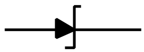
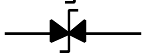
Transient Voltage Suppressor Diodes

1. INTRODUCTION

They are P-N junctions made from silicon, formed through a diffusion process, with zener breakdown, (avalanche), and specifically conceived to limit over voltages and dissipate high transient power with very short response times (1 pico sec) (10^{-12}).
They are manufactured un two versions:

-Unidirectional, symbol: 

-Bi-directional, symbol: 

To protect continuous current, unidirectional ones are used, with the cathode in the positive part of the voltage.

Bi-directional ones are used with either positive or negative voltage as they are basically two diodes in opposition.

These are commonly used in a.c. circuits due to its simetrical characteristic V-I.

These components fail when presented with power peak higher than the maximum P_{pp} of the diode which causes the silicon to fuse thereby shortcircuiting the diode.

Joining-up of diodes.

When a circuit has to be protected from over voltages of a high voltage or current value, the diodes may be grouped in serie or in parallel with the aim of creating a higher voltage (in the serie case) or a higher power (in the parallel case).

2. PROPERTIES OF SUPPRESSOR DIODES

The most important properties of these diodes are:

-Very short reponse times.

-Very small dynamic impedances in the conduction zone.

-Good clamping factors (1) due to the previous property.

-Good stability in long term storage and operation.

-High dissipation power of high power combined with over voltages of a short duration.

(1) The clamping factor is represented by V_{cl}/V_{BR}: i.e. the ratio between the maximum over voltage for a given current and the maximum voltage which the diode can withstand in continuous operation.

3. ELECTRICAL PARAMETERS

These protection components may be identified by a characteristic in the V-I graph, where electrical parameters in reverse and forward operation, (according to fig. 1 and 1-1) would be the following:

3.1. Reverse characteristics

V_{RM}: Rated reverse stand-off voltage, in which the diode does not conduct.

I_{RM}: Maximum reverse leakage current for a given V_{rm}.

V_{BR}: Breakdown Voltage or Knee Voltage is the voltage value above which the current increases very fast (avalanche point) for a slight increase in voltage.

I_{BR}: Test current for measuring Breakdown voltage or Knee voltage (V_{BR}).

V_{CL}: Maximum protection voltage a pulse with a I_{PP} peak value.

I_{PP}: Peak pulse current of a time and a determinate wave amplitude. (Usually, exponential pulse 10/1000 µs).

P_{PP}: Peak Pulse Power. It is the product I_{PP} x V_{CL}.

T_{CL}: Time taken by the suppressor diode to enter in avalanche. Owing to the fact that this physical phenomenon is extremely fast (around 1 pico sec) the absorption of overvoltages lasting a short time is guaranteed. (nsec).

C_o: Diode capacity at zero volts and 1 MHz.

3.2. Forward characteristics

V_F: Maximum forward voltage.

I_F: Forward current, continuous.

I_{FSM}: Rated forward pulse current.

3.3. Forward/reverse characteristics on V-I graph.

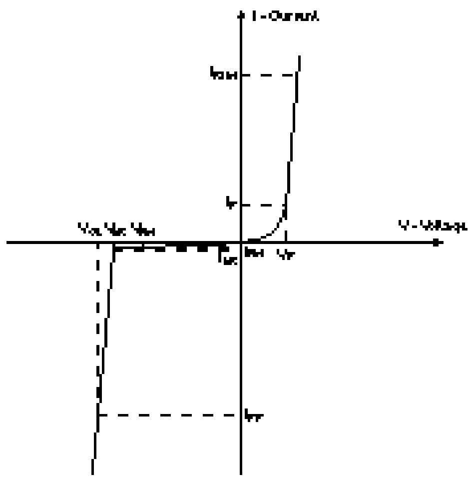


Fig. 1. V-I graph showing electric characteristics of a suppressor diode (unidirectional).

3.4. Forward/reverse characteristics on V-I graph.

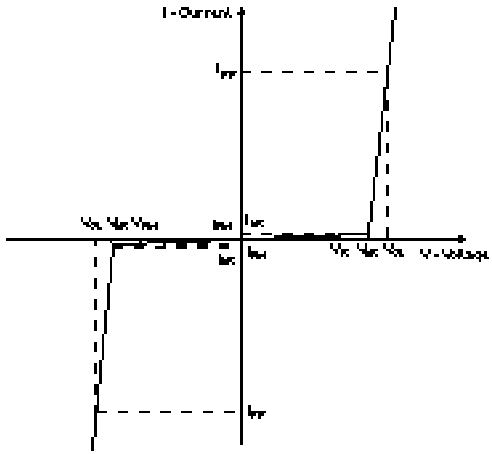


Fig. 1.1. V-I graph showing electric characteristics of a suppressor diode (bidirectional).

4. CHARACTERISTIC DATA

4.1. Breakdown voltage or knee voltage (V_{BR}).

This voltage is specified at a Tamb. of 25 °C.

4.2. Clamping voltage (V_{CL}).

Each suppressor diode has a specified V_{CL} voltage and current pulse I_{PP}.

The test pulse for the peak current and the campling voltage is a shock wave pulse characterised by a rise time and a fall time. Fig. 2.

The rise time lasts between 8 and 10 µsec and is defined between 10 and 90% of the maximum current value.

The fall time is that which the current takes to go down to 50% of the peak value, between 20 and 1.000 µsec.

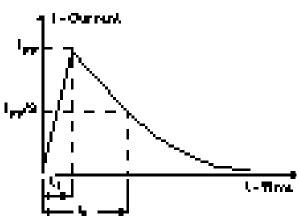


Fig. 2. Current impulse waveform.

	t_1 µs	t_2 µs
Wave 8/20 µs	8	20
Wave 10/1.000 µs	10	1.000

If the pulse applied to the diode differs from the standard (8/20 or 10/100µs) the maximum V_{CL} value reached may be calculated using the current level, the duration of the pulse and the temperature of the diode before the pulse. See Figs. 3, 4 and 5.

4.3. Maximum transient power for suppressor diodes

4.3.1. Exponential wave

The Power-Time diagram, showing an exponential wave, should be used to determine the maximum a suppresor diode can withstand for a specific time. (see fig. 3).

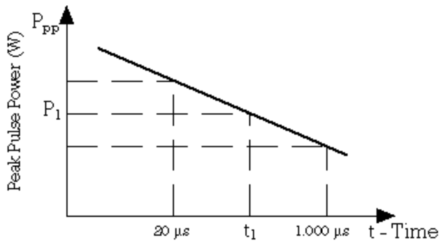


Fig. 3.Maximum power of a non-standard exponential pulse.
This curve is provided in the data sheets.

In order to calculate the power which a suppressor diode will withstand for the time, t_1, we trace a line perpendicular to the time axis (t) until it meets the Power-Time straight line. We then draw a line from this point parallel to the time axis so as to obtain the Power value (P_1).

4.3.2. Waves different from the exponential

In order to calculate the power which the suppresor diode will withstand when a wave different from the standard (exponential) one is used, we need to refer to the equivalent exponential wave which generates the same energy as the wave.

Equivalent waves are:

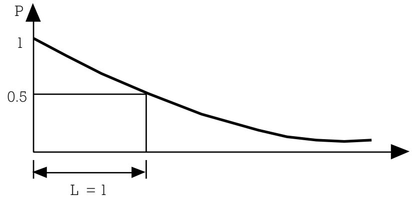


Fig. 4.1. Exponential pulse.

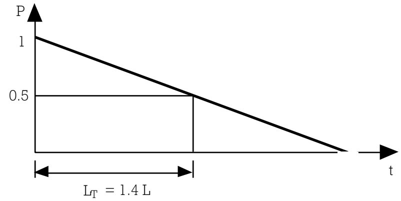


Fig. 4.2. Sawtooth pulse.

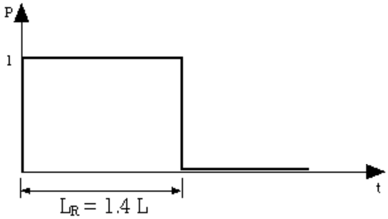


Fig. 4.3. Rectangular pulse.

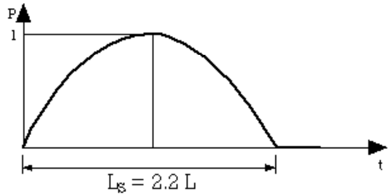


Fig. 4.4. Sinusoidal pulse.

The pulses shown in the previopus figures, with identical amplitude values, are of the same energy which should be dissipated by the protector diode.

Likewise, it will be seen that both the rectangular and the sawtooth pulse has a duration 1.4 times greater than the exponential with the sinusoidal being 2.2. times greater.

The calculation requires a correction of the time of the wave originally looked at and this is then refered to the exponential curve. Once this has been done, the maximum power which the suppressor diode will withstand is calculated on the Power-Time curve as if the wave were exponential.

The power versus time diagram for a standard surge (exponential waveform) of a 1.500 W/l msec suppressor is showed. It is ahowed also the modified characteristic when the applied waveform is rectangular or sinusoidal.

In order to calculate the power in other waveforms it is only required to draw a paralell line in the Power-Time diagram by the point of the standard power at 1 msec and 1,4 msec for rectangular pulses and 2,2 msec for sinusoidal pulses.

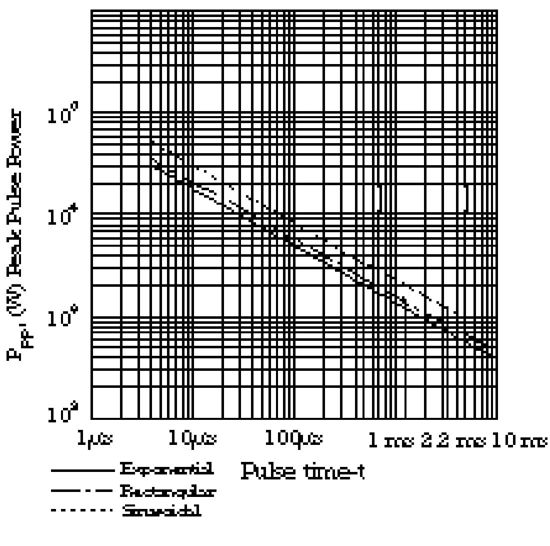


Fig. 4.5.Power versus time for different surge waveforms (1.500 W/l ms. exponential).

4.4. Derating curve

The curve in figure 5 and 5.1. shows the modification of the peak power (P_{PP}) if the initial temperature of the diode is greater than 25 °C.

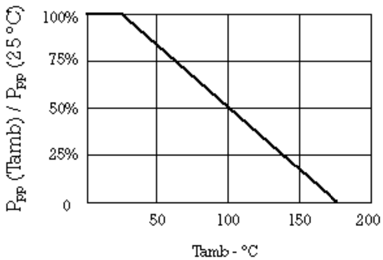


Fig. 5. Derating curve for T_j = 175 °C.

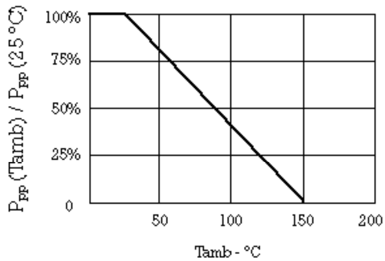


Fig. 5.1. Derating curve for T_j = 150 °C.

4.5. Response time (T_{CL})

As we have already said, the main function of suppressor diodes is to eliminate the overvoltages produced by current pulses (current surges).

given that these current surges are not produced by connection inductances, it can be stated that these diodes provide an instant reponse.

It should be wire in mind that the avalanche phenomenon of a silicon diode is extremely fast (theoretical value of 1 pico sec).

4.6. Test circuit and waveform

The most usual test circuit is the following: (see Fig. 6).

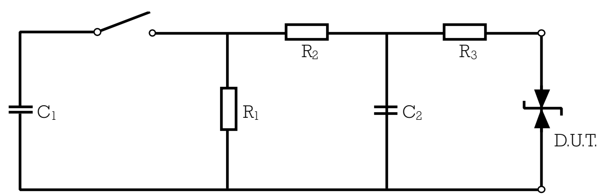


Fig. 6. Test Circuit.

The capacitor C_1 is charged with a variable voltage depending on the type of diode to be tested. The resistances R1, R2 and R3 are variable according to the durating of the pulse to be checked and the maximum current.

By means of a high voltage and current switch the above mentioned capacitor is discharged on the diode undergoing testing.

With the assistance of a KEYTEK surge generator the clamping voltage value is obtained for a given pulse current.

The wave form obtained is similar to hat in fig. 7 and 7.1.

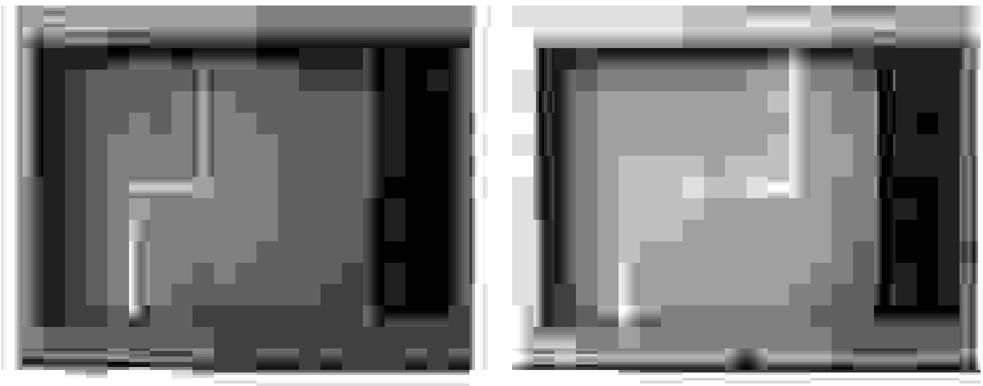


Fig. 7. Waveforms in suppressor diodes.

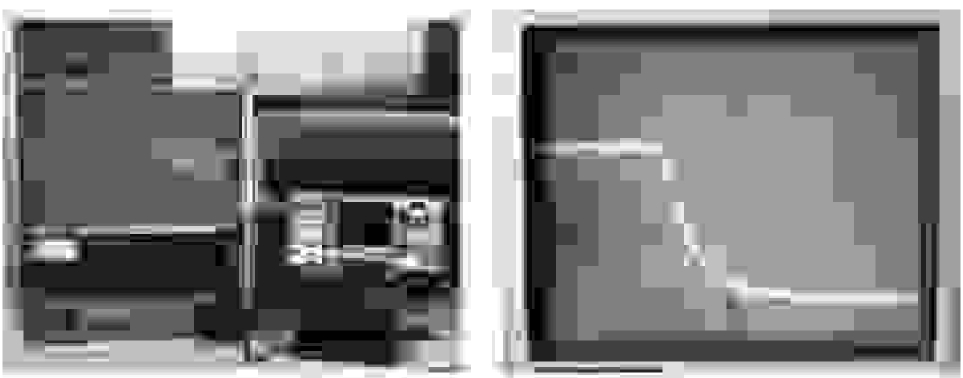


Fig. 7.1. Keytek measurement equipment.

Failure mechanism

Failure in a suppressor diode occurs when there is energy at its terminals greater than rhat which suppressor can withstand. The diode shortcircuits. Protection of the charge is guaranteed for a time, t, which is obtained from the I^2t (integral charge limit) which the diode can withstand.

It is a advisable to have a circuit breaker fitted which cuts off the supply of current for an excessively long time.

5. CALCULATION AND CHOICE OF TVS DIODES

When attempting to provide suitable protection for a circuit, it is advisable to choose the optimun component which guarantees the suppression of overvoltages which occur.

In the first part of the calculation the maximum voltage which the circuit has to withstand without deterioration is taken into account. This fixes the maximum clamping voltage of the suppressor diode.

This information together with the peak current which is produced in the suppressor allows us to choose the suitable power:

$$P_{PP} = V_{CL} \times I_{PP}$$

As an example we are going to invent a circuit (see Fig. 8). With a 12 supply and with components whose maximum allowed voltage is 18 volts.

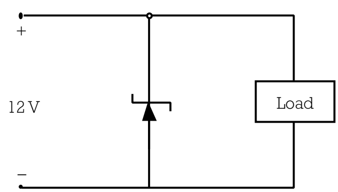
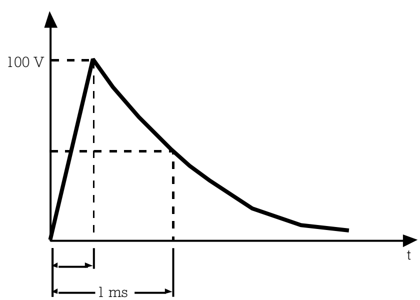


Fig. 8. Circuit to be protected.

This circuit is randomly subjected to exponential pulse of a peak value of 100 volts and duration of 1.000 µsec.

Fig. 9 - Fig. 8. Circuit pulse wave



Assuming that the terminal resistance of the circuit, r_i, is 10 ohms and the maximum operating temperature is limited to 45 °C, we have:

$$V_{CL} = 18\ V;\ I_{PP} = \frac{V_P - V_{CL}}{r_i} = \frac{100 - 18}{10} = 8.2\ Amp.$$

where $P_{PP} = V_{CL} \times I_{PP} = 18 \times 8.2 = 147.6$ Watts

and $P_{PP} = 147.6$ Watts.

On appling the derating factor (see Figs. 5 and 5.1) which exists between 25 and 45 °C, we have:

$$\frac{P\ (45\ \text{degrees centigrade})}{P\ (25\ \text{degrees centigrade})} = 0.875$$

And as the suppressor will have to withstand 25 °C:

$$P\ 25\ \text{degrees C}) = \frac{P\ (45\ \text{dregrees C})}{0.875} = \frac{147.6}{0.875} = 168.6\ \text{Watts.}$$

The type which correspond to these characteristics is the BZW04 series as the peak power is sufficient to withstand the above peak.

The BZW04-13 diode corresponds to the following characteristics:

V_{RM} = 12.8 V

V_{BR} = 15 V

V_{CL} = 21.2 V

I_{PP} = 19 A

P_{PP} = 400 W/l msec

With the above data, we now need to know the W_{CL} clamping voltage which is reached when a peak current of 8.2 A. is produced.

To do this, the following formula is apllied:

$$V_{CL} = V_{BR} + rd \cdot I_{PP}$$

Which gives us the clamping voltage from the differential resistence.

$$r_d = \frac{V_{CL} - V_{BR}}{I_{PP}} = \frac{21.2 - 15}{19} = 0.32$$

V_{CL} (8.2 A) = 15 + 0.32 · 8.2 = 17.67 V.

The calculation before the V_{CL} one was made at a temperature of 25 °C but in our example we were thinking of a temperature of 45 °C. We therefore have to correct the voltage we have calculated as the temperature coefficient is positive.

For the mentioned voltage, the temperature coefficient is 0.075%C. See 3.1. Therefore:

$$V_{CL}\text{ (45 degrees C)} = V_{CL}\text{ (25 degrees C)} + \frac{0.075}{100} \cdot (45 - 25)\, V_{CL}\text{ (25)}$$

V_{CL} (45 degrees C) = 17.67 + 0.26 = 17.93 Volts

This value of 17.93 volts meets the protection requirements os the above circuit for the BXW04-13, offering complete protection to the components which cannot withstand more than 18 volts.

5.1. Variation in the breakdown voltage with reference to temperature

In the following table, values are given in percent for each degree centigrade for the variation in the breakdown voltage in suppressor diodes.

The variation coefficient is positive and the increase should be taken into account in the clamping voltage.

Breakdown voltage (volts)	Temperature coefficient (%/degrees C)
7.5	+0.035
8.2	+0.055
9.1	+0.055
10	+0.070
11	+0.075
12	+0.075
13	+0.075
15	+0.075
16	+0.085
18	+0.085
20	+0.085
22	+0.085
24	+0.085
27	+0.085
30	+0.085
33	+0.085
36	+0.085
39	+0.085
43	+0.095
47	+0.095
51	+0.095

Breakdown voltage (volts)	Temperature coefficient (%/degrees C)
56	+0.095
62	+0.105
68	+0.105
75	+0.105
82	+0.105
91	+0.11
100	+0.11
110	+0.11
120	+0.11
130	+0.11
150	+0.11
160	+0.11
170	+0.11
180	+0.11
200	+0.11
220	+0.11
250	+0.11
300	+0.11
350	+0.11
400	+0.11
440	+0.11

6. NOTES ON APPLICATIONS

The circuits shown in the following diagrams are typical applications. The user will incorporate suppressor diodes, in his own circuit, in places where suitable protection is needed.

Engineers involved in circuit desing should reduce the circuits path which connect the suppressor diode to the power load to be protected. The aim of this being reduce the effect of L di/dt (See.4.11, installation considerations).

They should also choose a suppressor diode with a V_{RM} which is greater than the circuit supply voltage.

The suppressor diodes should be placed at a secondary level, i.e. after a line impedance. Its use in primary protection should only be made in combination with suppressor elements with high current capacity such as gas valve which filter pulses of width duration.

In the case of high impedance insulation transformers, the suppressor diode is most suited for power supply and card sources. This is due to its low differential resistance and ideal for clamping the overvoltage pulses produced.

6.1. Protection against line transient (fig. 10)

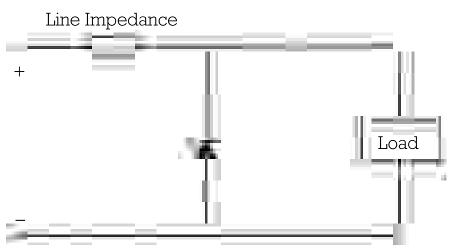


Fig. 10

6.2. Suppression of transients caused by load switching (Fig. 11)

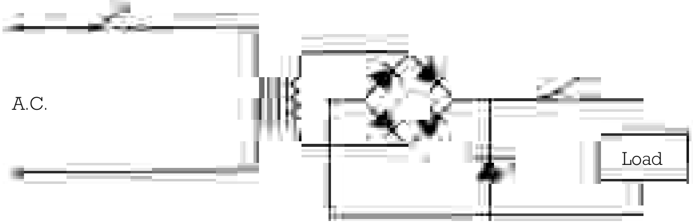


Fig. 11

6.3. EMI limiting (Fig. 12)

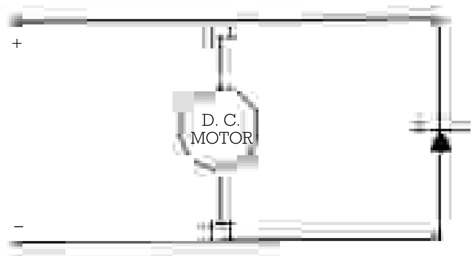


Fig. 12

6.4. Suppression of transients on A.C. supplies (Fig. 13)

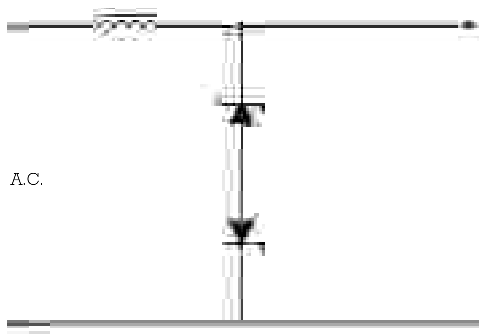


Fig. 13

6.5. Relay and contactor transient limiting (Fig. 14 and 15)

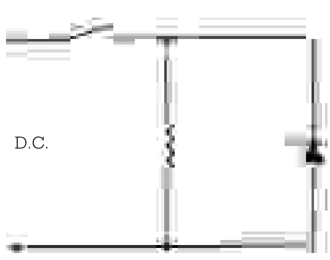


Fig. 14

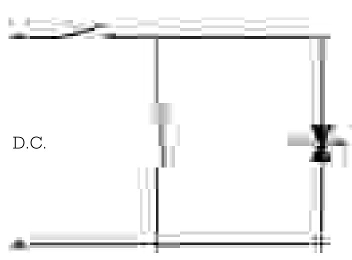


Fig. 15

6.6. Suppression of transients caused by load shorting (Fig. 16)

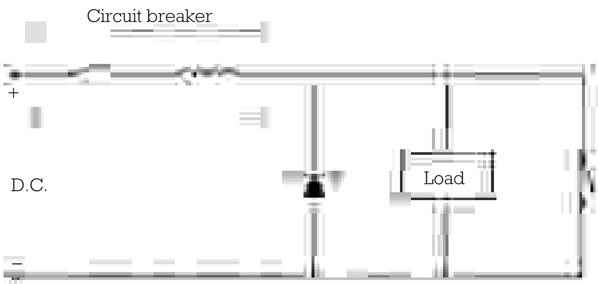


Fig. 16

6.7. Circuit protection from overvoltage supply power (Fig. 17)

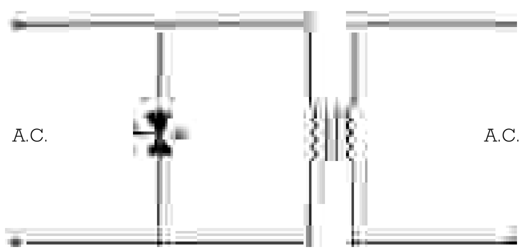


Fig. 17

6.8. A.C. supply protection (Fig. 18)

Fig. 18

6.9. R.F. coupling (Fig. 19 and 20)

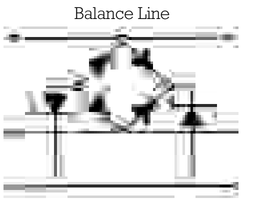


Fig. 19

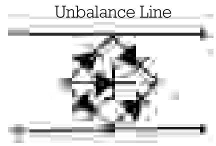


Fig. 20

6.10. A.C. supply protection (Fig. 21)

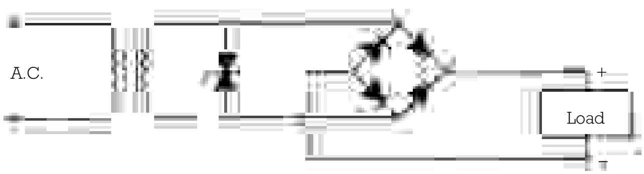


Fig. 21

6.11. Installation considerations

- Locate the transient suppressor diode as close to the device or circuit to be protected as possible.
- Minimize the «common path» through the diode to minimize voltage spikes produced by fast risetime transients in lead and wiring stray inductance. See figure 22-1 and 22-2.

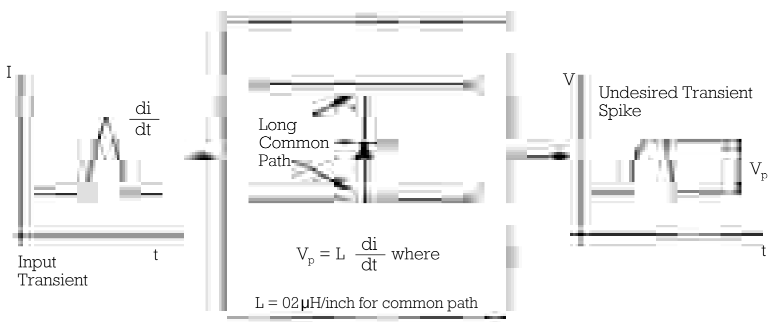


Fig. 22-1. Minimizing the common path. Incorrect method.

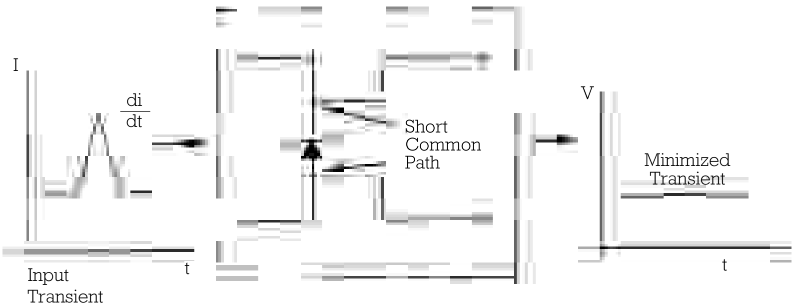


Fig. 22.2. Minimizing the common path. Correct method.

6.12. Other considerations

Mounting instructions

6.12.1. Minimum distance from body to soldering point, 4 mm.

6.12.2. Maximum solder temperature, 300 °C.

6.12.3. Maximum soldering time, 3.5 seg.

6.12.4. Do not bend lead at point closer than:

2 mm. to the body for DO-15

3 mm. to the body for DO-201 AE

4 mm. to the body for P-6