Photodiode/Phototransistor Application Circuit

FUNDAMENTAL PHOTODIODE CIRCUITS

Figures 1 and 2 show the fundamental photodiode circuits.

The circuit shown in Figure 1 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 1 (B) shows the operating point for a load resistor (R_L) without application of bias to the photodiode.

Figure 2 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 Id $\times$ R_L when the light is interrupted, and this point should be noted in designing the circuit.

Figure 2 (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:

- High-speed response
- Wide-proportional-range of output
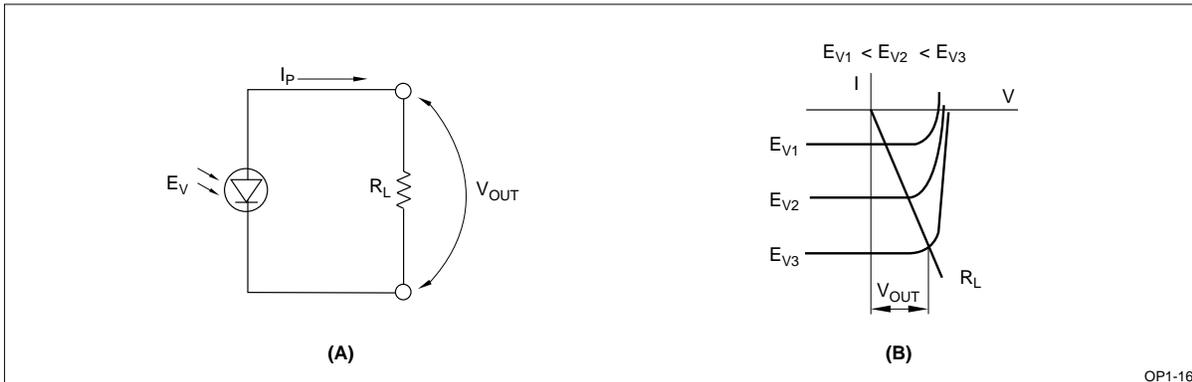
Therefore, this circuit is generally used.

Figure 1. Fundamental Circuit of Photodiode (Without Bias)
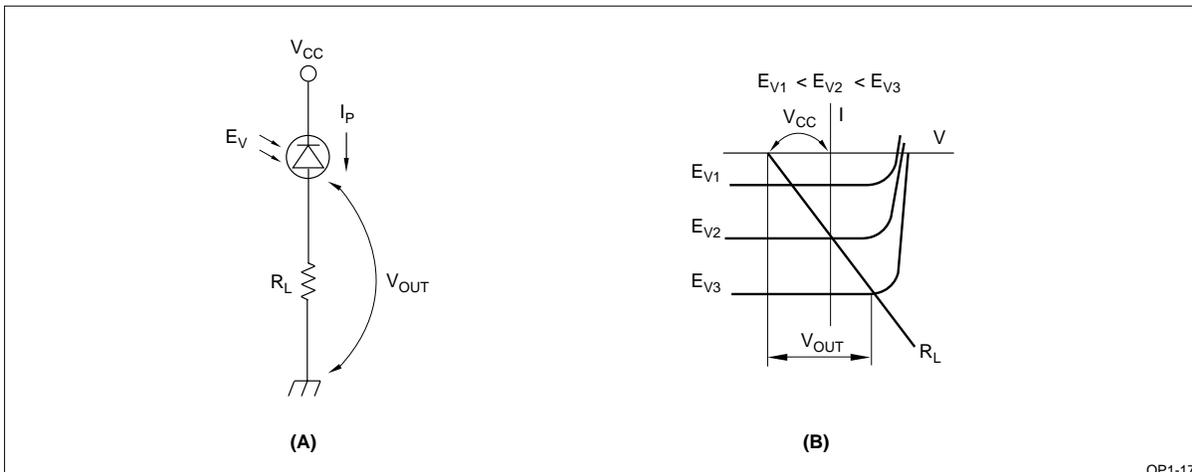

Figure 2. Fundamental Circuit of Photodiode (With Bias)

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 3 and 4 show photocurrent amplifiers using transistors.

The circuit shown in Figure 3 are most basic combinations of a photodiode and an amplifying transistor. In the arrangement of Figure 3 (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 3 (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 4 shows simple amplifiers utilizing negative feedback.

In the circuit of Figure 4 (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.

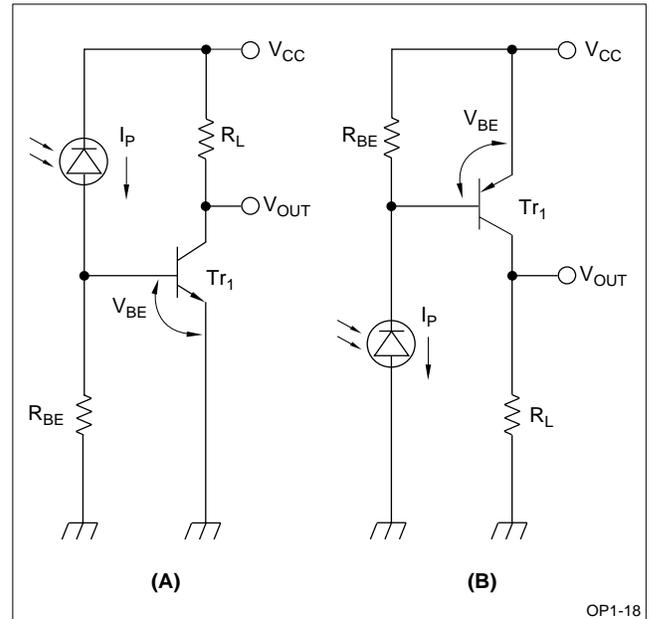The circuit of Figure 4 (B) has an additional transistor (Tr_2) to provide a larger output current.

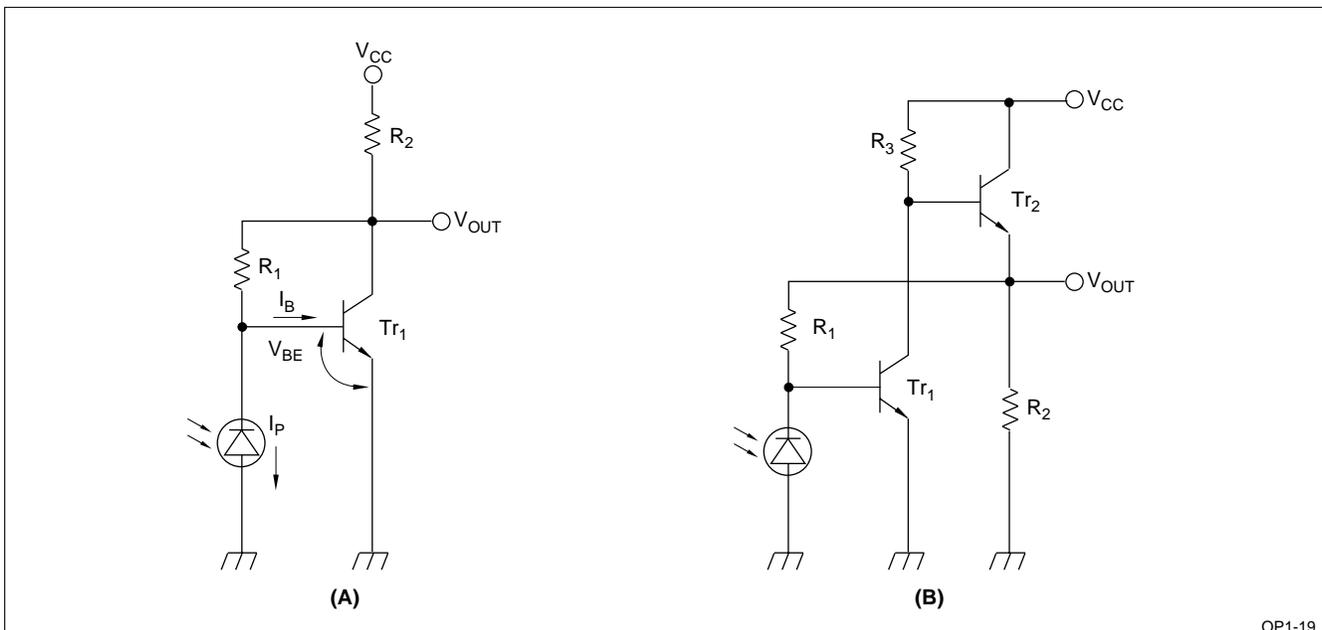**Figure 3. Photocurrent Amplifier Circuit using Transistor**

Figure 4. Photocurrent Amplifier Circuit with Negative Feedback

AMPLIFIER CIRCUIT USING OPERATIONAL AMPLIFIER

Figure 6 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 6 (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:

• Less influence by dark current

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

Figure 5 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.
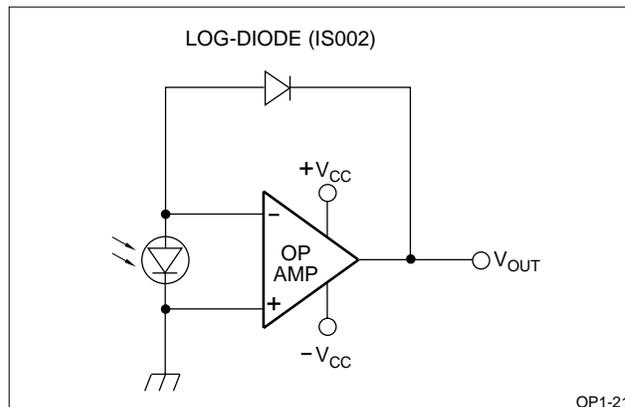

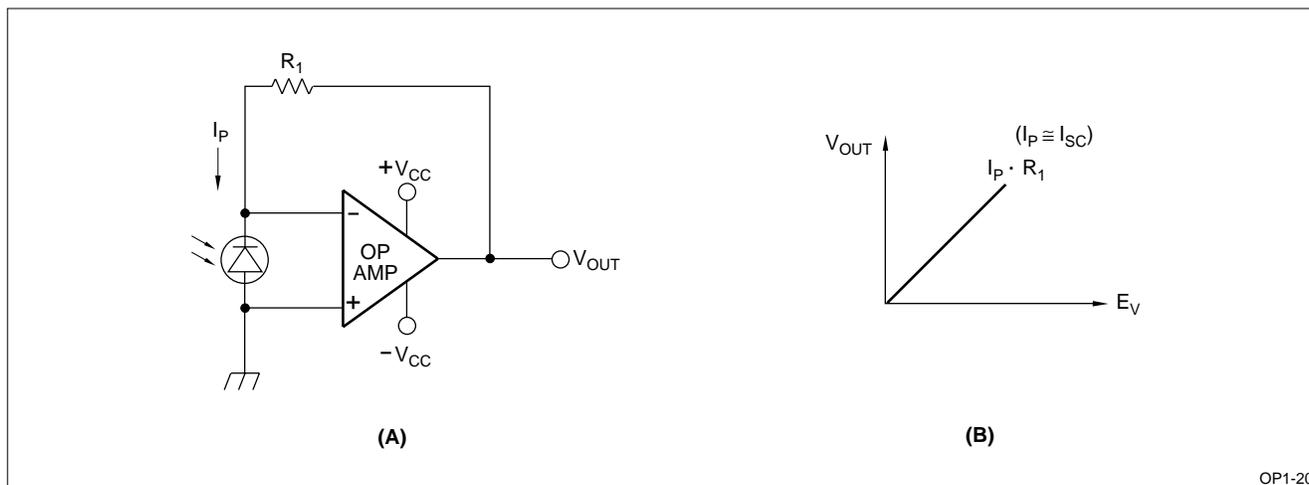**Figure 5. Logarithmic Photocurrent Amplifier using an Operational Amplifier**

Figure 6. Photocurrent Amplifier using an Operational Amplifier (Without Bias)

LIGHT DETECTING CIRCUIT FOR MODULATED LIGHT INPUT

Figure 7 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.

The circuit shown in Figure 7 detects the light input by differentiating the rising and falling edges of a pulse signal. To amplify a very small input signal, an FET providing a high input impedance is used.

COLOR SENSOR AMPLIFIER CIRCUIT

Figure 8 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:

$$V_{OUT} = \frac{kT}{q} \times \log\left(\frac{I_{SC2}}{I_{SC1}}\right) \times \frac{R_2}{R_1}$$

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.
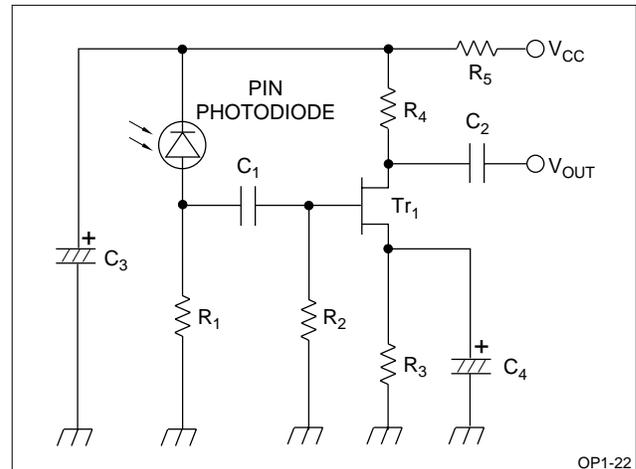

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Figure 7. Light Detecting Circuit for Modulated Light Input PIN Photodiode
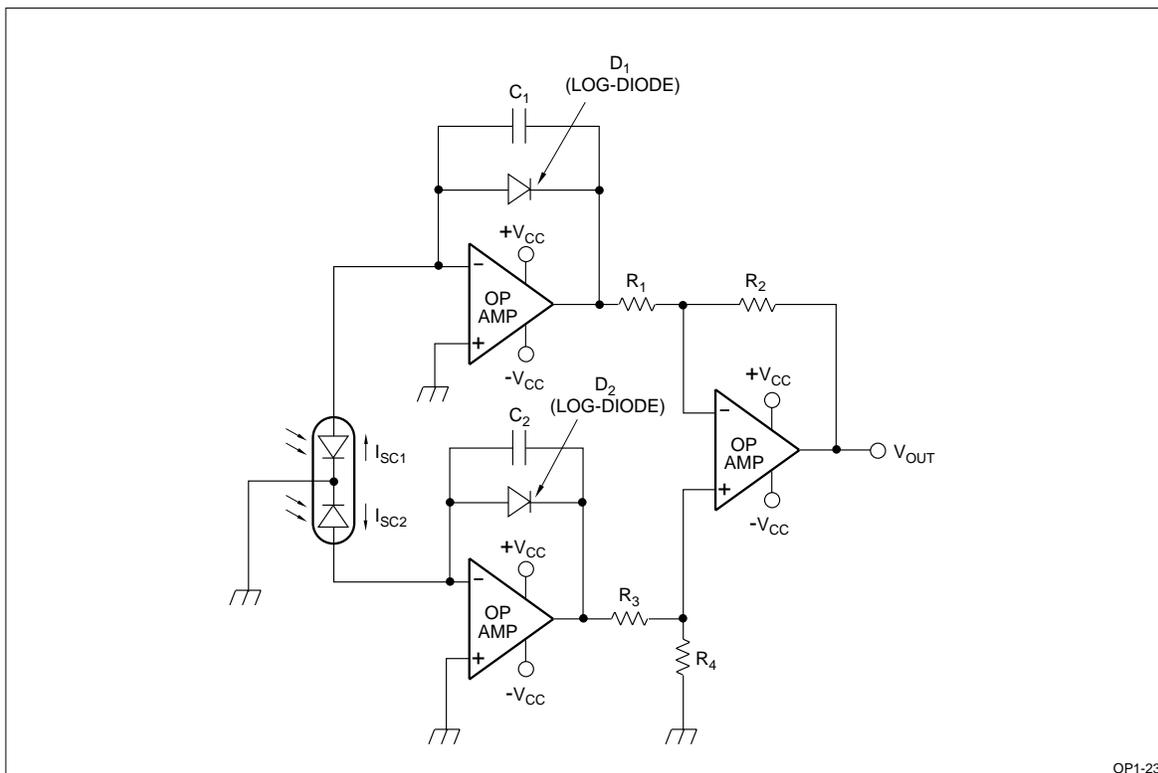

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Figure 8. Color Sensor Amplifier Circuit

FUNDAMENTAL PHOTOTRANSISTOR CIRCUITS

Figures 9 and 10 show the fundamental phototransistor circuits. The circuit shown in Figure 9 (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 9 (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 Figure 9 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 10 (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 10 (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

Figure 11 shows the transistor amplifiers used to amplify the collector current of the phototransistor using a transistor (Tr_1). The circuit in Figure 11 (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:

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

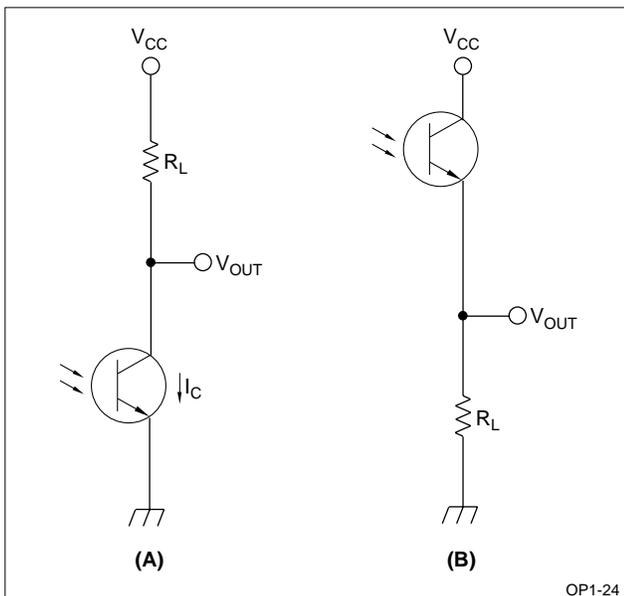Where I_{CBO} is the dark current of phototransistor and I_C is the collector current.

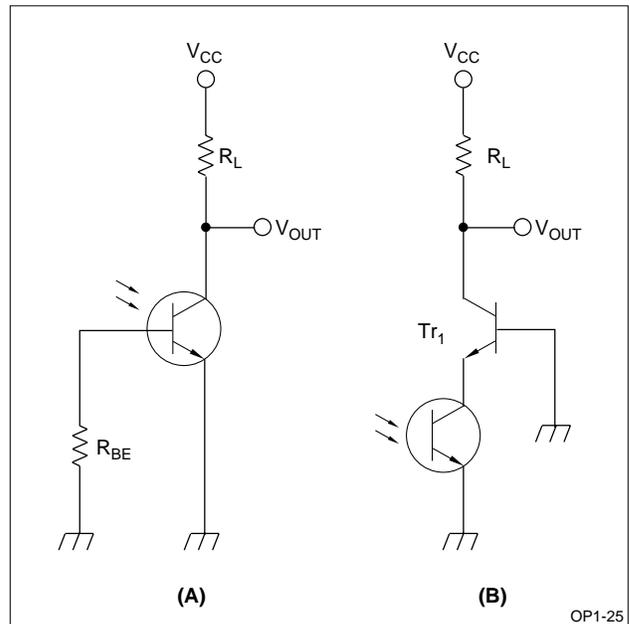**Figure 10. Fundamental Phototransistor Circuit (II)**

Figure 11. Amplifier Circuit using Transistor
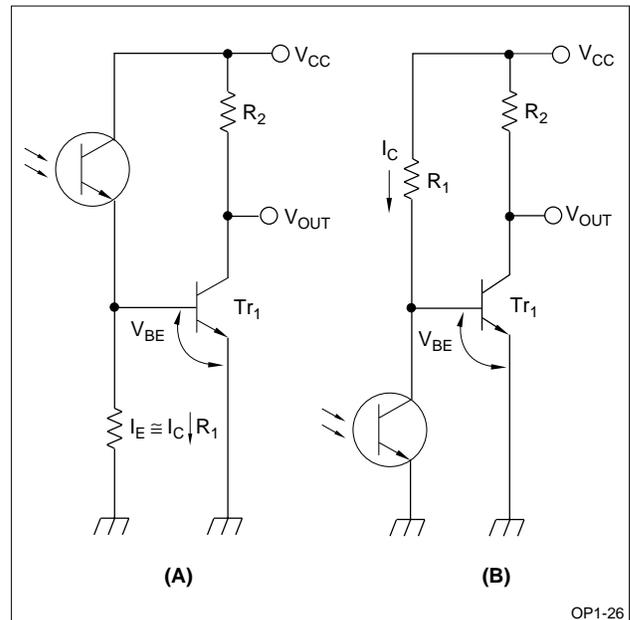

Figure 9. Fundamental Phototransistor Circuit (I)

MODULATED SIGNAL DETECTION CIRCUIT

Figure 12 shows 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 is greatly amplified.

AMPLIFIER CIRCUIT USING OPERATIONAL AMPLIFIER

Figure 13 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 13 (A) has a negative bias (-V) for the emitter against the virtually grounded collector potential. Figure 13 (B) shows the output voltage vs. irradiation intensity characteristics.

AUTO-STROBOSCOPE CIRCUIT

Figure 14 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.
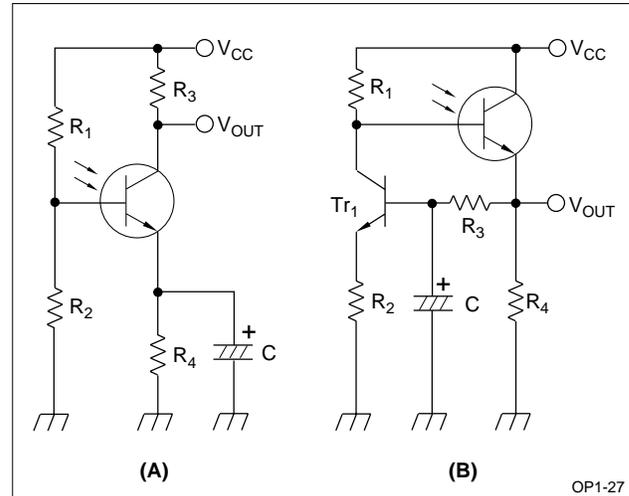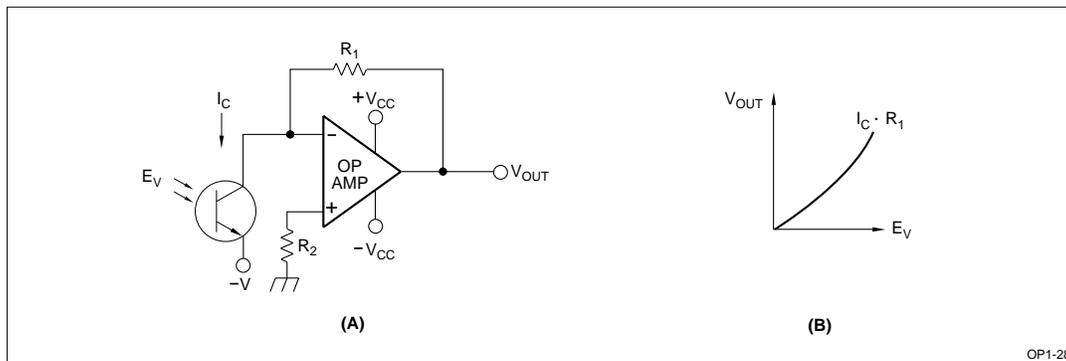

Figure 12. Modulated Signal Detection Circuit

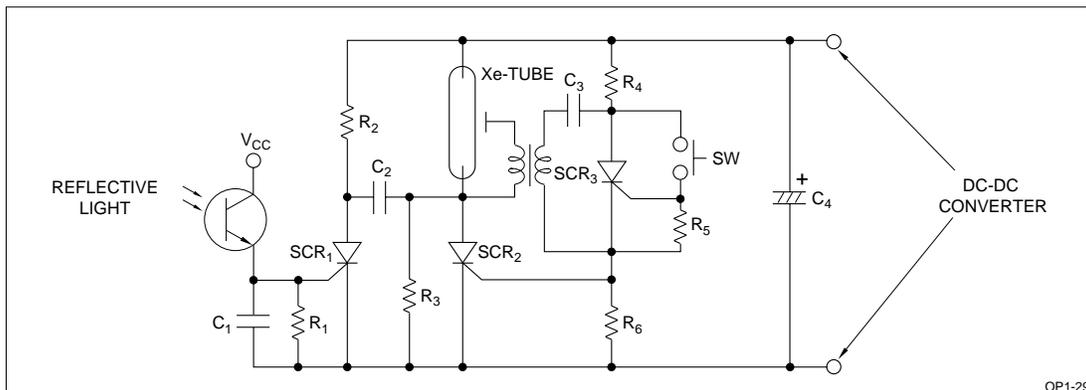**Figure 13. Amplifier Circuit using an Operational Amplifier**

Figure 14. Auto-Stroboscope Circuit

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