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# FUJI PLANAR ZENER DIODE


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## I. INTRODUCTION

With the diversification of electronic circuits and advancement of various semiconductor devices, it is becoming more important to stabilize the electronic circuit voltage in order to attain high performances and ensure reliable operations. Zener diodes are, as well known, most conveniently and advantageously applied for this purpose, while the requirements are increasing escalated both technically and economically, especially on three essential points of high reliability, small size and low price.

In addition to the ZB1 series of zener diodes hitherto being supplied in large quantity, Fuji Electric has completed two new series of planar zener diodes; the 500 mW EQA01 series and 1 W EQB01 series. For both series the novel planar techniques are exploited for improved characteristics and operational reliability. New zener diodes are also characterized by a compact size of the pin head type and by a flame retardant epoxy resin encapsulation.

New series now cover zener voltages ranging from 5 V to 35 V and can be responded to any market requirements.

## II. STRUCTURE AND MANUFACTURING TECHNIQUES

There are several types of junction structure of the zener diode pellets including the alloy type, the diffusion type and the epitaxial type. The planar type, however, is best suited to mass production and the reliability is also high. Fuji Electric has established a basic technique in which the planar pellet is adapted to the resin mold encapsulation, i.e. there are new techniques for the stabilization of the pellet, plating, soldering, etc. which will be described later. Both the EQA01 and the EQB01 series are thus being mass produced.

### 1. Structure

In the structure, the silicon pellet which has been stabilized is soldered between the pinhead type leads and the diode is sealed with epoxy resin using a transfer mold method. The outerview is shown in *Fig. 1*.

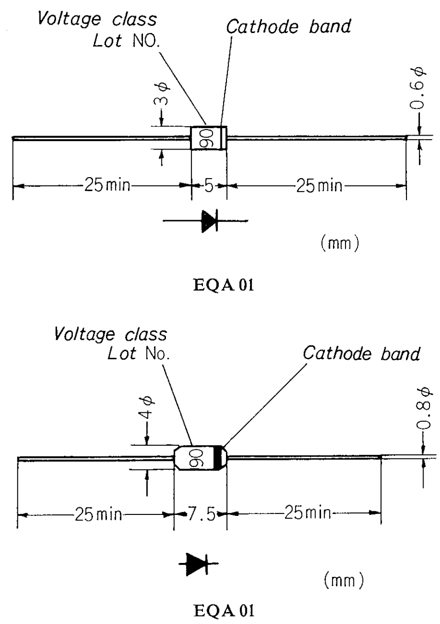



*Fig. 1* Dimensions of new zener diode series

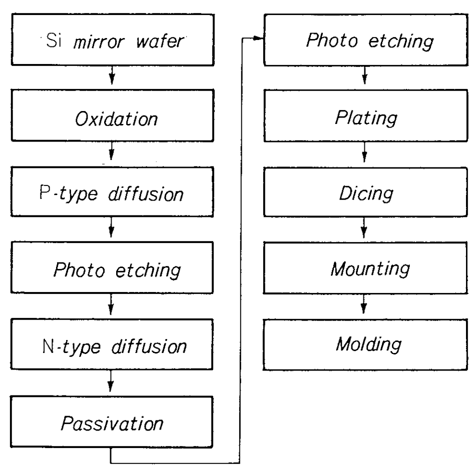



*Fig. 2* Flow chart of manufacturing process

### 2. Manufacturing Process

*Fig. 2* shows the flow chart for the manufacturing process for the EQA01 and the EQB01 series. The processes from oxidation to diffusion are the same as those used for ordinary planar type elements, but newly developed techniques are used for the passivation, plating and soldering process.

### 3. Passivation Technique

Since it is followed by plating and soldering processes, the surface passivation treatment must be particularly thorough. There are many cases when troubles will arise in the reliability of the element if this treatment is incomplete. At Fuji Electric, a special film coating is performed on the wafer surface after diffusion. In this way, high reliability is maintained since there is no damage to the pellet surface during the plating or soldering processes.

### 4. Plating Technique

There are various difficult conditions in electrode plating in planar type elements such as follows:

1) Every units are isolated electrically or electrochemically at the surface of the silicon wafer by means of the P-N junction. Therefore, electrolytic plating can not be used and the electroplating must be performed. However, it is difficult to achieve uniform metal deposition on individual elements.
2) Effective fluoric acid treatment or alkali treatment can not be performed as an activation pretreatment of the plating on the silicon surface in order to maintain stability of the surface protection.
3) Surface roughening treatment such as sand blasting can not be used from the view points of protection of surface and the diffused junction.

There have been reports of various types of surface pretreatment and plating methods used in the past to solve these problems. However, even with these methods, a sufficiently plated electrode can not be obtained. Fuji Electric uses an original method for pretreatment in which a thin uniform coat is achieved by primary nickel plating. Fuji has also developed a special compound plating liquid which allows the stronger adhesion between metal and silicon and better solderability.

### 5. Asssembly

Even when a passivated planar pellet is used, the characteristics of the zener diodes are still greatly influenced by the assembly process. In particular, the thermal and mechanical characteristics are mainly determined by the assembly process. For example, the solder used in the soldering process must not only have good wetness on the electrode of the silicon surface and lead wire, but should also be strong in respect to thermal fatigue. The solder material and soldering conditions used in both the EQA01 and EQB01 series have been selected with particular care considering these points. Thus, there is a high degree of stability in respect to thermal and mechanical stresses as well as shocks. In the encapsulation process, transfer molding using a flame retarding epoxy resin is employed so that the thermal stability is high.

## III. RATINGS AND CHARACTERISTICS

*Table 1* and 2 show the ratings of the EQA01 (allowable power loss: 500 mW) and the EQB01 (allowable power loss: 1,000 mW) planar type zener diodes respectively.

### 1. Ratings

There are three maximum ratings: the junction temperature ($T_j$), the storage temperature ($T_{stg}$) and the allowable power loss ($P_Z$). Since the reliability of the element could be reduced if it is used at ratings in excess of these maximum ratings, it is necessary that the diodes be designed for actual application at less than the maximum ratings. Since the measurement of the $T_j$ in actual circuits is rather specialized, generally, the ambient temperature and the power dissipated at the zener diode under the most severe conditions is measured and if the reduction characteristics of the allowable power loss are fulfilled at this ambient temperature, the diode can be used with sufficiently high reliability. However, when the diodes are used under special conditions such as when heat radiation or convection is received from other electronic parts or when heat radiation from lead wires is very good or very bad, there are large errors when only the relation between the ambient temperature and the power dissipation are used and the $T_j$ estimation is often wrong. Therefore, because of these conditions, the case temperature and lead wire temperature of the zener diode are measured under the most severe conditions and the circuit has to be designed for operation below the $T_j$ obtained from the graph in *Fig. 3* which shows the relation between the case and lead wire temperatures and the allowable power loss.

### 2. Characteristics

1) Breakdown characteristics

One of the most important characteristics in zener diodes are the breakdown characteristics. The gradient of the breakdown characteristics varies according to the zener voltage, junction structure. A typical example of the breakdown characteristics of the planar type zener diode EQA01 is compared with those of the mesa-type zener diode in *Fig. 4*.

2) Zener impedance

The zener impedance indicates the gradient of the build-up characteristics of the current in the breakdown region. It is a differential impedance at the zener current $I_Z$. The value of the zener impedance depends on the zener current and the zener voltage. In the same voltage class, there is a tendency for the impedance to decrease as the zener current increases, and this tendency increases as the voltage class becomes higher. *Fig. 5* shows the zener impedance and the zener voltage characteristics. Since

*Table 1* **Ratings of EQB 01 zener diodes**

Maximum Rating
- Allowable power dissipation ($P_z$) 500 mW ($T_a$=25°C)
- Junction temperature ($T_j$) 125°C
- Storage temperature ($T_{stg}$) −30°C～+125°C

Electrical characteristics ($T_a$=25°C)

| Type No. | | Zener voltage | | | | Zener impedance | | Zener impedance at low current | | Reverse current | | Temperature coefficient |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $V_Z$ (V) | | | $I_Z$ (mA) Test current | $R_Z$ (Ω) max | $I_Z$ (mA) Test current | $R_{ZK}$ (Ω) max | $I_{ZK}$ (mA) Test current | $I_S$ (μA) max | $V_r$ (V) Test voltage | $\gamma_Z$ (%/°C) nom |
| | | min | nom | max | | | | | | | | |
| EQA01–05 | | 4.5 | 5.0 | 5.6 | 15 | 25 | 15 | 1,600 | 0.50 | 5 | 1 | +0.01 |
| | R | 4.5 | 4.8 | 5.0 | | | | | | | | |
| | S | 4.7 | 5.0 | 5.3 | | | | | | | | |
| | T | 5.0 | 5.3 | 5.6 | | | | | | | | |
| EQA01–06 | | 5.3 | 6.0 | 6.6 | 15 | 20 | 15 | 1,600 | 0.50 | 5 | 2 | +0.03 |
| | R | 5.3 | 5.6 | 5.9 | | | | | | | | |
| | S | 5.7 | 6.0 | 6.3 | | | | | | | | |
| | T | 5.9 | 6.3 | 6.6 | | | | | | | | |
| EQA01–07 | | 6.3 | 6.9 | 7.5 | 15 | 15 | 15 | 700 | 0.25 | 5 | 3.5 | +0.04 |
| | R | 6.3 | 6.7 | 7.1 | | | | | | | | |
| | S | 6.7 | 7.1 | 7.5 | | | | | | | | |
| EQA01–08 | | 7.1 | 7.8 | 8.4 | 15 | 13 | 15 | 500 | 0.25 | 5 | 4 | +0.05 |
| | R | 7.1 | 7.5 | 7.9 | | | | | | | | |
| | S | 7.6 | 8.0 | 8.4 | | | | | | | | |
| EQA01–09 | | 8.0 | 8.8 | 9.5 | 15 | 15 | 15 | 600 | 0.25 | 3 | 5 | +0.055 |
| | R | 8.0 | 8.9 | 9.0 | | | | | | | | |
| | S | 8.5 | 9.0 | 9.5 | | | | | | | | |
| EQA01–10 | | 9.0 | 9.8 | 10.5 | 15 | 15 | 15 | 600 | 0.25 | 3 | 7 | +0.06 |
| | R | 9.0 | 9.5 | 10.0 | | | | | | | | |
| | S | 9.5 | 10.0 | 10.5 | | | | | | | | |
| EQA01–11 | | 10.1 | 11.1 | 11.8 | 15 | 17 | 15 | 600 | 0.25 | 3 | 8 | +0.065 |
| | R | 10.1 | 10.6 | 11.2 | | | | | | | | |
| | S | 10.6 | 11.2 | 11.8 | | | | | | | | |
| EQA01–12 | | 11.2 | 12.2 | 13.1 | 15 | 17 | 15 | 600 | 0.25 | 1 | 10 | +0.065 |
| | R | 11.2 | 11.8 | 12.4 | | | | | | | | |
| | S | 11.9 | 12.5 | 13.1 | | | | | | | | |
| EQA01–13 | R | 12.5 | 13.2 | 13.9 | 15 | 20 | 15 | 600 | 0.25 | 1 | 11 | +0.068 |
| EQA01–14 | R | 13.3 | 14.0 | 14.7 | 10 | 20 | 10 | 000 | 0.25 | 1 | 11 | +0.07 |
| EQA01–15 | R | 14.2 | 15.0 | 15.8 | 10 | 20 | 10 | 600 | 0.25 | 1 | 12 | +0.07 |
| EQA01–16 | R | 15.2 | 16.0 | 16.8 | 10 | 20 | 10 | 600 | 0.25 | 1 | 12.5 | +0.07 |
| EQA01–17 | R | 16.2 | 17.0 | 17.9 | 10 | 25 | 10 | 600 | 0.25 | 1 | 13 | +0.075 |
| EQA01–18 | R | 17.1 | 18.0 | 18.9 | 10 | 30 | 10 | 600 | 0.25 | 1 | 14 | +0.075 |
| EQA01–19 | R | 18.1 | 19.0 | 20.0 | 10 | 30 | 10 | 600 | 0.25 | 1 | 15 | +0.075 |
| EQA01–20 | R | 19.0 | 20.0 | 21.0 | 10 | 35 | 10 | 600 | 0.25 | 1 | 16 | +0.075 |
| EQA01–21 | R | 20.1 | 21.2 | 22.3 | 10 | 35 | 10 | 600 | 0.25 | 1 | 17 | +0.08 |
| EQA01–22 | R | 21.3 | 22.4 | 23.5 | 5 | 35 | 5 | 600 | 0.25 | 1 | 18 | +0.08 |
| EQA01–24 | R | 22.4 | 23.6 | 24.8 | 5 | 40 | 5 | 600 | 0.25 | 1 | 19 | +0.08 |
| EQA01–25 | R | 23.7 | 25.0 | 26.3 | 5 | 40 | 5 | 600 | 0.25 | 1 | 20 | +0.08 |
| EQA01–26 | R | 25.2 | 26.5 | 27.8 | 5 | 50 | 5 | 600 | 0.25 | 1 | 22 | +0.08 |
| EQA01–28 | R | 26.6 | 28.0 | 29.4 | 5 | 50 | 5 | 600 | 0.25 | 1 | 23 | +0.08 |
| EQA01–30 | R | 28.5 | 30.0 | 31.5 | 5 | 70 | 5 | 600 | 0.25 | 1 | 24 | +0.085 |
| EQA01–32 | R | 29.9 | 31.5 | 33.1 | 5 | 70 | 5 | 600 | 0.25 | 1 | 25 | +0.085 |
| EQA01–33 | R | 31.8 | 33.5 | 35.2 | 5 | 90 | 5 | 600 | 0.25 | 1 | 27 | +0.085 |
| EQA01–35 | R | 33.8 | 35.5 | 37.3 | 5 | 90 | 5 | 700 | 0.25 | 1 | 28 | +0.085 |

***Table 2* Ratings of EQA01 zener diodes**

Maximum rating

| | | |
|---|---|---|
| Allowable power dissipation ($P_z$) | 1 W ($T_a$=25°C) |
| Junction temperature ($T_j$) | 125°C |
| Storage temperature ($T_{stg}$) | −30～+125°C |

Electrical characteristics ($T_a$=25°C)

| Type No. | Zener voltage | | | | Zener impedance | | Zener impedance at low current | | Reverse current | | Temperature coefficient |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $V_Z$ (V) min | $V_Z$ (V) nom | $V_Z$ (V) max | $I_Z$ (mA) Test current | $R_Z$ (Ω) max | $I_Z$ (mA) Test current | $R_{ZK}$ (Ω) max | $I_{ZK}$ (mA) Test current | $I_S$ (μA) max | $V_r$ (V) Test voltage | $\gamma_Z$ (%/°C) nom |
| EQB01-05 | 4.5 | 5.0 | 5.6 | 30 | 23 | 30 | 1,550 | 0.50 | 5 | 1 | +0.01 |
| EQB01-06 | 5.3 | 6.0 | 6.6 | 30 | 18 | 30 | 1,550 | 0.50 | 5 | 2 | +0.03 |
| EQB01-07 | 6.3 | 6.9 | 7.5 | 30 | 14 | 30 | 650 | 0.25 | 5 | 3.5 | +0.04 |
| EQB01-08 | 7.1 | 7.8 | 8.4 | 30 | 12 | 30 | 450 | 0.25 | 5 | 4 | +0.05 |
| EQB01-09 | 8.0 | 8.8 | 9.5 | 30 | 14 | 30 | 550 | 0.25 | 3 | 5 | +0.055 |
| EQB01-10 | 9.0 | 9.8 | 10.5 | 30 | 14 | 30 | 550 | 0.25 | 3 | 7 | +0.06 |
| EQB01-11 | 10.1 | 11.0 | 11.8 | 30 | 16 | 30 | 550 | 0.25 | 3 | 8 | +0.065 |
| EQB01-12 | 11.2 | 12.2 | 13.1 | 30 | 16 | 30 | 550 | 0.25 | 1 | 10 | +0.065 |
| EQB01-13 | 12.5 | 13.2 | 13.9 | 30 | 18 | 30 | 550 | 0.25 | 1 | 11 | +0.068 |
| EQB01-14 | 13.3 | 14.0 | 14.7 | 20 | 18 | 20 | 550 | 0.25 | 1 | 11 | +0.07 |
| EQB01-15 | 14.2 | 15.0 | 15.8 | 20 | 18 | 20 | 550 | 0.25 | 1 | 12 | +0.07 |
| EQB01-16 | 15.2 | 16.0 | 16.8 | 20 | 18 | 20 | 550 | 0.25 | 1 | 12.5 | +0.07 |
| EQB01-17 | 16.2 | 17.0 | 17.9 | 20 | 22 | 20 | 550 | 0.25 | 1 | 13 | +0.075 |
| EQB01-18 | 17.1 | 18.0 | 18.9 | 20 | 25 | 20 | 550 | 0.25 | 1 | 14 | +0.075 |
| EQB01-19 | 18.1 | 19.0 | 20.0 | 20 | 25 | 20 | 550 | 0.25 | 1 | 15 | +0.075 |
| EQB01-20 | 19.0 | 20.0 | 21.0 | 20 | 30 | 20 | 550 | 0.25 | 1 | 16 | +0.075 |
| EQB01-21 | 20.1 | 21.2 | 22.3 | 10 | 30 | 10 | 550 | 0.25 | 1 | 17 | +0.08 |
| EQB01-22 | 21.3 | 22.4 | 23.5 | 10 | 30 | 10 | 550 | 0.25 | 1 | 18 | +0.08 |
| EQB01-24 | 22.4 | 23.6 | 24.8 | 10 | 35 | 10 | 550 | 0.25 | 1 | 19 | +0.08 |
| EQB01-25 | 23.7 | 25.0 | 26.3 | 10 | 35 | 10 | 550 | 0.25 | 1 | 20 | +0.08 |
| EQB01-26 | 25.2 | 26.5 | 27.8 | 10 | 45 | 10 | 550 | 0.25 | 1 | 22 | +0.08 |
| EQB01-28 | 26.6 | 28.0 | 29.4 | 10 | 45 | 10 | 550 | 0.25 | 1 | 23 | +0.08 |
| EQB01-30 | 28.5 | 30.5 | 31.5 | 10 | 60 | 10 | 550 | 0.25 | 1 | 24 | +0.085 |
| EQB01-32 | 29.9 | 31.5 | 33.1 | 10 | 60 | 10 | 550 | 0.25 | 1 | 25 | +0.085 |
| EQB01-33 | 31.3 | 33.5 | 35.2 | 10 | 80 | 10 | 550 | 0.25 | 1 | 27 | +0.085 |
| EQB01-35 | 33.3 | 35.5 | 37.3 | 10 | 80 | 10 | 650 | 0.25 | 1 | 28 | +0.085 |

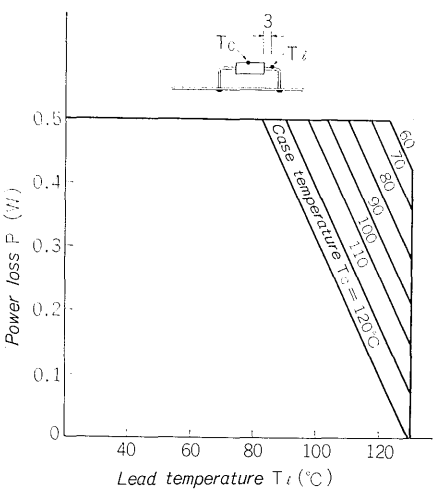



***Fig. 3* Lead temperature versus power loss of EQA 01**

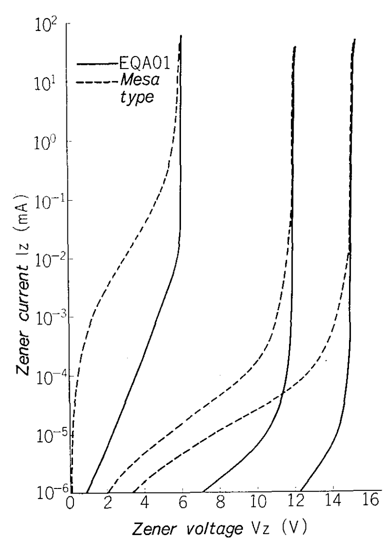



***Fig. 4* Zener voltage versus zener current**

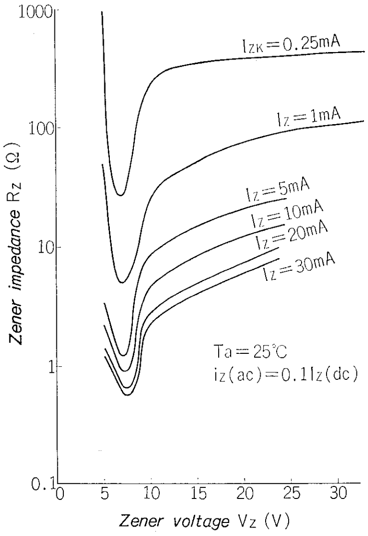



*Fig. 5* **Zener impedance versus zener voltage**

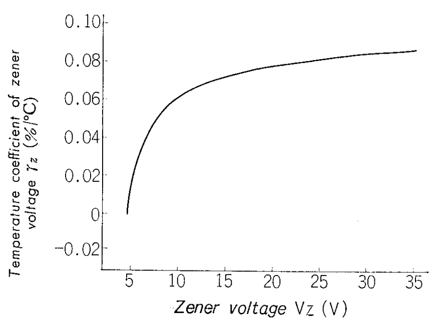



*Fig. 6* **Temperature coefficient versus zener voltage of EQA 01**

it is evident that the zener impedance values differ somewhat in accordance with the measured current, it is necessary to consider the measuring method and the measured temperature when comparing the value of the zener impedance.

3) Temperature coefficient of zener voltage

There are two types which can be considered to cause breakdown: the zener breakdown by tunneling effect and the avalanche breakdown by the collisions of electrons in the P-N junction region. These breakdowns have a boundry of around 6 V. At lower voltages, they are caused mainly by the zener effect and at higher voltages by the avalanche effect. Around this boundry voltage, various different effects can be seen. The temperature coefficient of the breakdown voltage is negative in the zener region, positive in the avalanche region and zero at around 5 V. The temperature coefficients of zener voltage $\gamma_Z$ is obtained from the following equation by measuring the zener voltages at a normal temperature of $T_1$ and a high temperature of $T_2$ with a test current of $I_Z$. The results are shown in *Fig. 6*.

$$\gamma_Z = [\{V_{Z(T_2)} - V_{Z(T_1)}\} / V_{Z(T_1)}] \times 100/(T_2 - T_1) \quad [\%/°C]$$

## IV. APPLICATION

1) Series connection

Zener diodes can be connected in series when a single diode does not have sufficient ratings. Sometimes, the series connection has advantages from the viewpoint of power loss, zener impedance and the change of zener voltage. Some precautions are however necessary for series connection. When two diodes having zener voltages $V_{Z1}$ and $V_{Z2}$ ($V_{Z1} > V_{Z2}$) are series connected, the resulting zener voltage $V_Z$ and the allowable powerloss $P$ become,

$$V_Z = V_{Z1} + V_{Z2}$$
$$P = I_Z\ (V_{Z1} + V_{Z2})$$

respectively, where $I_Z$ is the allowable zener current. As $P$ is not always equal to $2P_Z$, where $P_Z$ is the allowable powerloss of a single diode, the series connection should be designed to satisfy $P_Z \geqq I_Z\ V_{Z1}$. The temperature coefficient of zener voltage $\gamma_Z$ becomes,

$$\gamma_Z = (V_{Z1}\ \gamma_{Z1} + V_{Z2}\ \gamma_{Z2})/(V_{Z2}\ + V_{Z2})$$

where $\gamma_{Z1}$ and $\gamma_{Z2}$ are the temperature coefficients for each diode. *Fig. 6* shows the temperature coefficient of EQA01. It can be improved by combining lower voltage diodes since the lower voltage diode has lower temperature coefficient.

2) Constant voltage supply

*Fig. 7* shows an example of the most fundamental circuit for constant voltage supply. In this case, the input voltage $V_I$, series resistance $R_S$, current flowing through the zener diode $I_Z$ and power dissipation at the diode $P_Z$ of the circuit can be calculated from following equations:

$$V_I = R_s(I_Z + I_L) + V_Z$$
$$R_S = [V_{I(\min)} - V_{Z(\max)}]/[I_{Z(\min)} + I_{L(\max)}]$$
$$I_{Z(\max)} = [V_{I(\max)} - V_{(Z\min)}]/R_S - I_{L(\min)}$$
$$P_{Z(\max)} = [\{V_{I(\max)} - V_{(Z\min)}\}/R_S - I_{L(\min)}]\ V_{Z(\max)}$$

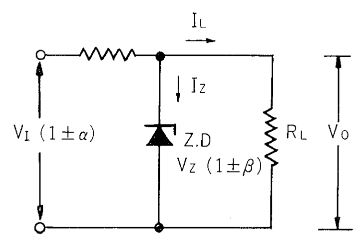



*Fig. 7* **Zener diode shunt regulator**

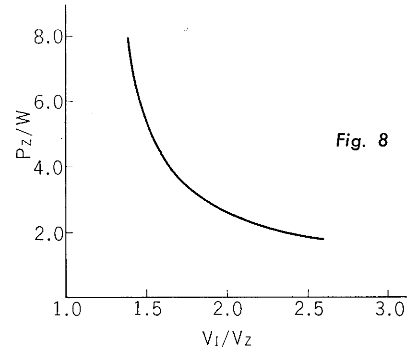



*Fig. 8* **Power consumption versus voltage of zener diode shunt regulator**

*Fig. 8* shows the relation between power dissipation and input voltage of the circuit of *Fig. 7* under an assumption that the fluctuation ratio of input voltage $\alpha$ is 15% and that of zener voltage $\beta$ is 10%. The fluctuations of input voltage and load current must be taken into consideration in designing such a circuit.

*Fig. 9* shows another basic example of constant voltage supply which contains a transistor and a zener diode. The load is connected to emitter of the transistor, and the zener diode to base. The transistor is controlled by the difference between the load voltage and the reference voltage.

3) Protection from surge

(1) Protection from line surge

The zener diode combined with a fuse can be advantageously used for protecting the electronic circuit, as shown in an example of *Fig. 10*. When an overvoltage is imposed on the circuit, the zener diode absorbs excess voltage and if surge current exceeds the rating of zener diode, the fuse blows to protect the device.

(2) Protection of transistors from overvoltage

Since transistors and similar semiconductor devices are usually vulnerable to overvoltage, the circuit including many transistors should be protected from surge voltage. *Fig. 11* shows an example of protection circuit for a transistorized ignitor, and *Fig. 12* shows another example for a DC-DC converter of surge protection. In these case, the zener diode is chosen so that the zener voltage is slightly lower than the avalanche breakdown voltage of collector junction of transistor.

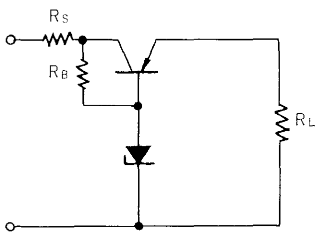
4) Noise clipper

Undesirable voltage like that shown by the dotted line of *Fig. 13* (a) is generated when contact of switch or relay is opened, especially when the connected load is inductive. To avoid this, a zener diode can be applied as shown in *Fig. 13* (b). The zener diode should, of course, be chosen in this case so that it has a slightly higher zener voltage than line peak voltage as well as an enough power dissipating capacity.

5) Zero voltage switch

In a phase-controlled thyristor circuit, as usually adapted in temperature controller, an excess current variation can easily be induced by switching-on of thyristor and gives various undesirable effects upon electrical equipment, such as radio interference. Zener voltage switching circuit shown in *Fig. 14* solves such troubles. As shown in this basic circuit, a rectangular-shaped pulse arising sharply upon an instance when line voltage passes near zero point, is generated by zener diode ZD1 and imposed on a differencial circuit consisting of $R_2$ and $C_1$. A pulse therefrom nearly synchronized to zezo point of line voltage triggers the thyristor, thus preventing the noise interference.

*Fig. 9* Emitter follower regulator



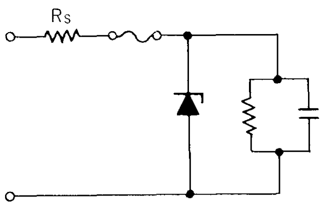




*Fig. 10* Overvoltage protection with zener diode and fuse

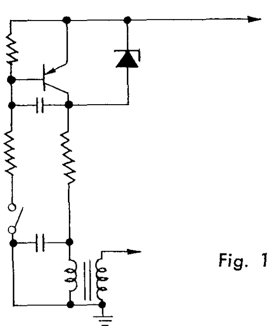
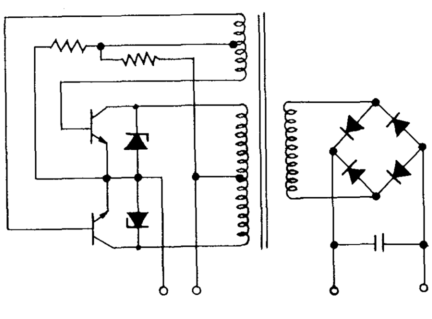
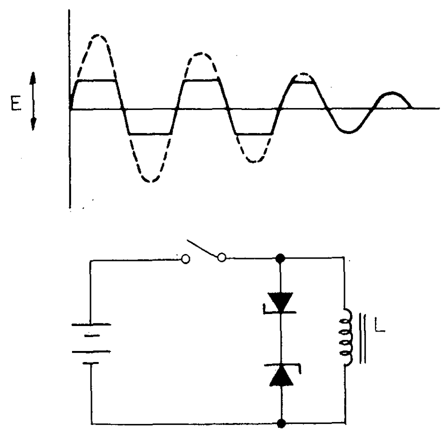


*Fig. 11* Transistor ignition system with zener diode overvoltage protection

*Fig. 12* DC-DC converter with surge protecting zener diodes






(a)

(b)

*Fig. 13* Noise clipper

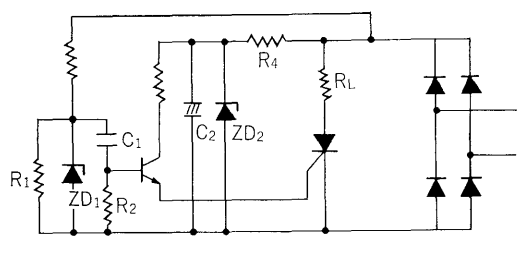



*Fig. 14* Zero voltage switch