8-2 How to Use Photocouplers

8-2-1 LED Control Circuit

DC drive

An example of controlling LED drive current by switching on and off the power supply, is shown in Fig. 8-34.

In this case, resister R is

$$R = \frac{V_{IN} - V_F}{I_F}$$

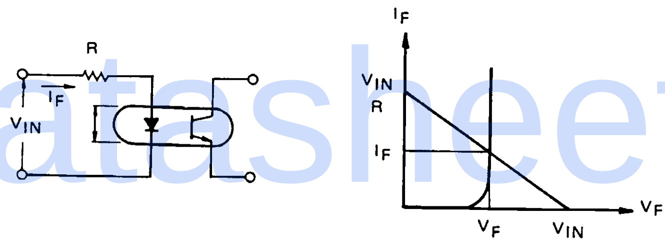


Fig. 8-34 Simple drive circuit for an LED

For example, when I_F = 10 mA, $V_{F(MAX)}$ = 1.35V, and V_{IN} = 5V

$$R = \frac{5 - 1.35}{10\ \text{mA}} = 365\Omega$$

Therefore, it should be at R = 360Ω. Assuming that V_F = 0.9V due to its fluctuation or temperature dependence, the value of I_F is 11.4 mA.

Reverse voltage protection

When a reverse surge voltage is applied on a light emitting diode, a Si diode (for example, 1S1588) should be connected in reverse parallel with the light emitting diode so that the reverse surge voltage bypasses the LED.

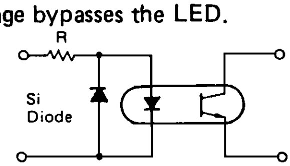


Fig. 8-35 Protection from reverse voltage by silicon diode

Threshold voltage

When the input voltage is not absolutely zero or some unnecessary steady current flow is in a data transmission line, the threshold voltage of LED should be raised up to a certain level by connecting a resistor in parallel with the light emitting diode. (Fig. 8-36)

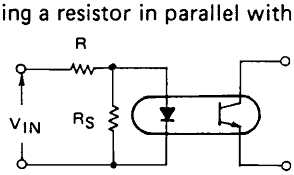


Fig. 8-36 Threshold voltage

If the forward voltage of LED which is in the zero-light-emission V_T, the off-level input voltage $V_{IN(OFF)}$, and the off-level input current $I_{IN(OFF)}$ are given by

$$V_{IN\,(off)} = V_T + R\frac{V_T}{R_S}$$

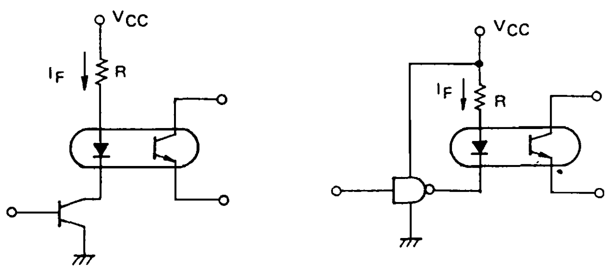
$$= \left(1 + \frac{R}{R_S}\right) V_T$$

$$I_{IN(off)} = \frac{V_T}{R_S}$$

In the case of the Toshiba-IRED, the value of V_T is 0.5V.

Driving by transistor or IC

In Fig. 8-37 are shown examples of LED driving circuits by using transistor or IC.



$$R = \frac{V_{CC} - V_F - V_{CE(sat)}}{I_F} \qquad R = \frac{V_{CC} - V_F - V_{OL}}{I_F}$$

Fig. 8-37 Driving by transistor or IC

AC drive

In this case, a rectifying bridge is used as shown in Fig. 8-38.

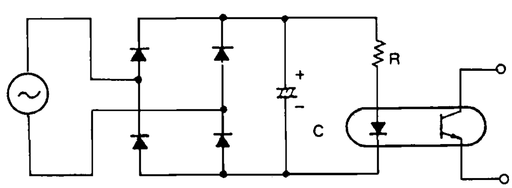


Fig. 8-38 AC drive

8-2-2 Phototransistor Coupler Output Circuit

(1) Base terminal

The transistor action of an output photo transistor, is achieved by receiving a light signal from LED. Then the base terminal of the transistor is not necessary in general so that devices are used without the base terminal. However, the base-terminal is used in the case of forward current threshold action, and improvement of the dark current, linearity, and switching speed of photocouplers.

o **Improvement of dark current**

The dark current of an output phototransistor increases exponentially with respect to temperature. When we use the circuit in Fig. 8-39 and the output voltage level is decreased by this effect, certainly it is possible to transfer wrong signals to the next stage. Adding a resistor between the base and emitter terminal to pass the leakage current at the collector-base junction(I_{CBO}) to R_{BE} makes it possible to decrease both the dark current and the wrong effect to the next stage. In Fig.8-40 is shown an example of I_D-R_{BE} characteristics. (See the respective data in detail)

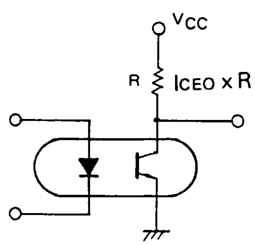


Fig. 8-39 Basic circuit

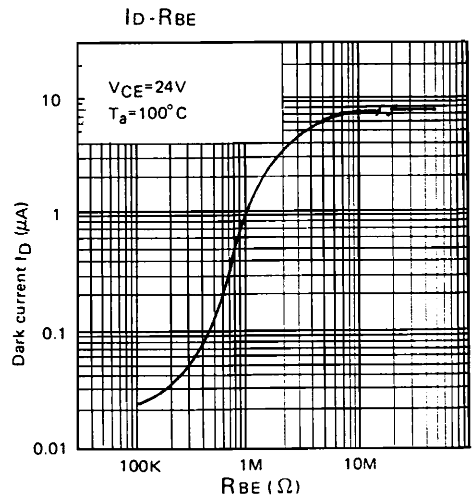


Fig. 8-40 Dark current vs. RBE

- **Forward current threshold action**

Fig. 8-41 shows the relationship between the forward current IF of LED and the collector current I_C of phototransistor. If the resistor R_{BE} is added between base and emitter, the photocurrent I_{PB} is bypassed through R_{BE} and the collector current cannot flow until the $V_{BE\ (on)}$ voltage appears, as shown in Fig. 8-42. For example, when R_{BE} = 0.2 MΩ, collector current $I_C < 0.1$ mA at I_F = 1 mA, the collector current decreases to one tenth of its value in case of $R_{BE} = \infty$. This shows that the forward current threshold action is possible by adding a suitable value of R_{BE}. This is effective in preventing spurious noise signals appearing at the input side.

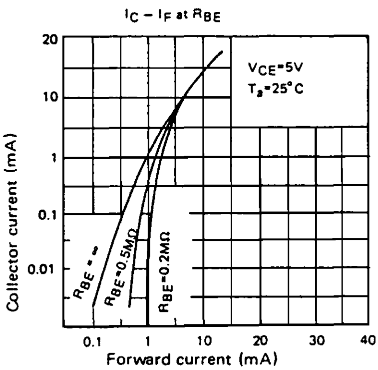


Fig. 8-41 Collector current vs. forward current

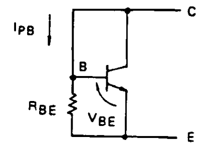


Fig. 8-42

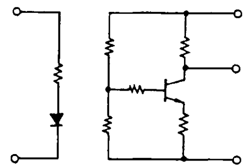


Fig. 8-43 Bleeder Method

- **Improvement of linearity**

The collector current of a phototransistor is large because the photo-current I_{PB} is amplified by h_{FE} of a transistor. However, the collector current is unstable due to the fluctuation of h_{FE} depend on I_{PB}, V_{CE}, and temperature. Generally, for linear application, the collector voltage is set at about half of the supply voltage, however, the transistor action point is shifted for the above reason.

In order to stabilize the collector voltage, it is better to use DC biasing by the bleeder method as shown in Fig. 8-43.

(2) Common noise at the base terminal

When a photocoupler with a base terminal is used, the base terminal acts like an antenna in the open state and picks up a noise. In particular, when a high pulse voltage is applied between the input and output, the induction noise from the base lead terminal and the noise from the capacitance between the input and output are added together to act as an input signal. In this case, adding a capacitance (C_{BE}) between the base and emitter is able to absorb the transitional noise from the base terminal and prevents the error action. However, care must be taken regarding the slowering of response time(examples is shown in Fig. 8-44)

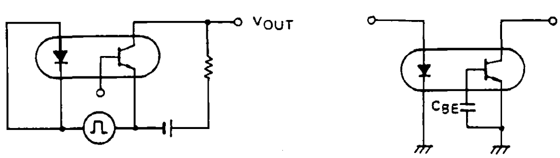


Fig. 8-44 Common noise absorption by C_{BE}

8-2-3 Photo Tyristor Coupler Output Circuit

In transmitting electric signals between circuits having different grounds potential, isolation transformers (pulse transformers), lead relays have been widely used until now. However, for such problems as service life, reliability, space factor, easiness for mounting to circuit board and mounting density, photo couplers have become generally employed.

In the field of industrial control equipment, with the advancement of equipment automation and realization of central control, application of photo couplers has been further expanded. In this field, as a result of wide use of microcomputer, photo couplers are used in interfaces between CPU and I/O cards as presented by sequence controllers, and in interface between microcomputer and power device in such household electric equipment as electric oven, air conditioner and in such office machines as copier.

Especially, a photo thyristor coupler, when used as a power TRIAC gas trigger device, has more merits than a pule transformer and small lead relay which have been used until now.

For instance, when a pulse transformer is used, sufficient trigger pulse width enough to ignite a power TRIAC or a trigger circuit for generating trigger pulses continuously for more than 1 ms is necessary and this makes the circuit to be more expensive.

From this viewpoint, when a photo thyristor coupler is used as an ON/OFF switch of a gate circuit, power can be simply controlled only by driving input side LEDs by TTL gate. Furthermore, in the mechanical contact switching of a lead relay, phase control is not possible as response speed is slow and when operating frequency is high, its life can be adversely affected. In this point, a photo thyristor coupler is superior to conventional pulse transformers and lead relays.

With this background, recently a photo thyristor coupler has been made available in many kinds and its range of application is more and more expanding. The fundamental characteristics, precautions in use and application circuits of these photo thyristor couplers are described here.

<u>Turn-On Mechanism of Photo Thyristor</u>

There are several important turn-on mechanisms of photo thyristors. The first one is the mechanism by gate current I_G which is normally applied to ordinary thyristors.

The second one is the mechanism to ignite a photo thyristor by a light from a light emitting diode, which is applied to a photo thyristor coupler.

The third one is the turn-ON/OFF mechanism through increase of leakage current I_{CO}. ICO increases by about 2 times per 8°C at high ambient temperature and a photo thyristor is turned ON/OFF in $\alpha PNP + \alpha PNP \rightarrow 1$. Further, if voltage between the anode and cathode rushes into the avalanche break down state by exceeding break over voltage V_{BO} of a device, a photo thyristor is turned ON by this avalanche current, which is however undesirable.

The final one is the turn-on by dv/dt. If a rapid forward voltage rise (dv/dt) is applied between the anode and cathode of a photo thyristor, the thyristor may be ignited even when that voltage applied is less than break over voltage V_{BO} of the photo thyristor and furthermore, LED current is shut off.

When a device is in forward voltage blocking state, the center junction j_2 shown in Fig. 8-12 is reverse biased and the junction capacity C_{j2} in Fig. 8-45 is generated. If forward voltage changes rapidly, charging current i_{j2} flows to C_{j2}. because of this charging current i_{j2}, electron is injected through J_1 and J_2, respectively, thus igniting a photo thyristor as in the turn-on mechanism by the above-stated $I_{P\lambda}$ (I_F). This injected current is expressed by the following equation:

$$i_{j2} = C_{j2} \times V^{1/K} \times dv/dt$$

$K = 2 \sim 3$

V : Applied voltage

Further a critical value of dv/dt immediately before a photo thyristor is turned off is called dv/dt capability or build-up rate of critical off voltage and expressed in V/us. As current gains of two transistors increase as a result of rise of the junction temperature T_j, dv/dt capability is reduced as shown in the graph of Fig. 8-46. This may further increase transient voltage when the power switch is turned on and mulfunction at time of commutation of inductive load and therefore, it is necessary to take measure described later.

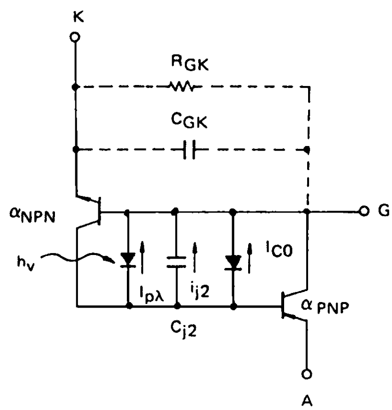


Fig. 8-45 Equivalent Circuit of Photo Thyristor

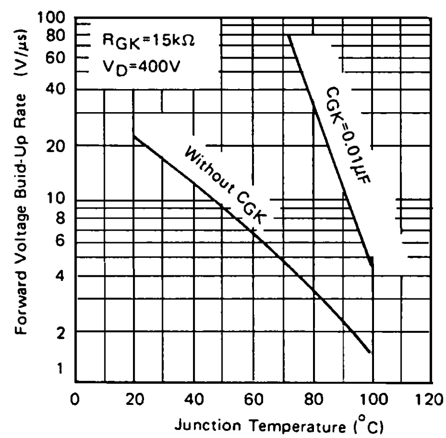


Fig. 8-46 dv/dt vs Junction Temperature

Basic Circuit and Erroneous Ignition Preventive Measure

Generation of dv/dt closely relates to transient voltage when the switch is turned on or off. Mechanisms for generating transient voltage applied to the photo thyristor circuit are shown in Fig. 8-47 and 8-48.

When ON/OFF of an AC circuit by a photo thyristor, the thyristor is positively turned off at an interval of 1/2 cycle. In case of resistance load, when current becomes zero, voltage also becomes zero and voltage build-up immediately after commutation shows a gentle sine wave of supply voltage.

However, in such a photo thyristor circuit of reverse parallel connection with a inductive load as shown in Fig. 8-49, immediately after current of SPT-1 drops below holding current and SPT-1 is turned off, a peak value of supply voltage is rapidly applied in the forward direction of SPT-2. If this forward voltage build-up rate dv/dt is too large, V_{BO} drops due to charging current by the junction capacity C_{j2} of the photo thyristor, and finally erroneous ignition and malfunction of the circuit and system will be caused.

So, in order to positively turn off SPT-2 (not to allow turn-off by dv/dt), it is considered as counterplan to capacitance C_1 insert to erase overshoot by load inductance (L) and insert R_1 as a resistor for limiting surge (di/dt) from a capacitor when the photo thyristor is ignited. Generally, when R_1 = 100 Ω and C_1 = 0.1 μF are used in an actual inductive circuit, it is possible to suppress dv/dt at time of commutation to about 1 ~ 1.5V/μs. The waveform of dv/dt at this example is shown in Fig. 8-51.

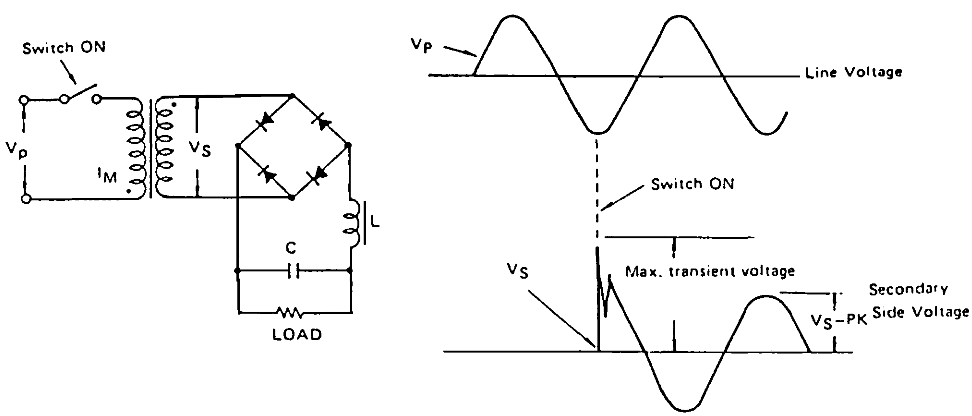


Fig. 8-47 Generation of Transient Voltage When Power Switch of Transformer Primary Side is ON

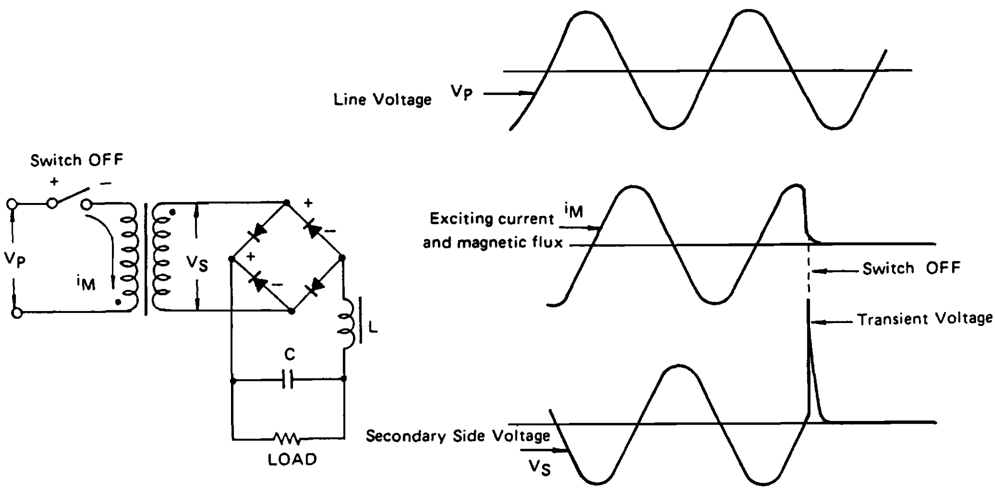


Fig. 8-48 Generation of Transient Voltage when Power Switch of Transformer Primary Side is OFF

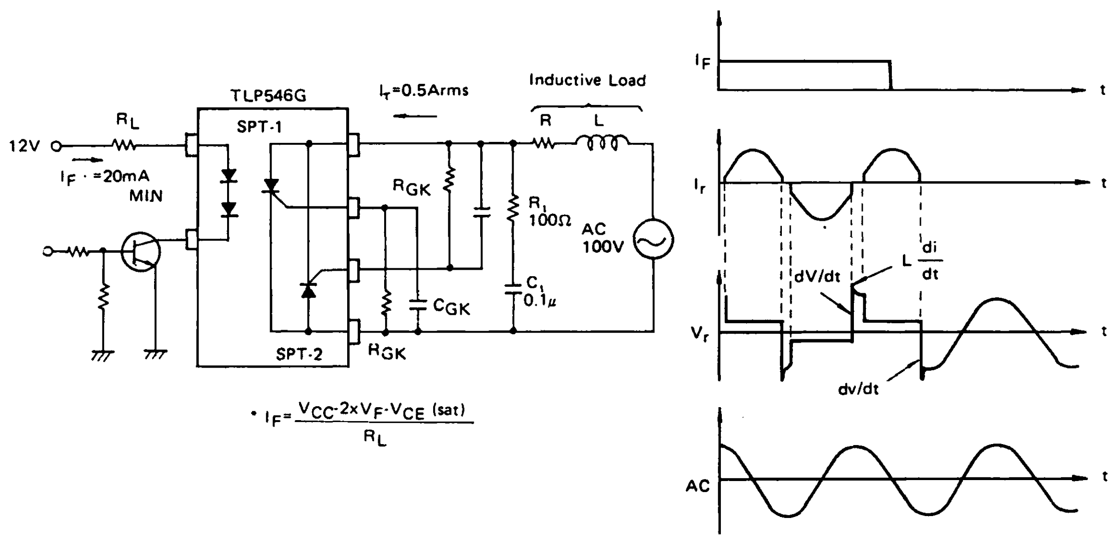


Fig. 8-49 Control of Inductive Load by Photo Thyristor of Parallel Connection

It is necessary to keep dv/dt of a photo thyristor at about 2 V/μs when operated at high ambient temperature Ta = 100°C. From the characteristic curve shown in Fig. 8-46, C_{GK} = 0.01 μF and R_{GK} = 15 kΩ are optimum. As dv/dt vs T_j characteristic differs depending upon used devices it is necessary to refer to the technical data of manufacturers.

Fig. 8-50 shows an example of a circuit using reverse parallely connected small size photo thyristor coupler (I_T = 0.1 ~ 0.2 Arms). In this case photo thyristor couplers works as the main triac photo trigger devices, when several ampere ~ several tens ampere load current is turned ON/OFF.

C_{GK} shown in Fig. 8-50 increases dv/dt capability, maintaining high gate sensitivity for DC and low frequency trigger signals. By bypassing displacement current of C_{j2} dur to dv/dt to the cathode by C_{GK} in the equivalent circuit in Fig. 8-45, the regeneration feedback gain of the photo thyristor can be suppressed, and it will prevent erroneus ignition.

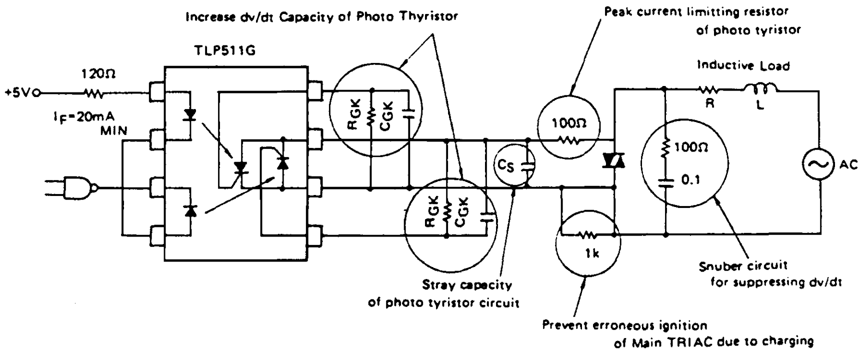


Fig. 8-50 Use of Photo Thyristor of Parallel Connection as TRIAC trigger element

An representative example of characteristics of the relation between C_{GK} and dv/dt capability is shown in Fig. 8-52. In case of photo thyristor couplers available in the market, C_{GK} = 0.001 ~ 0.1 μF is used. Further, as a matter of course, if C_{GK} is set up, the turn-on time t_{ON} becomes longer. Normally, t_{ON} ≅ 20 ~ 30 μs at C_{GK} = 0.01 μF and over drive factor I_F/I_{FT} = 1.5.

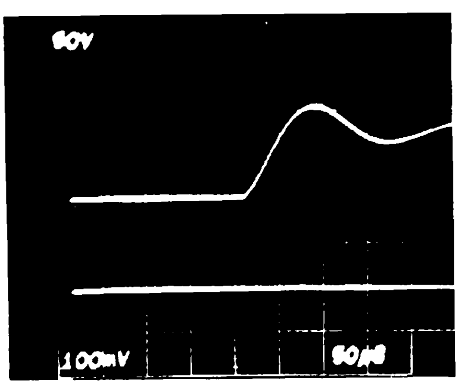


Fig. 8-51 dv/dt Suppression Effect by Snuber Circuit of R=100Ω, C=0.1μF at Time of Comutation

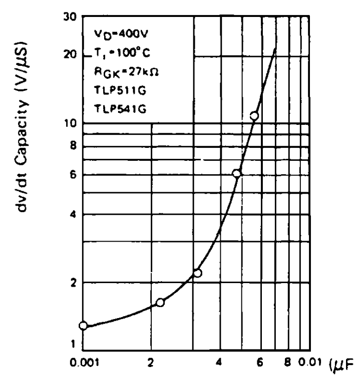


Fig. 8-52 C_{GK} Dependency of dv/dt Capacity

The gate sensitivity of a photo thyristor has been designed high (I_{GT} = 5 ~ 30 μF) so that it is turned ON by minute photo current $I_{P\lambda}$ and therefore, the thyristor is apt to be erroneously ignited by leakage current I_{CO} generated at high temperature operation. So, to assure stable operation, R_{GK} is inserted to bypass I_{CO} to cathode as shown in Fig. 8-50.

Further, as R_{GK} also bypasses gate current i_{j2} by dv/dt, dv/dt capability also increases.

However, as $I_{P\lambda}$ obtained by light energy from LED is bypassed to the cathode, contribution rate as gate current drops and I_{FT} (minimum current of LED required for igniting a photo thyristor) becomes large. And if R_{GK} is too small, LED cannot be triggered. Representative characteristics of this I_{FT} vs R_{GK} are shown in Fig. 8-53.

When full-wave rectification is performed by a diode bridge and its switching is made by photo thyristors, one set of photo thyristor couplers is sufficient enough and it will be expected to be economical. In Fig. 8-54, a simple solid relay which consists of photo thyristor couplers and a main triac is shown as an example of the basic application of photo thyristor couplers.

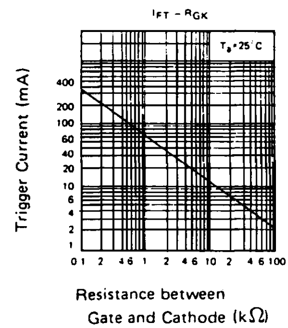


Fig. 8-53 R_{GK} Dependency of I_{FT}

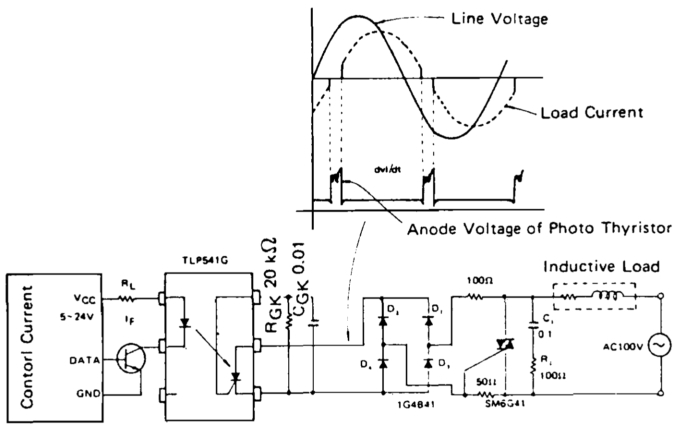


Fig. 8-54 Application of Photo Thyristor Coupler

This circuit is generally used for motor control and various load switching. As anode current of a photo thyristor drops below holding current (I_F = 0.2 mA) and is turned off when the main TRIAC is ignited, the photo thyristor itself does not almost need the power.

8-2-4 Interface Circuit between TTLs using Photo-transistor Coupler

A circuit using a DIP 4 pin photo coupler as an interface between TTLs is shown in Fig. 8-55. In order to assure positive ON/OFF operation of TTL, LED current I_F should be set to satisfy I_{OL} which is decided by R_C and I_{IL}.

Example of Design Specifications

Operating temperature:	0 ∿ 70°C
Data speed:	5 k bits/sec
Supply voltage:	V_{CC} = 5V ± 5%
Operating life:	20 years (170,000 hours)
System working ratio:	50%

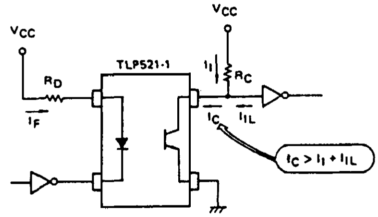


Fig. 8-55 Interface Circuit between TTLs using 4 pin photo coupler

Specifications for products required for designing are shown in Table 8-5.

Table 8-5: Principal Characteristics of TLP521-1

Item	Symbol	Test condition (Ta=25°C)		min	typ	max	Unit
Forward Voltage	V_F	I_F=10 mA		1.0	1.15	1.3	V
Collector and Emitter Breakdown Voltage	$V_{(BR)CEO}$	I_C=0.5 mA		55			V
Emitter and Collector Breakdown Voltage	$V_{(BR)ECO}$	I_E=0.1 mA		7			V
Collector Dark Current	I_{CEO}	I_F=0, V_{CE}=24 V		—	10	100	nA
		I_F=0, V_{CE}=24V, Ta=85°C		—	2	50	μA
Current Transfer Ratio	CTR (I_C/I_F)	I_F=5 mA, V_{CE}=5 V	A rank	50	—	600	%
			GB rank	100	—	600	
			GR rank	100	—	300	
			BL rank	200	—	600	
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	I_F = 5 mA, I_C = 1 mA		—	0.1	0.4	V

▼ Setting of R_C (max)

Set R_C (max) by switching time and dark current I_{CEO} (max) at max. operating temperature of the photo coumpler.

The relation between switching time and R_L (load resistance), R_C is shown as following.

As data speed is 5 kbits/sec, total switching time is

$$T = tr + td + tf + ts \leq 200\,\mu s$$

Load resistance R_L is obtained from the switching time (saturation operation) characteristic in Fig. 8-56 so that T becomes 100 μs, considering device distribution in order to secure $T \leq 200\ \mu s$. From this graph, R_L = 4.7 kΩ is obtained. Here, R_L can be expressed by parallel resistance of the standard TTL input resistance P_{IN} and R_C. (Fig. 8-57)

$$R_L = R_C // P_{IN}$$

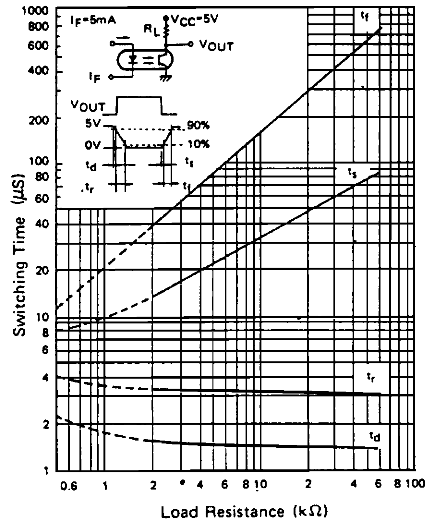


Fig. 8-56 Load Resistance vs Switching Time

As R_L = 4.7 kΩ > R_{IN} = 4 kΩ, R_C may be indefinite ($R_C = \infty$) but R_C (max) against dark current $I_{CEO(max)}$ is limited.

The relation between I_{CEO} (max) and R_C (max) is shown below.

$$R_{C(max)} = \frac{V_{CC(min)} - V_{IH}}{I_{CEO(max)} + I_{IH}}$$

Then, I_{CEO} (max) at Ta = 70°C is estimated. Temperature dependency of I_{CEO} (typ) with a parameter of V_{CE} = 5V/10V/24V is shown in Fig. 8-58.

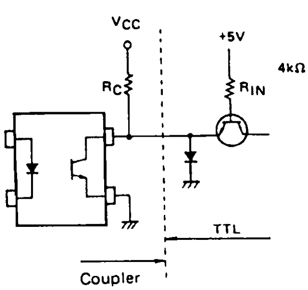


Fig. 8-57 R_L can be expressed by R_{IN} and R_C

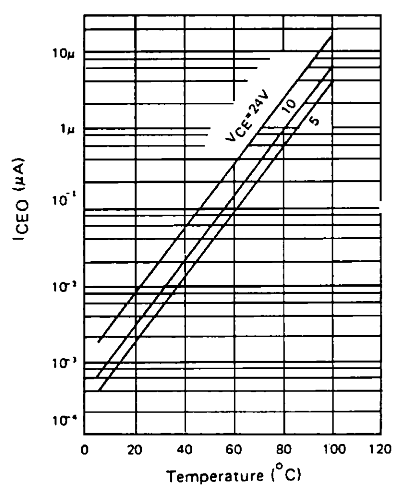


Fig. 8-58 I_{CEO} **vs Temperature**

In the case of the TLP521-1, $I_{CEO\ (max)}$ = 50 μA at Ta = 85°C and V_{CE} = 24V and therefore, taking V_{CE} dependency and Ta dependency into consideration from Fig. 8-58, $I_{CEO\ (max)}$ at Ta = 70°C and V_E = 5V is estimated.

V_{CE} dependency:	$I_{CEO(typ)}$ is 1/4 times at V_{CE} = 24V to 5V
Ta dependency:	$I_{CEO(typ)}$ is 1/4 times at Ta = 85°C to 70°C

Therefore, $I_{CEO(max)}$ at Ta = 70°C and V_{CE} = 5V is estimated to be,

$$I_{CEO} = 50\,\mu A \times \frac{1}{4} \times \frac{1}{4} = 3.1\,\mu A$$

Accordingly, $R_{C\ (max)}$ will be obrained as following

$$R_{C(max)} = \frac{4.75V - 2V}{3.1\,\mu A + 40\,\mu A} = 64\ k\Omega$$

▼ Setting of Forward Current I_F

Maximum forward current I_F is I_F = 16 mA from $I_F \leq I_{OL}$ and maximum allowable value of I_F is 50 mA from Fig. 8-59. However, it should be kept as small as possible as CTR degradation increases with the increase of forward current. Fig. 8-60 shows degradation of CTR. In order to expect the continuous operating life of approx. 100,000 hours, forward current should be set at I_F = 10 mA ± 50%.

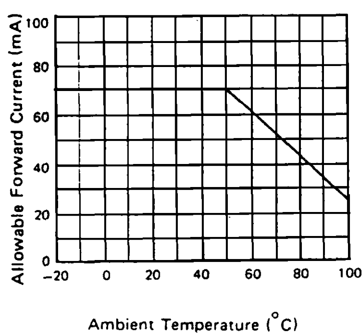


Fig. 8-59 Ambient Temperature vs. Allowable Forward Current (TLP521-1)

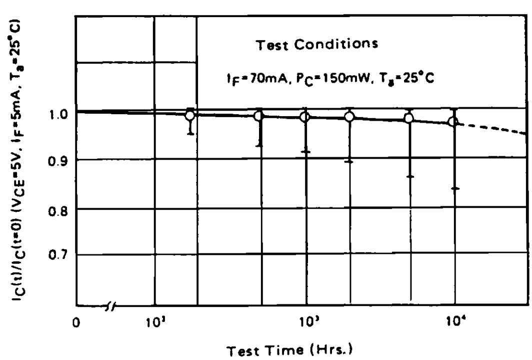


Fig. 8-60 Life Test Data (CTR degradation)

▼ Setting of I_F Limiting Resistance R_D

Forward Current (typ.) is expressed by the following formula:

$$I_F = \frac{V_{CC} - V_{F(typ)} - V_{OL}}{R_{D(typ)}}$$

where $V_{F(typ)}$ is obtained from a technical data.
then, $V_{F(typ)}$ = 1.15V (at I_F = 10 mA)

Therefore, R_D is given as following.

$$R_D = \frac{5V - 1.15V - 0.4V}{10\ mA}$$

$$= 345\Omega$$

Therefore, R_D = 330Ω ± 5% will be optimum.

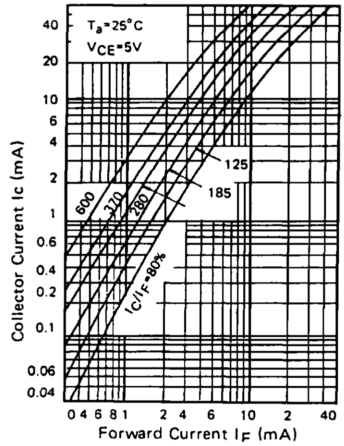


Fig. 8-61 I_C vs I_F by parameter I_C/I_F

When $I_{F(min)}$ and $I_{F(max)}$ should be checked to make sure,

$$I_{F(min)} = \frac{V_{CC(min)} - V_{F\ (max)} - V_{OL}}{R_{D(max)}}$$

$$= \frac{4.75V - 1.3V - 0.4V}{314\Omega}$$

$$= 9.7\ mA$$

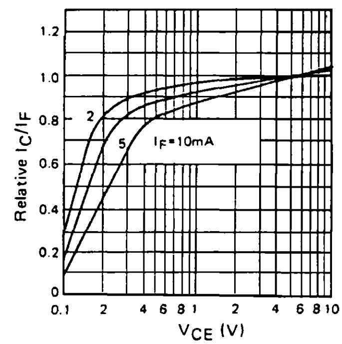


Fig. 8-62 I_C/I_F vs. V_{CE}

$$I_{F(max)} = \frac{V_{CC(max)} - V_{F(min)} - V_{OL}}{R_{D(min)}}$$

$$= \frac{5.25V - 1.0V - 0.4V}{347}$$

$$= 11.1\ mA$$

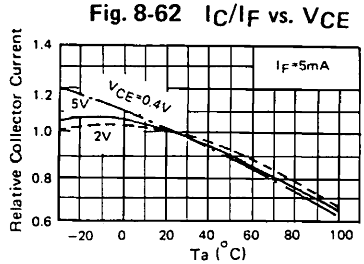


Fig. 8-63 Collector Current vs. Ta

▼ Setting of Pull-Up Resistance R_C

When a value of collector current I_C in the worst case is assumed to be min I_C, it can be expressed by the following relation:

$$R_C \geq \frac{V_{CC(max)} - V_{OL}}{\min I_C - I_{IL}}$$

$$\min I_C = I_{C(min)} \times D_{IF} \times D_t \times D_{VCE} \times D_{Ta}$$

where,

D_t : I_C degradation rate after certain time has passed.

D_{IF} : I_C change rate at I_F setting for catalog conditions.

D_{VCE} : I_C drop rate under $V_{CE(sat)}$ condition.

D_{Ta} : I_C fluctuation rate within operating temperature T_{OPR}.

These values are obtained from technical data.

In the case of the TLP521-1:

From Fig. 8-60, D_t = 0.5 (t = 17 x 10^{-5}, H_R x 50% working ratio)

From Fig. 8-61, D_{IF} = 2.5 (I_F = 10 mA)

From Fig. 8-62, D_{VCE} = 0.8 (V_{CE} = 0.4V)

From Fig. 8-63, D_{Ta} = 0.75 (Ta = 70°C)

On the other hand, as $I_{C(min)}$ = 2.5 mA (I_F = 5 mA x $I_C/I_{F(min)}$ = 50%),

min I_C = 2.5 mA x 2.5 x 0.5 x 0.8 x 0.75 = 1.8 mA

However, if based on these data, the following formula can not be formed

$$\min I_C - I_{IL} > \frac{V_{CC(max)} - V_{OL}}{R_{C(min.)}}$$

Therefore, a photo coupler with higher CTR should be selected. In the case of the TLP521-1 (GB), as $I_{C(min)}$ is guaranteed to be 5 mA, min I_C will become 3.6 mA. Accordingly, $R_{C(min)}$ can be obtained as following;

$$R_{C(min)} = \frac{5.24 - 0.4}{3.6 - 1.6} = 2.4\ k\Omega$$

In other words, R_C can be set from 2.4 kΩ to 64 kΩ but it is also need to consider the switching speed, required by a system and the certainty of logical ON/OFF. If the switching speed is attached to be important, R_C should be set to be near to $R_{C(min)}$. On the other hand, if the certainty of ON/OFF operation (this may be taken as the operating life) is considered as important, a value close to $R_{C(max)}$ should be selected. In this case, since Dt is assumed to be 0.5, the switching speed should be considered to be important. So, Rc is obtained as 4.7 kΩ.

8-2-5 TRIAC Drive Circuit Using Photo Coupler

Such electronic equipment as electronic oven, copier, auto-door, etc. have become controlled by microcomputer recently and interface between power circuit and microcomputer logic becomes more and more important. In this paragraph, a triac drive circuit which has especially wide applications as a power circuit is explained.

(1) **Drive by Photo Darlington Coupler**

Gate trigger current I_{GT} of 3 ~ 16A class TRIAC is necessary 20 ~ 50 mA. Accordingly, I_G = 40 ~ 50 mA is necessary as gate current and therefore, a photo Darlington coupler with high CTR is used. An example of this circuit is shown in Fig. 8-64.

Example of Design Specifications

Operating temperature:	−30 ~ 85°C
Switching capability	100V, $3A_{RMS}$
Supply voltage:	V_{CC} = 5V ±5%
Operating life:	20 years (170,000 hours)
System working ratio:	50%

First, the TLP570 is used in this example.

<Design Procedures>

▼ Setting of Forward Current I_F

In the same manner as in the above mentioned TTL interface, I_F is set to be 10 mA and therefore, R_D = 330Ω and $I_{F(min)}$ = 9.7 mA ≒ 10 mA are obtained.

▼ Setting of R_C

The minI_C (the minimum value) of the TLP570 is 42 mA when $I_{C(min)}$ is 100 mA (I_F = 10 mA, V_{CE} = 1.2V) and variable factors are assumed as following:

$D_t = 0.6$

$D_{IF} = 1$

$D_{Ta} = 0.7$

Therefore, R_C is calculated as following:

$$R_C = \frac{V_Z - V_{CE(sat)}}{\min\ I_C} = \frac{6.8\ V - 1.2\ V}{42\ mA} = 133\ \Omega$$

Therefore, R_C = 130 Ω (1/4W) is optimum.

▼ Setting of Other Constants

R_Z is given by the following equation:

$$R_Z = \frac{V_{AC} - V_Z - V_{F(D_1)}}{I_Z}$$

By substituting I_Z = 20 mA and V_F = 1V into this formula, R_Z = 4.6 kΩ is obtained. Power consumption of R_Z is $I_Z{}^2 R$ = 1.8W. Therefore, R_Z = 4.7 kΩ (3W) is optimum. 47Ω, 0.1μF between T_1 - T_2 is snubber circuit to surge absorption.

(2) **400V/8A TRIAC Drive Circuit**

In the case of a 8A class TRIAC, gate trigger current I_G is as high as 50 mA and therefore, I_G = 100mA is required. So, the circuit shown in Fig. 8-65 is better.

The design procedures are briefly described below.

- ▼ As I_F = 10 mA, R_D = 330Ω
- ▼ As I_G = 100 mA, R_E = 33Ω
- ▼ As I_C = 10 mA, R_C = 470Ω

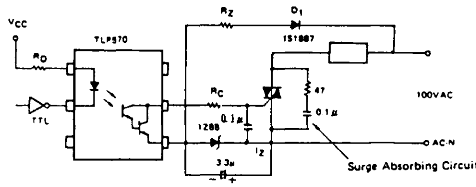


Fig. 8-64 3A TRIAC Drive Circuit

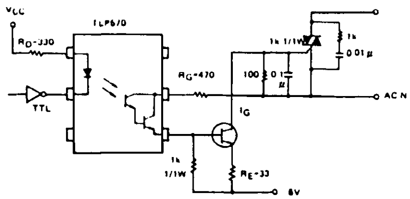


Fig. 8-65 8A TRIAC Drive Circuit

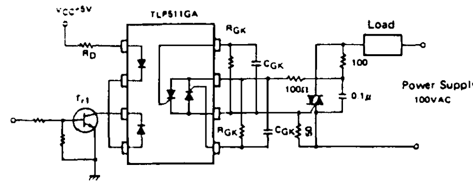


Fig. 8-66 Thyristor Coupler TRIAC Drive Circuit

(3) Drive by Reverse Parallel Thyristor Coupler

The TRIAC driving through a unidirectional conducting thyristor coupler with a bridge rectifier circuit has been principally described until this paragraph. When reverse parallel thyristor couplers are used, following merits can be derived:

① A bridge rectifier circuit can be eliminated, thus reducing number of components and simplifying circuits

② As independent photo thyristors are reverse parallelly connected and either one is always non-conductive for half cycle, commutating dv/dt of photo couplers does not exist intrinsically.

An example of the circuit using reverse parallel thyristor couplers is shown in Fig. 8-66.

Example of Design Specifications

Operating temperature:	−30 ~ 85°C
dv/dt capability:	10V/μs min.
Operating life:	20 years (170,000 hours)
System working ratio:	50%

In this example, the TLP511GA Photo Coupler is used.

Design Procedures

▼ Setting of R_{GK}, C_{GK}

As trigger energy of photo-electric trigger is extremely less than that of current trigger, R_{GK} is set at relatively high level as 10k ~ 33 kΩ and therefore, gate sensitivity increases and dv/dt capability decreases. In this case, even when no trigger gate input is applied, if voltage between anode and cathode rises to exceed a certain critical value (dv/dt capability), the circuit is turned on. This dv/dt capacity is in reverse strongly depends proportional to gate sensitivity. And it depends on R_{GK}, C_{GK} and Ta strongly as shown by (a), (b) and (c) in Fig. 8-67. From Fig. 8-67, R_{GK} and C_{GK} which satisfy dv/dt ≧ 10 V/us of the design specifications are set as follows:

R_{GK} = 27 kΩ , C_{GK} = 0.01 μF

▼ Setting of Forward Current I_F

Minimum LED current $I_{F(min)}$ required for trigger is given by

$$I_{F(min)} = I_{FT(max)} \times D_{Ta} \times D_{RGK} \times D_t \times D_{ON}$$

where,

$I_{FT(max)}$: I_F value, required for turn-on (7 mA from technical data)

D_{Ta} : 1.2 from temperature characteristics of I_{FT}.

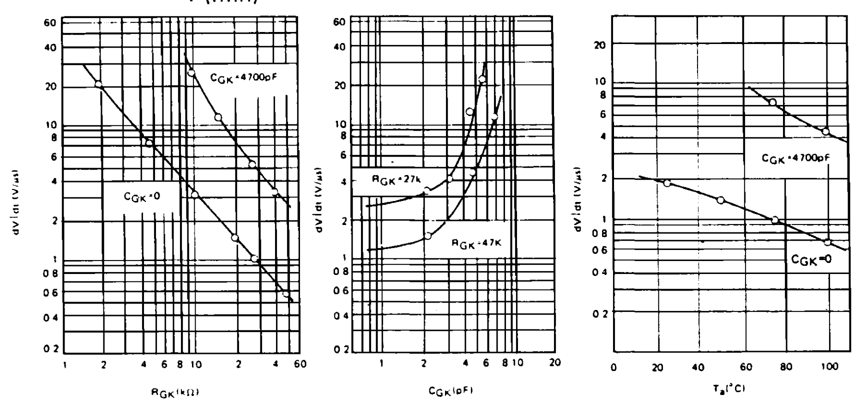
D_{RGK} : Ratio 1 which is obtained from R_{GK} dependence characteristics of I_{FT}

D_t : 1.3, from I_{FT} degradation

D_{ON} : 2, Overdrive factor

Therefore, $I_{F(min)}$ = 20 mA is obtained. But the direct driving by TTL is impossible, so Tr_1 is used as a LED driver.

From $R_D = \dfrac{V_{CC} - 2V_F - V_{CE(sat)}}{I_{F(min)}}$, R_D = 120 Ω ± 5% is optimum.



(a) dv/dt vs. R_{GK} (Ta=100°C) (b) dv/dt vs. R_{GK} (Ta=100°C) (c) dv/dt vs. Ta (R_{GK}=27kΩ)

Fig. 8-67 Thyristor Coupler Characteristics

8-2-6 AC Switching Circuit Using Thyristor Coupler

In this paragraph, as the basic circuit of a solid state relay (SSR), Fig. 8-68 is shown. In this circuit, the methods for selecting R_{GK} and C_{GK} and deciding control current (forward current I_F) are described as following.

Example of Design Specifications

Operating temperature:	T_{opr} = 0 to 70°C
Supply voltage:	V_{CC} = 5V ± 5%
Resistance variation:	±5%
Operating life:	170,000 hours (about 20 years)
System working ratio:	50%

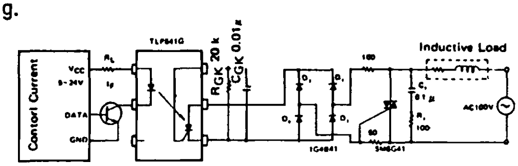


Fig. 8-68 Example of SSR Circuit

▼ Selection of Components

In the circuit shown in Fig. 8-68, the TLP541G is used as the photo thyristor coupler.

However, as the TLP541G is of unidirectional conduction type, the 1G41B is used as a rectifying bridge.

In order to turn ON/OFF 100V, 2A load, the SM6G14 is used as a main TRIAC. Further a circuit with R = 100Ω and C = 0.1 μF is adequate for a snubber circuit. R = 50Ω which is set up between G and T_2 of the TRIAC is to bypass charging current by capacitance of a diode bridge or photo thyristor.

▼ Setting of R_{GK}, C_{GK}

As load is inductive, dv/dt capacity should be designed to be large as a measure against the above-stated problems. When the SM6G14 is turned on, as no power flows through the TLP541G, power loss is less and T_j rise due to self-power dissipation is not so much. Therefore, the maximum junction temperature of the photo thyristor is considered to be maximum ambient temperature plus the heat spread from LED side. LED forward current I_F is limited to be $I_F \leqq 30$ mA from the relation of a longer life as described later and even when this heat generation is added, the junction temperature of thyristor coupler, $T_{j(SCR)}$ will be below about 80°C.

With effect of the snubber circuit taken into consideration, dv/dt = 2 ~ 3V/μs is kept at $T_{j(SCR)}$ = 80°C and V_{DRM} = 280V which is twice of maximum supply voltage.

To give a margin to dv/dt, R_{GK} = 27 kΩ, C_{GK} = 0.01 μF are considered to be adequate from the characteristic curve in Fig. 8-52. C_{GK} can be increased to a level where no trouble due to long turn-on time of the thyristor coupler is generated.

▼ Setting of Forward Current

Minimum forward current I_F for turning on a photo thyristor is defined to be trigger LED current I_{FT}. I_F which is required here is obtained from the following formula:

$$I_F = I_{FT(max)} \times D_{Ta} \times D_{RGK} \times D_t \times D_{ton}$$

where,

$I_{FT(max)}$: I_{FT} which is initially guaranteed in technical data

D_{Ta} : A relative value of temperature dependency of I_{FT} within a range of 1.1~1.2 times

D_{RGK} : A relative value of R_{GK} dependency of I_{FT}.
No correction is necessary as R_{GK} = 27 kΩ which is the same as measuring condition of manufacturer.

D_t : Compensation factor of I_{FT} degradation. It is necessary to confirm with manufacturer. Fig. 8-69 is referred to here.

D_{ton} : Overdrive factor to shorten turn-on time. In this case, estimated at D_{ton} = 1.2

As the examples:

$I_{FT(max)}$ = 7mA at Ta = 25°C, R_{GK} = 27 kΩ

D_{RGK} = 1 at R_{GK} = 27 kΩ

D_t = 1.3 at 8.5 x 10^4 Hrs (working ratio 50%)

D_{ton} = 1.5

Therefore, minimum required value of I_F is given as following.

$I_{F(min)} \cong 16$ (mA)

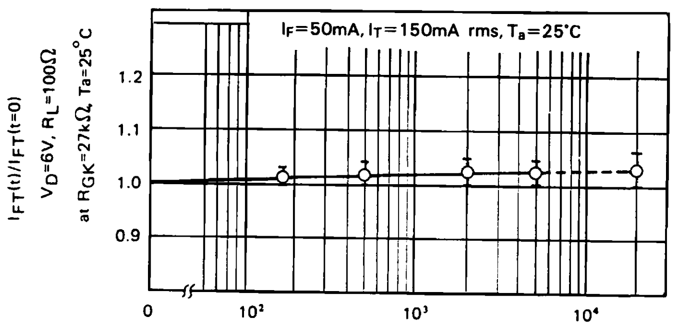


Fig. 8-69 Life Test Results of LED Trigger Current I_{FT} (TLP541G)

Zero-Cross Switch Circuit

When a switch is turned on, current suddently changes and, the radio frequency interference (RFI) is generated by rush current, or transient voltage.

To minimize RFI there is a method to make a switching around the zero cross point of AC voltage. This is called the zero voltage switching or zero-cross switching.

Fig. 8-70 shows an example of the zero-cross switch constructed using the photo thyristor coupler TLP541. In this circuit, the photo thyristor is turned ON only when voltage between T_1 and T_2 of TRIAC is around zero voltage and TRIAC is triggered.

In this zero-cross system voltage between $T_1 \sim T_2$ is divided by resistors R_1 and R_2 and transistor T_{r1} is saturated by this divided voltage. That is, as photo current Ip of the photo thyristor flows from the gate through T_{r1} and shorted to the cathode when voltage is other than zero, the photo thyristor is not turned ON even when V_{IN} is applied.

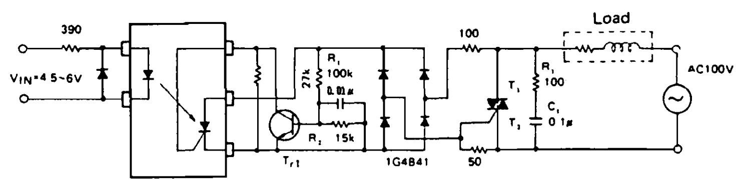


Fig. 8-70 Zero Cross SSR Circuit

Power Control of Magnetron for Microwave Oven

Fig. 8-71 shows an example of power control circuit of an microwave oven. This circuit consist of a phase shift circuit using Uni Junction Transistor 2SH21. The LED trigger phase of the TLP511G is delayed from line voltage by about 90°. Thus, delay in current rise generated by inductive load of main thyristor SM16G14 is reduced and oscillation of magnetron is stabilized.

The trigger circuit operates at duty ratio set in the timer circuit and power of the microwave oven is controlled by oscillation ON/OFF of the magnetron.

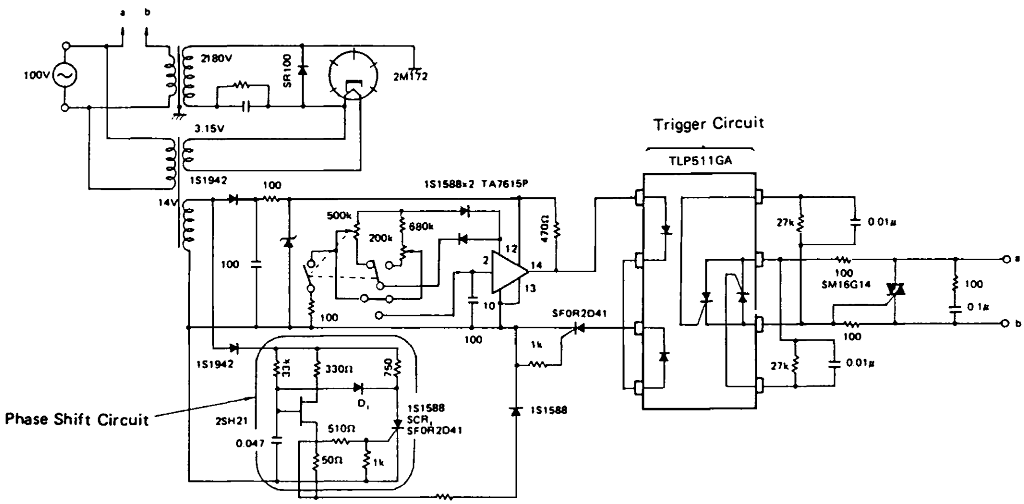


Fig. 8-71 Power Control Circuit of Electronic Oven

Driving of Motor in Normal and Reverse Directions

Fig. 8-72 shows the driving circuit of a reversible motor in the normal/reverse direction with high power photo thyristor couplers applied. Recently, photo thyristors are available in the market, of which power capability reach to ON/OFF load current of about 1 Arms. In this circuit, the TLP546G drives a motor of 4W output. The TLP546G has an aluminium radiating plate of 2 ~ 3 cm^2 embeded in DIP mold and is able to turn ON/OFF 1 Arms at ambient temperature Ta = 40°C.

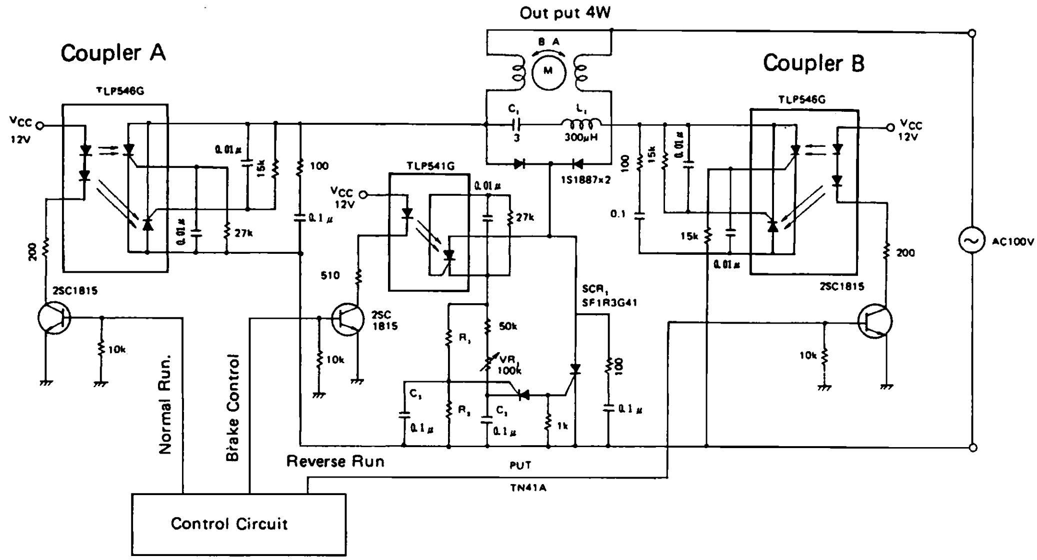


Fig. 8-72 Reversible Motor Normal/Reverse Drive Circuit

Inductive L_1 shown in Fig. 8-72 is necessary for suppressing surge current from C_1 and should be set at 200 ~ 500 μH.

Control signal for switching driving of the photo couplers from direction A to direction B or vice versa requires a pause time more than 1/2 cycle. In other words, if Coupler B is turned ON when Coupler A has not been turned OFF, excessive discharge current suddenly flows from C_1 to both Couplers A and B and devices are completely broken. Fig. 8-73 shows discharge current from C_1 when a 5Ω resistor is inserted for L_1 and its peak value has reached 45A.

For braking, the TLP546G is operated. When the TLP546G is turned ON, PUT is operated to turn OFF SCR_1 at a certain phase difference. When DC component is applied, the reversible motor is braked. As discharge surge current is also generated from C_1 at this time, it is indispensable to insert L_1.

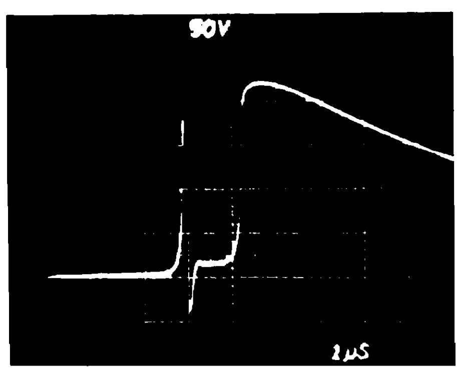


Fig. 8-73 Discharge Surge Current from Condenser C_1 (Voltage Drop of 5Ω Resistor)