'INFRARED' LIGHT-EMITTING DIODE APPLICATION CIRCUITS

Serial Connection And Parallel Connection

Figure 1 shows the most basic and commonly used circuits for driving light-emitting diodes.

In Figure 1(A), a constant voltage source (V_{CC}) is connected through a current limiting resistor (R) to an LED so that it is supplied with forward current (I_F). The I_F current flowing through the LED is expressed as $I_F = (V_{CC} - V_F)/R$, providing a radiant flux proportional to the I_F. The forward voltage (V_F) of the LED is dependent on the value of I_F, but it is approximated by a constant voltage when setting R.

Figures 1(B) and 1(C) show the circuits for driving LEDs in serial connection and parallel connection, respectively. In arrangement (B), the current flowing through the LED is expressed as $I_F = (V_{CC} - V_F \times N)/R$, while in arrangement (C), the current flowing through each LED is expressed as $I_F = (V_{CC} - V_F)/R$ and the total supply current is $N \times I_F$, where N is the number of LEDs.

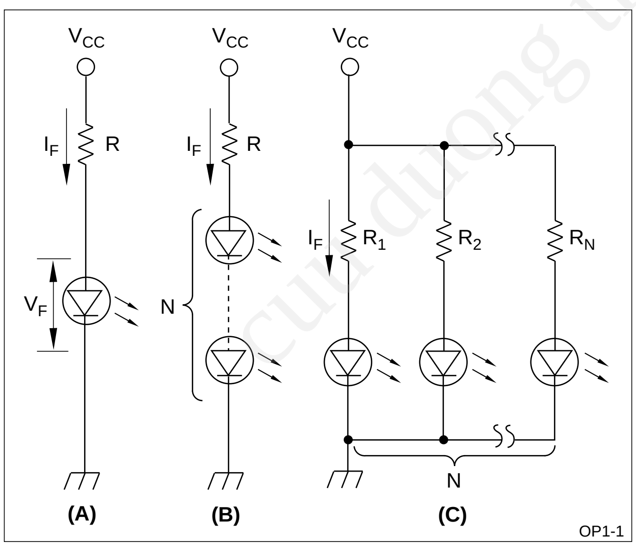

Figure 1. Driving Circuit of Light-Emitting Diode (LED)

The V_F of an LED has a temperature dependency of approximately -1.9 mV/°C. The operating point for the load R varies in response to the ambient temperature as shown in Figure 2.

Constant Current Drive

To stabilize the radiant flux of the LED, the forward current (I_F) must be stabilized by using a constant current source. Figure 3 shows a circuit for constantly driving several LEDs using a transistor. The transistor (Tr_1) is biased by a constant voltage supplied by a zener diode (ZD) so that the voltage across the emitter follower loaded by resistor R_E is constant, thereby making the collector current ($I_C = I_F$) constant. The I_C is given as $I_C = I_E = (V_Z = V_{BE})/R_E$. If too many LEDs are connected, the transistor enters the saturation region and does not operate as a constant current circuit. The number of LEDs (N) which can be connected in series is calculated by the following equations.

$$V_{CC} - N \times V_F - V_E > V_{CE}\ (sat)$$

$$V_E = V_Z - V_{BE}$$

These equations give:

$$N < (V_{CC} - V_Z + V_{BE} - V_{CE}(sat))/V_F$$

Figures 4 and 5 show other constant current driving circuits that use diodes or transistors, instead of zener diodes.

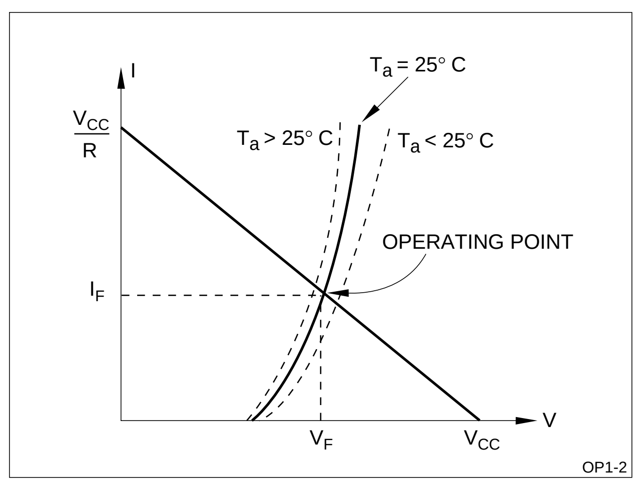

Figure 2. Current vs. Voltage of Light-Emitting Diode (LED)

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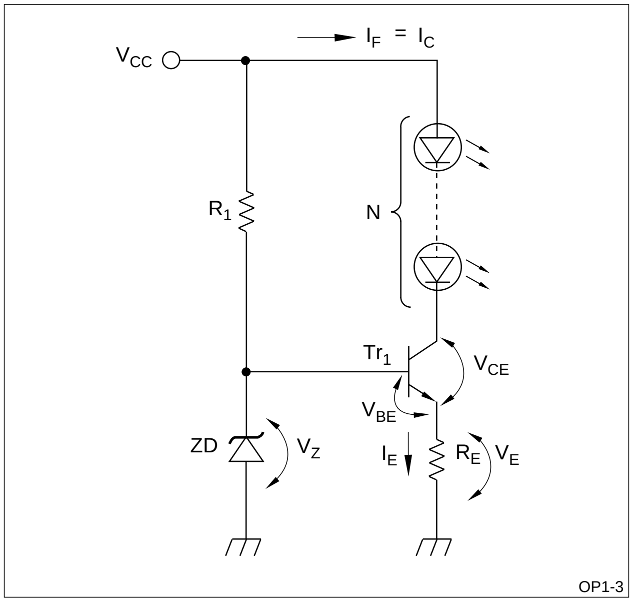

Figure 3. Constant Current Driving Circuit (1)

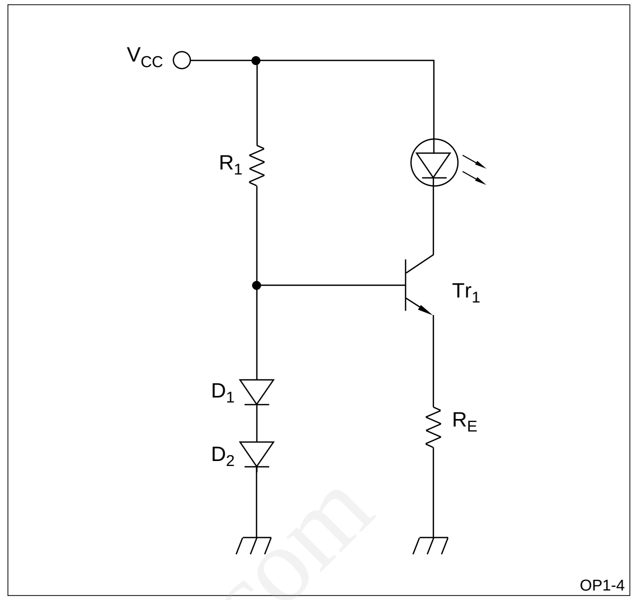

Figure 4. Constant Current Driving Circuit (2)

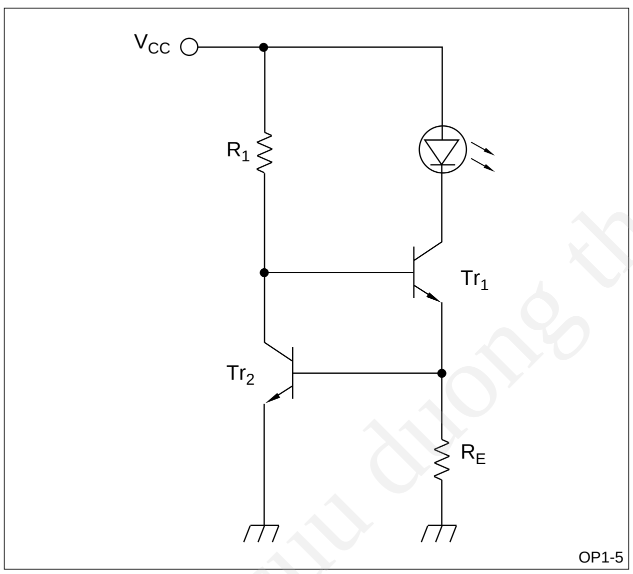

Figure 5. Constant Current Driving Circuit (3)

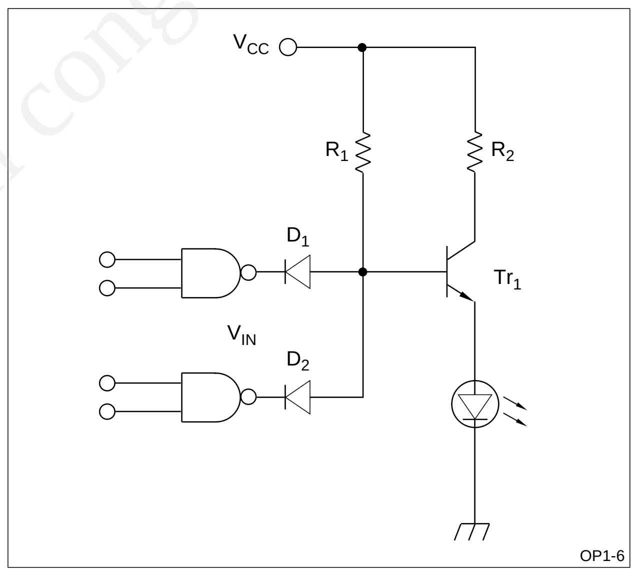

Figure 6. Connection with the TTL Logic Circuit (1)

Driving Circuit Activated By A Logic IC

Figures 6 and 7 show LED driving circuits that operate in response to digital signals provided by TTL or CMOS circuits.

Figure 8 shows a driving circuit connected with a high level logic circuit.

In Figure 6, a high input signal V_{IN} from a TTL circuit makes the NPN transistor (Tr_1) conductive so that the forward current (I_F) flows through the LED. Accordingly, this circuit operates in the positive logic mode, in which a high input activates the LED.

In Figure 7, a low input signal V_{IN} from a TTL circuit makes the PNP transistor (Tr_1) conductive so that the forward current flows through the LED. This circuit operates in the negative logic mode, in which a low input activates the LED.

In Figure 8, the circuit operates in the positive logic mode, and current I_F is stabilized by constant current driving so that the radiant flux of LED is stabilized against variations in the supply voltage (V_{CC}).

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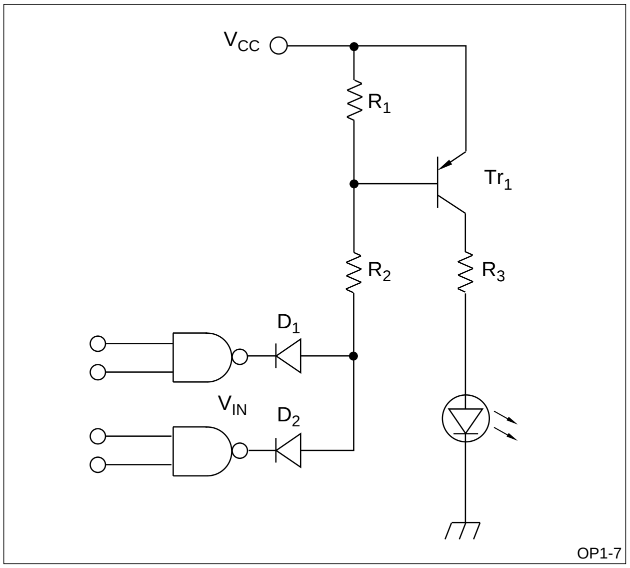

Figure 7. Connection with the TTL Logic Circuit (2)

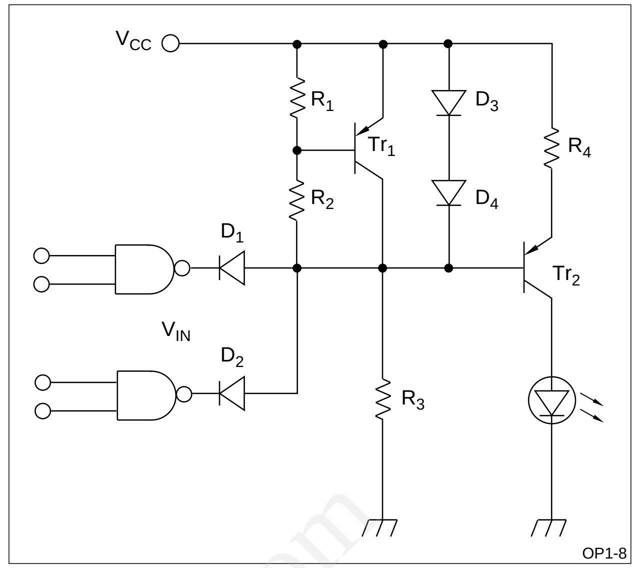

Figure 8. Connection with the TTL Logic Circuit (3)

Driving Circuit With An AC Signal

Figure 9 (A) shows a circuit in which an AC power source supplies the forward current (I_{F1}) to an LED. A diode (D_1) in inverse parallel connection with the LED protects the LED against reverse voltage, suppressing the reverse voltage applied to the LED lower than V_{F2} by using a reverse voltage protection diode of an LED. The LED provides a radiant flux proportional to the applied AC current, (emitting only in half wave).

Figure 9 (B) shows the driving waveform of the AC power source.

Figure 10 (A) shows a driving circuit which modulates the radiant flux of LED in response to a sine wave or modulation signal. Figure 10 (B) shows modulation operation.

If an LED and light detector are used together in an environment of high intensity disturbing light, it is difficult for the light detector to detect the optical signal. In this case, modulating the LED drive signal alleviates the influence of disturbing light and facilitates signal detection.

To drive an LED with a continuous modulation signal, it is necessary to operate the LED in the linear region of the light-emitting characteristics. In the arrangement of Figure 10, a fixed bias (I_{F1}) is applied to the LED using R_1 and R_2 so that the maximum amplitude of the modulation signal voltage (V_{IN}) lies within the linear portion of the LED characteristics. Moreover, to stabilize the radiant flux of the LED, it is driven by a constant current by the constant current driving circuit shown in Figure 3. The capacitor (C) used in Figure 10 (A) is a DC signal blocking capacitor.

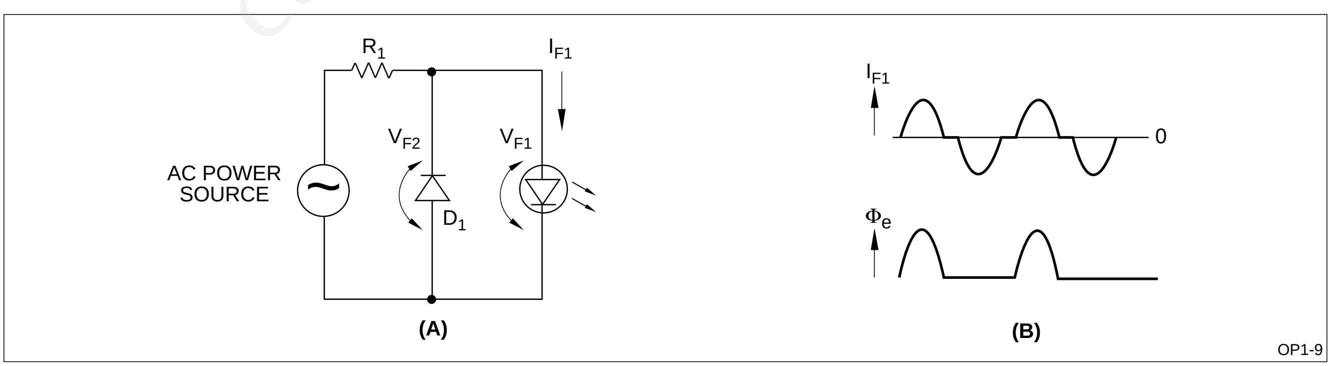

Figure 9. (A) Driving Circuit with AC Power Source (B) Driving Waveform

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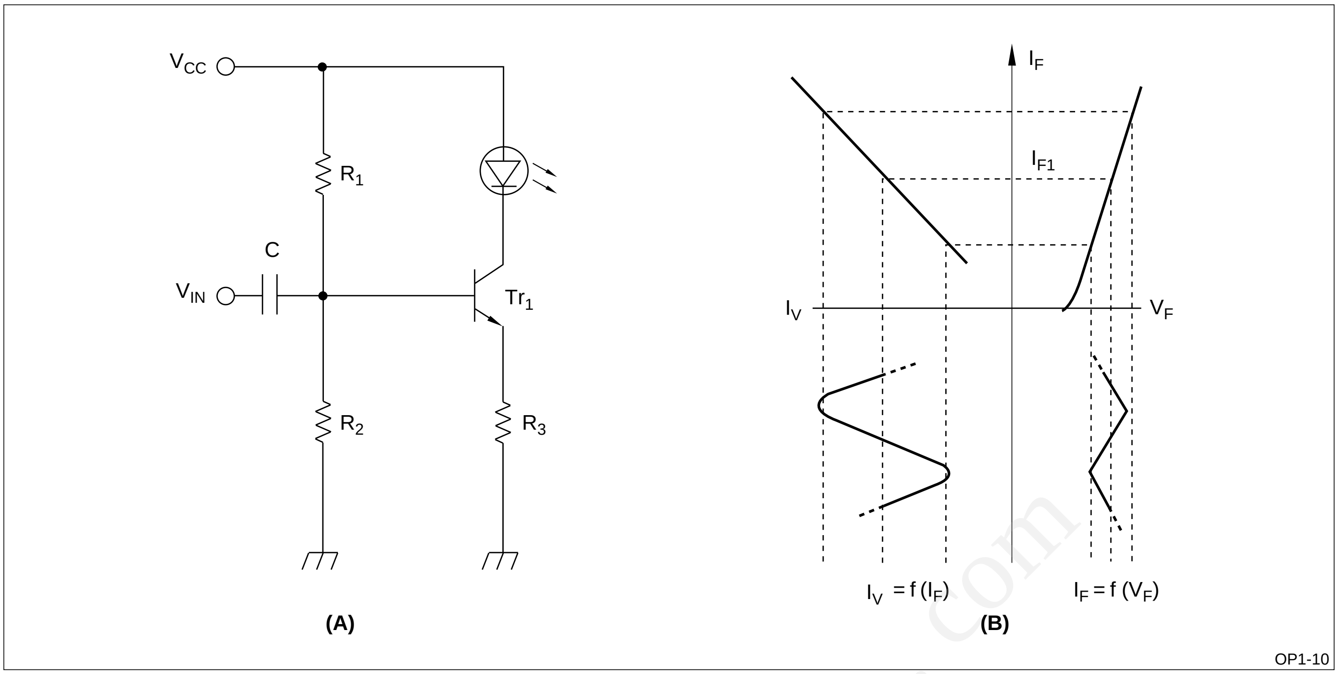

Figure 10. (A) Modulation Driving Circuit
(B) Modulation Operation

Pulse Driving

LED driving systems fall into three categories: DC driving system, AC driving system (including modulation systems), and pulse driving system.

Features of the pulse driving system:

1. Large radiant flux
2. Less influence of disturbing light
3. Information transmission

1. The radiant flux of the LED is proportional to its forward current (I_F), but in reality a large I_F heats up the LED by itself, causing the light-emitting efficiency to fall and thus saturating the radiant flux. In this circumstance, a relatively large I_F can be used with no risk of heating through the pulse drive of the LED. Consequently, a large radiant flux can be obtained.

2. When an LED is used in the outdoors where disturbing light is intense, the DC driving system or AC driving system which superimposes an AC signal on a fixed bias current provides low radiant flux, making it difficult to distinguish the signal (irradiation of LED) from disturbing light. In other words, the S/N ratio is small enough to reliably detect the signal. The pulse driving system provides high radiant flux and allows the detection of signal variations at the rising and falling edges of pulses, thereby enabling the use of LED-light detector where disturbing light is intense.

3. Transmission of information is possible by variations in pulse width or co unting of the number of pulse used to encode the LED emission.

Figures 11 through 14 show typical pulse driving circuits. Figure 15 shows the pulse driving circuit used in the optical remote control. The circuit shown in Figure 11 uses an N-gate thyristor with voltage between the anode and cathode oscillated at a certain interval determined by the time constant of C × R so that the LED emits light pulse. To turn off the N-gate thyristor, resistor R_3 must be used so that the anode current is smaller than the holding current (I_H), i.e., $I_H > V_{CC}/R_3$. Therefore, R_3 has a large value, resulting in a large time constant ($\tau \pm C \times R_3$) and the circuit operates for a relatively long period to provide short pulse widths. The circuit shown in Figure 12 uses a type 555 timer IC to form an astable multivibrator to produce light pulses on the LED. The off-period (t_1) and the on-period (t_2) of the LED are calculated by the following equations.

$t_1 = 1n2 \times (R_1 + R_2) \times C_1$

$t_2 = 1n2 \times R_2 \times C_1$

The value of R_1 is determined so that the rating of I_{IN} of a 555 timer IC is not exceeded, i.e. $S_1 > V_{CC}/I_{IN}$.

This pulse driving circuit uses a 555 timer IC to provide wide variable range in the oscillation period and light-on time. It is used extensively.

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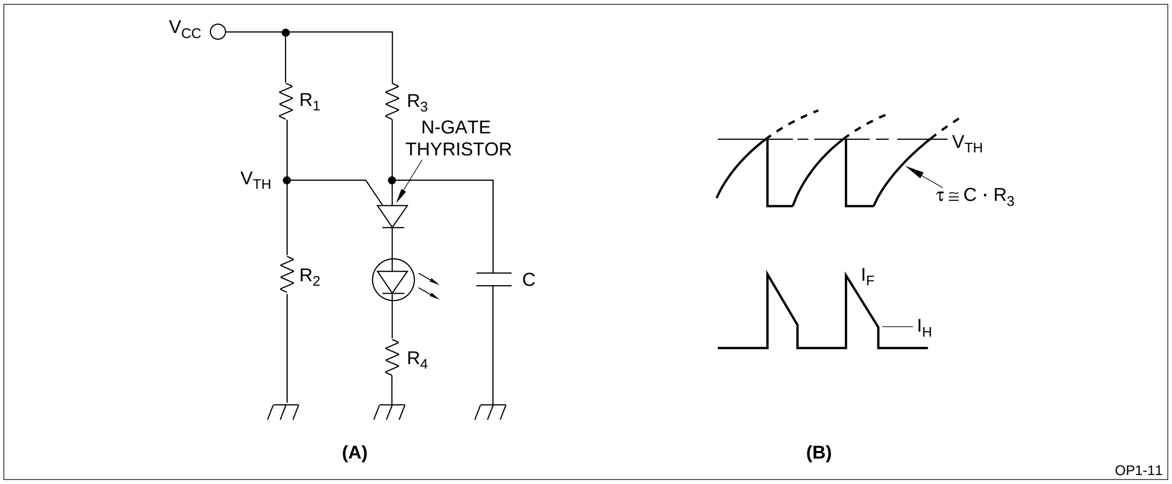

Figure 11. (A) Pulse Driving Circuit using N-Gate Thyristor (B) Operating Waveform

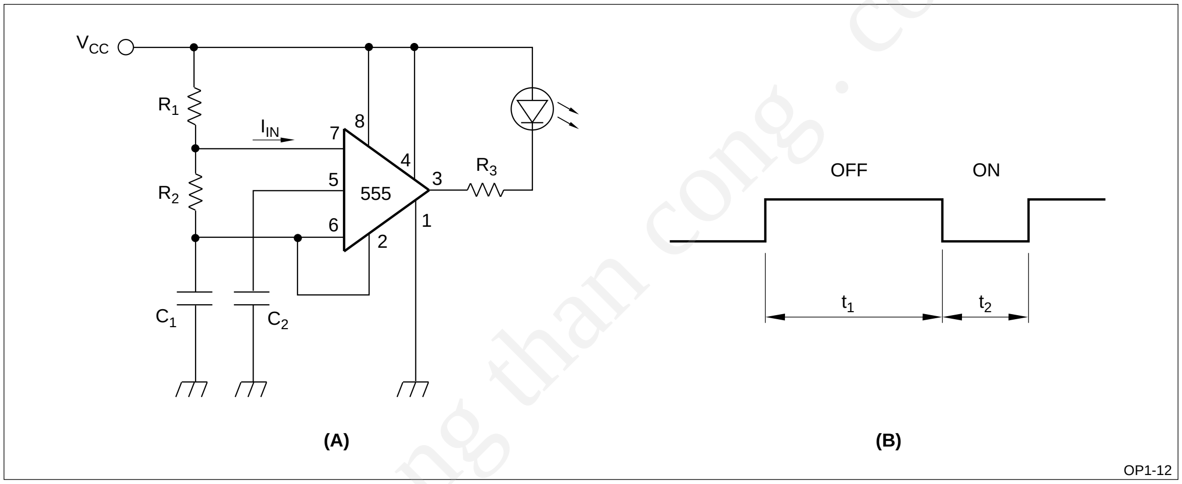

Figure 12. (A) Pulse Driving using a 555 Timer IC (B) Output Waveform

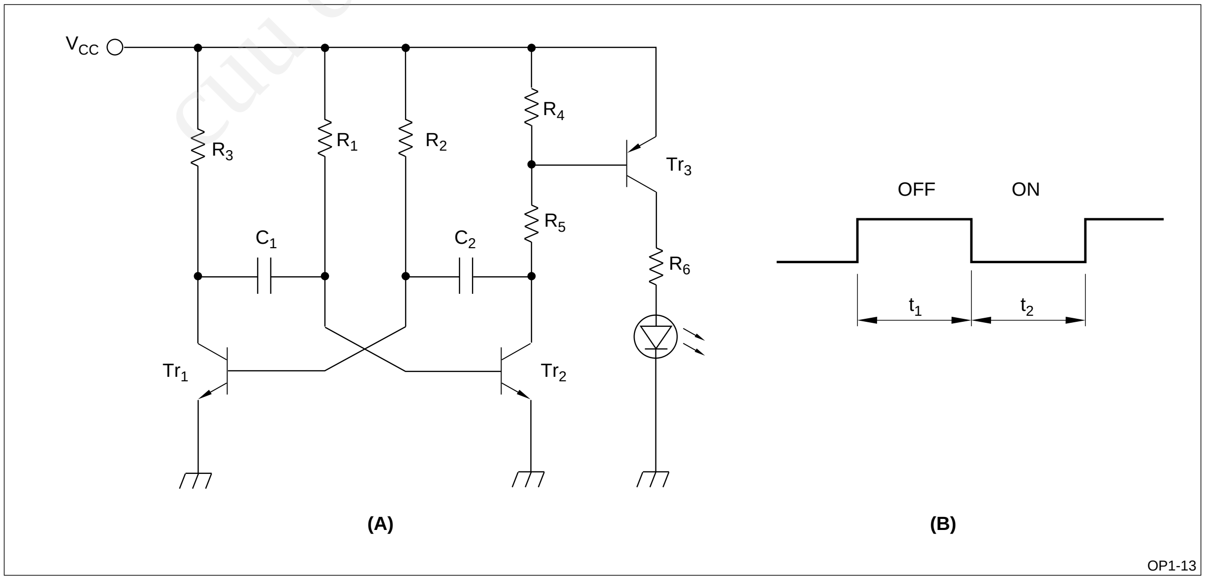

Figure 13. (A) Pulse Driving Circuit using Astable Multivibrator (B) Output Waveform

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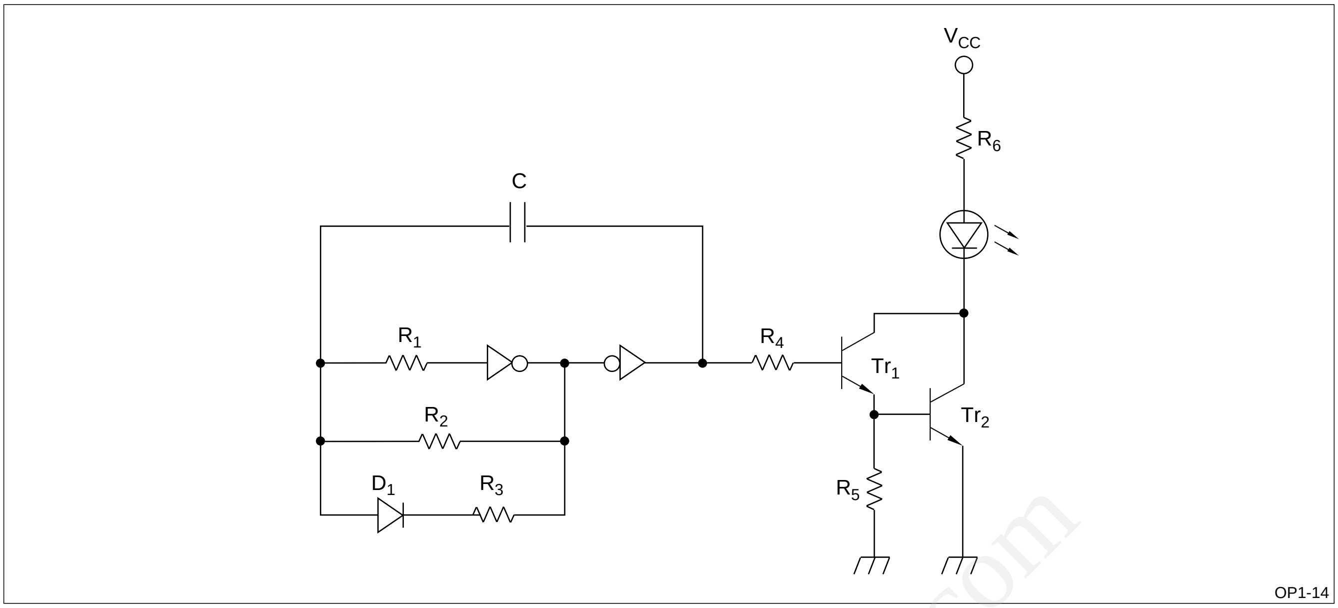

Figure 14. Pulse Driving Circuit using CMOS Logic IC

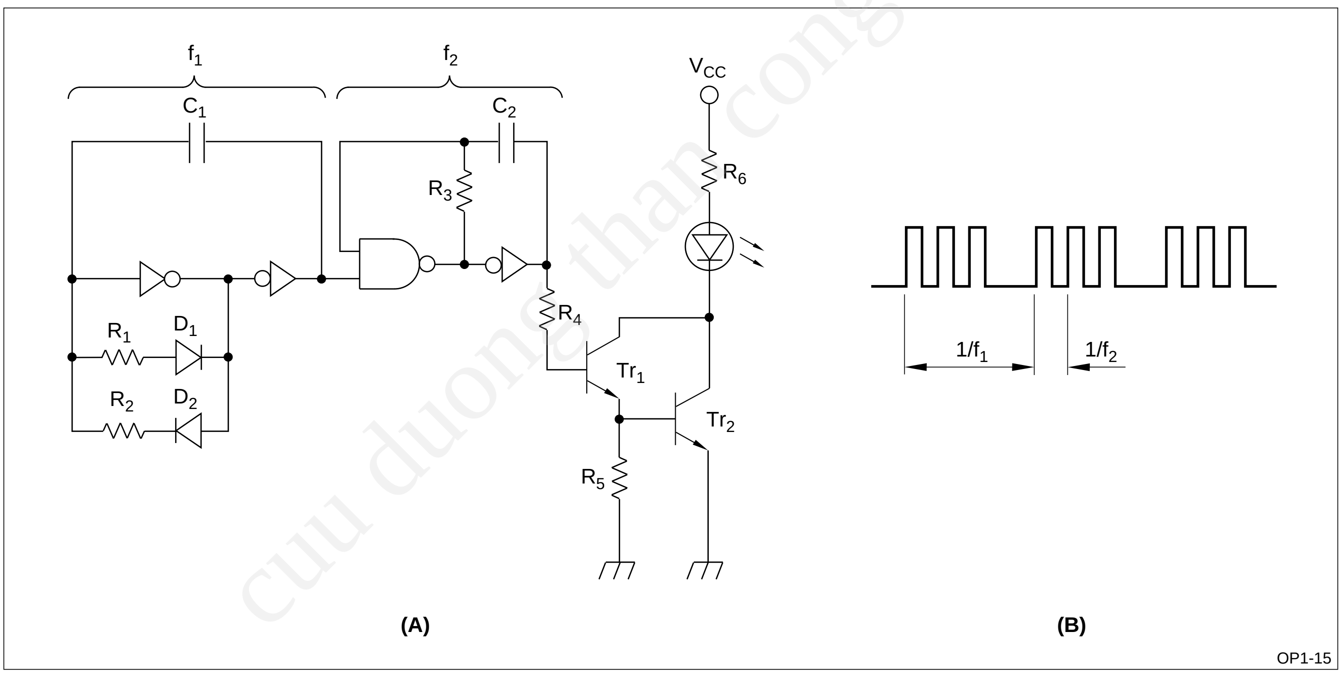

Figure 15. (A) Pulse Driving Circuit
(B) Output Waveform

The circuit shown in Figure 13 uses transistors to form an astable multivibrator for pulse driving an LED. The off-period (t_1) of the LED is given by $C_1 \times R_1$, while its on-period (t_2) is given by $C_2 \times R_2$. For oscillation of this circuit, resistors must be chosen so that the R_1/R_3 and R_2/R_5 ratios are large.

The circuit shown in Figure 14 uses a CMOS logic IC (inverter) to form an oscillation circuit for pulse driving an LED. The pulse driving circuit using a logic IC provides a relatively short oscillation period with a 50% duty cycle.

Figure 15 (A) shows an LED pulse driving circuit used for the light projector of the optical remote control and optoelectronic switch. The circuit is arranged by combining two different oscillation circuits i.e., a long period oscillation (f_1) superimposed with a short period oscillation (f_2) as shown in Figure 15 (B). Frequencies f_1 and f_2 can be set independently.

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PHOTODIODE/PHOTOTRANSISTOR APPLICATION CIRCUITS

Fundamental Photodiode Circuits

Figures 16 and 17 show the fundamental photodiode circuits.

The circuit show in Figure 16 transforms a photocurrent produced by a photodiode without bias into a voltage. The output voltage (V_{OUT}) is given as $V_{OUT} = 1_P \times R_L$. It is more or less proportional to the amount of incident light when $V_{OUT} < V_{OC}$. It can also be compressed logarithmically relative to the amount of incident light when V_{OUT} is near V_{OC}. (V_{OC} is the open-terminal voltage of a photodiode).

Figure 16 (B) shows the operating point for a load resistor (R_L) without application of bias to the photodiode.

Figure 17 shows a circuit in which the photodiode is reverse-biased by V_{CC} and a photocurrent (I_P) is transformed into an output voltage. Also in this arrangement, the V_{OUT} is given as $V_{OUT} = I_P \times R_L$. An output voltage proportional to the amount of incident light is obtained. The proportional region is expanded by the amount of V_{CC} {proportional region: $V_{OUT} < (V_{OC} + V_{CC})$} . On the other hand, application of reverse bias to the photodiode causes the dark current (I_d) to increase, leaving a voltage of $I_d \times R_L$ when the light is interrupted, and this point should be noted in designing the circuit.

Figure 17 (B) shows the operating point for a load resistor R_L with reverse bias applied to the photodiode.

Features of a circuit used with a reverse-biased photodiode are:

1. High-speed response
2. Wide-proportional-range of output

Therefore, this circuit is generally used.

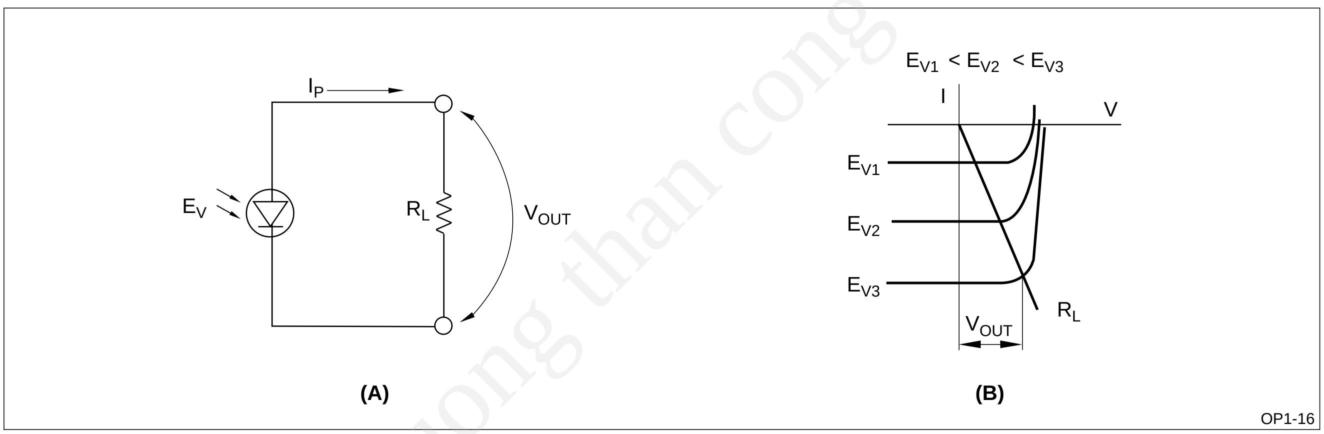

Figure 16. (A) Fundamental Circuit of Photodiode (without bias)

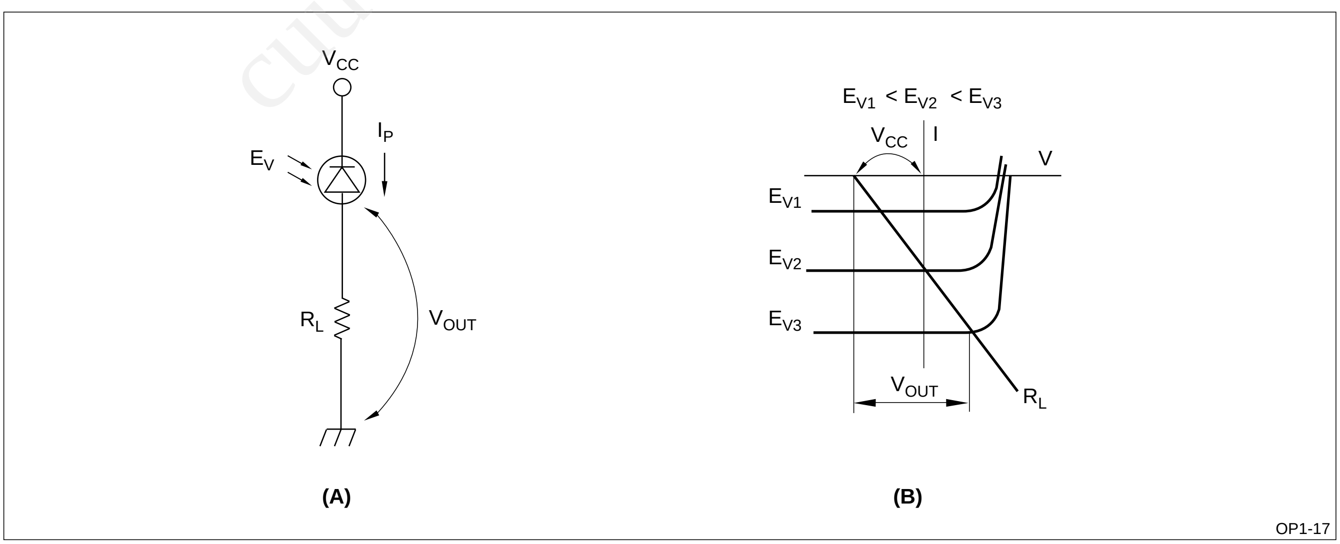

Figure 17. Fundamental Circuit of Photodiode (with bias)

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The response time is inversely proportional to the reverse bias voltage and is expressed as follows:

$r = C_j \times R_L$

$C_j = A(V_D - V_R) - \frac{1}{n}$

C_j: junction capacitance of the photodiode

R_L: load resistor

V_D: diffusion potential (0.5 V ~ 0.9 V)

V_R: Reverse bias voltage (negative value)

n: 2 ~ 3

Photocurrent Amplifier Circuit Using The Transistor Of Photodiode

Figures 18 and 19 show photocurrent amplifiers using transistors.

The circuit shown in Figure 18 are most basic combinations of a photodiode and an amplifying transistor. In the arrangement of Figure 18 (A), the photocurrent produced by the photodiode causes the transistor (Tr_1) to decrease its output (V_{OUT}) from high to low. In the arrangement of Figure 18 (B), the photocurrent causes the V_{OUT} to increase from low to high. Resistor R_{BE} in the circuit is effective for suppressing the influence of dard current (I_d) and is chosen to meet the following conditions:

$R_{BE} < V_{BD}/I_d$

$R_{BE} > V_{BE} / \{I_P - V_{CC}/(R_L \times h_{FE})\}$

Figure 19 shows simple amplifiers utilizing negative feedback.

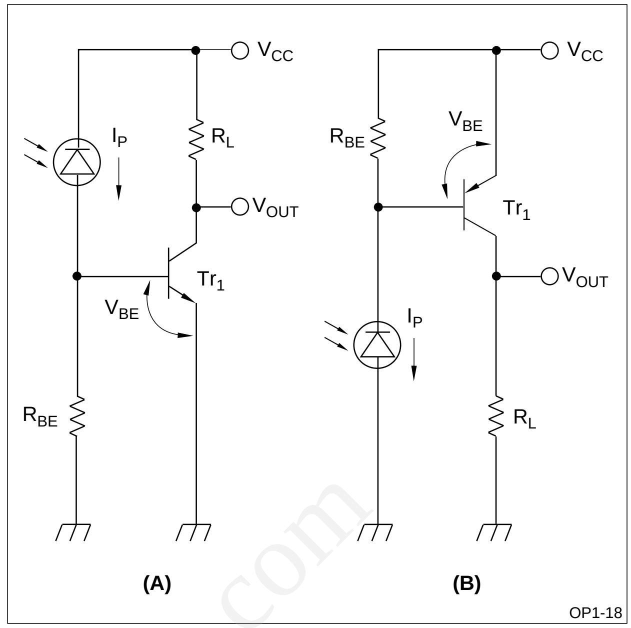

Figure 18. Photocurrent Amplifier Circuit using Transistor

In the circuit of Figure 19 (A), the output (V_{OUT}) is given as:

$V_{OUT} = I_P \times R_1 + I_B \times R_1 + V_{BE}$

This arrangement provides a large output and relatively fast response.

The circuit of Figure 19 (B) has an additional transistor (Tr_2) to provide a larger output current.

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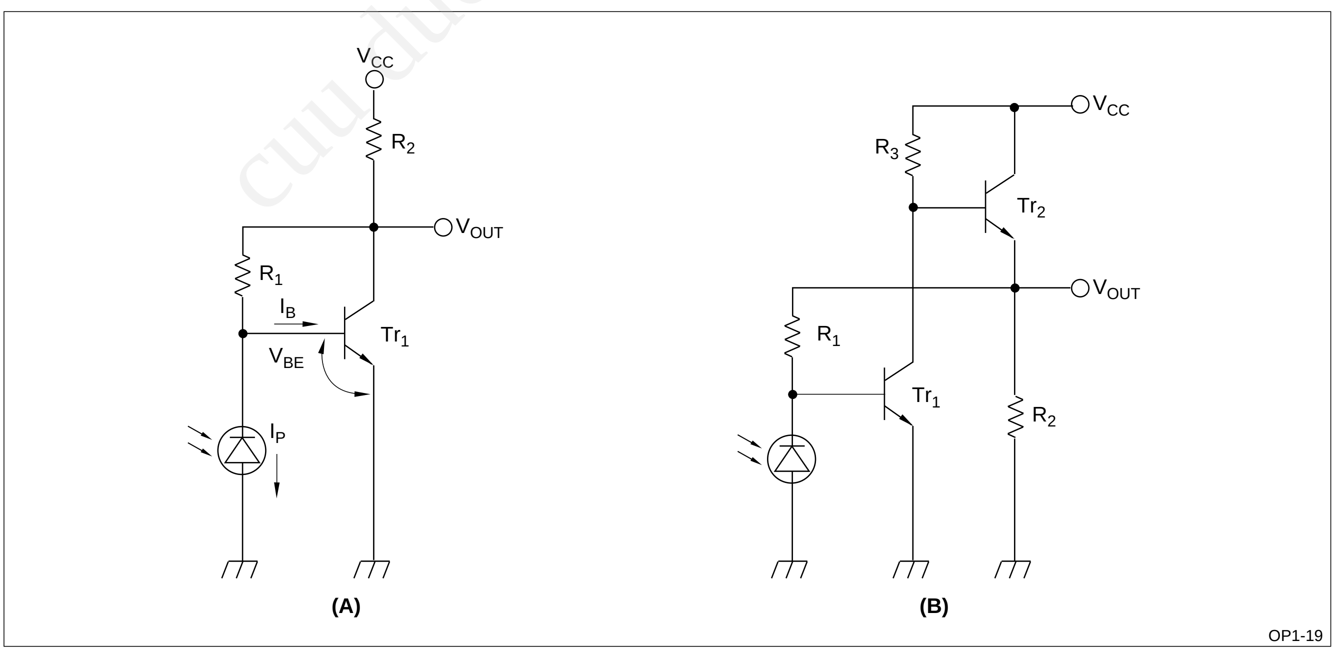

Figure 19. Photocurrent Amplifier Circuit with Negative Feedback

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Amplifier Circuit Using Operational Amplifier

Figure 20 shows a photocurrent-voltage conversion circuit using an operational amplifier. The output voltage (V_{OUT}) is given as $V_{OUT} = I_F \times R_1$ ($I_P \cong I_{SC}$). The arrangement utilizes the characteristics of an operational amplifier with two input terminals at about zero voltage to operate the photodiode without bias. The circuit provides an ideal short-circuit current (I_{SC}) in a wide operating range.

Figure 20 (B) shows the output voltage vs. radiant intensity characteristics. An arrangement with no bias and high impedance loading to the photodiode provides the following features:

1. Less influence by dark current

2. Wide linear range of the photocurrent relative to the radiant intensity.

Figure 21 shows a logarithmic photocurrent amplifier using an operating amplifier. The circuit uses a logarithmic diode for the logarithmic conversion of photocurrent into an output voltage. In dealing with a very wide irradiation intensity range, linear amplification results in a saturation of output because of the limited linear region of the operational amplifier, whereas logarithmic compression of the photocurrent prevents the saturation of output. With its wide measurement range, the logarithmic photocurrent amplifier is used for the exposure meter of cameras.

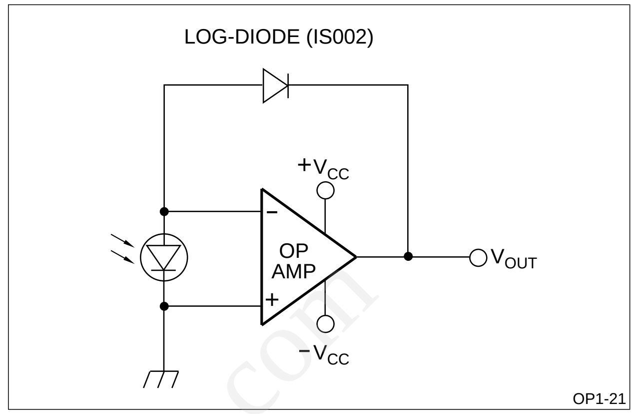

Figure 21. Logarithmic Photocurrent Amplifier using an Operational Amplifier

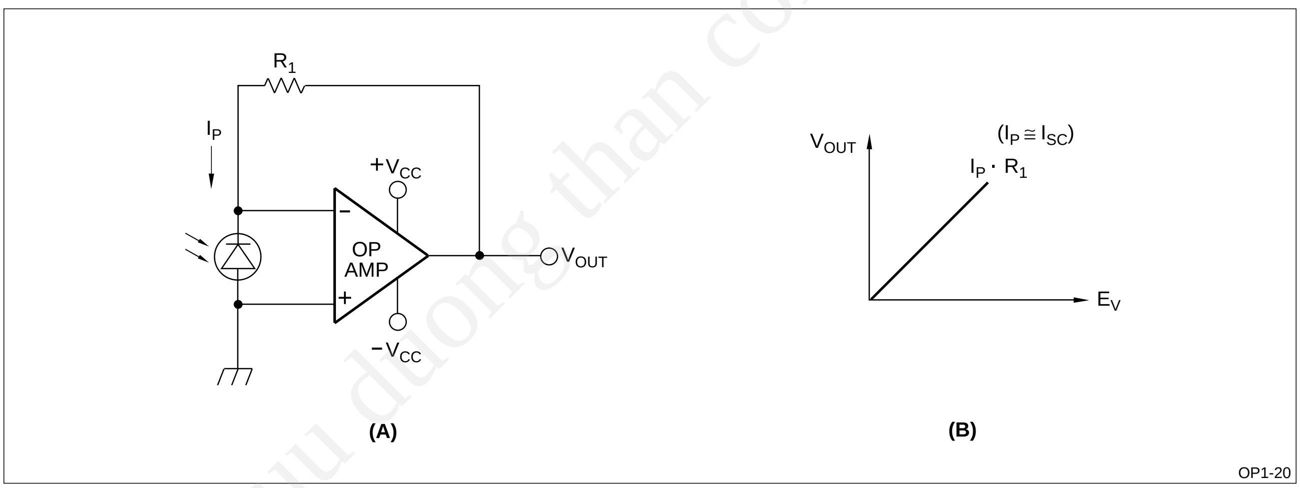

Figure 20. Photocurrent Amplifier using an Operational Amplifier (without bias)

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Light Detecting Circuit For Modulated Light Input

Figure 22 shows a light detecting circuit which uses an optical remote control to operate a television set, air conditioner, or other devices. Usually, the optical remote control is used in the sunlight or the illumination of a fluorescent lamp. To alleviate the influence of such a disturbing light, the circuit deals with pulse-modulation signals.

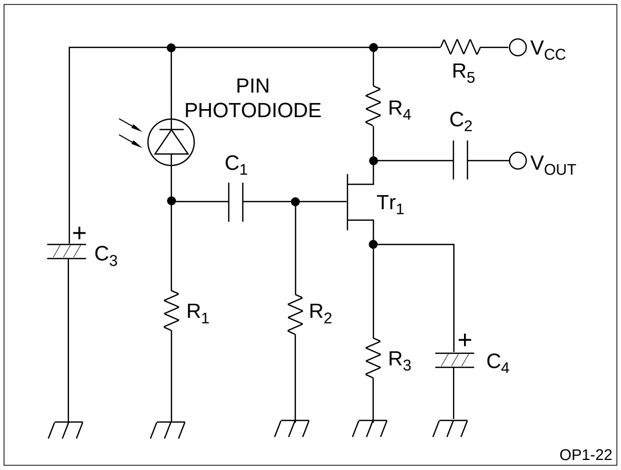

Figure 22. Light Detecting Circuit for Modulated Light Input PIN Photodiode

The circuit shown in Figure 22 detects the light input by differentiating the rising and falling edges of a pulse signal. To amplify a very small input signal, an FET proving a high input impedance is used.

Color Sensor Amplifier Circuit

Figure 23 shows a color sensor amplifier using a semiconductor color sensor. Two short circuit currents (I_{SC1}, I_{SC2}) conducted by two photodiodes having different spectral sensitivities are compressed logarithmically and applied to a subtraction circuit which produces a differential output (V_{OUT}). The output voltage (V_{OUT}) is formulated as follows:

$$V_{OUT} = \frac{kT}{q} \times \log\left(\frac{I_{SC2}}{I_{SC1}}\right) \times A$$

Where A is the gain of the differential amplifier. The gain becomes $A = R_2/R_1$ when $R_1 = R_3$ and $R_2 = R_4$, then:

$$V_{OUT} = \frac{kT}{q} \times \log\left(\frac{I_{SC2}}{I_{ISC1}}\right) \times \frac{R_2}{R_1}$$

The output signal of the semiconductor color sensor is extremely low level. Therefore, great care must be taken in dealing with the signal. For example, low-biased, low-drift operational amplifiers must be used, and possible current leaks of the surface of P.W.B. must be taken into account.

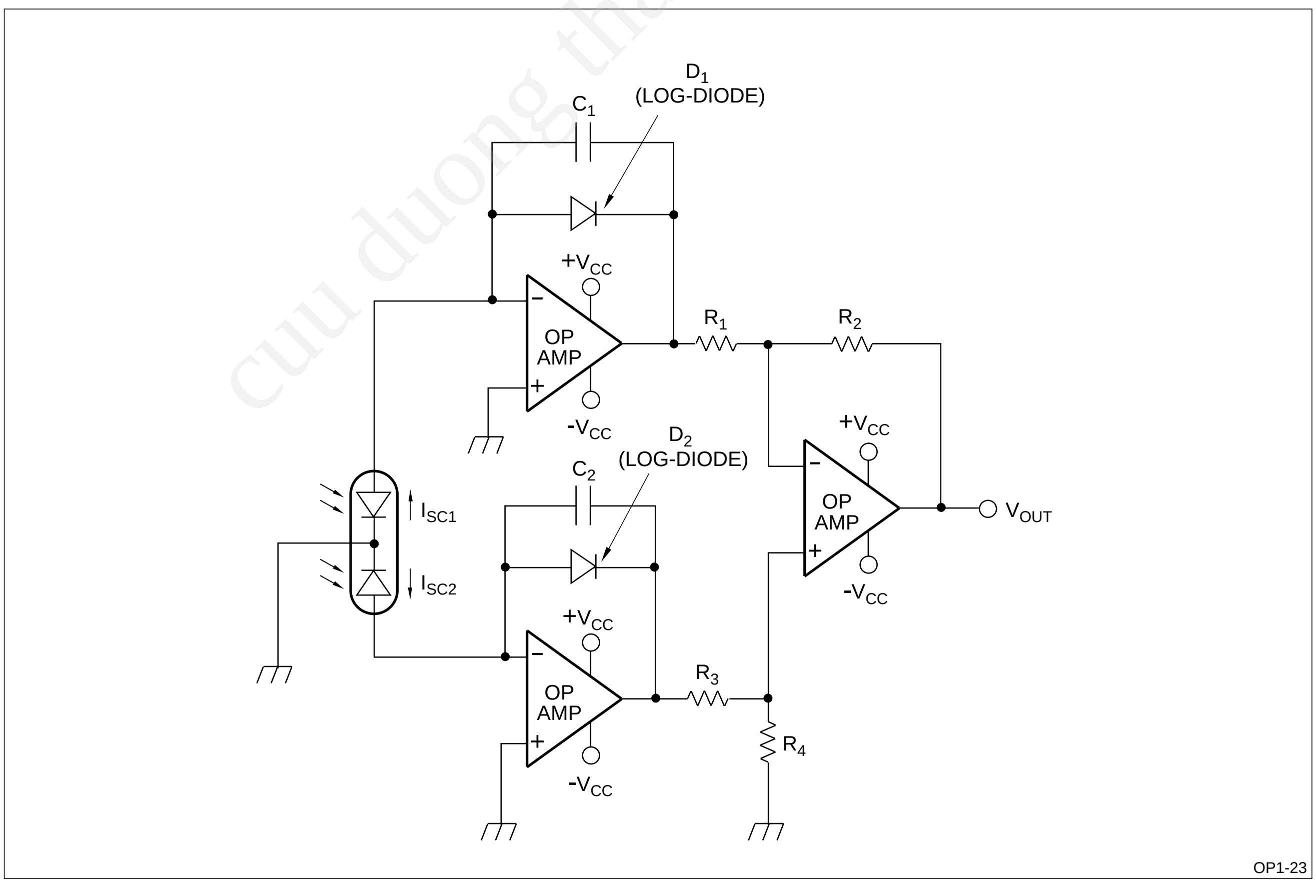

Figure 23. Color Sensor Amplifier Circuit

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Fundament Phototransistor Circuits

Figures 24 and 25 show the fundamental phototransistor circuits. The circuit shown in Figure 24 (A) is a common-emitter amplifier. Light input at the base causes the output (V_{OUT}) to decrease from high to low. The circuit shown in Figure 24 (B) is a common-collector amplifier with an output (V_{OUT}) increasing from low to high in response to light input. For the circuits in Figures 24 (A) and 24 (B) to operate in the switching mode, the load resistor (R_L) should be set in relation with the collector current (I_C) as $V_{CC} < R_L \times I_C$.

The circuit shown Figure 25 (A) uses a phototransistor with a base terminal. A R_{BE} resistor connected between the base and emitter alleviates the influence of a dark current when operating at a high temperature. The circuit shown in Figure 25 (B) features a cascade connection of the grounded-base transistor (Tr_1) so that the phototransistor is virtually less loaded, thereby improving the response.

Amplifier Circuit Using Transistor

Figures 26 (A) and 26 (B) show the transistor amplifiers used to amplify the collector current of the phototransistor using a transistor (Tr_1). The circuit in figure 26 (A) increases the output from high to low in response to a light input. The value of resistor R_1 depends on the input light intensity, ambient temperature, response speed, etc., to meet the following conditions:

$R_1 < V_{BE}/I_{CEO}, R_1 > V_{BE}/I_C$

Where I_{CBO} is the dark current of phototransistor and I_C is the collector current.

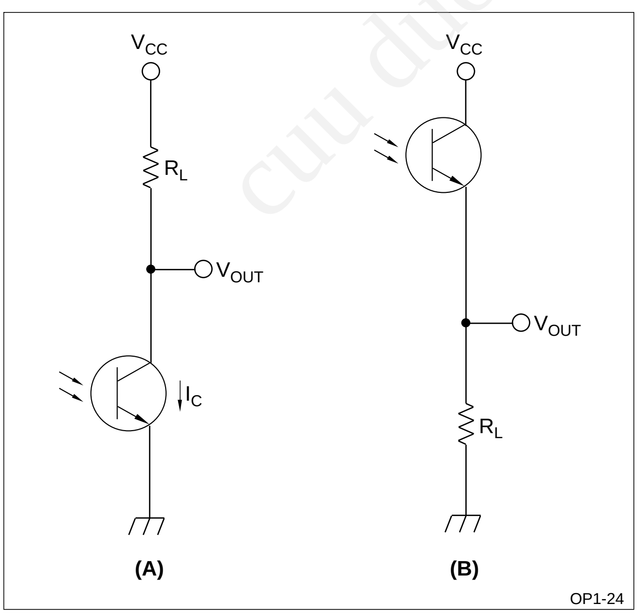

Figure 24. Fundamental Phototransistor Circuit (I)

Modulated Signal Detection Circuit

Figures 27 (A) and 27 (B) show the circuits used to detect a modulated signal such as an AC or pulse signal. The phototransistor has a base terminal with a fixed bias through resistors R_1 and R_2. An R_4 emitter resistor maintains the DC output voltage constant. A modulated signal provides a base current through bypass capacitor C causing current amplification so that the signal greatly amplified.

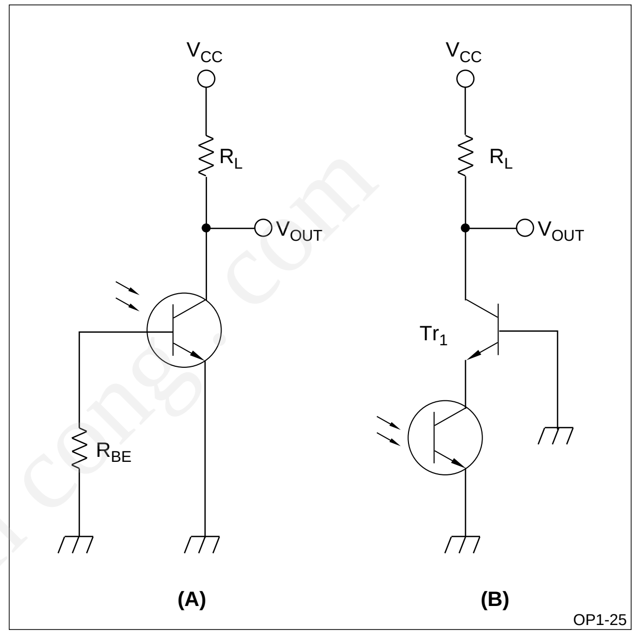

Figure 25. Fundamental Phototransistor Circuit (II)

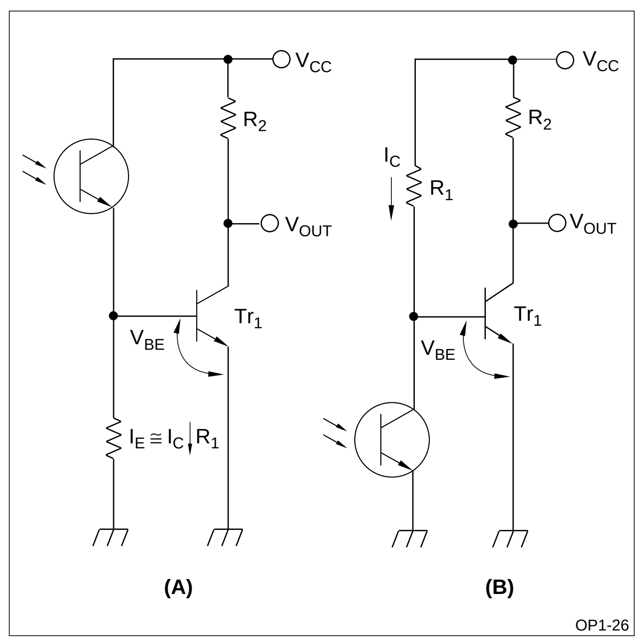

Figure 26. Amplifier Circuit Using Transistor

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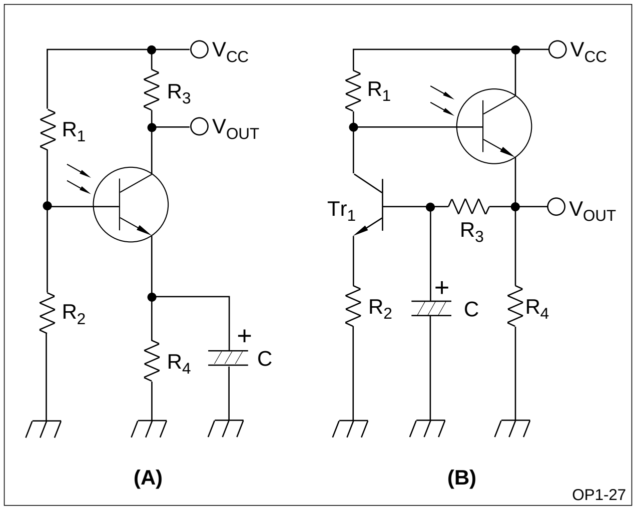

Figure 27. Modulated Signal Detection Circuit

Amplifier Circuit Using Operational Amplifier

Figure 28 shows a current-voltage conversion circuit using an operational amplifier. Its output voltage (V_{OUT}) is expressed as $V_{OUT} = I_C \times R_1$.

The current-voltage conversion circuit for the phototransistor is basically identical to that of the photodiode, except that the phototransistor requires a bias. The circuit shown if Figure 28 (A) has a negative bias (-V) for the emitter against the virtually grounded collector potential. Figure 28 (B) shows the output voltage vs. irradiation intensity characteristics.

Auto-stroboscope Circuit

Figure 29 shows the auto-stroboscope circuit of the current cut type. This circuit is most frequently used because of advantages such as continuous light emission and lower battery power consumption.

When the switch is in the ON-state, the SCR_2 and SCR_3 turn on to discharge capacitor C_4 so that the xenon lamp is energized to emit light. The anode of the SCR_2 is then reverse-biased, causing it to turn off and light emission of the xenon lamp ceases. The irradiation time is set automatically in response to variations in the collector current of the phototransistor. This follows the intensity of reflected light from the object and the value of C_1 in the circuit. In other words, the irradiation time is long for a distant object, and short for a near object.

PHOTOCOUPLER/PHOTOTHYRISTOR COUPLER/PHOTOTRIAC COUPLER APPLICATION CIRCUITS

For the effective use of photocouplers, the usage utilizing the features and fundamental circuits using photocouplers are described below.

Logic Gate Circuit Using Photocouplers

Figure 30 shows logic gates using photocouplers and their associated truth tables. The circuit of Figure 30 (A) forms an AND gate while the circuit of Figure 30 (B) forms an OR gate. These circuits are converted to a NAND gate and NOR gate, respectively, when the R_L load resistor is connected to the collector.

Level Conversion Circuit

Figure 31 shows simple level converters using a photocoupler. The circuit simple level converters using a photocoupler. The circuit shown in Figure 31 (A) converts the MOS level to the TTL level. Because of the small output current from the MOS IC, a photocoupler with a high current transfer ratio (CTR) at low input is required.

The circuit shown in Figure 31 (B) is a Schmitt trigger arranged using a photocoupler and transistor and a convert signal into an arbitrary level.

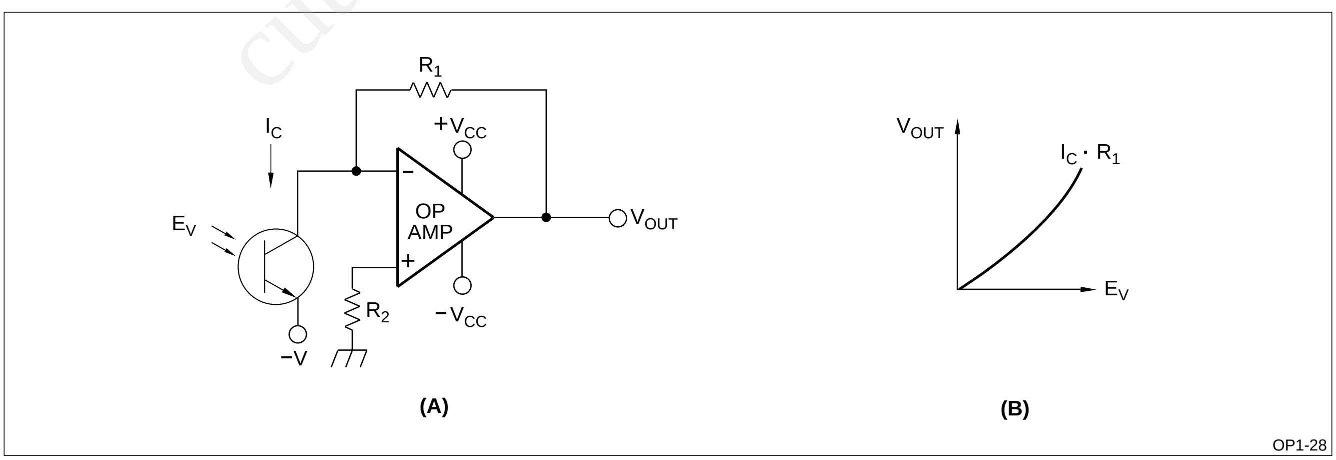

Figure 28. Amplifier Circuit using an Operational Amplifier

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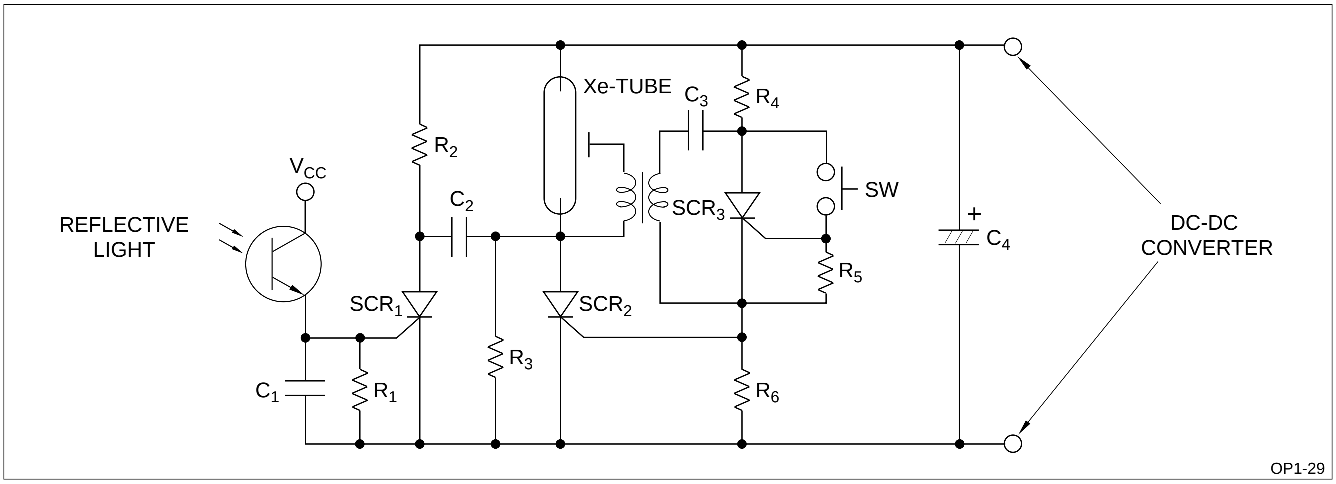
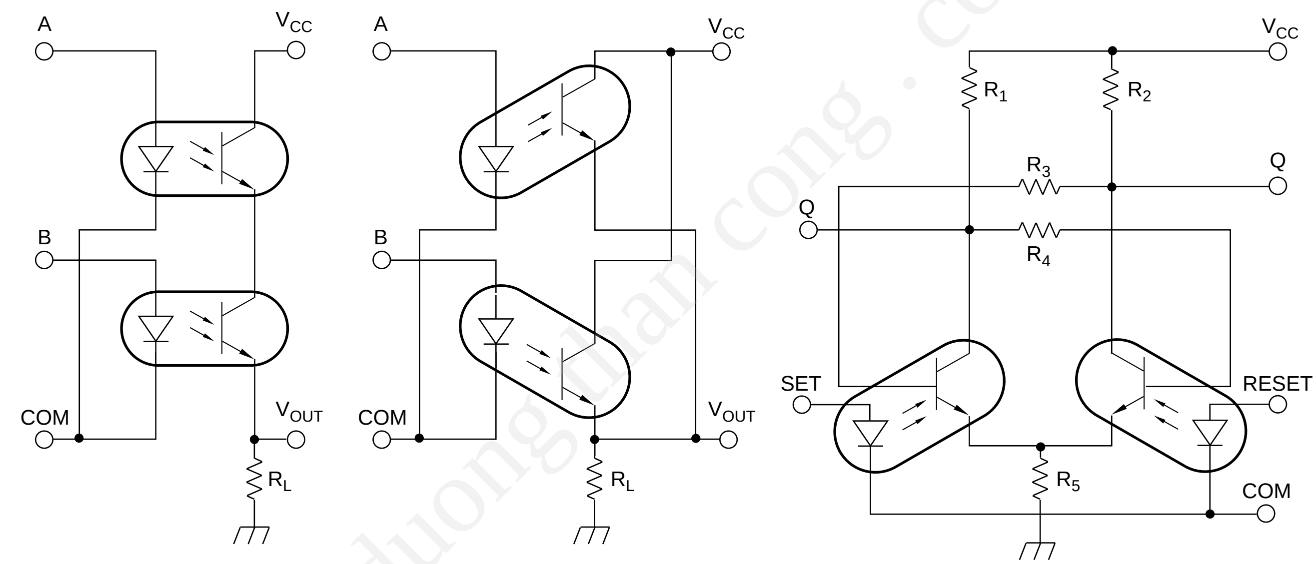


Figure 29. Auto-Stroboscope Circuit



A	B	V_{OUT}
H	H	H
H	L	L
L	H	L
L	L	L

(A) AND GATE AND ITS TRUTH TABLE

A	B	V_{OUT}
H	H	H
H	L	H
L	H	H
L	L	L

(B) OR GATE AND ITS TRUTH TABLE

t_n		t_{n+1}	
R	S	Q	$\overline{Q}$
H	H	X	X
H	L	L	H
L	H	H	L
L	L	X	X

Output marked by "X" are indeterminate

(C) R-S FLIP-FLOP AND ITS TRUTH TABLE

OP1-30

Figure 30. Logic Gate Circuits using Photocouplers

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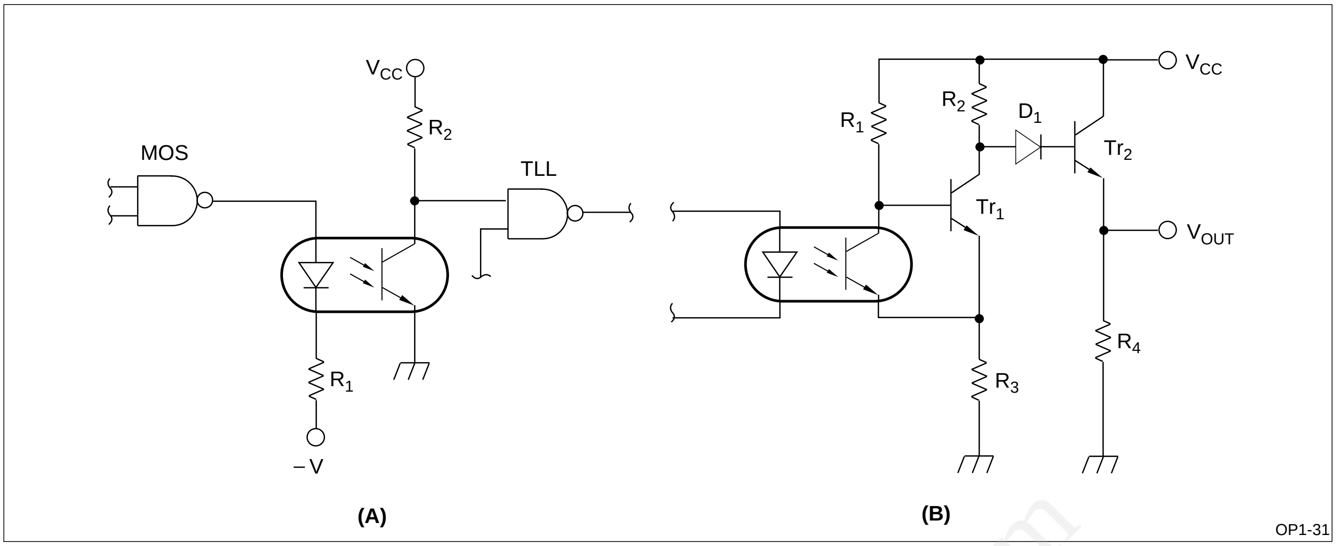

Figure 31. Level Conversion Circuit

Isolation Amplifier

Figure 32 shows a non-modulated isolation amplifier operable with low-frequency signals. In the arrangement, the photocoupler input is biased by DC forward current which is superimposed by a low-frequency signal. This gives the operating region of the good linearity of photocoupler. The DC bias current is adjusted by VR_1.

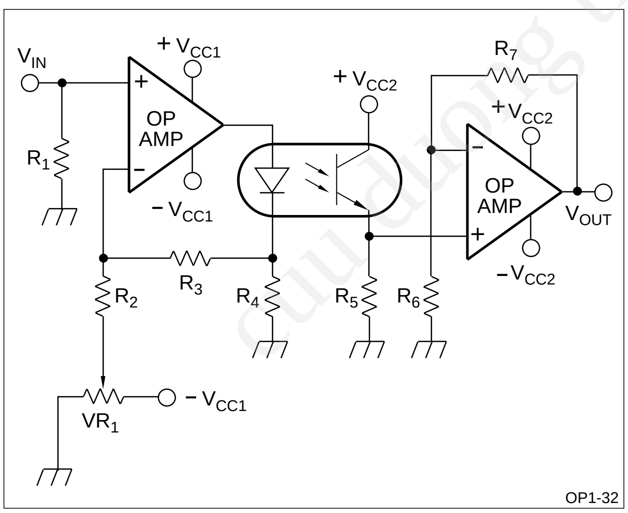

Figure 32. Isolation Amplifier

Noise Protection

Figure 33 shows some noise protection examples. The example shown in Figure 33 (A) includes the parallel connection of a capacitor (C_1) and resistor (R_1) across the input of the photocoupler where relatively long signal lines are connected for example where a computer and a terminal unit. The larger the capacitance of C_1, the greater the effect is expected, although signal propagation time is sacrificed.

The examples in Figure 33 (B) and 33 (C) use a photocoupler with a base terminal. Example (B) is effective against noise, but only in exchange for the response time, while example (C) tends to have low current transfer ratio (CTR).

However, when the photocoupler is operated in the switching mode, the base terminal tends to be affected by noise. Therefore, the use of photocouplers without a base terminal is recommended.

Lamp Driving Circuit and Relay Driving Circuit

Figures 34 and 35 show circuits for driving a lamp and relay, respectively, directly at the output of the photocoupler.

For this purpose, a suitable photocoupler includes a Darlington transistor providing a high CTR. The circuit shown in Figure 34 includes an R_2 resistor for supplying a preheating current to the lamp so as to prevent a rush current in lighting the lamp. The circuit in Figure 35 includes a diode D_1 for suppressing a counter-electromotive voltage produced when the relay is in the OFF-state.

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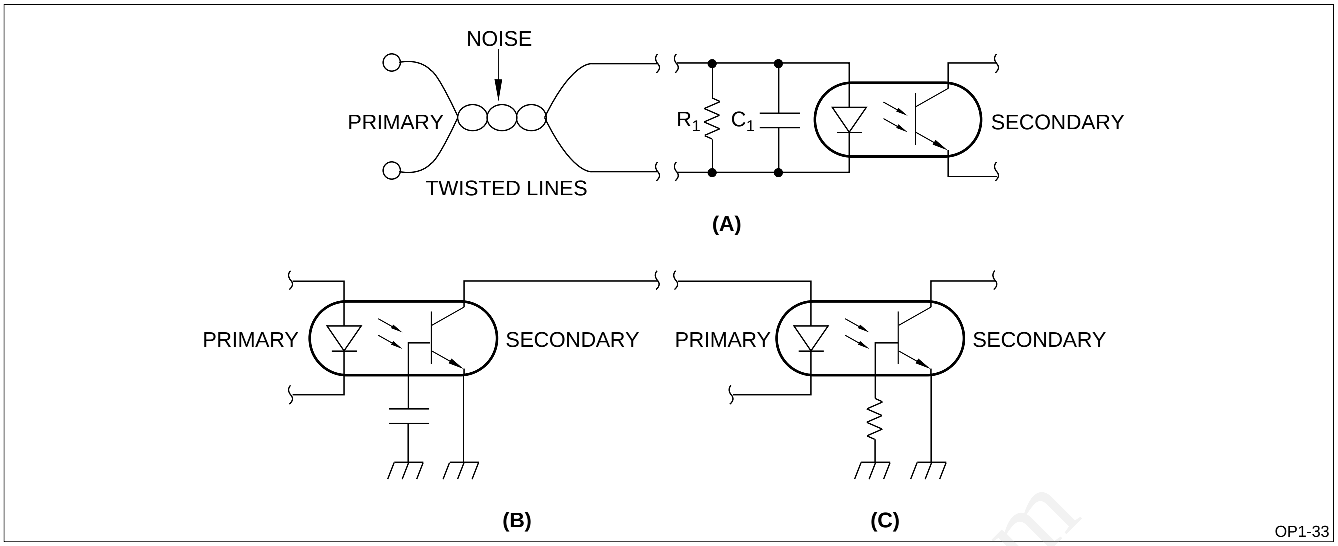

Figure 33. Noise Protection Example

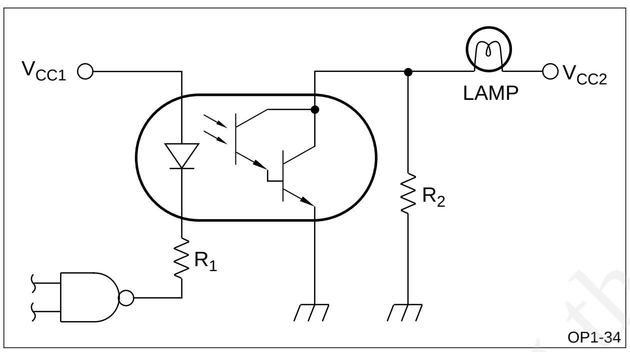

Figure 34. Lamp Driving Circuit

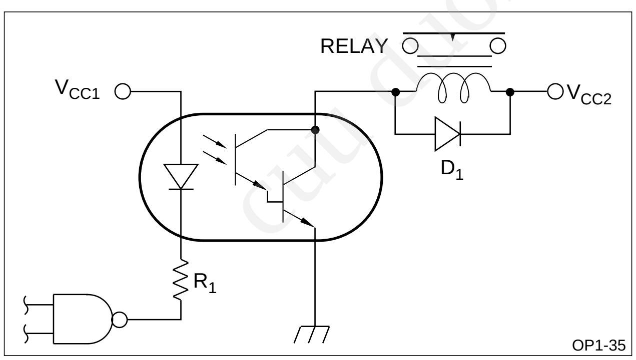

Figure 35. Relay Driving Circuit

Current Monitoring Circuit

The current monitoring circuit shown in Figure 36 is designed to detect and indicate leak current in a circuit using a photocoupler. The LED indicator lights off if the leak current exceeds the V_F/R_1 value.

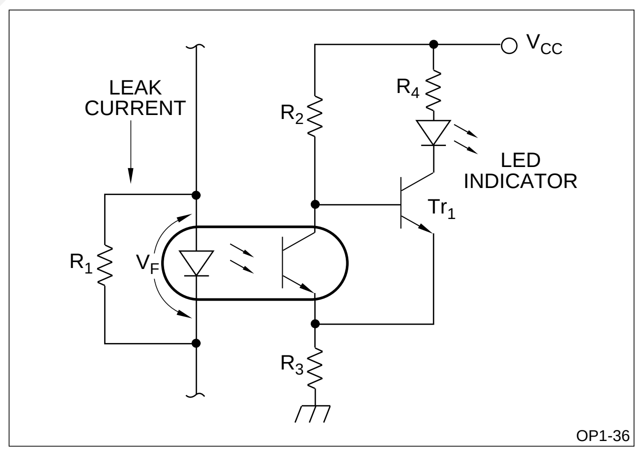

Figure 36. Current Monitoring Circuit

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Solid State Relay

Solid State Relay Using Photocoupler

Figure 37 shows a solid state relay circuit using a photocoupler. Figure 37 includes an input circuit, photocoupler, thyristor for triggering, rectifying diode bridge, snubber circuit, and high power triac. In operation, the photocoupler turns on the thyristor for triggering and its ON-current activates the high power triac to drive the load. Because of a low collector withstand voltage and the low output current of the photocoupler, a thyristor for triggering is needed to interface it with power control devices such as a power triac or power thyristor.

By appropriately choosing the R_1 and R_2 values, a high sensitive solid state relay having a wide range of input signal of the photocoupler type is realized. The zero-cross voltage is determined from the voltage division ratio by R_4 and R_5.

Solid State Relay Using Photothyristor Coupler

Figure 38 shows the drive circuit of thyristor using a half-wave control type photothyristor coupler.

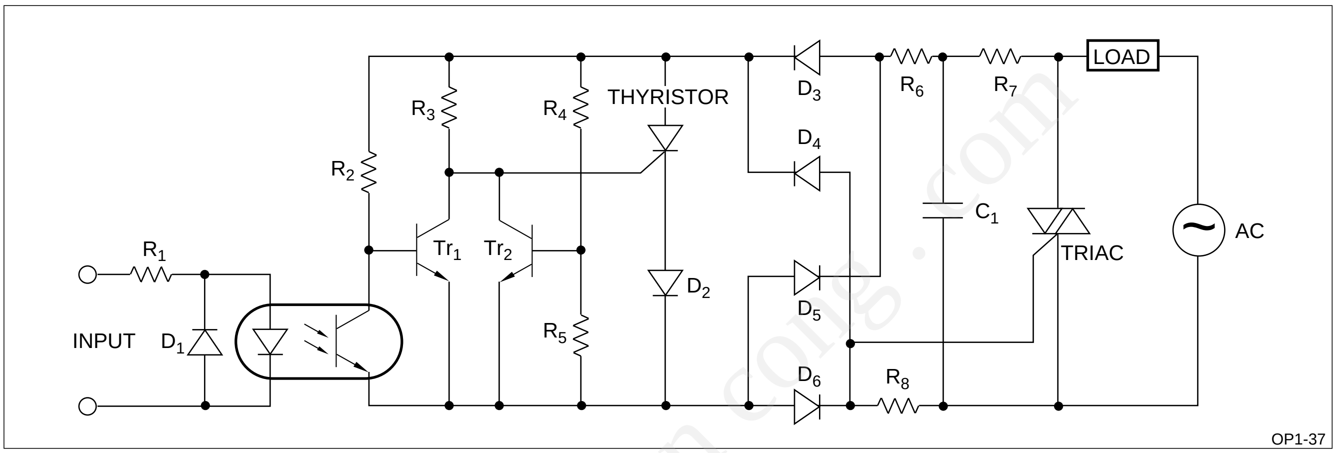

Figure 37. Solid State Relay with Built-in Zero-Cross Circuit

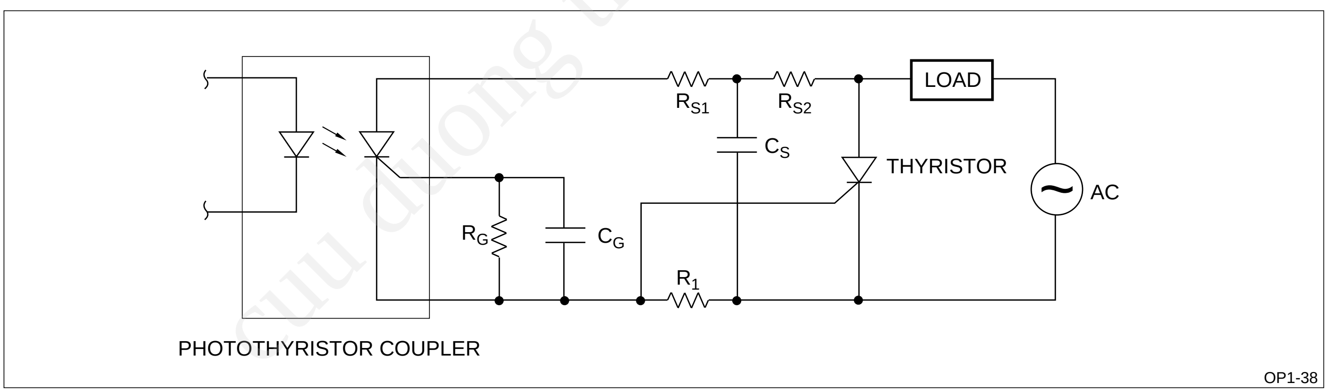

Figure 38. Large Power Thyristor Drive Circuit

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Figure 39 shows the drive circuit of triac using a half-wave control type photothyristor coupler. In this circuit, D_1 ~ D_4 rectifying bridges are required for AC control using a half-wave control type photothyristor coupler.

Figure 40 shows the drive circuit of triac using a full-wave control type photothyristor coupler.

In each figure, R_1 is a resistor used to prevent mistriggering of a large power thyristor and triac by leak current (I_{DRM}) when the photothyristor coupler is OFF. Therefore, the setting is required by checking the photothyristor coupler (I_{DRM}) and gate trigger current (I_{GT}) of a large power thyristor and triac. R_{S1}, R_{S2} and C_S form a snubber circuit.

Solid State Relay Using Phototriac Coupler

Figure 41 shows the basic operating circuit of a triac using a phototriac coupler.

Figure 42 shows a circuit example of controlling forward and reverse rotation of the motor, using a control signal as one example of phototriac coupler application circuit.

Input Drive Circuit

Figure 43 shows the input drive circuit of a solid state relay (SSR). (A) and (B) operate with a positive signal, and (C) and (D) operate with a negative signal. (B) and (C) are effective when the output current of control circuit is small.

(E) is a drive circuit using IC (TTL/DTL), which operates when IC is in the "L" state.

(F) and (G) are drive circuits using CMOS IC, each of which cannot drive the primary side of SSR with CMOS IC only; it therefore drives via a transistor.

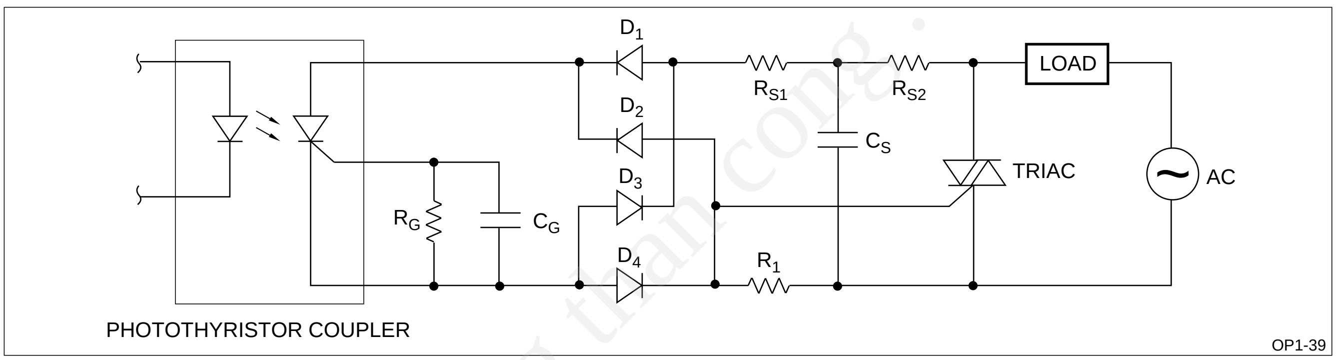

Figure 39. Triac Drive Circuit (I)

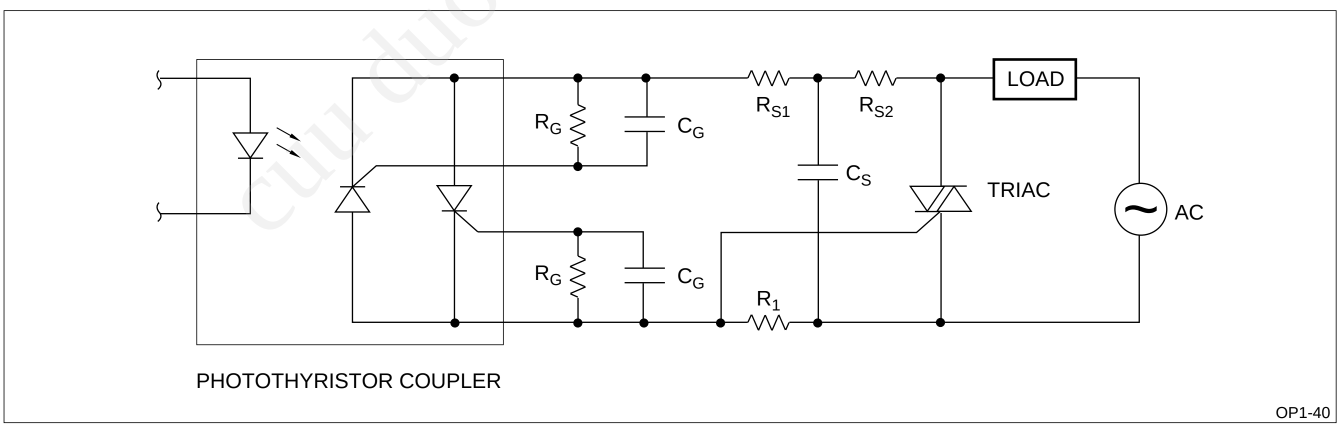

Figure 40. Triac Drive Circuit (II)

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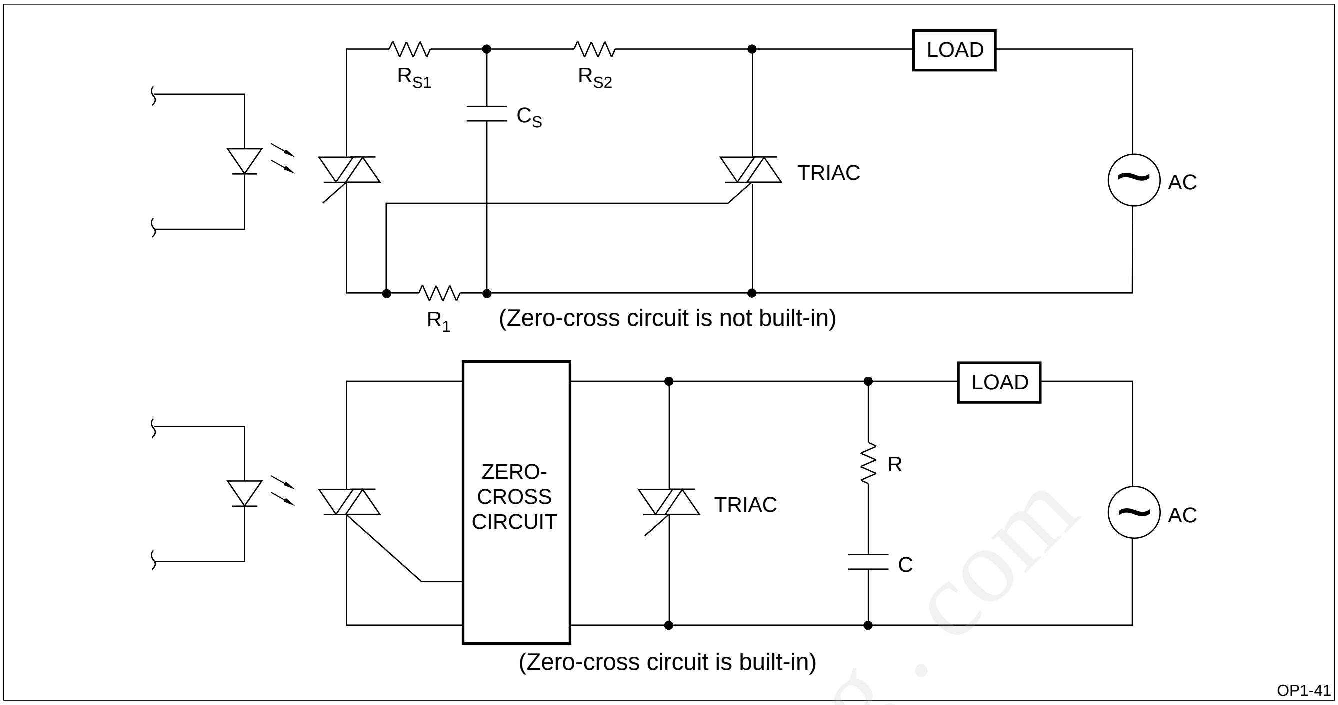

Figure 41. Triac Drive Circuit (III)

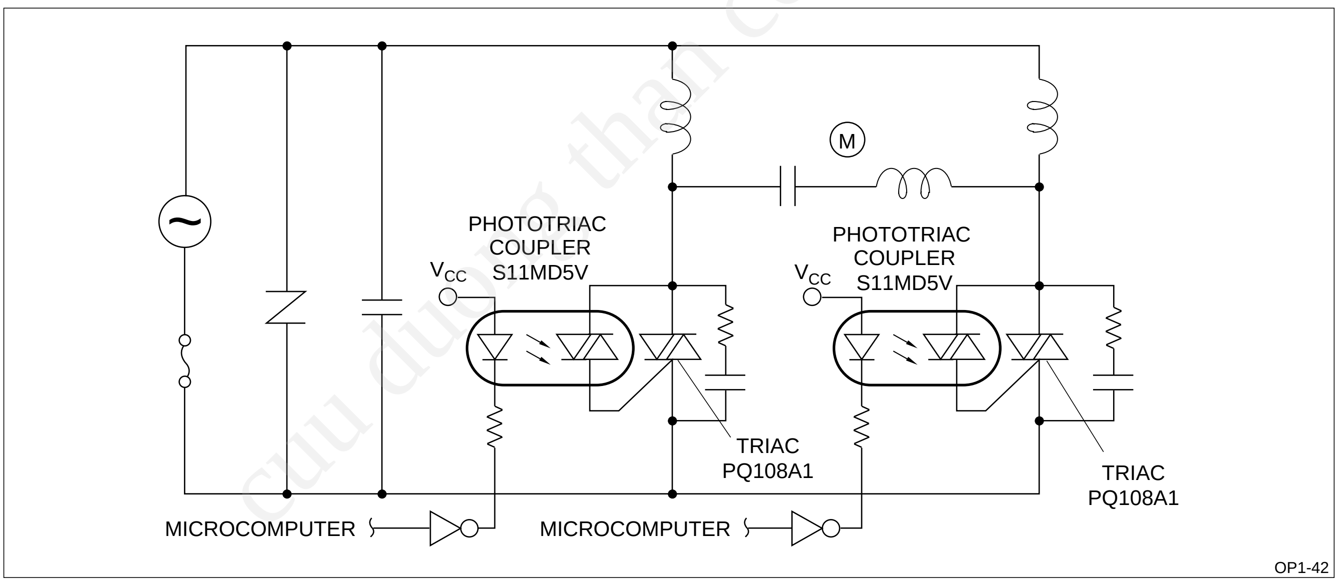

Figure 42. Motor Drive Circuit

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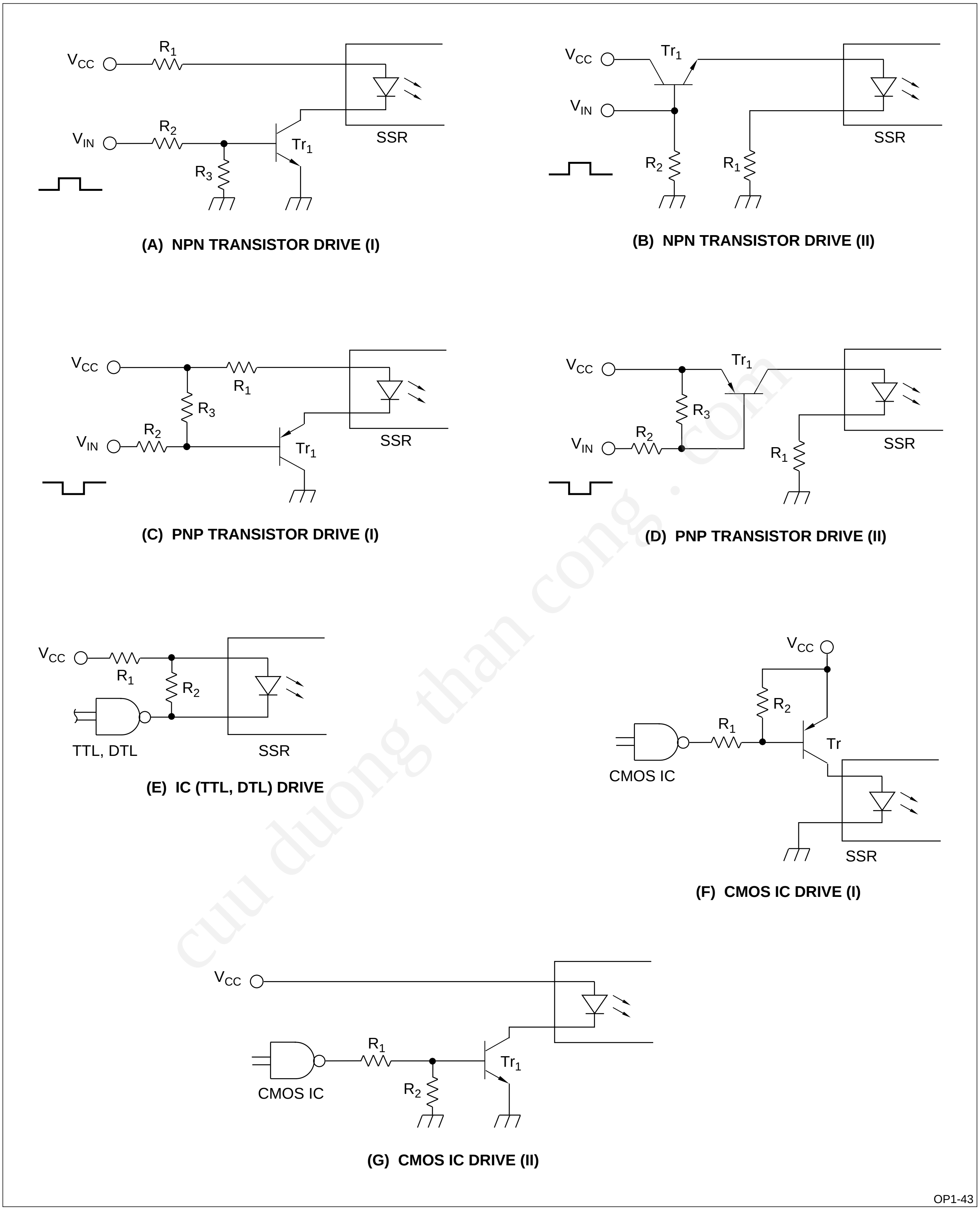

Figure 43. Input Drive Circuit

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Arrival Bell Signal Detection Of Telephone

Figure 44 shows a circuit for transmitting an arrival bell signal to a telephone related device while maintaining the electrical isolation between the device and the telephone subscriber line. The ring signal is an AC signal (75 Vrms, 16 Hz) superimposed on the 48 V line.

A non-polarized photocoupler (designed for AC input response) is suited for this purpose.

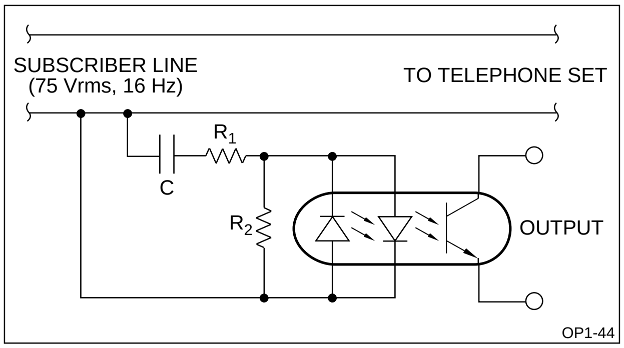

Figure 44. Telephone Arrival Bell Signal Detection

Telephone Line Interface

Figure 45 shows an interface circuit used to link a telephone related device to the telephone line. Through parallel connections of photocouplers, telephone related devices can be linked to the telephone line.

Telephone Line Polarity Detection (Ring Counter)

Figure 46 shows an example of a photocoupler used for the polarity detecting circuit in a telephone line.

Dial Pulse Monitor Circuit

Figure 47 shows an example in which a photocoupler is actuated due to dial pulse current if the circuit is connected to the telephone line, the light detector side of photocoupler operates as a dial pulse monitor circuit.

Power Control Circuit By Bell Signal

Figure 48 shows an application example for ON/OFF switching of the power supply of a particular equipment by a telephone bell signal.

Servo Motor Driving Circuit

Figure 49 shows an inverter-type AC servo motor speed control circuit. A transistorized inverter is featured to readily control an AC motor in a wide speed range. It is increasingly used in appliances such as air conditioners.

The photocoupler is used to drive the power transistor base amplifier so that it interfaces with a microcomputer. Because of the high surge voltage applied to the PWM base signal circuit (input) and driver circuit (output) at the switching of magnetic polarity, a high noise resistance (high dv/dt) photocoupler is used.

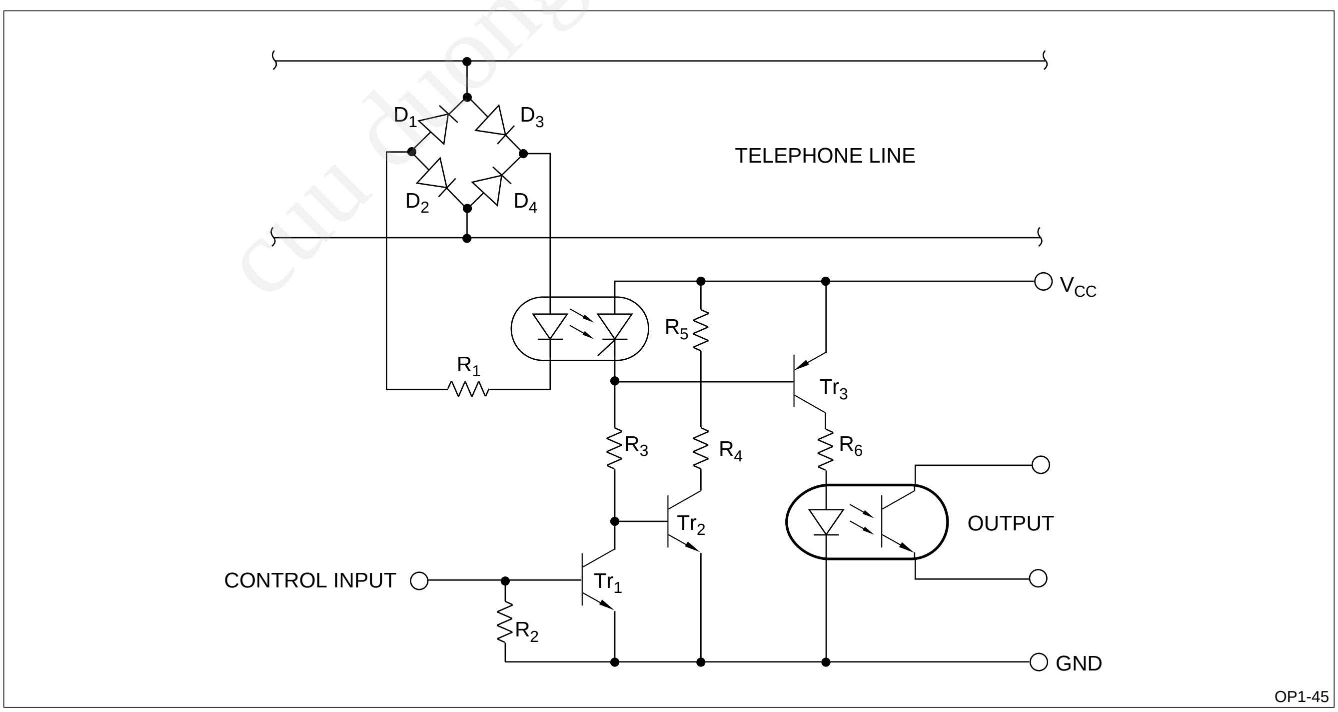

Figure 45. Telephone Line Interface

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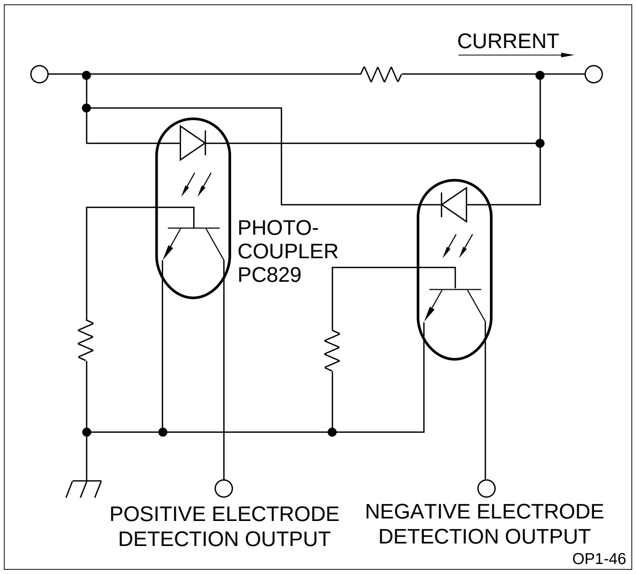

Figure 46. Telephone Line Polarity Detection Circuit

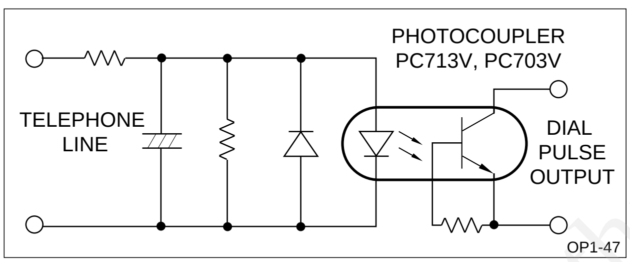

Figure 47. Dial Pulse Monitor Circuit

Servo Motor Braking Control Circuit

Figure 50 shows a servo motor braking control circuit in which a photocoupler is used to separate the control circuit from the brake driving circuit. A serial connection of C_2 and R_7 across the coil is designed to absorb the inductive current by the coil. C_1 is used to absorb high frequency noise on the DC power line.

Switching Regulator Circuit

Figure 51 shows a switching regulator circuit using a photocoupler.

In operation, the AC power line voltage is rectified into a DC voltage and is inverted into an AC voltage of around 50 kHz. It is then converted back to a DC voltage by a choke-input rectifying circuit. The output voltage is determined by the values of R_1, R_2, and ZD.

Chopper Circuit

Figure 52 shows a chopper circuit featuring high response and low signal amplification.

Conventional choppers are formed by FETs and transistors and create problems by switching spike noise which adversely affects the output signal.

Use of a photocoupler allows electrical isolation of the control and amplifying circuits. A small signal can then readily be amplified with no affect from spike noise.

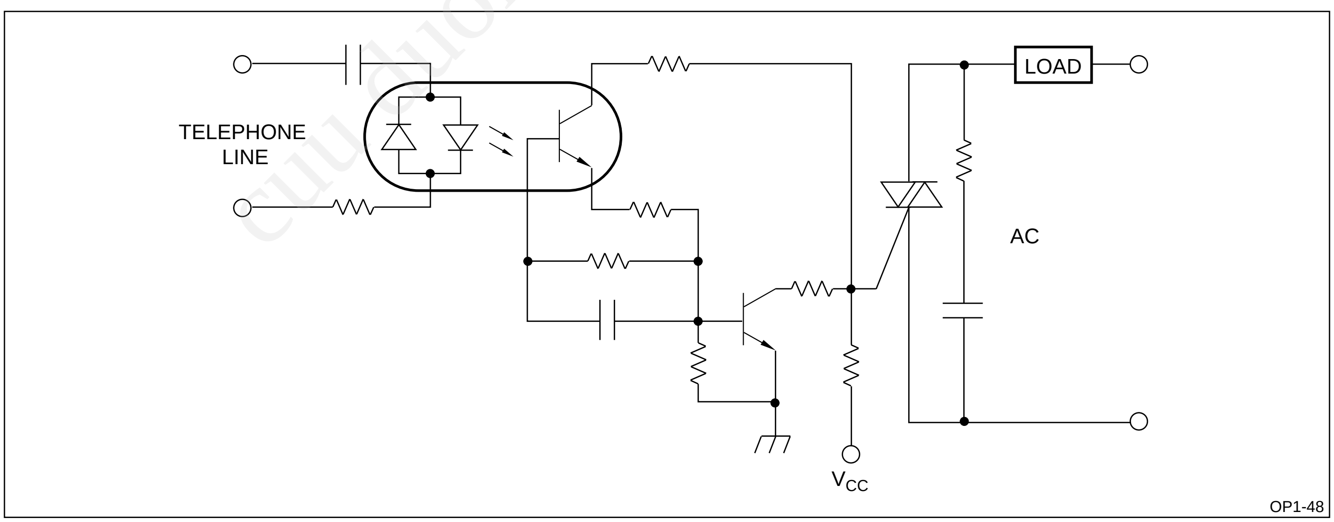

Figure 48. Power Control Circuit by Bell Signal

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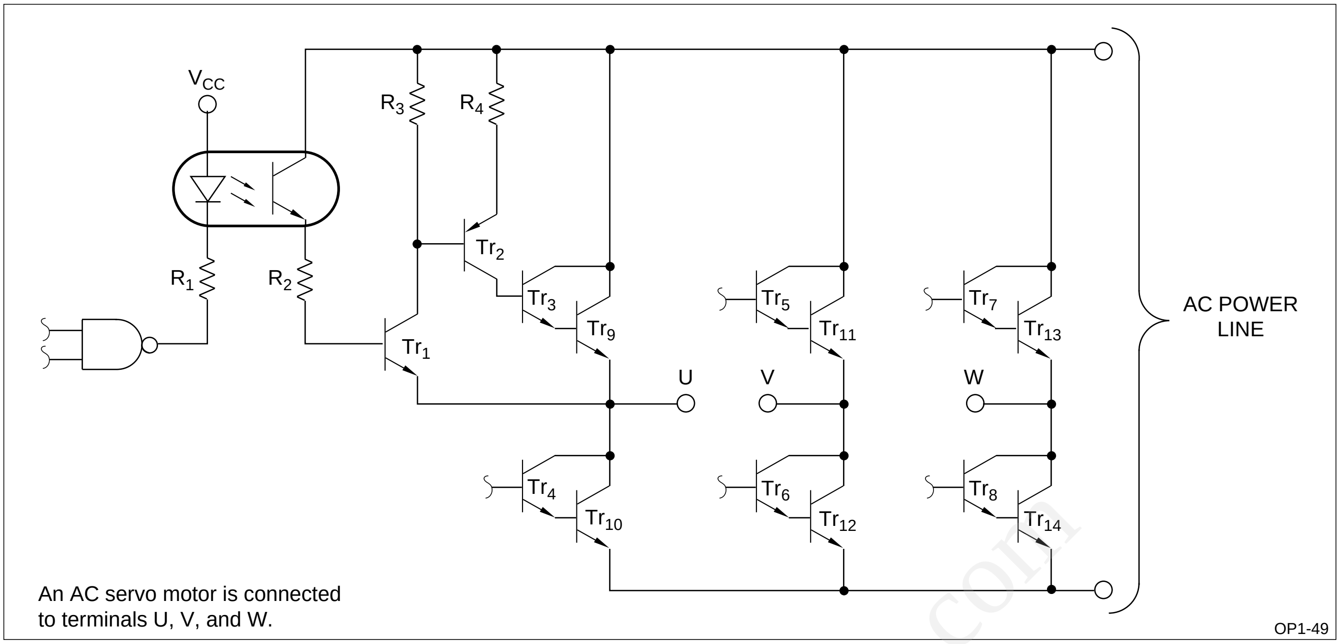

Figure 49. Servo Motor Driving Circuit

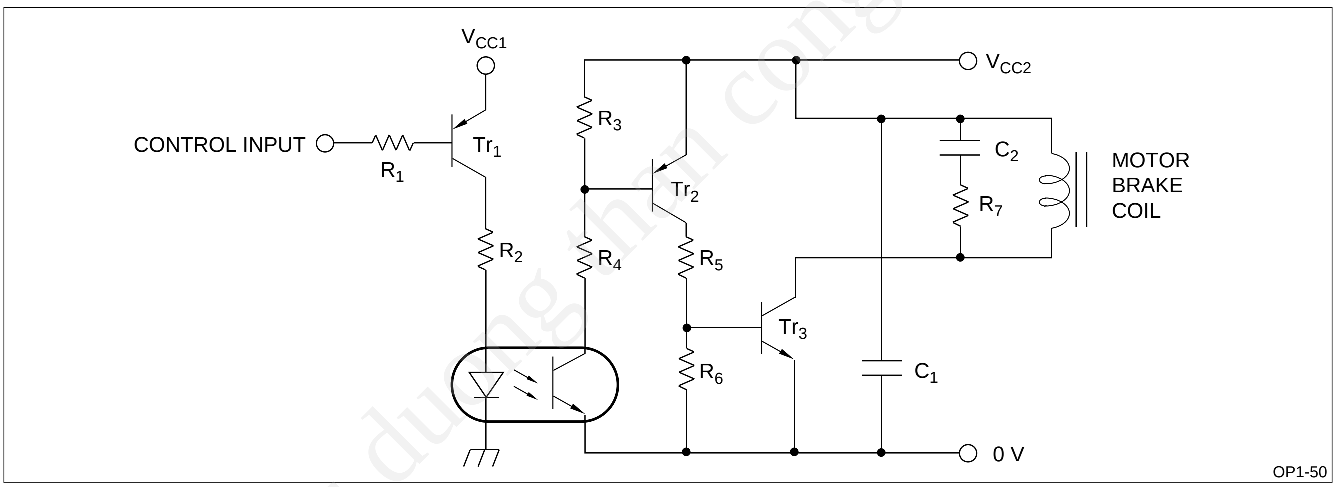

Figure 50. Servo Motor Brake Control Circuit

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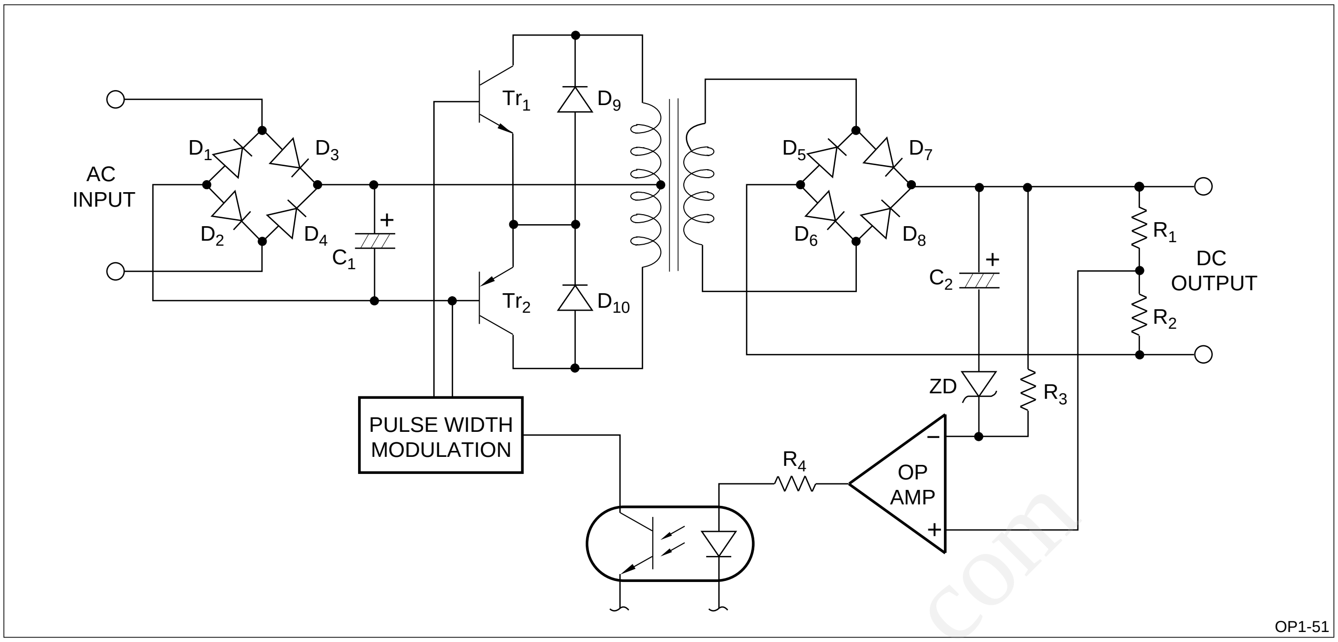

Figure 51. Switching Regulator Circuit

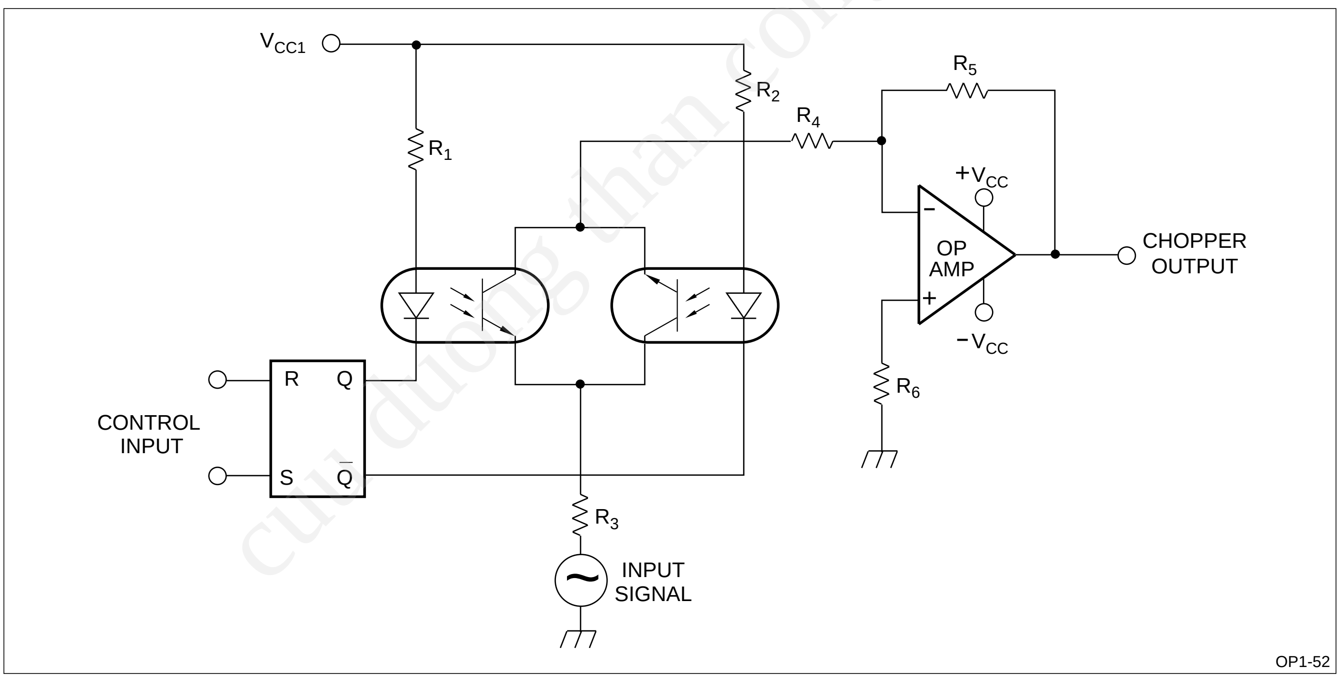

Figure 52. Chopper Circuit

Electrostatic Printer Control Circuit

In an electrostatic printer, the print head driving circuit, which operates at high voltage, is separated from the control circuit.

A photocoupler with a high isolation voltage between the input and output is useful in the electrostatic printer control circuit. Figure53 shows an electrostatic printer control circuit using a photocoupler.

Photocoupler Application Fields

Table 1 summarizes the industrial applications of the photocoupler.

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PHOTOINTERRUPTER APPLICATION CIRCUITS

Photointerrupters are used to detect the passage or existence of an object. Accordingly, an output digital signal, i.e., high or low, is required in most applications.

Photointerrupters fall into two categories: transmissive and reflective. Many variations in performance, such as detecting gap width, resolution and focal distance are provided to meet various application needs.

The fundamental circuits for operating a photointerrupter are described below.

DC Signal Processing Circuits

Figure 54 shows signal processing circuits for a transmissive type photointerrupter.

This type of photointerrupter provides an output signal with a relatively large S/N ratio, allowing detection of an object with a simple circuit as shown below, Circuits (A), (B) and (C) are used with a logic circuit, while (D) is used in the case of a large current leaks. The voltage division by resistors R_3 and R_4 determine the threshold level of detection.

AC Signal Processing Circuits

Figure 55 shows the signal processing circuits of a reflective type photointerrupter.

This type of photointerrupter provides a very small output signal with an inferior S/N ratio. Therefore, the AC signal processing circuit eliminates disturbing light and amplifies only a varying signal.

Circuit (A) is fixed level slicing, (B) is a floating level slicing, and (C) is light level compensating circuit.

Detection Of Moving Objects

Figure 56 shows a circuit example including a transmissive type photointerrupter for detecting a moving object, such as a coin. In operation, the output (V_{OUT}) is high when the object is absent and low for a certain period as the object passes through the gap of the photointerrupter. The duration of a "low" signal is determined from values C_2 and R_4.

Detection Of Paper Moving Direction And Speed

The circuit in Figure 57 includes two photointerrupters disposed at a certain interval so that the moving direction and speed of a sheet of paper are detected by the outputs of the circuit.

Detection Of A Tape Edge

The circuit in Figure 58 is designed to correct the edge position of tape when wound on a reel. Two photointerrupters are located at both edges of the tape. The circuit provides differential output V_{OUT1} and V_{OUT2}. The reel position is controlled in the traversing direction so that the difference between V_{OUT1} and V_{OUT2} is zero.

Detection Of Disk Rotation

Figure 59 shows a circuit designed to detect the number of rotations of a disk using a transmissive type photointerrupter. The slit signal is converted into digital signal as shown in Figure 60 and is used for motor speed control.

Detection Of Arm Angle In Record Player

Figure 61 shows a mechanism for correcting the angular deflection of the player tone arm using the differential outputs of two photointerrupters so that the tone arm is always parallel to the tangent of the grooves in the disk.

Detection Of Cassette Tape End

Figure 62 shows a circuit designed to detect the end of cassette tape using a reflective type photointerrupter so that the tape driving motor is deactivated at the end of the tape.

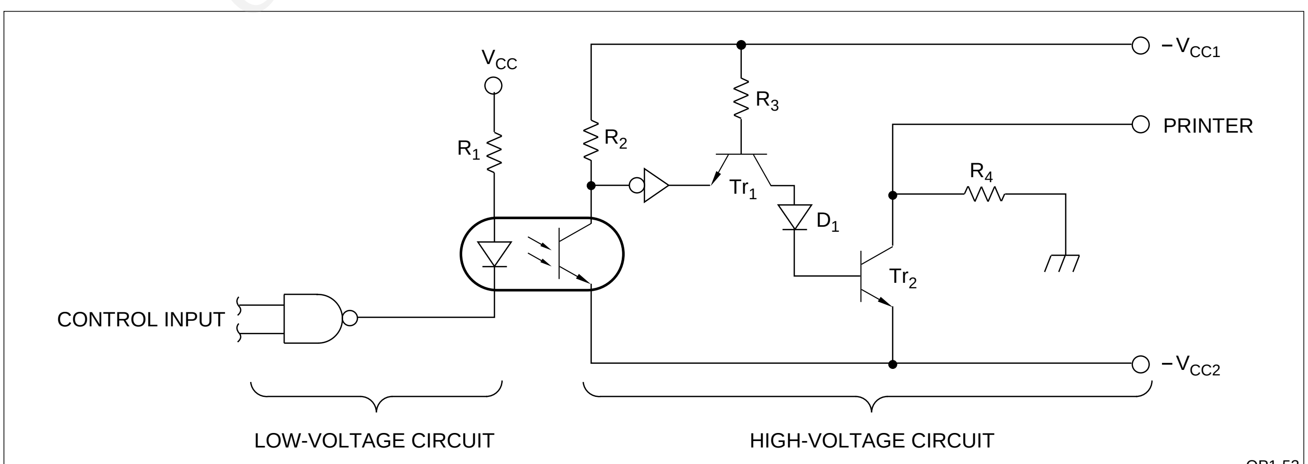

Figure 53. Electrostatic Printer Control Circuit

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Table 1.
Photocoupler Application Fields

FIELD		EQUIPMENT	APPLICATIONS
A	Computer peripheral	Computer peripherals and I/O units	Interface circuit between computer and peripheral
			Battery backup circuit
B	Control equipment	Programmable controllers, numerical control machines	Isolation circuit in input unit
			Contact input circuit for small signal
			Isolation of signal transmission system
			Servo motor control circuit
		Power control, distribution board	Current monitoring circuit
			Contact input circuit
			Noise protection circuit
			AC power line monitoring circuit
			Ground isolation
		Elevator, auto-door	Isolation of signal transmission system
			Auto-door control circuit
		Others	Self-hold switch circuit
			Lamp and relay driving system
C	Instrument	Measuring, testing instruments	Isolation of signal transmission system (line driver, line receiver)
			I/O isolation of isolation amplifier
			Inductive noise protection circuit
			Level conversion circuit
D	Office equipment	Copiers, facsimiles	Ground isolation
			Power circuit (primary-secondary isolation)
		Printers	High voltage control circuit of electrostatic printer
			Printer drive circuit
			I/O interface
E	Automatic vendors		I/O interface
			Commodity/ticket selection circuit
F	Home appliances	Television sets	Audio multiplexing circuit isolation
			R - G - B signal interface
			Power circuit
		Electronic sewing machines	Motor control circuit
		Microwave oven, room heaters	Ground isolation
			I/O interface
		Air-conditioners	Inverter control base amplifier circuit
			Over-current detection circuit
G	Audio equipment	Players, cassette tape recorders	Power circuit (primary-secondary isolation)
			Isolation of signal transmission system
H	Telephone system	Telephone sets	Dial pulse monitoring circuit
			Ring signal counter circuit
			Chiming circuit
			Modem switching circuit
		Exchangers	Subscriber line/control system separation
I	Power supply unit	Switching regulators	Pulse width modulation circuit
			Feedback circuit
			Isolation between primary and secondary

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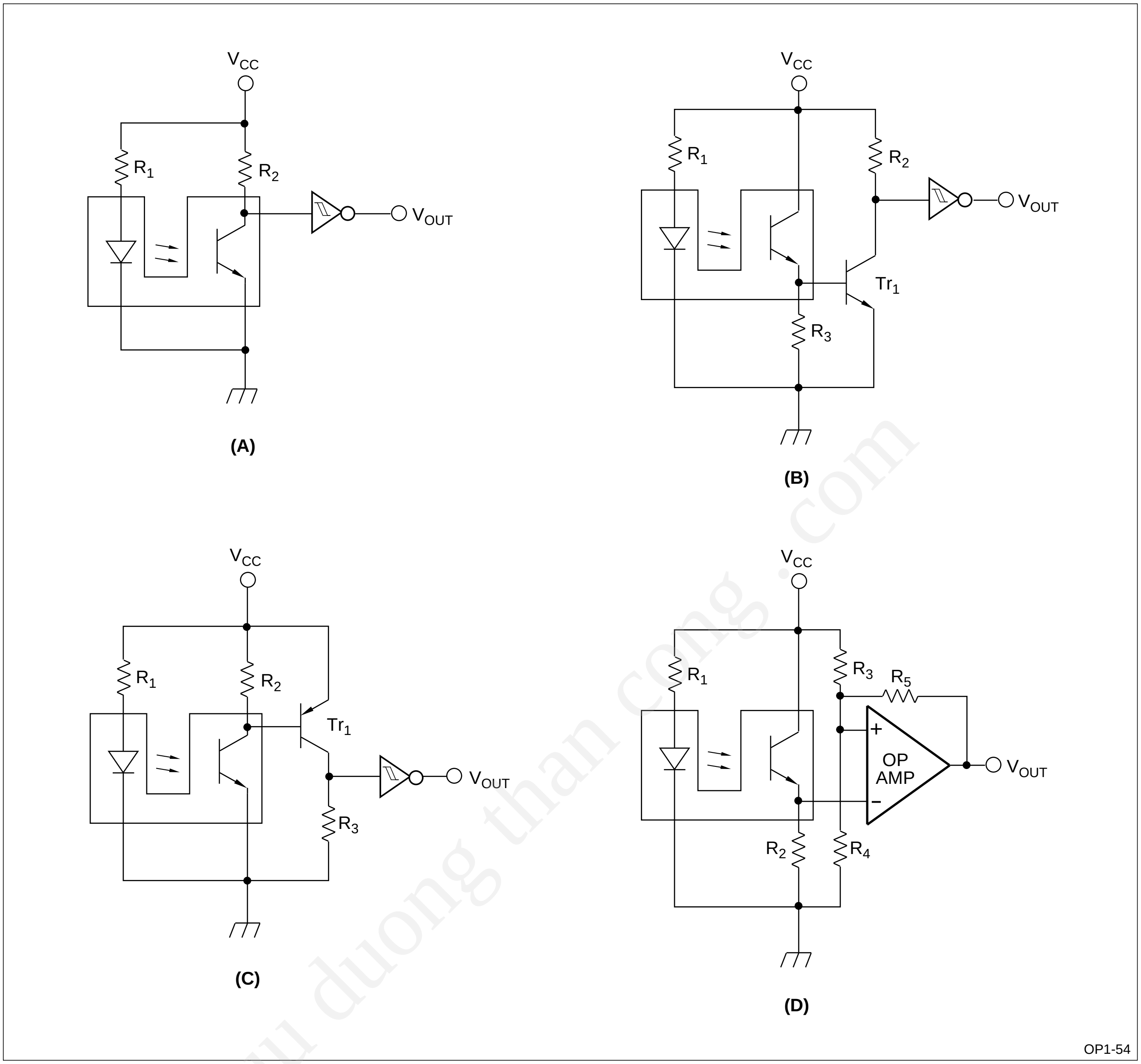

Figure 54. DC Signal Processing Circuit

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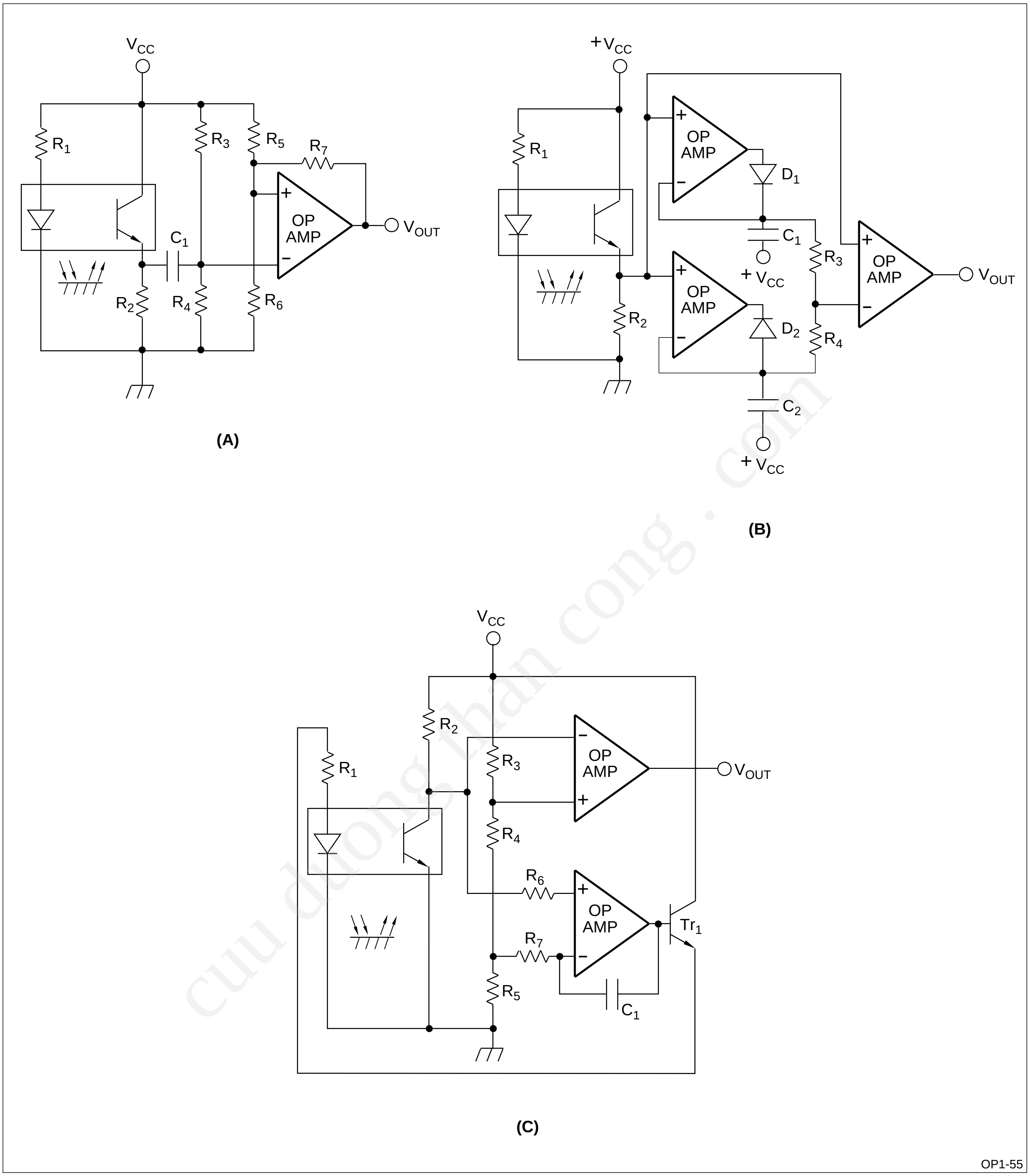

Figure 55. AC Signal Processing Circuits

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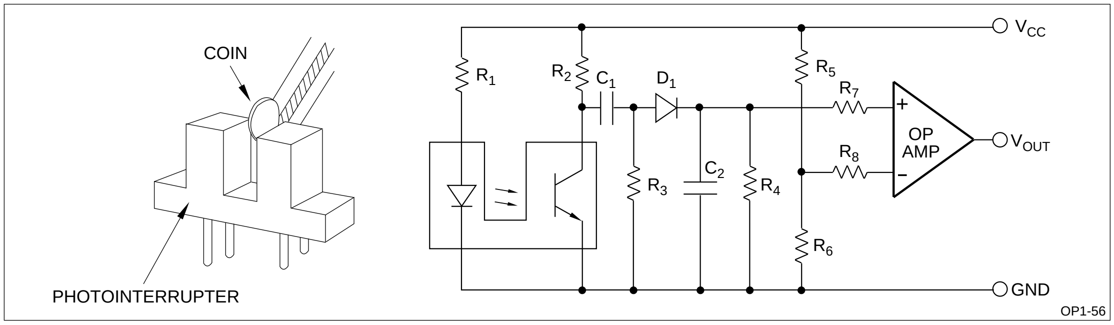

Figure 56. Detection of Moving Objects

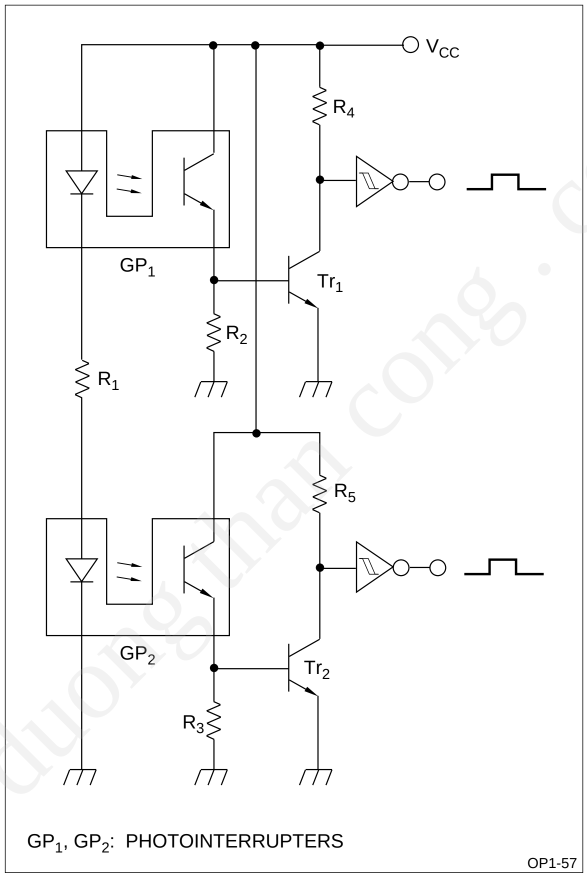

Figure 57. Paper Moving Direction and Speed Detection

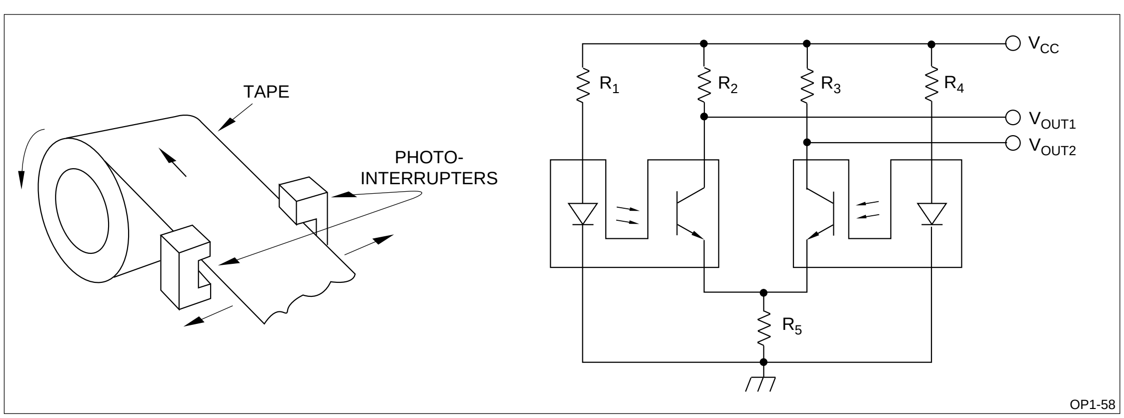

Figure 58. Tape Edge Detection

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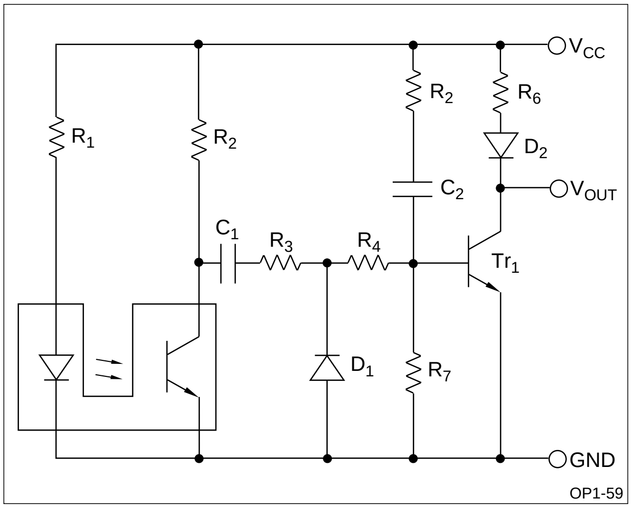

Figure 59. Detection of Disk Rotation

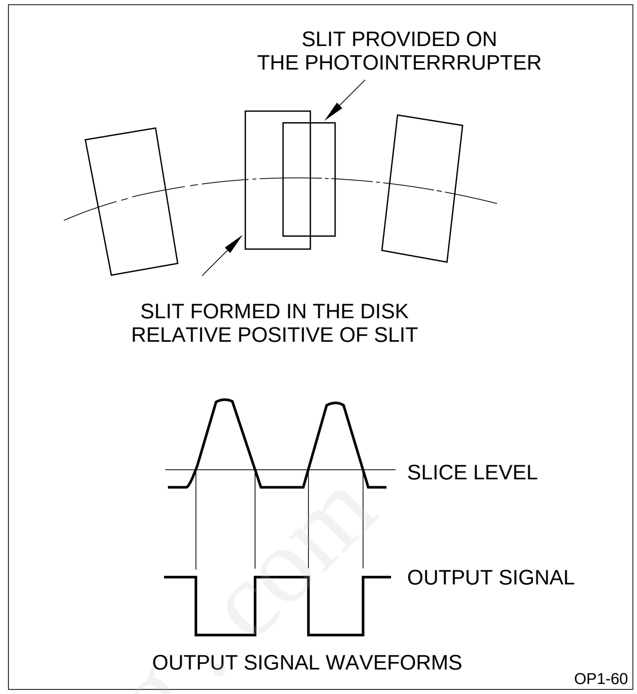

Figure 60. Detected Signal Waveform using Disk

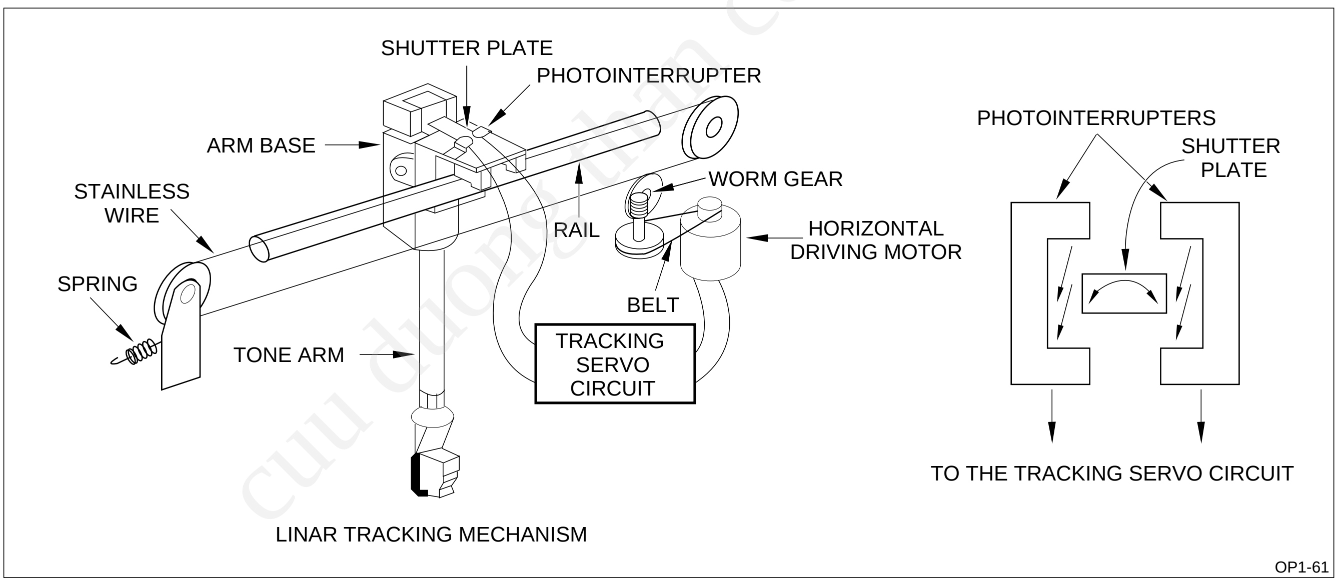

Figure 61. Arm Angle Position Detection in Record Player

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Weight Detection In Electronic Balance

Figure 64 shows a weight detection example in electronic balance. Two photointerrupters are used together to count the number of slits formed in the disk and to discriminate the upward and downward movement of the tray.

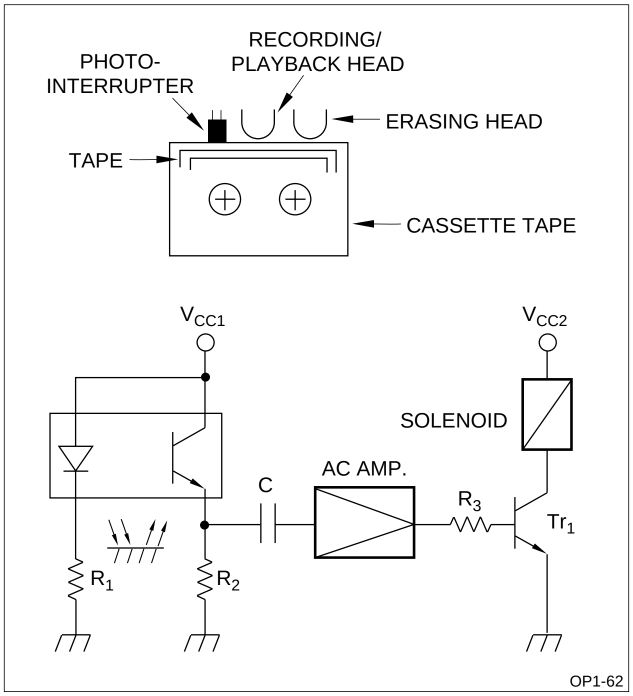
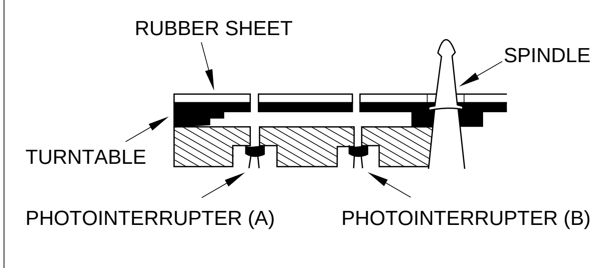


Figure 62. Tape End Detection in Cassette Desk



DISK SIZE	PHOTOINTER-RUPTER (A)	PHOTOINTER-RUPTER (B)	INSTRUCTION
None	OFF	OFF	Do not lower the tone arm
30 cm disk	ON	ON	30 cm disk position detecting circuit: ON, 33 1/3 rpm
17 cm disk	OFF	ON	17 cm disk position detecting circuit: ON, 45 rpm

OP1-63

Figure 63. Disk Size Detection

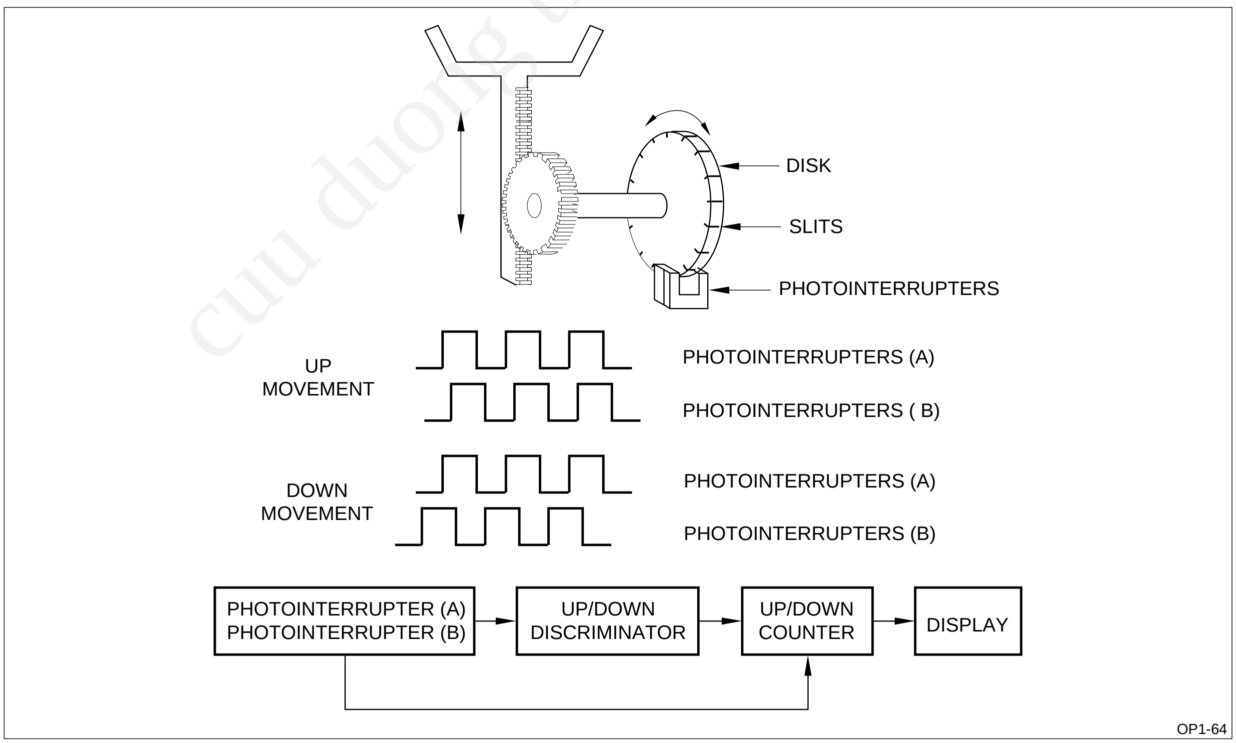


Figure 64. Weight Detection in Electronic Balance

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Speed Alarm Device

Figure 65 shows the mechanism and circuit of a speed alarm device in which a disk is provided coaxially on the speedometer pointer and the associated photointerrupter responds to the output section of the disk to activate the acoustic element.

Upper/lower Limit Detection In Measuring Instrument

Figure 66 shows a mechanism and circuit for detecting the upper and lower limit on the instrument scale indicated by the pointer. The instrument pointer is provided with a mask tab which moves in the gap of the photointerrupters located at the upper and lower limit positions of the scale. The circuit lights a red LED when the pointer reaches the upper limit, a yellow LED when the lower limit is reached, or a green LED when the pointer is within the proper range.

Card Mark Reader

Figure 67 shows a card mark detecting circuit operating according to the floating level slice system using the envelope circuit. The circuit is sensitive and less affected by paper quality and smears. Yet it performs consistently even if the sensor output falls by half.

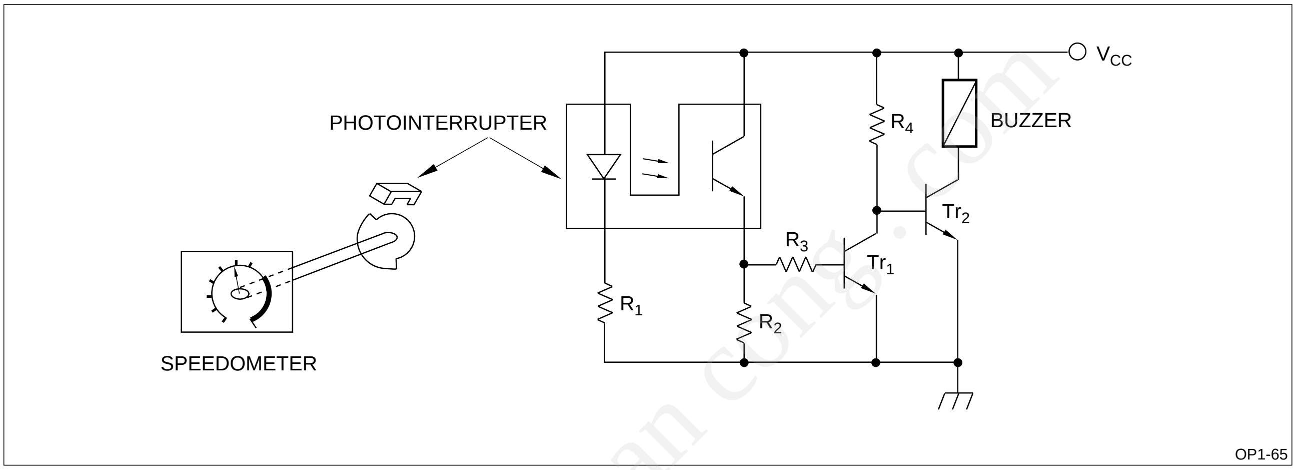

Figure 65. Speed Alarm Device

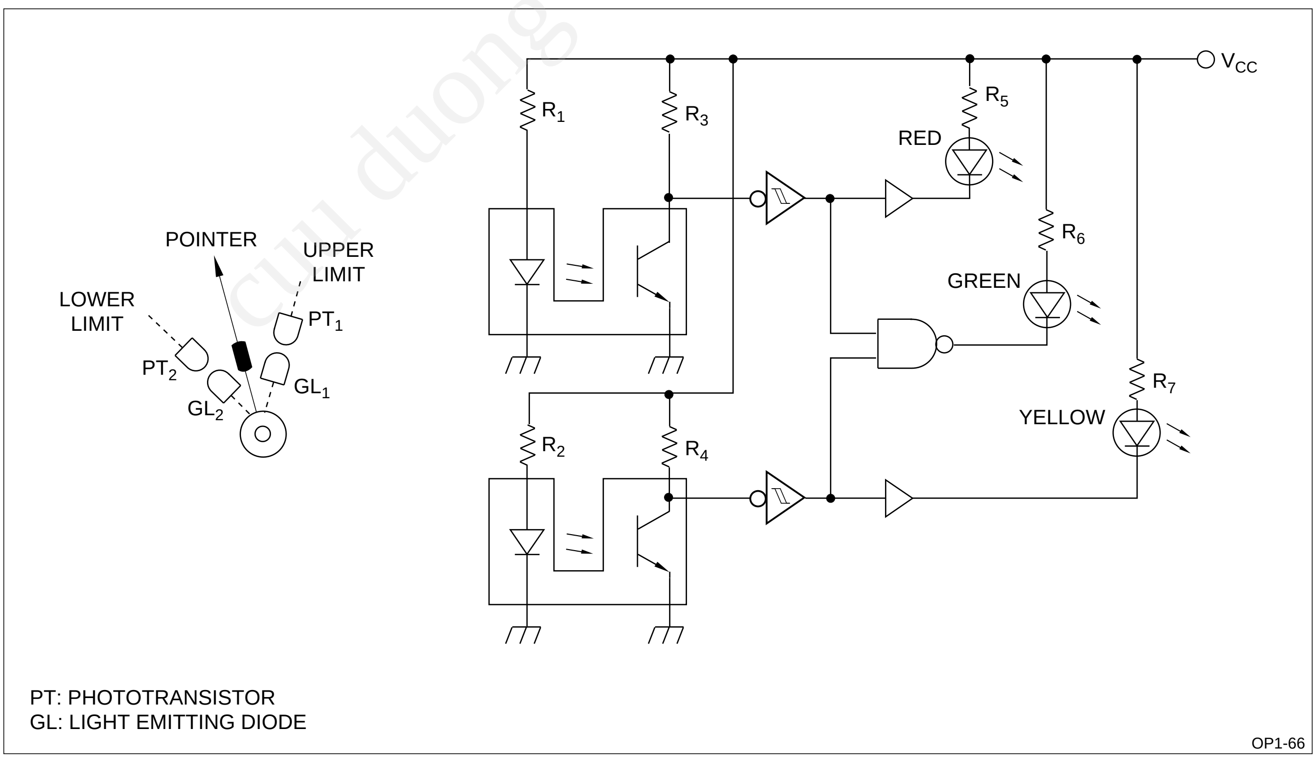

Figure 66. Upper/Lower Limits Detection in Instrument

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Although the marking must be done carefully, particularly to prevent faint or thin marks and imperfect erasure, any spot or mark outside the specified entry position must be disregarded by referring to the timing signal.

Figure 67 shows the circuit for a mark reader.

Figure 68 shows the signal waveforms observed at various parts of the circuit.

Copy Paper Feed Detection In Copier

Figure 69 shows circuit example using a reflective type photointerrupter designed to detect paper fed from the paper stocker.

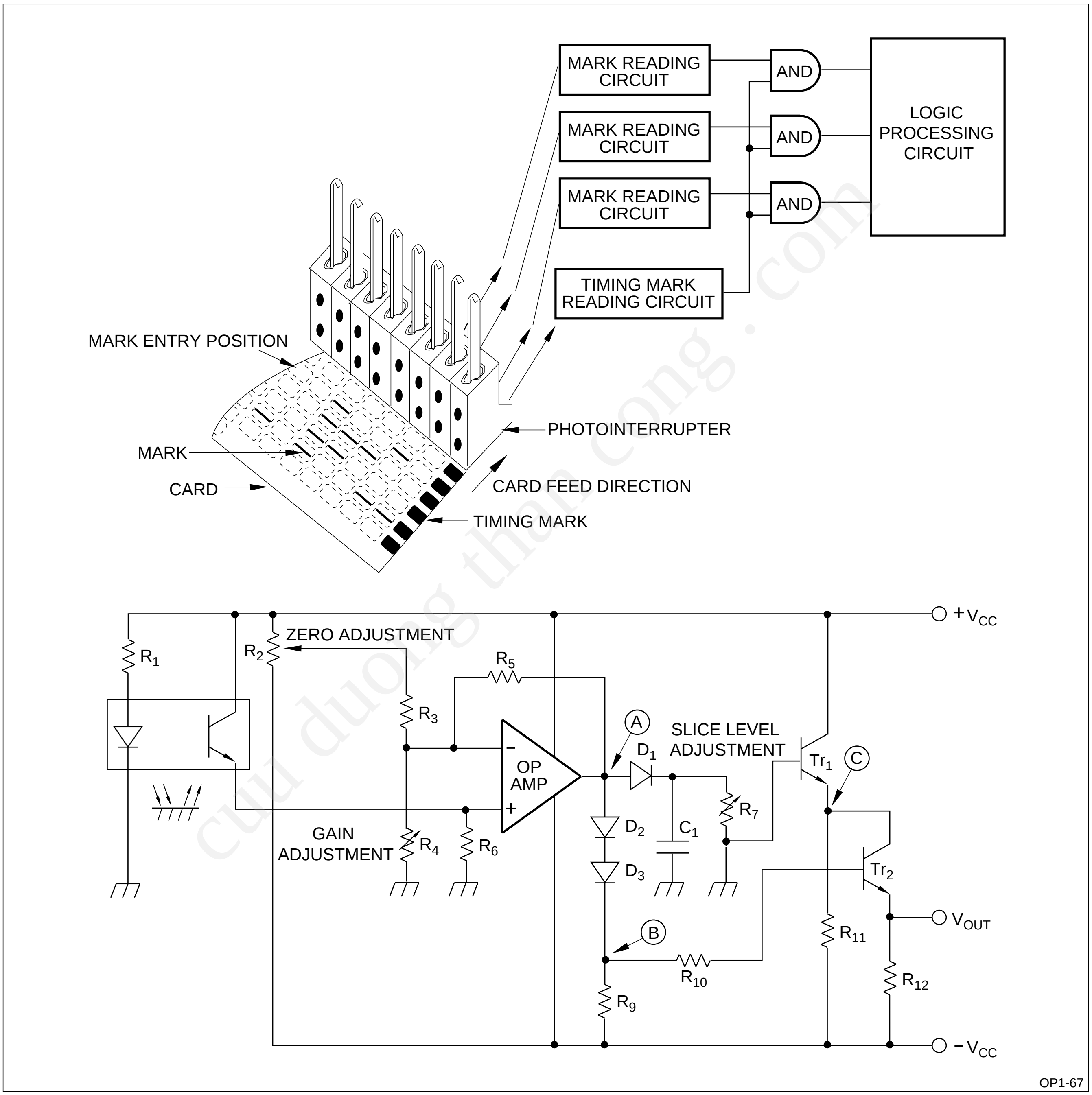

Figure 67. Card Mark Reading Circuit

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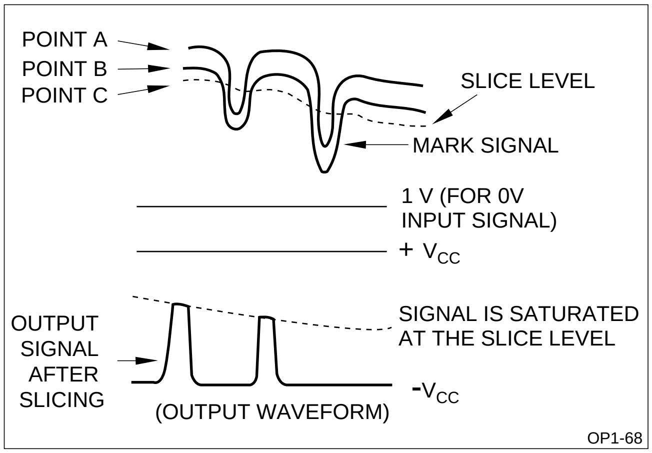

Figure 68. Card Mark Detecting Signal

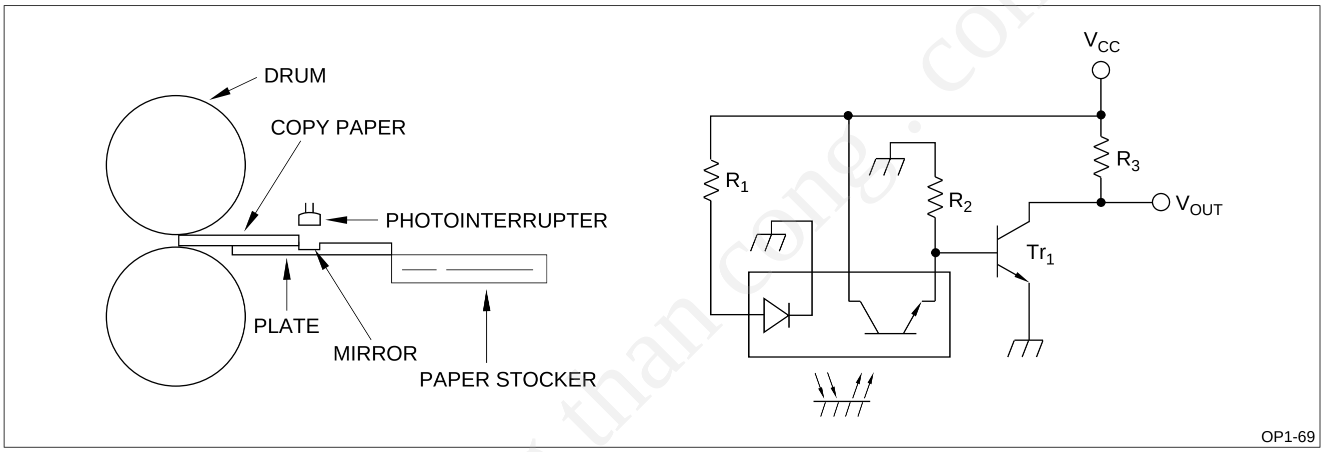

Figure 69. Copy Paper Feed Detection in Copier

Print Paper Detection

Figure 70 and 71 show the circuit example using a reflective type photointerrupter designed to detect the existence of print paper (detection of a mark on the paper).

The circuit in Figure 70 employs the floating level slicing system in which the threshold level is varied depending on the white level. The key of this circuit is the setup of load resistor R_2 so that the voltage of point A is not saturated by the collector current of the phototransistor at the white level.

The circuit in Figure 71 uses a peak hold circuit so as to detect the peak of the white level in advance. The threshold level is set in accordance with the peak value. The value of R_2 is also determined in this circuit so that the operating point of the phototransistor is not saturated.

Smoke Detector

Figure 72 shows the example of a smoke detector using a reflective type photointerrupter.

The infrared light emitted from the LED of the photointerrupter is dispersed by particles of smoke. The dispersion of light is sensed by the light detector of the photointerrupter.

Thread-cut Detection

Figure 73 shows the example of thread-cut detection, in which a cut thread falls across the gap of the photointerrupter, and circuit detects a slight variation in the output of the photointerrupter. A high resolution photointerrupter is used to detect such slight signal.

Photointerrupter Application Fields

Table 2 summarizes the application fields of photointerrupters.

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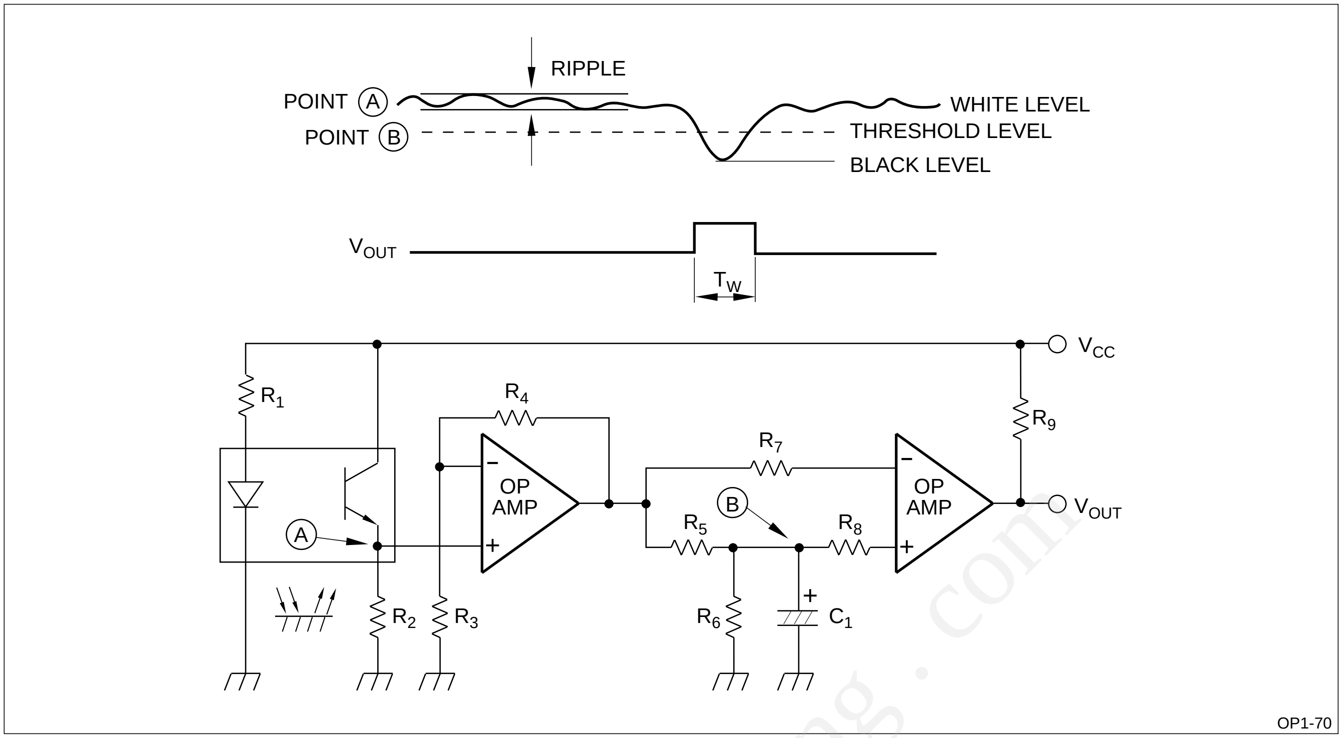

Figure 70. Print Paper Detection

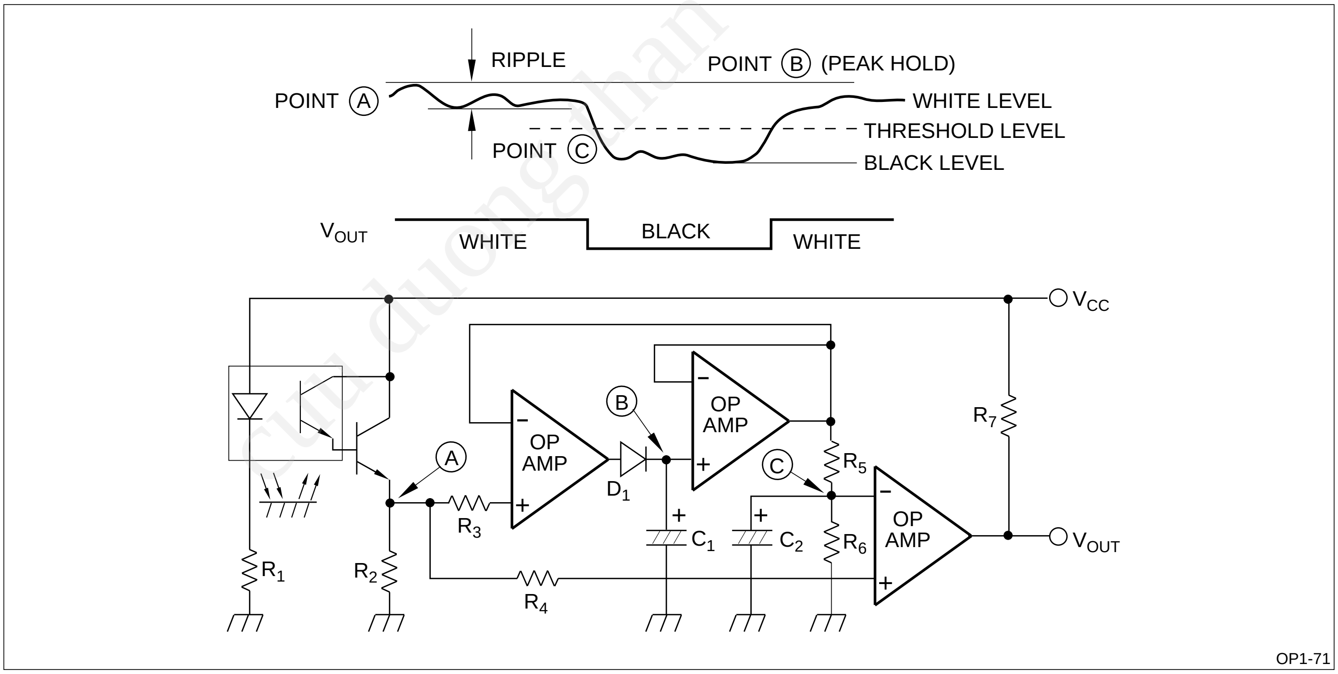

Figure 71. Print Paper Detection (II)

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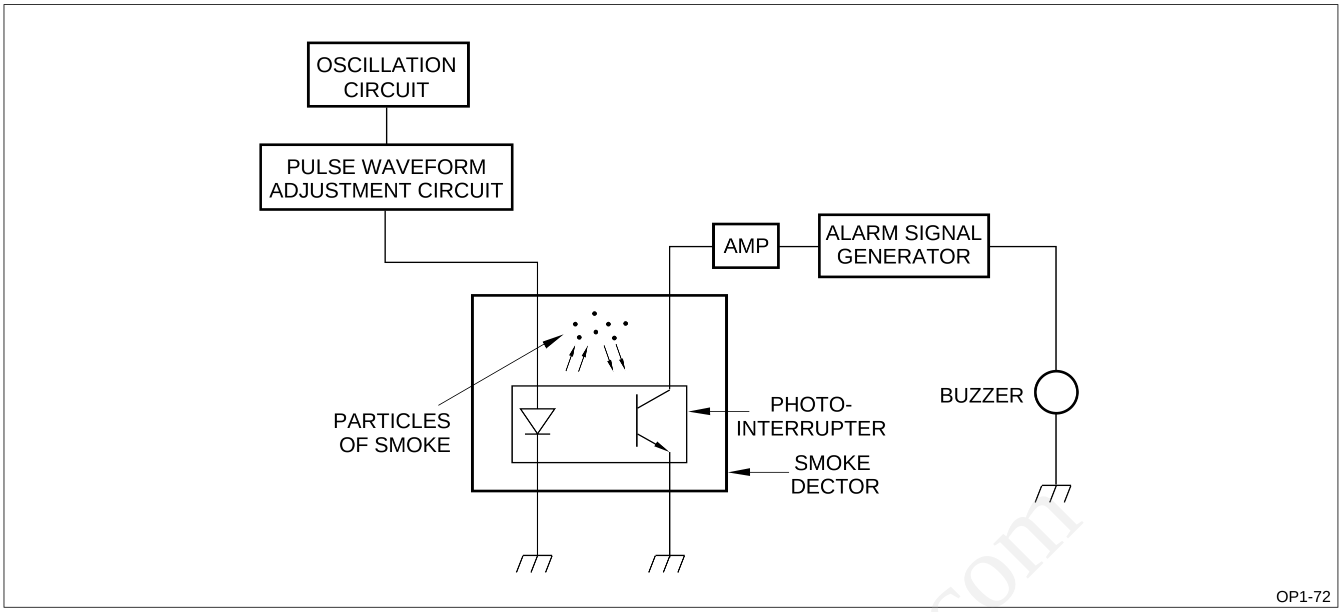

Figure 72. Smoke Detector

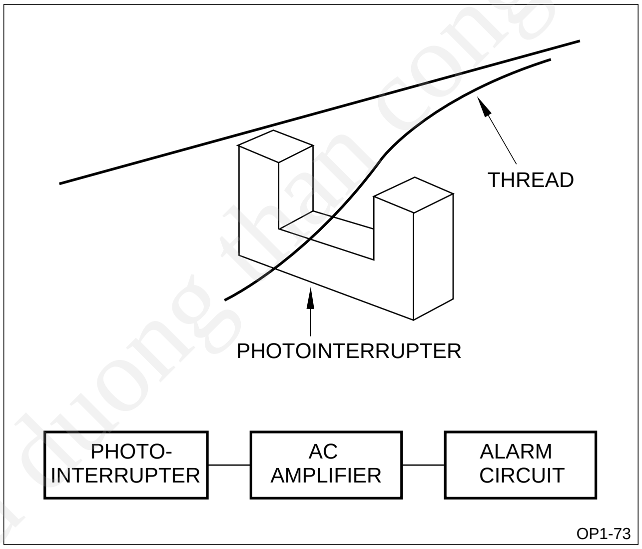

Figure 73. Thread-Cut Detection

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Table 2.
Photointerrupter Application Fields

FIELD		EQUIPMENT	APPLICATIONS
A	Computer peripheral devices	Input/output units	Paper tape reader, punched card reader
		Magnetic disk unit	Head start position detection (heading)
			Disk write-protection notch detection (erasure prevention)
B	Measuring instruments	Industrial measuring instruments	Upper of panel meter/lower limit detection
			Counter circuit
		Electronic micrometer, caliper	Detection of the number of rotations, and rotational direction
		Electronic balances	Weight counter
		Water meters, gas meters	Flow meter
C	Office equipment	Copiers	Paper feed timing detection
			Paper feed direction detection
			Drum timing detection
			Toner quantity detection
		Facsimiles	Paper feed timing detection
			Paper passage detection
		Printers	Timing detection of print drum
			End detection of inked ribbon
			Timing detection of paper-out and paper feed
		ECRs	Bar code reading
D	Automobiles	Speedometers	Speed alarm, power steering, automatic doorlocks, auto-driving controls
E	Automatic vending machines		Coin passage detection
	Ticket vending machines		Ticket paper detection
F	Home appliances	VCRs	End detection of magnetic tape
			Slack detection of magnetic tape
			Rotation control of tape reel
		Electronic sewing machines	Needle up/down position detection
			Thread-cut detection
			Lower thread quantity detection
			Pattern recognition
		Room heaters	Fuel quantity detection
G	Audio equipment	Record players	Rotational speed monitoring of turntable
			Disk size detection
			Tone arm angle detection
			Unrecorded portion detection
		Cassette tape recorders	Tape end detection/Auto-return position detection
			Counter circuit
H	Medical equipment	Pulse counter	Pulse detection
I	Communications equipment	Transceivers	Digital tuning circuits
J	Others	Fuel pumps	Automatic shut off devices
		Telephone responders	Tape end detection
		Smoke detectors	Smoke particle detection

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SOLID STATE RELAY APPLICATION CIRCUITS

Solid state relays (SSR) have extensive applications, from industrial equipment to home appliances, including SSRs for triggering for activating high power thyristors and triacs and SSRs for power control for directly switching AC loads. The following describes the fundamental circuit example of SSRs.

(1) Snubber circuit

Application of a voltage above the rating at the output side of SSR would result in a malfunction or even destruction of the device due to overcurrent. The snubber circuit is designed to absorb and suppress impulse noise.

Figure 74 shows some examples of a snubber circuit.

Circuit (A) is most commonly used for CR absorbers.

Circuit (B) is more effective for noise absorption since it can have a smaller Rg value.

Circuit (C) uses a varistor which can absorb high energy noise such as that caused by lightning.

The values of the resistors and capacitors in the snubber circuit depend on the kind of load and power capacity.

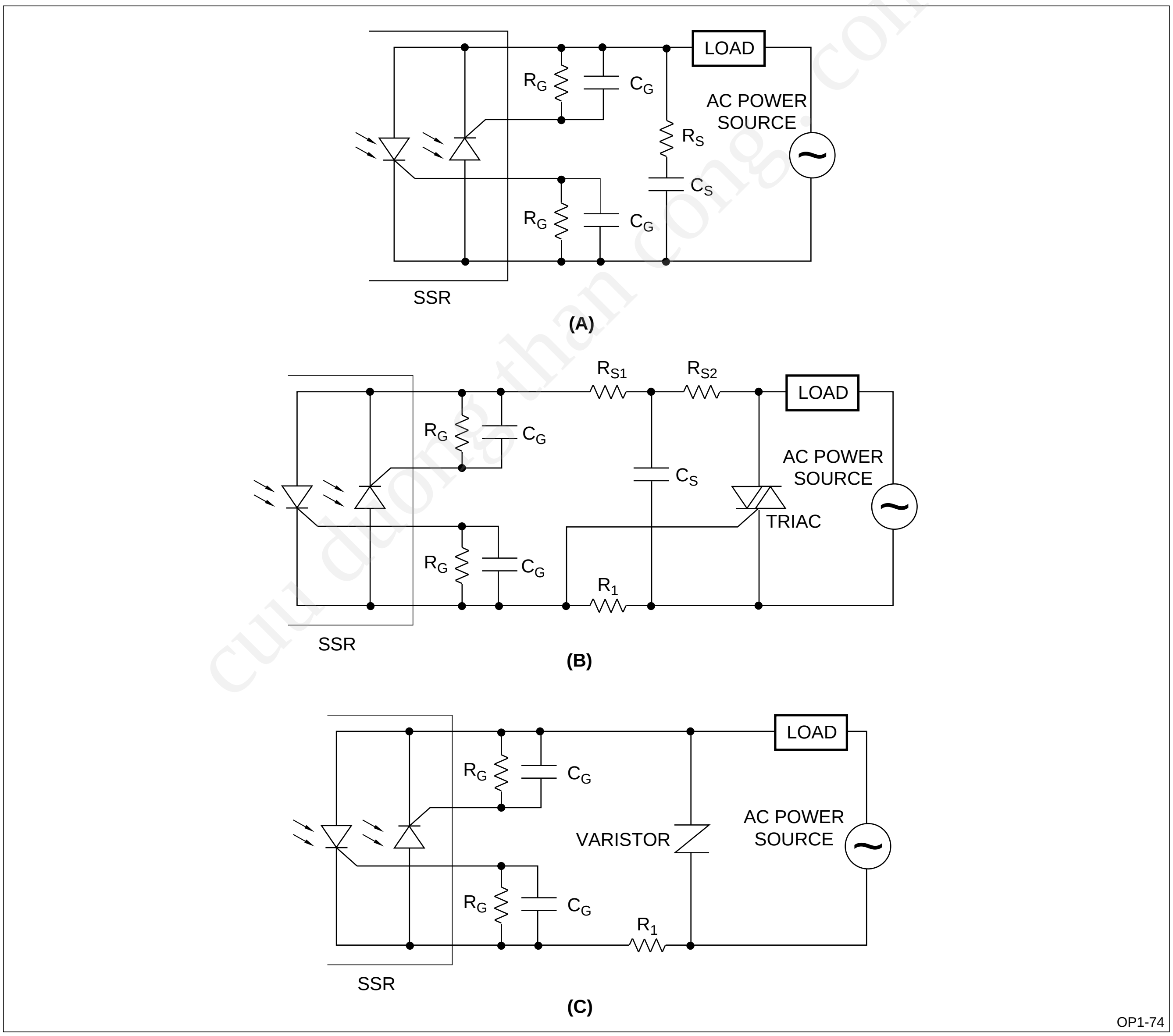

Figure 74. Snubber Circuits

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Serial/Parallel Connections

Figures 75 and 76 show the circuit of two SSRs connected in series and parallel, respectively. The following precautions should be considered when operating two photothyristors type SSRs connected in series or parallel.

For Serial Connections:

Due to dispersion of leak current in forward and reverse of photothyristors, there can be a difference in the voltage across each device. For this reason, a resistor (R_1, R_2) is connected in parallel with each device so as to minimize the voltage difference.

There are dispersion in the critical rate of rise of off-state voltage (dV/dt) among photothyristors depending on the junction capacity and sensitivity of devices. For this reason, the serial connection of resistor and capacitor (R_S, C_S) is connected in parallel to each device so that both SSRs are balanced.

For Parallel Connections:

(1) Two SSRs connected in parallel must be turned on simultaneously. If one SSR turns on first, the other SSR has both its terminals short-circuited through the first one and possibly cannot turn on even if the device has low on-voltage characteristics. For this reason, adjustments must be done through the gate resistor or gate capacitor so that both SSRs have an equal turn-on time.

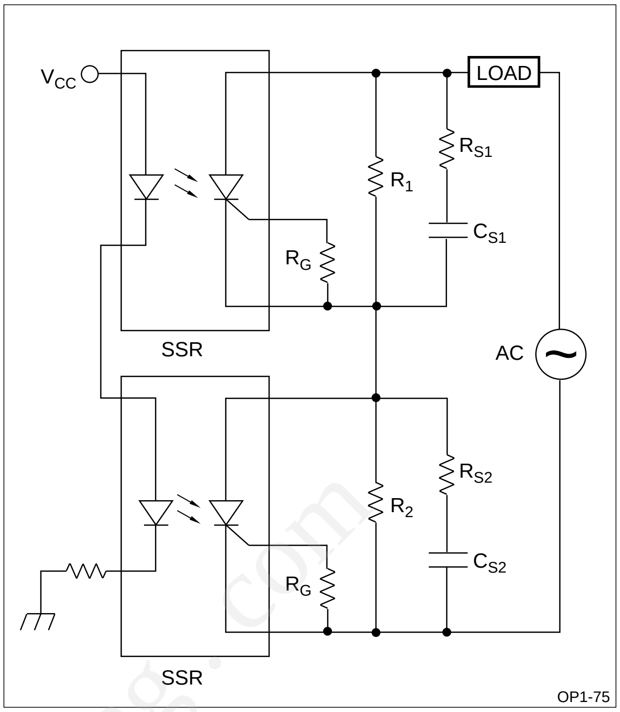

Figure 75. Serial Connection Example

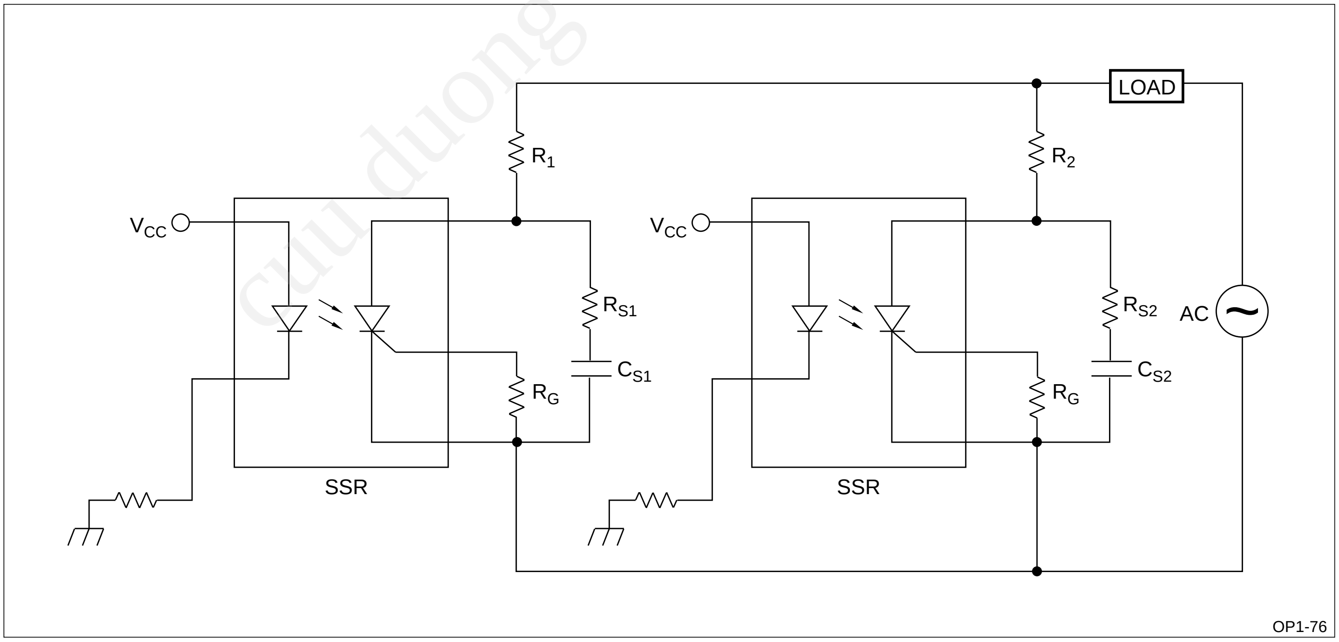

Figure 76. Parallel Connection Example

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(2) There are slight differences in the turn-on voltage according to devices. This causes an unbalanced current distribution among the photothyristors, resulting in the possibility of an overcurrent. On this account, a resistor of low resistance is connected serially to the photothyristor so as to adjust the on-voltage. This equalizes the current distribution in both devices.

Zero-cross circuit

Figure 77 shows a zero-cross circuit using photocouplers, As shown in waveforms A and B, both photocouplers are off around the zero voltage level of the AC power voltage. One of the photocouplers is on in the remaining time. Accordingly, a zero-detect signal can be produced by taking the logical product of signals A and B. A zero-cross made SSR is thus arranged through activation of the SSR by the zero-detect signal Q.

This system is particularly useful in operating multichannel SSRs in a zero-cross mode in a programmable controller etc.

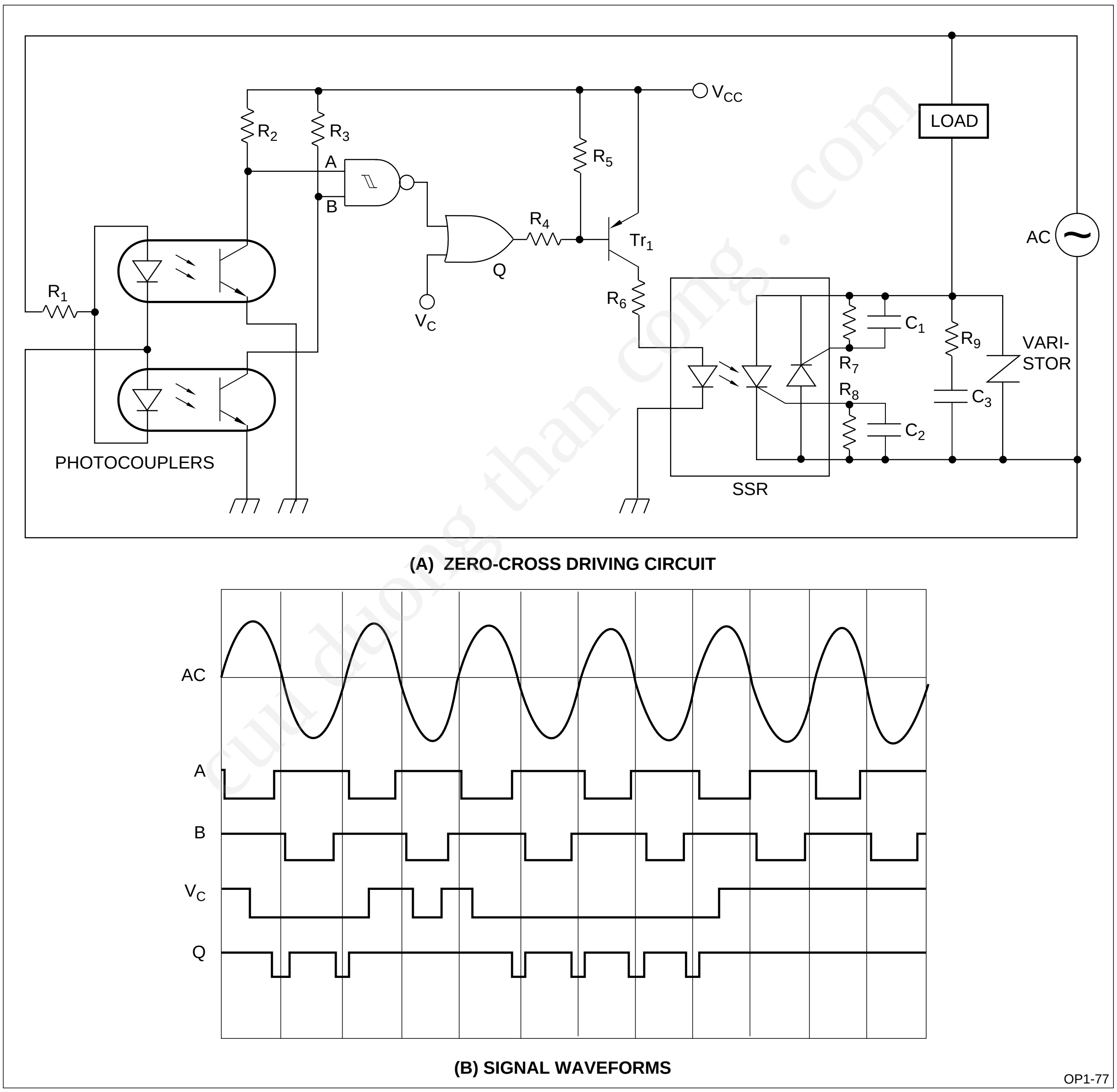

Figure 77. Zero-Cross Circuit

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Application Circuits Of SSR

Programmable Controller

A programmable controller is a sequence controller which takes the place of conventional relay sequence controllers. It consists of a CPU, memory, I/O interface and peripheral devices for programming. The input/output unit of the programmable controller employs photocouplers for the input post and photocouplers or SSRs for the output in place of conventional relay contacts.

Figure 78 is a block diagram of a typical programmable controller.

Figure 79 shows the circuit of an output unit including 8 or 16 SSRs. The SIP-type SSR features a compact, built-in snubber circuit and input current limiting resistors and is frequently used in modern programmable controllers.

Copier

Figure 80 (A) shows an internal view of a copy machine in which SSRs are used. Figure 80 (B) shows a circuit example of the copy lamp control circuit using SSRs.

The copy lamp has a start-up period of several power cycles in which a rush current 10 times or more than the steady-state current flows as shown in Figure 80 (C), causing control circuits of Figure 80 (B), the SSR is shunted by resistor R_1 so as to supply a small current to the lamp for preheating. This reduces the rush current when starting.

Reversible Motor Driver

Figure 81 (A) shows the circuit of a reversible motor driver using an SSR. The circuit operates in response to the input signal shown in Figure 81 (B) to produce the motor current and voltage shown in Figure 81 (C).

The reversible motor in driven in the forward or reverse direction by one of two SSRs. If both SSRs are made conductive simultaneously, the motor will overheat. To prevent this, a time length of 1/2 cycle or more is used in switching the rotational direction as shown if Figure 81 (B). Each SSR is applied across its output terminals with a voltage twice the peak-to-peak voltage of the power line. Therefore, for a 100 VAC power source, SSRs with a withstand voltage of 300 V or more must be used.

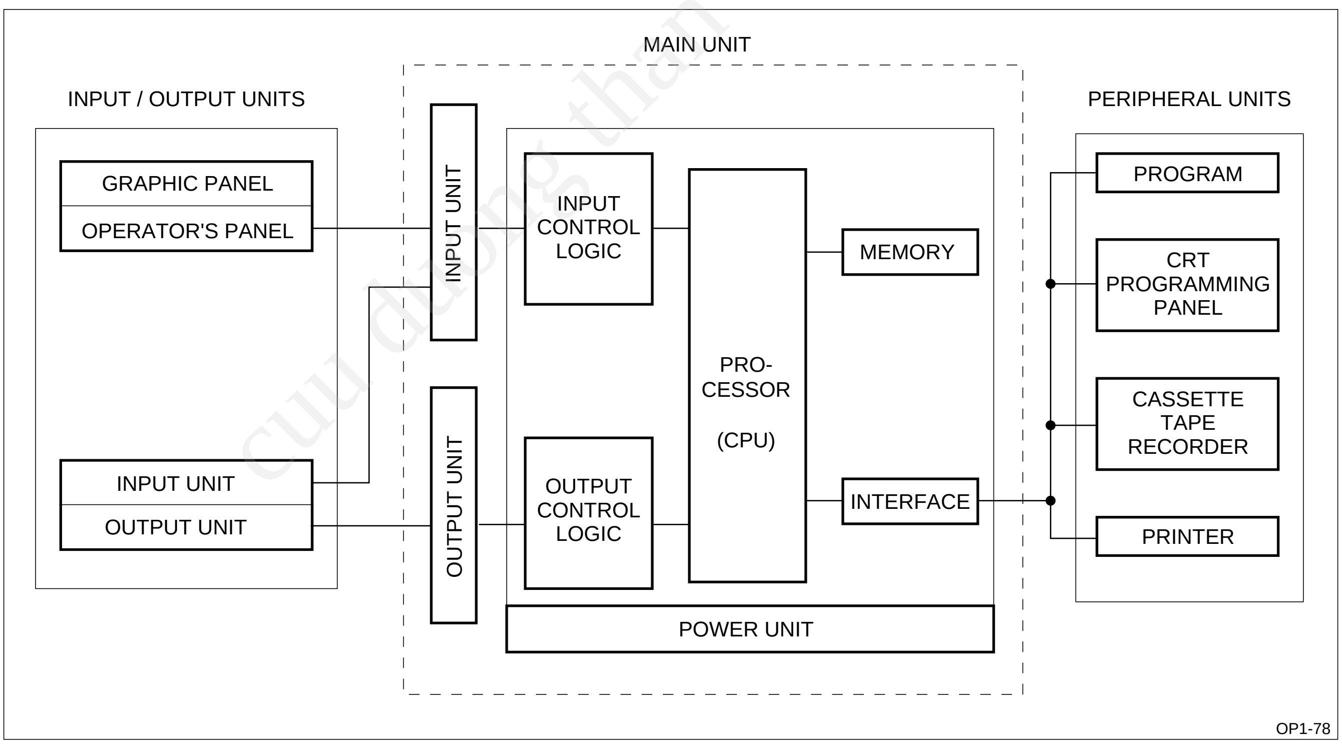

Figure 78. Block Diagram of Programmable Controller

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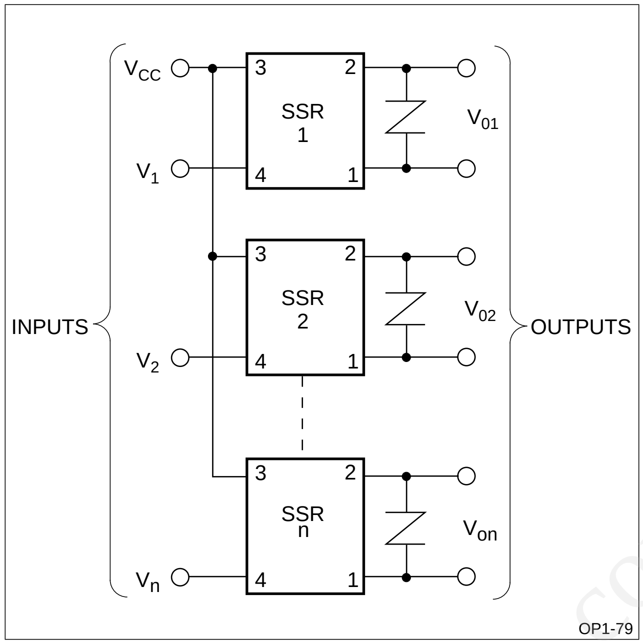

Figure 79. Programmable Controller Output Unit

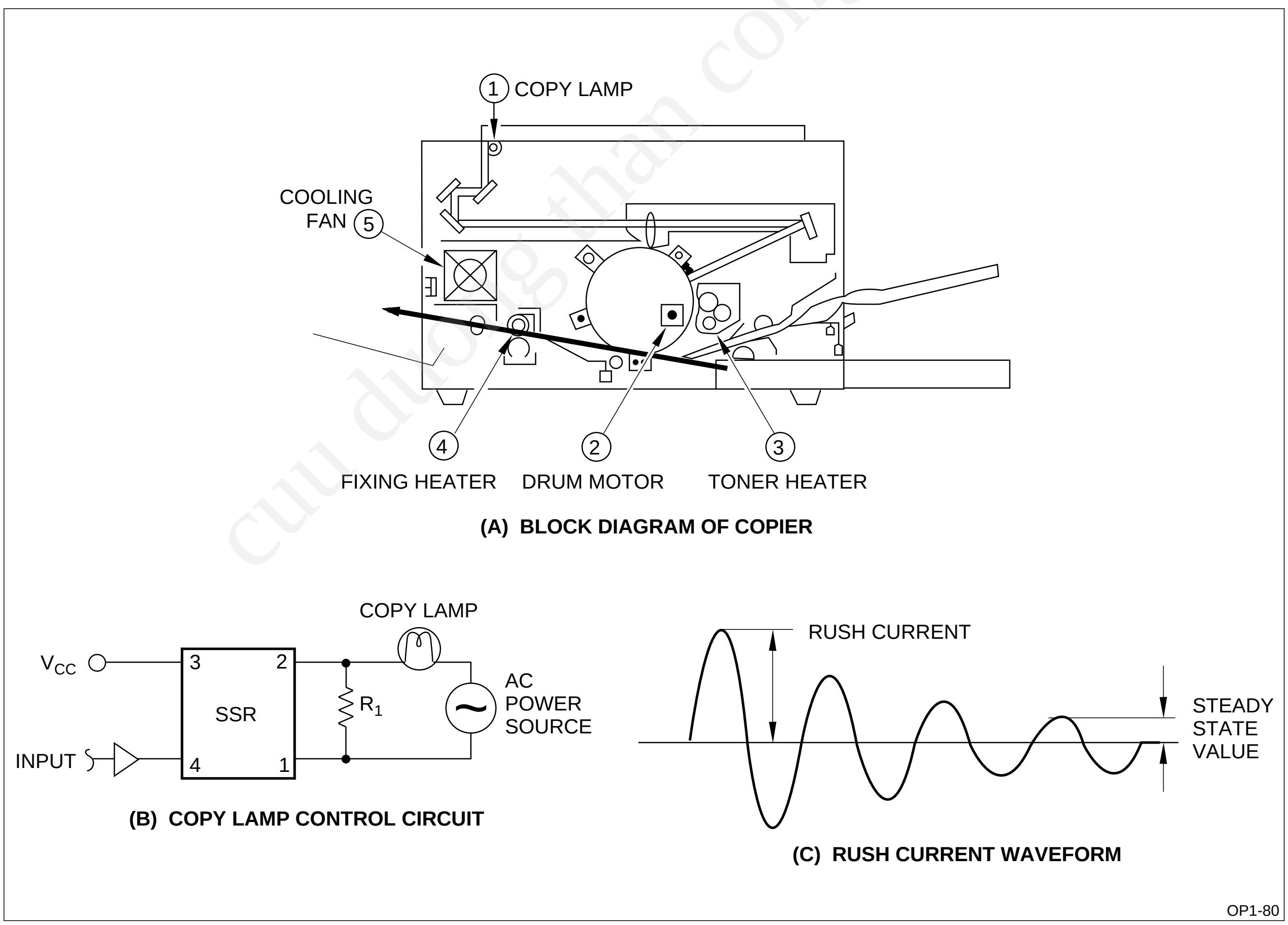

Figure 80. Copier

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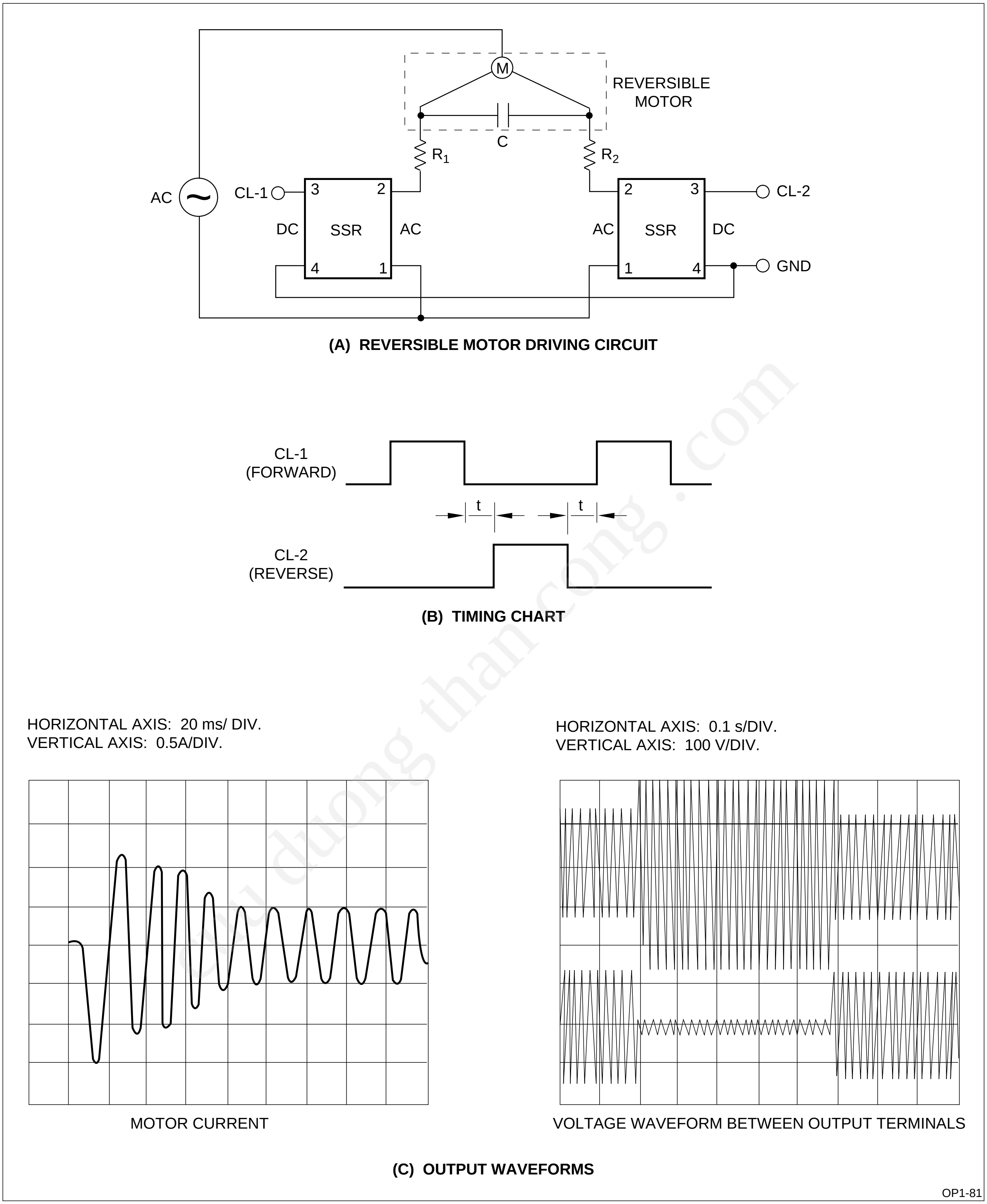

Figure 81. Reversible Motor Driver

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Heater Control Circuit

Figure 82 shows a heater control circuit designed to maintain a constant temperature. A copper-constantan thermocoupler is used as a temperature sensor. An SSR is used to switch the power to the heater. The circuit shown features a wide temperature setting range and high control accuracy. Setup is made by a variable resistor (VR).

Microcomputerized Rice Cooker

In the circuit arrangement of Figure 83, three heaters (a main heater, side heater and lid heater) installed in a rice cooker are controlled by two SSRs. The three heaters are connected in series. The side and lid heaters are short-circuited by the cooking SSR during the cooking, while the warming SSR is turned on and off cyclically on completion of cooking so as to maintain a constant temperature inside the rice cooker.

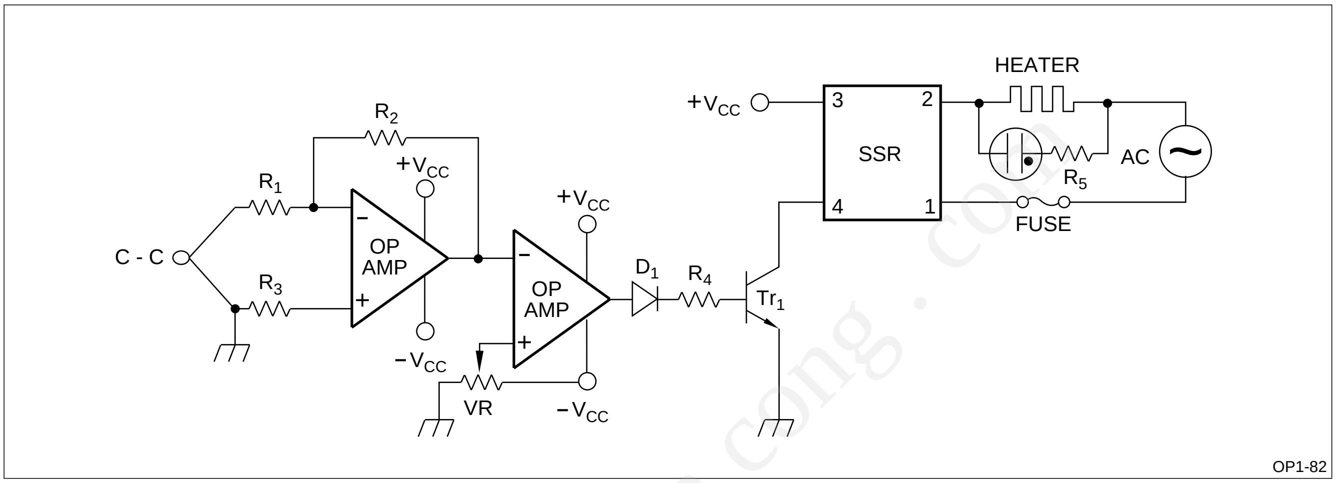

Figure 82. Heater Control Circuit

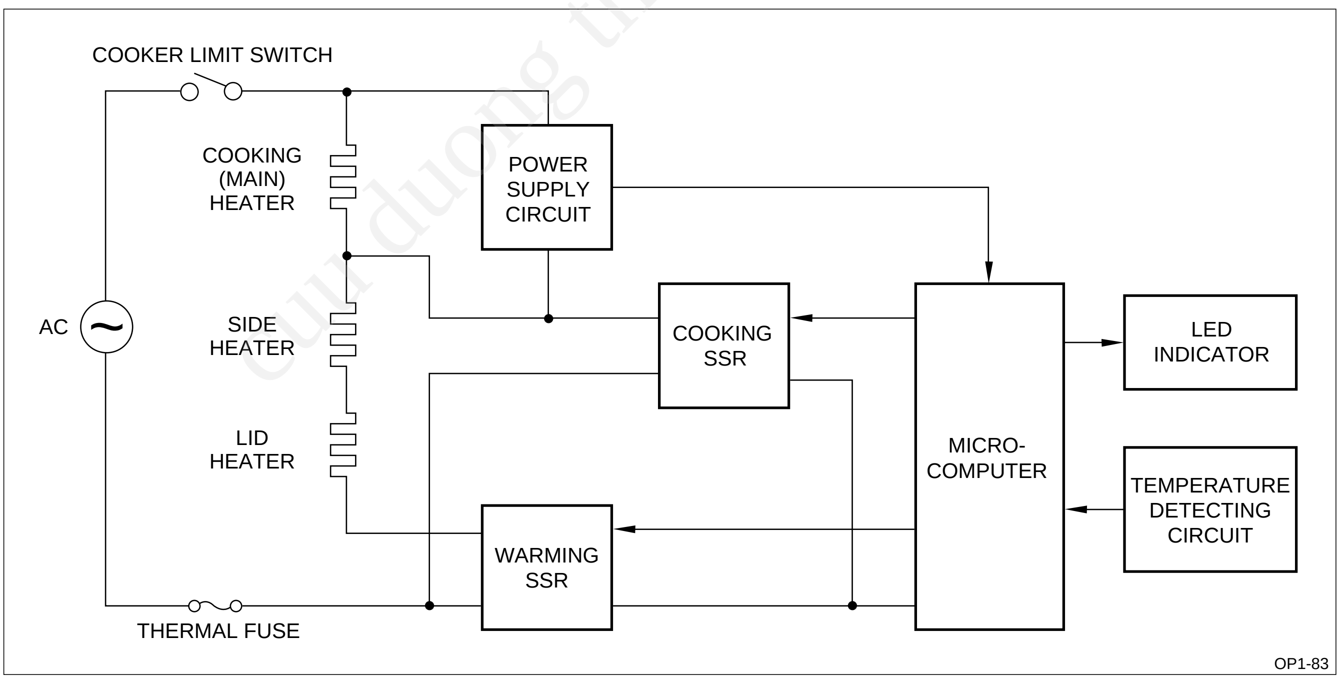

Figure 83. Microcomputerized Cooker

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Table 3.
SSR Application Fields

FIELD		EQUIPMENT	APPLICATION
A	Home appliances	Air conditioners	On/off control of compressor, Speed control of blower motor
		Washing machine	Speed control pulsator
		Refrigerators	On/off control of compressor, defrosting circuit
		Electric blankets	Automatic temperature control
		Electric carpets	Automatic temperature control
		Electric jars	Automatic temperature control
		Electric powered tools	Motor speed control
		Electric sewing machines	Motor speed control
B	Office equipment	Copiers	On/off control of copy lamp, heater control
		Facsimiles	Speed control of motor (drum)
		Computers	Power switching of peripheral equipment
		Printers	On/off and speed control of motor
		Photograph processors	Exposure control
C	Automobiles	Ignition system	Switching of discharge circuit
		Generators	Output voltage control
		Others	On/off control of wiper motor and side mirror motor
D	Automatic vending machines	Coin sensors	Interface between coin sensor and indicator
		Vendors	On/off control of solenoid and indicator
E	Control equipment	Electric furnaces	On/off and temperature control of heater
		Process controllers	On/off and speed control of motor, an/off control of solenoid
		Programmable controllers	Output board (interface)
		Numerical control machines	On/off control of motor and solenoid
		Elevators	On/off control of indicator lamp, open/close control of door, on/off control of fan motor
F	Illuminators and others	Traffic signals	Flickering control of lamp
		Electric sign boards	On/off control of road information lamp
		Fluorescent lamps	Lighting circuit
		Illumination controllers	Phase control circuit

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