2

The Power Diode

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2.1 Diode as a Switch

Among all the static switching devices used in power electronics (PE), the power diode is perhaps the simplest. Its circuit symbol, shown in Fig. 2.1, is a two terminal device, and with terminal A known as the anode and terminal K known as the cathode. If terminal A experiences a higher potential compared to terminal K, the device is said to be forward biased and a forward current (I_F) will flow through the device in the direction as shown. This causes a small voltage drop across the device (<1 V), which under ideal conditions is usually ignored. By contrast, when a diode is reverse biased, it does not conduct and the diode then experiences a small current flowing in the reverse direction called the leakage current. Both forward voltage drop and leakage current are ignored in an ideal diode. In PE applications a diode is usually considered to be an ideal static switch.

The characteristics of a practical diode depart from the ideals of zero forward and infinite reverse impedance, as shown in Fig. 2.2a. In the forward direction, a potential barrier associated with the distribution of charges in the vicinity of the junction, together with other effects, leads to a voltage drop. In the case of silicon this is in the range of 1 V for currents in the normal range. In the reverse direction, within the normal voltage operating range, a very small current flows that is largely independent of the voltage. For practical purposes the static characteristics are often represented as shown in Fig. 2.2b. In Fig. 2.2b the forward characteristic is expressed as a threshold voltage V_O with a linear incremental or slope resistance *r*. The reverse characteristic remains the same over the range of possible leakage currents irrespective of voltage within the normal working range.

2.2 Some Properties of PN Junction

From the forward and reverse-biased condition characteristics, one notices that when the diode is forward biased, current rises rapidly as the voltage is increased. Current in the reverse-biased region is significantly small until the breakdown voltage of the diode is reached. Once the applied voltage is over this limit, the current will increase rapidly to a very high value limited only by an external resistance.

DC Diode parameters. The most important are the following:

- ***Forward voltage*** V_F is the voltage drop of a diode across *A* and *K* at a defined current level when it is forward biased.
- ***Breakdown voltage*** V_B is the voltage drop across the diode at a defined current level when it is beyond reverse-biased level. This is known as avalanche.
- ***Reverse current*** I_R is the current at a particular voltage, and which is below the breakdown voltage.

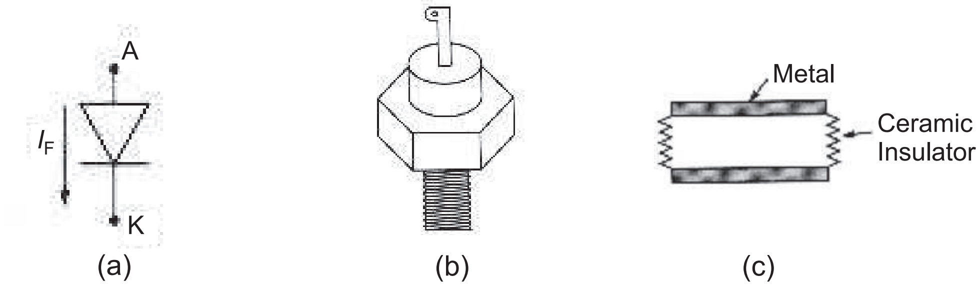

FIGURE 2.1 Power diode: (a) symbol; (b) and (c) types of packaging.

AC Diode parameters. Very common are the following:

- ***Forward recovery time*** t_{FR} is the time required for the diode voltage to drop to a particular value after the forward current starts to flow.
- ***Reverse recovery time*** t_{RR} is the time interval between the application of reverse voltage and the reverse current dropped to a particular value as shown in Fig. 2.2. Parameter t_a is the interval between the zero crossing of the diode current and when it becomes I_{RR}. On the other hand, t_b is the time interval from the maximum reverse recovery current to ≈ 0.25 of I_{rr}. The ratio of the two parameters t_a and t_b is known as the softness factor SF. Diodes with abrupt recovery characteristics are used for high-frequency switching. See Fig. 2.3 for soft and abrupt recovery.

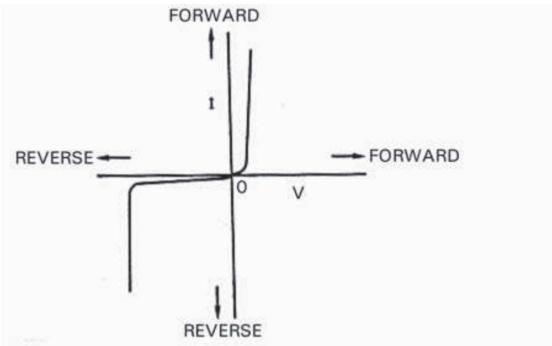

FIGURE 2.2a Typical static characteristic of a power diode (forward and reverse have different scale).

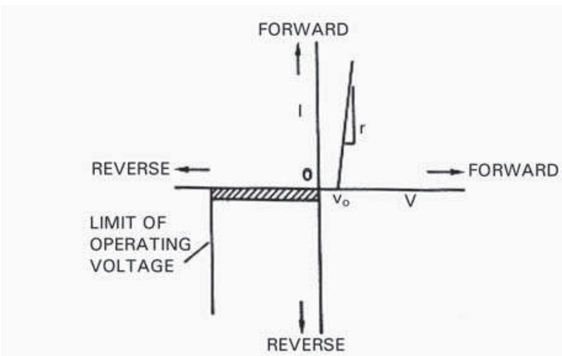

FIGURE 2.2b Practical representation of the static characteristic of a power diode.

In practice, a design engineer frequently needs to calculate reverse recovery time in order to evaluate the possibility of high-frequency switching. As a rule of thumb, the lower t_{rr} is, the faster the diode can be switched [1].

$$t_{rr} = t_a + t_b \tag{2.1}$$

If t_b is negligible compared to t_a (which commonly occurs), then the following expression is valid:

$$t_{rr} = \sqrt{\frac{2Q_{RR}}{di/dt}}$$

from which the reverse recovery current

$$I_{rr} = \sqrt{\frac{di}{dt} 2Q_{RR}}$$

where Q_{RR} is the storage charged, and can be calculated from the area enclosed by the path of the recovery current.

Example 2.1 The manufacturer of a selected diode gives the rate of fall of the diode current $di/dt = 20\,\text{A}/\mu\text{s}$, and a reverse recovery time of $t_{rr} = 5\,\mu\text{s}$. What value of peak reverse current do you expect?

Solution. The peak reverse current is given as:

$$I_{rr} = \sqrt{\frac{di}{dt} 2Q_{RR}}$$

The storage charge Q_{RR} is calculated as $Q_{rr} = \frac{1}{2} di/dt t_{rr}^2 = 1/2 \times 20\ \text{A}/\mu\text{s} \times (5 \times 10^{-6})^2 = 50\ \mu\text{C}$. Hence

$$I_{rr} = \sqrt{20 \frac{a}{\mu s} \times 2 \times 50\ \mu C} = 44.72\ A$$

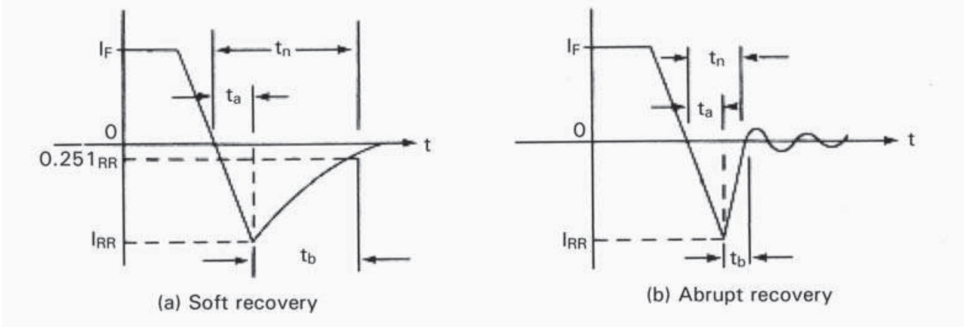

FIGURE 2.3 Diode reverse recovery process with various softness factors. (a) Soft recovery; and (b) abrupt recovery.

Diode Capacitance C_D is the net diode capacitance including the junction (C_J) plus package capacitance (C_P).

In high-frequency pulse switching a parameter known as transient thermal resistance is of vital importance because it indicates the instantaneous junction temperature as a function of time under constant input power.

2.3 Common Diode Types

Depending on their applications, diodes can be segregated into the following major divisions:

Small Signal Diode. These are the semiconductor devices used most often in a wide variety of applications. In general purpose applications, they are used as a switch in rectifiers, limiters, capacitors, and in wave shaping. The common diode parameters a designer needs to know include forward voltage, reverse breakdown voltage, reverse leakage current, and recovery time.

Silicon Rectifier Diode. These are the diodes that have high forward-current carrying capability, typically up to several hundred amperes. They usually have a forward resistance of only a fraction of an ohm while their reverse resistance is in the megaohm range. Their primary application is in power conversion, such as for power supplies, UPS, rectifiers/inverinverters etc. In case of current exceeding the rated value, their case temperature will rise. For stud mounted diodes, their thermal resistance is between 0.1 to 1° C/W.

Zener Diode. Its primary applications are in the voltage reference or regulation. However, its ability to maintain a certain voltage depends on its temperature coefficient and impedance. The voltage reference or regulation application of Zener diodes are based on their avalanche properties. In the reverse-biased mode, at a certain voltage the resistance of these devices may suddenly drop. This occurs at the Zener voltage V_X, a parameter the designer knows beforehand.

Figure 2.4 shows a circuit in which a Zener diode is used to control the reference voltage of a linear power supply. Under normal operating conditions, the transistor will transmit power to the load (output) circuit. The output power level will depend on the transistor base current. A very high base current will impose a large voltage across the Zener and it may attain Zener voltage V_X, at which point it will crush and limit the power supply to the load.

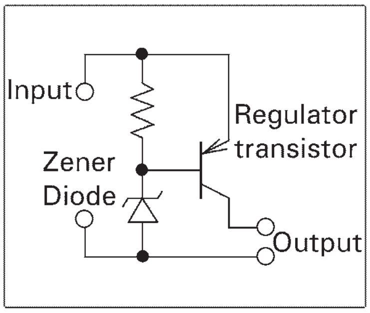

FIGURE 2.4 Voltage regulator with a Zener diode for reference.

Photodiode. When a semiconductor junction is exposed to light, photons generate hole-electron pairs. When these charges diffuse across the junction, they produce photo current. Hence this device acts as a source of current that increases with the intensity of light.

Light-Emitting Diode (LED). Power diodes used in PE circuits are high-power versions of the commonly used devices employed in analog and digital circuits. They are manufactured in many varieties and ranges. The current rating can be from a few amperes to several hundreds while the voltage rating varies from tens of volts to several thousand volts.

2.4 Typical Diode Ratings

2.4.1 Voltage Ratings

For power diodes, a data sheet will give two voltage ratings. One is the repetitive peak inverse voltage (V_{RRM}) and the other is the nonrepetitive peak inverse voltage. The nonrepetitive voltage (V_{RM}) is the diode's capability to block a reverse voltage that may occur occasionally due to an overvoltage surge. On the other hand, repetitive voltage is applied on the diode in a sustained manner. To understand this, let us look at the circuit in Fig. 2.5a.

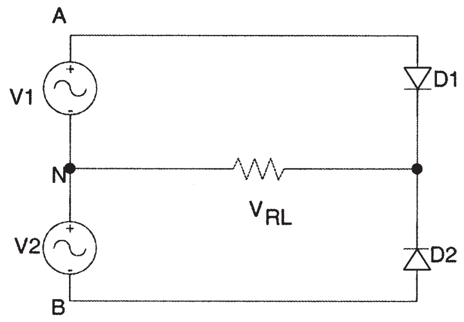

FIGURE 2.5 (a) The circuit.

EXAMPLE 2.2. Two equal source voltages of 220 V peak and phase-shifted from each other by 180° supply a common load: (a) Show the load voltage; (b) describe when diode $D1$ will experience V_{RRM}; and (c) determine the V_{RRM} magnitude considering a safety factor of 1.5.

SOLUTION. (a)The Input voltages, load voltage, and the voltage across D1 when it is not conducting (V_{RRM}) are shown in Fig. 2.5b.

(b) Diode D1 will experience V_{RRM} when it is not conducting. This happens when the applied voltage V1 across it is in the negative region (from 70 to 80 ms as shown in Fig. 2.5b) and consequently the diode is reverse biased. The actual ideal voltage across it is the peak value of the two input voltages $220 \times 2 = 440$ V. This is because when $D1$ is not conducting, $D2$ is. Hence, V_{an}, V_{bn} is also applied across it because $D2$ is practically shorted.

(c) The $V_{RRM} = 440$ V is the value under ideal circumstances. In practice, however, higher voltages may occur due to stray circuit inductances and/or transients due to the reverse recovery of the diode. These are hard to estimate. Hence, a design engineer would always use a safety factor to cater to these overvoltages, that is, a diode with a $220 \times 2 \times 1.5 = 660$ V rating.

2.4.2 Current Ratings

Power diodes are usually mounted on a heat sink. This effectively dissipates the heat arising due to continuous conduction. Current ratings are estimated based on temperature rise considerations. The data sheet of a diode normally specifies three different current ratings. These are: (1) the average current; (2) the rms current; and (3) the peak current. A design engineer must ensure that each of these values are never exceeded. To do that, the actual current (average, rms, and peak) in the circuit must be evaluated either by calculation, simulation, or measurement. These values must be checked against the ones given in the data sheet for that selected diode. The calculated values must be less than or equal to the data sheet values. The following example shows this technique.

EXAMPLE 2.3 The current waveform passing through a diode switch in a switch-mode power-supply application is shown in Fig. 2.6. Find the average, rms and peak currents.

SOLUTION. The current pulse duration is shown to be 0.2 ms within a period of 1 ms and with a peak amplitude of 50 A. Hence the required currents are:

$$I_{average} = 50 \times \frac{0.2}{1} = 10 \text{ A}$$

$$I_{rms} = \sqrt{50^2 \times \frac{0.2}{1}} = 22.36 \text{ A}$$

$$I_{rms} = 50 \text{ A}$$

Sometimes, a surge current rating and its permissible duration are also given in a data sheet. For protection of diodes and other semiconductor devices, a fast acting fuse is required.

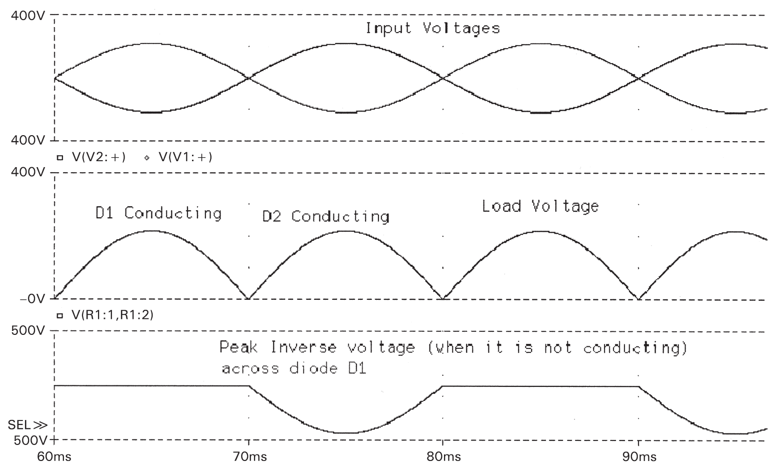

FIGURE 2.5 (b) The waveforms.

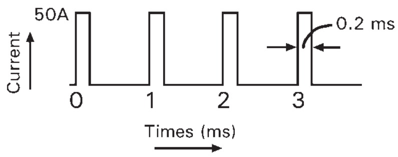

FIGURE 2.6 The current waveform in Example 2.3.

These fuses are selected based on their I^2t rating, which is normally specified in a data sheet for a selected diode.

2.5 Snubber Circuits for Diode

Snubber circuits are essential for diodes used in switching circuits. It can save a diode from overvoltage spikes, which may arise during the reverse recovery process. A very common snubber circuit for a power diode consists of a capacitor and a resistor connected in parallel with the diode as shown in Fig. 2.7.

When the reverse recovery current decreases, the capacitor by virtue of its property will try to retain the voltage across it, which is approximately the voltage across the diode. The resistor, on the other hand, will help to dissipate some of the energy stored in the inductor, which forms the I_{rr} loop. The dv/dt across a diode can be calculated as:

$$\frac{dv}{dt} = \frac{0.632*V_S}{\tau} = \frac{0.632*V_S}{R_S*C_S} \qquad (2.2)$$

where V_S is the voltage applied across the diode.

Usually the dv/dt rating of a diode is given in manufacturer datasheets. By knowing dv/dt and R_S, one can choose the value of the snubber capacitor C_S. Here R_S can be calculated from the diode reverse recovery current:

$$R_S = \frac{V_S}{I_{rr}} \qquad (2.3)$$

The designed dv/dt value must always be equal or lower than the dv/dt value found from the data sheet.

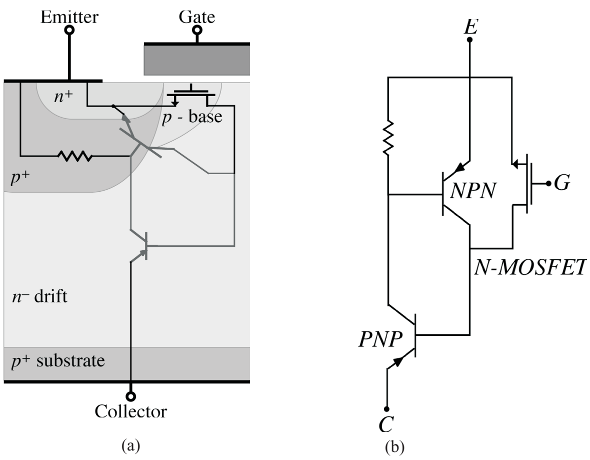

FIGURE 2.7 A typical snubber circuit.

2.6 Series and Parallel Connection of Power Diodes

For specific applications when the voltage or current rating of a chosen diode is not enough to meet the designed rating, diodes can be connected in series or in parallel. Connecting them in series will give the structure a high voltage rating that may be necessary for high-voltage applications [2]. However, one must ensure that the diodes are properly matched, especially in terms of their reverse recovery properties. Otherwise, during reverse recovery there may be large voltage unbalances between the series-connected diodes. Additionally, due to differences in reverse recovery times, some diodes may recover from the phenomenon earlier than the others, thereby causing them to bear the full reverse voltage. All of these problems can effectively be overcome by connecting a bank of a capacitor and a resistor in parallel with each diodes as shown in Fig. 2.8.

If a selected diode cannot match the required current rating, one may connect several diodes in parallel. In order to ensure equal current sharing, the designer must choose diodes with the same forward voltage drop properties. It is also important to ensure that the diodes are mounted on similar heat sinks and are cooled (if necessary) equally. This will affect the temperatures of the individual diodes, which in turn may change the diode forward characteristics.

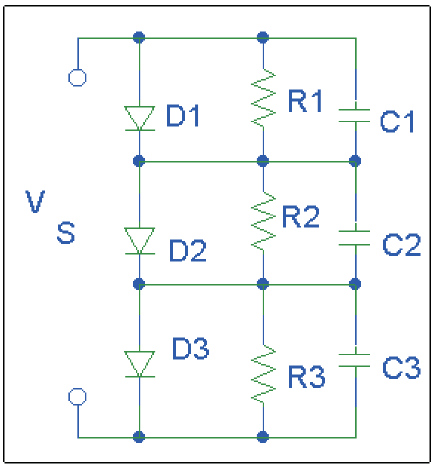

FIGURE 2.8 Series-connected diodes with necessary protection.

Tutorial 2.1 Reverse Recovery and Overvoltages

Figure 2.9 shows a simple switch mode power supply. The switch (1-2) is closed at $t = 0$ S. When the switch is open, a freewheeling current $I_F = 20$ A flows through the load (RL), freewheeling diode (DF), and the large load circuit inductance (LL). The diode reverse recovery current is 20 A and it then

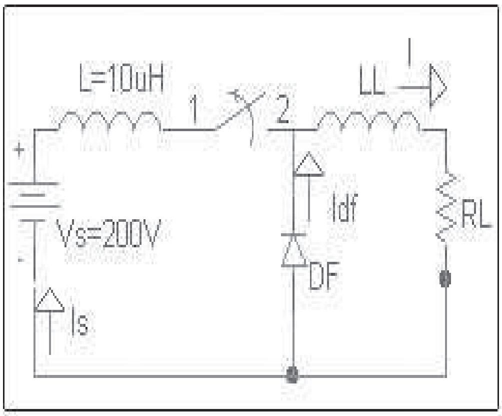

FIGURE 2.9 A simple switch mode power supply with freewheeling diode.

decays to zero at the rate of 10 A/μS. The load is rated at 10 Ω and the forward on-state voltage drop is neglected.

(a) Draw the current waveform during the reverse recovery (I_{rr}) and find its time (t_{rr}).
(b) Calculate the maximum voltage across the diode during this process (I_{rr}).

Solution. (a) A typical current waveform during reverse recovery process is shown in Fig. 2.10 for an ideal diode.

When the switch is closed, the steady-state current is $I_{SS} = 200\ \text{V}/10\ \Omega = 20\ \text{A}$, because under the steady-state condition the inductor is shorted. When the switch is open, the reverse recovery current flows in the right-hand side loop consisting of LL, RL, and DF. The load inductance LL is assumed to be shorted. Hence, when the switch is closed, the loop equation is [3]:

$$V = L\frac{di_S}{dt} \quad \text{from which} \quad \frac{di_S}{dt} = \frac{V}{L} = \frac{200}{10} = 20\ \text{A}/\mu\text{S}$$

At the moment the switch is open, the same current keeps flowing in the right-hand side loop. Hence,

$$\frac{di_d}{dt} = -\frac{di_S}{dt} = -20\ \text{A}/\mu\text{S}$$

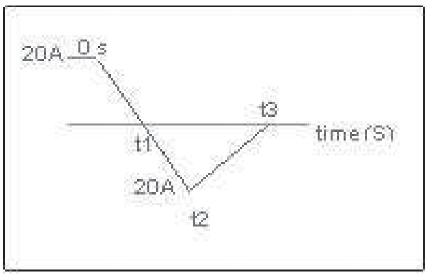

FIGURE 2.10 Current through the freewheeling diode during reverse recovery.

from time zero to time t_1 the current will decay at a rate of 20 A/S and will be zero at $t_1 = 20/20 = 1/\mu\text{S}$. The reverse recovery current starts at this point and according to the given condition becomes 20 A at t_2. From this point on, the rate of change remains unchanged at 20 A/μS. Period $t_2 - t_1$ is found:

$$t_2 - t_1 = \frac{20\ A}{20\ \text{A}/\mu\text{S}} = 1\ \mu\text{S}$$

From t_2 to t_3 the current decays to zero at the rate of 20 A/μS. The required time is

$$t_3 - t_2 = \frac{20\ A}{10\ \text{A}/\mu\text{S}} = 2\ \mu\text{S}$$

Hence the actual *reverse recovery time*: $t_{rr} = t_3 - t_1 = (1 + 1 + 2) - 1 = 3\ \mu\text{S}$.

(b) The diode experiences the maximum voltage only when the switch is open. This is due to both the source voltage 200 V and the newly formed voltage caused by the change in current through inductor *L*. The voltage across the diode,

$$V_D = -V + L\frac{di_S}{dt} = -200 + (10 \times 10^{-6})(-20 \times 10^{6}) = -400\ \text{V}$$

Tutorial 2.2 Ideal Diode Operation, Mathematical Analysis and PSPICE Modelling

This tutorial illustrates the operation of an ideal diode circuit. Most of the power electronic applications operate at a relatively high voltage and, in such cases, the voltage drop across the power diode is usually small. It is quite often justifiable to use the ideal diode model. An ideal diode has a zero conduction drop when it is forward-biased and has zero current when it is reverse-biased. The equations and the analysis presented here are based on an ideal diode model.

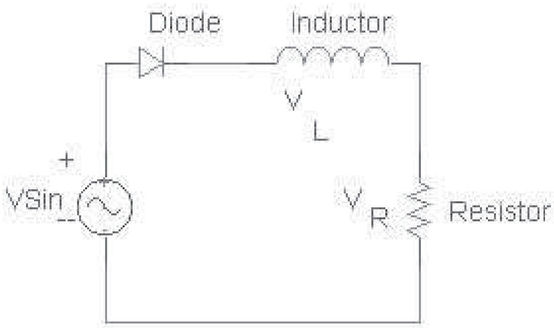

FIGURE 2.11 Circuit diagram.

Circuit Operation A circuit with a single diode and a very common RL load is shown in Fig. 2.11. The source V_S is an alternating sinusoidal source. Suppose $V_S = E_m \sin(\omega t)$. V_S is positive when $0 < wt < \pi$, and is negative when $\pi < \omega t < 2\pi$. When V_S starts to become positive, the diode begins conducting and the positive source keeps the diode in conduction until ωt reaches π radians. At that instant (defined by $\omega t = \pi$ radians), the current through the circuit is not zero and there is some energy stored in the inductor. The voltage across an inductor is positive when the current through it is on the increase and it becomes negative when the current through it tends to fall. When the voltage across the inductor is negative, it is in such a direction as to forward bias the diode. The polarity of voltage across the inductor is as shown in Figs. 2.12 and 2.13.

When V_S changes from a positive to a negative value, there is current through the load at the instant $\omega t = \pi$ radians and the diode continues to conduct until the energy stored in the inductor becomes zero. After that the current tends to flow in the reverse direction and the diode blocks conduction. The entire applied voltage now appears across the diode.

Circuit Analysis The expression for the current through the diode can be obtained from the following mathematical analysis [7]. It is assumed that the current flows for $0 < \omega t < \beta$, where $\beta > \pi$, when the diode conducts, and the driving function for the differential equation is the sinusoidal function defining the source voltage. During the period defined by $\beta < \omega t < 2\pi$, the diode blocks the current and acts as an open switch. For this period, there is no equation defining the behavior of the circuit. For $0 < \omega t < \beta$, Eq. (2.4) applies [7].

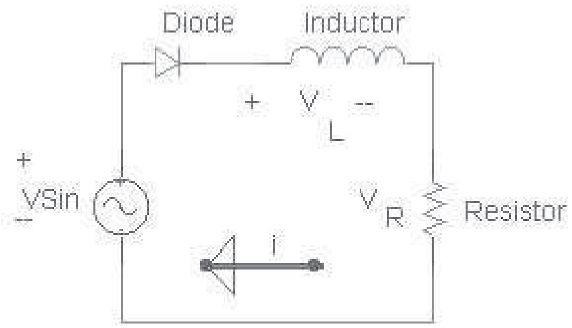

FIGURE 2.12 Current rising, $0 < \omega t < \pi/2$.

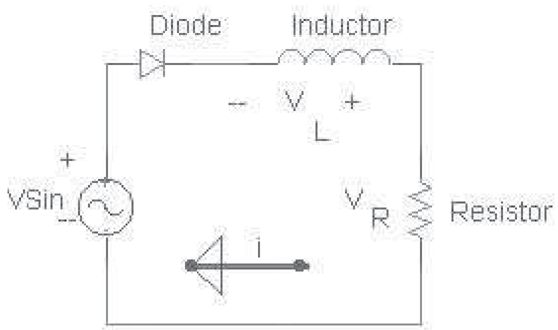

FIGURE 2.13 Current falling, $\pi/2 < \omega t < \pi$.

$$L\frac{di}{dt} + R^*i = E^* \sin(\theta), \text{ where } -0 \leq \theta \leq \beta \tag{2.4}$$

$$L\frac{di}{dt} + R^*i = 0 \tag{2.5}$$

$$\omega L\frac{di}{d\theta} + R^*i = 0 \tag{2.6}$$

$$i(\theta) = A^*e\frac{-R\theta}{\omega L}$$

Assuming a linear differential equation, the solution is found in two parts. The homogeneous equation is defined by Eq. (2.5). It is preferable to express the equation in terms of the angle θ instead of t. As $\theta = \omega t$, then $d\theta = \omega.dt$. Then Eq. (2.5) is converted to Eq. (2.6). Equation (2.7) is the solution to this homogeneous equation and is called the complementary integral.

The value of constant A in the complementary solution is to be calculated. The particular solution is the steady-state response and Eq. (2.8) expresses it. The steady-state response is the current that would flow in steady-state in a circuit that contains only the source, the resistor, and the inductor as shown in the circuit in Fig. 2.11, where the only element missing is the diode. This response can be obtained using the differential equation, the Laplace transform, or the ac sinusoidal circuit analysis. The total solution is the sum of both the complementary and the particular solution. It is shown in Eq. (2.9). The value of A is obtained using the initial condition. As the diode starts conducting at $\omega t = 0$ and the current starts building up from zero, $i(0) = 0$. The value of A is expressed by Eq. (2.10).

Once the value of A is found, the expression for current is known. After evaluating A, current can be evaluated at different values of ωt, starting from $\omega t = \pi$. As wt increases, the current continues to decrease. For some value of ωt, say β, the current would be zero. If $\omega t > \beta$, the current would drop to a negative value. As the diode blocks current in the reverse direction, the diode stops conducting when ωt is reached. Then an expression for the average output voltage can be obtained. Because the average voltage across the inductor has to be zero, the average voltage across the resistor and at the cathode of the diode are the same. This average value can be obtained as shown in Eq. (2.11).

$$i(\theta) = \left(\frac{E}{Z}\right) \sin(\omega t - \alpha) \tag{2.8}$$

where $\alpha = a\tan\left(\frac{\omega l}{R}\right)$, and $Z^2 = R^2 + \omega l^2$

$$i(\theta) = A^* e\left(\frac{-R\theta}{\omega l}\right) + \frac{E}{Z}\sin(\theta - \alpha) \quad (2.9)$$

$$A = \left(\frac{E}{Z}\right)\sin(\alpha) \quad (2.10)$$

Hence, the average output voltage:

$$V_{OAVG} = \frac{E}{2\pi}\int_0^{\beta} \sin\theta.d\theta = \frac{E}{2\pi}{}^*[1 - \cos(\beta)] \quad (2.11)$$

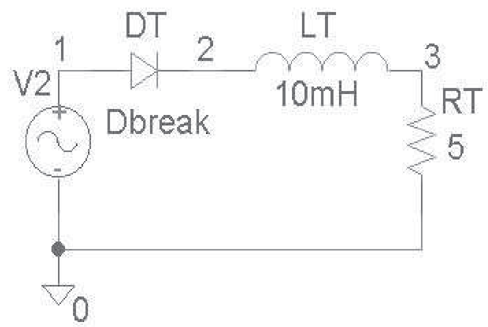

FIGURE 2.14 PSPICE circuit to study the diode R-L circuit.

PSPICE Modelling: For modelling the ideal diode using PSPICE, the circuit used is shown in Fig. 2.14. Here the nodes are numbered. The ac source is connected between nodes 1 and 0. The diode is connected between nodes 1 and 2 and the inductor links nodes 2 and 3. The resistor is connected from 3 to the reference node, that is, node 0.

The PSPICE program in text form is presented here:

```
*Half-wave rectifier with RL load
*An exercise to find the diode current
VIN 1 0 sin(0 100 V 50 Hz)
D1 1 2 Dbreak
L1 2 3 10 mH
R1 3 0 5Ω
.MODEL Dbreak D(IS=10N N=1 BV=1200 IBV=10E-3 VJ=0.6)
.TRAN 10 μs 100 μs 60 μs 100 μs
.PROBE
.OPTIONS (ABSTOL=1N RELTOL=.01 VNTOL=1MV)
.END
```

The diode is characterized using the MODEL statement. The TRAN statement controls the transient operation for a period of 100 ms at an interval of 10 ms. The OPTIONS statement sets limits for tolerances. The output can be viewed on the screen because of the PROBE statement. A snapshot of various voltages/currents are presented in Fig. 2.15.

It is evident from Fig. 2.15 that the current lags the source voltage. This is a typical phenomenon in any inductive circuit and is associated with the energy storage property of the inductor. This property of the inductor causes the current to change slowly, governed by the time constant $\tau = \tan^{-1}(\omega l/R)$. Analytically, this is calculated by the expression in Eq. 2.8.

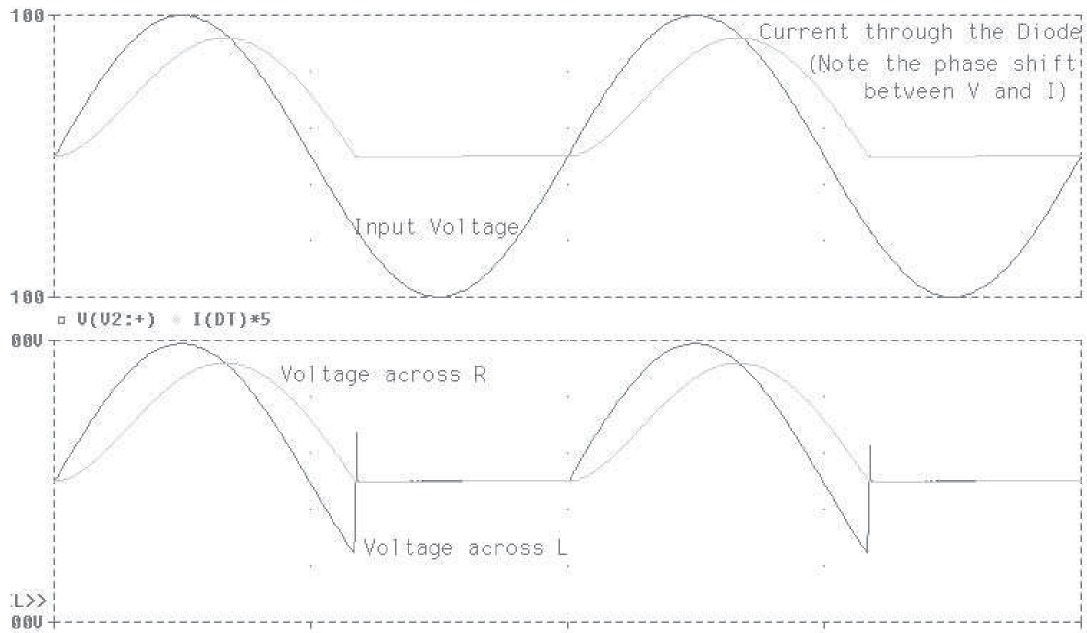

FIGURE 2.15 Voltage/current waveforms at various points in the circuit.

2.7 Typical Applications of Diodes

A. In rectification. Four diodes can be used to fully rectify an ac signal as shown in Fig. 2.16. Apart from other rectifier circuits, this topology does not require an input transformer. However, transformers are used for isolation and protection. The direction of the current is decided by two diodes conducting at any given time. The direction of the current through the load is always the same. This rectifier topology is known as the bridge rectifier.

The average rectifier output voltage

$$V_{dc} = \frac{2V_m}{\pi}$$

where V_m is the peak input voltage.

The rms rectifier output voltage

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

This rectifier is twice as efficient as a single-phase rectifier.

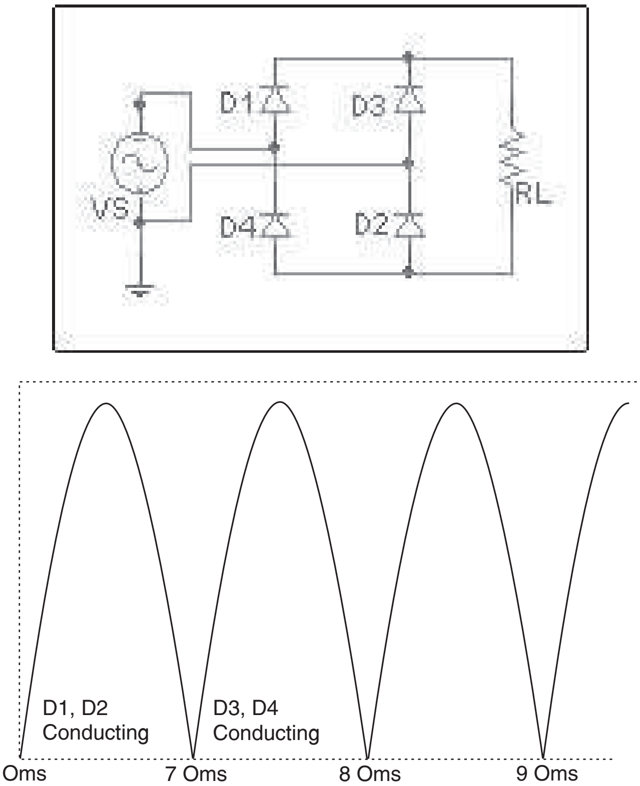

FIGURE 2.16 Full bridge rectifier and its output dc voltage.

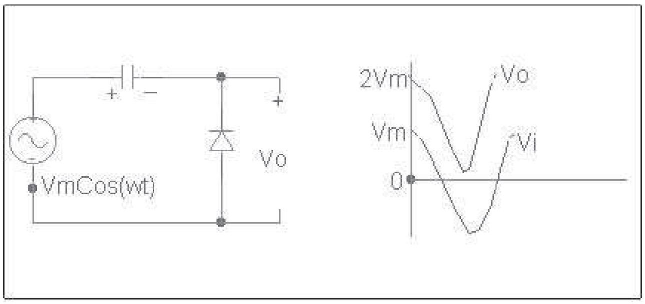

FIGURE 2.17 Voltage clamping with diode.

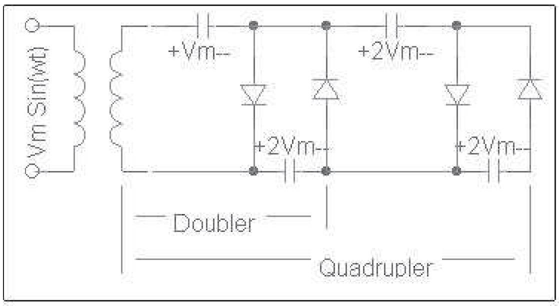

FIGURE 2.18 Voltage doubler and quadrupler circuit.

B. For Voltage Clamping. Figure 2.17 shows a voltage clamper. The negative pulse of the input voltage charges the capacitor to its max. value in the direction shown. After charging, the capacitor cannot discharge because it is open circuited by the diode. Hence the output voltage,

$$V_o = V_m + V_i = V_m(1 + \sin(\omega t))$$

The output voltage is clamped between zero and 2 V_m.

C. As Voltage Multiplier By connecting diodes in a predetermined manner, an ac signal can be doubled, tripled, and even quadrupled. This is shown in Fig. 2.18. The circuit will yield a dc voltage equal to 2 V_m. The capacitors are alternately charged to the maximum value of the input voltage.

2.8 Standard Datasheet for Diode Selection

In order for a designer to select a diode switch for specific applications, the following Tables and standard test results can be used. A power diode is chosen primarily based on forward current (I_F) and the peak inverse (V_{RRM}) voltage [5]. For example, the designer chose the diode type $V30$ from Table 2.1 because it closely matches his/her calculated values of I_F and V_{RRM} without exceeding those values. However, if for some reason only the V_{RRM} matches but the calculated value of I_F

comes in at a higher figure, one should select diode H14, and so on. A similar concept is used for V_{RRM}.

In addition to the forementioned diode parameters, one should also calculate parameters such as the peak forward voltage, reverse recovery time, case and junction temperatures etc. and check them against the datasheet values. Some of these datasheet values are provided in Table 2.2 for the selected diode $V30$. Figures 2.19–2.21 give the standard experimental relationships between voltages, currents, and power and case temperatures for our selected $V30$ diode. These characteristics help a designer to understand the safe operating range for the diode, and to make a decision as to whether or not a snubber or a heatsink should be used. If one is particularly interested in the actual reverse recovery time measurement, the circuit given in Fig. 2.22 can be constructed and experimented upon.

2.8.1 General-Use Rectifier Diodes

TABLE 2.1 Diode election based on average forward current $I_{F(avg)}$, and peak inverse voltage V_{RRM} [4]

$I_{F(avg)}$ (A)	V_{RRM} (V) Type	50	100	200	300	400	500	600	800	1000	1300	1500
0.4	$V30$	–	–	–	–	–	–	–	yes	yes	yes	yes
1.0	$H14$	–	yes	yes	yes	yes	yes	yes	yes	yes	–	–
1.1	$V06$	–	–	yes	–	yes	–	yes	yes	–	–	–
1.3	$V03$	–	–	yes	–	yes	–	yes	yes	–	–	–
2.5	$U05$	–	yes	yes	–	yes	–	yes	yes	–	–	–
3.0	$U15$	–	yes	yes	–	yes	–	yes	yes	–	–	–

Used with permission, [7].

TABLE 2.2 Details of diode for diode $V30$ selected from Table 2.1

Absolute maximum ratings[a,b] Item	Type		V30J	V30L	V30M	V30N
Repetitive Peak reverse Voltage	V_{RRM}	V	800	1000	1300	1500
Nonrepetitive Peak Reverse Voltage	V_{RSM}	V	1000	1300	1600	1800
Average Forward Current	$I_{F(AV)}$	A	0.4 (Single-phase, half sine wave 180° conduction TL = 100°C, Lead length = 10 mm)			
Surge(Nonrepetitive) Forward current	I_{FSM}	A	30 (Without PIV, 10 ms conduction, $T_j = 150$°C start)			
I^2t Limit Value	I^2t	A^2s	3.6 (Time = 2 ~ 10 ms, 1 = rms value)			
Operating Junction Temperature	T_j	°C	−50 ~ +150			
Storage Temperature	T_{stg}	°c]	−50 ~ +150			

[a] Lead mounting: lead temperature 300°C max. to 3.2 mm from body for 5 s. max.
[b] Mechanical strength: bending 90° × 2 cycles or 180° × 1 cycle, Tensile 2 kg, Twist 90° × 1 cycle.

TABLE 2.3 Characteristics ($T_L = 25$°C)

Item	Symbols	Units	Min.	Typ.	Max.	Test Conditions
Peak Reverse Current	I_{RRM}	μA	–	0.6	10	All class Rated V_{RRM}
Peak Forward Voltage	V_{FM}	V	–	–	1.3	$I_{FM} = 0.4$ Ap, single-phase, half sine wave 1 cycle
Reverse Recovery Time	trr	μs	–	3.0	–	$I_F = 22$ mA, $V_R = -15$ V
Steady-State Thermal Impedance	$R_{th(j-a)}$					
	$R_{th(j-1)}$	°C/W	–	–	80 50	Lead length=10 mm

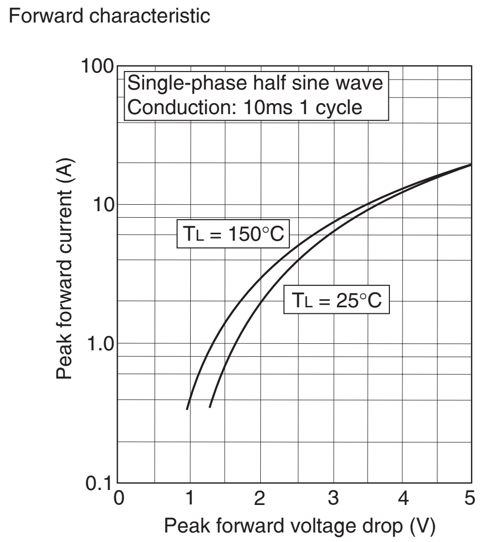

FIGURE 2.19 Variation of peak forward voltage drop with peak forward current.

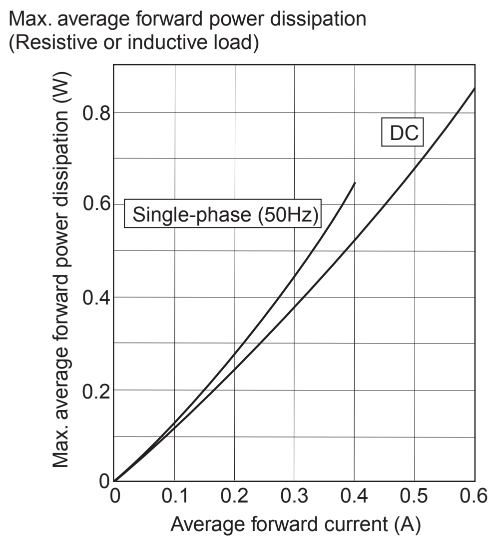

FIGURE 2.20 Variation of maximum forward power dissipation with average forward current.

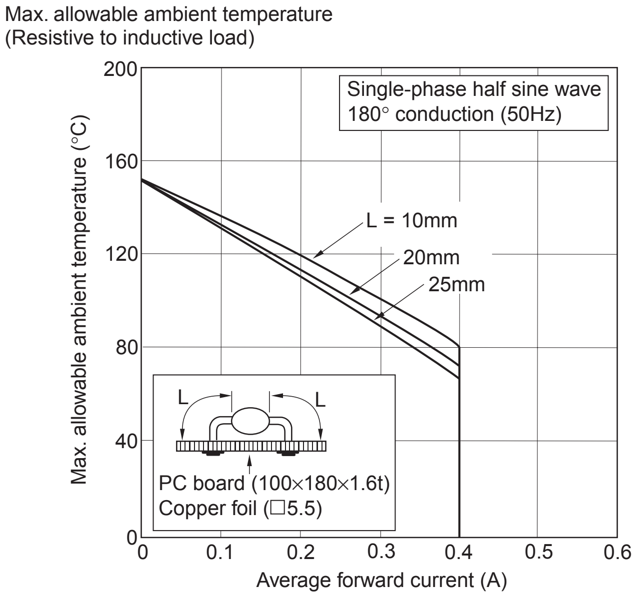

FIGURE 2.21 Maximum allowable case temperature with variation of average forward current.

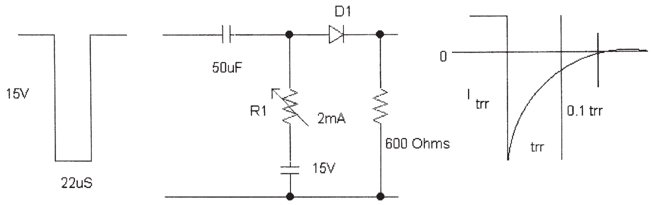

FIGURE 2.22 Reverse recovery time (t_{rr}) measurement.

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