatures of 85°C, whereas other manufacturers only guarantee this function up to 65°C.

Summary

The TEMIC photomodule series for remote-control systems represent a new generation of highly sensitive, integrated detectors. These devices are perfect for the most widely used transmission methods with either phase- or pulse-length modulation.

The most prominent property of the photomodule is the optimum transmission safety at a high sensitivity under disturbed ambient conditions. This safety and the long range guarantee the employer a secure function of his transmission system also under difficult ambient conditions. A further advantage is the compact form.

The ISO9001-controlled automatic large-volume production lines guarantee a continuously high reliability of the devices. TEMIC offers the manufacturers of modules the safety of a mature product. The devices contain the many years of experience of Europe's leader in infrared receivers.

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