TECHNICAL UNIVERSITY OF KOŠICE

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATICS

DEPARTMENT OF ELECTRONICS AND MULTIMEDIA COMMUNICATIONS

BASIC OF ELECTRONICS

Lecture 3

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Applied Informatics

Contents

References and Sources

[1] Attia, J. O.: *Electronics and Circuit Analysis using MATLAB.* CRC Press, Boca Raton London New York Washington, D.C., 1999.

[2] Fonstad, C. G: *Microelectronic Devices and Circuits.* McGraw-Hill Inc., New York, 1994.

[3] Galajda, P.– Lukáč, R.: *Elektronické prvky*. Merkury-Smékal, Košice, 2001.

[4] Galajda, P.– Lukáč, R.: *Elektronické obvody*. Merkury-Smékal, Košice, 2002.

[5] Rizzoni, G.*: Principles and Applications of Electrical Engineering,* 5th Edition. Ohio State University. McGraw-Hill Higher Education, 2007.

[6] Sandige, R.S.: *The Electrical Engineering Handbook.* Ed. Richard C. Dorf. Boca Raton: CRC Press LLC, 2000.

[7] Savant, C. J.– Roden, M. R – Carpenter, G. R.: *Electronic Circuit Design - An Engineering Approach*. The Benjamin/Cummings Publishing Company Inc., Menlo Park, California, 1987.

[8] Sedra, A. S.– Smith K. C.: *Microelectronic Circuits.* Oxford University Press, Inc., Oxford. New York, 1998.

1.8 Clippers and Clampers

Diodes have other applications in addition to rectification and detection. Among these are clipping an input signal or limiting only parts of the signal. Diodes are also used in restoring a dc level to an input signal.

1.8.1 Clippers

Clipping circuits are used to eliminate a part of a waveform that lies above or below some reference level. Clipping circuits are sometimes referred to as *limiters, amplitude selectors,* or *slicers.* The rectification circuits of the previous section use clipping action at the zero level. If a battery is added in series with the diode, a rectification circuit will clip everything above or below the battery voltage, depending upon the orientation of the diode. This is illustrated in Figure 1.34.

The output waveforms indicated in Figure 1.34 assume that the diodes are ideal. We now relax this assumption for the circuit of Figure 1.34(a) by including two additional parameters in the diode model. First, we assume that a voltage of $V\gamma$ must be overcome before the diode will conduct. Second, when the diode is conducting, we include a forward resistance, R_f. The effect of $V\gamma$ is to make the clipping level $V\gamma + V_B$ instead of V_B. The effect of the resistance is to change the flat clipping action to one that proportionately follows the input voltage (i.e., a voltage-divider effect). The resulting output is calculated as follows, and it is illustrated in Figure 1.35 ([34], Section 10.2).

For

$$v_i < V_B + V\gamma, \qquad v_o = v_i$$

For

$$v_i > V_B + V\gamma, \qquad v_o = v_i \frac{R_f}{R + R_f} + (V_B + V\gamma)\frac{R}{R + R_f}$$

Positive and negative clipping can be performed simultaneously. The result is a *parallel-biased clipper,* which is designed by using two diodes and two

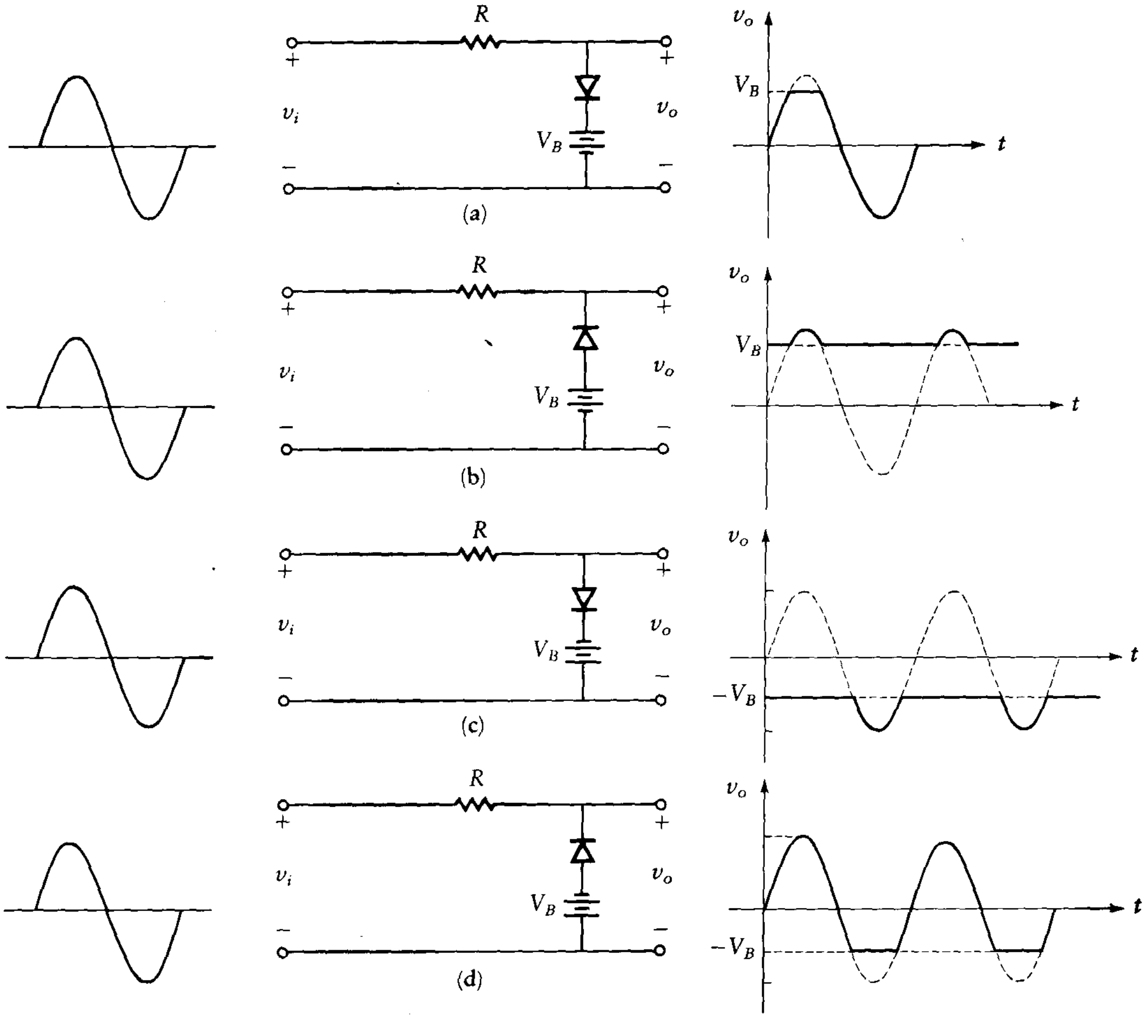


Figure 1.34 **Ideal clipping** circuits.

voltage sources oriented oppositely. The circuit produces the output waveshape as shown in Figure 1.36 when ideal diodes are assumed. The extension to practical diodes parallels the analysis leading to the results in Figure 1.35.

Another type of clipper is the *series-biased* clipper, which is shown in Figure 1.37. The 1-V battery in series with the input causes the input signal to be superimposed on a dc voltage of −1 V rather than being symmetrical about the zero axis. Assuming that this system uses an ideal diode, we find that the diode of Figure 1.37(a) will conduct only during the negative-going conditioned (i.e., shifted) input signal. When the diode is conducting, the output is zero. We have a nonzero output when the diode is not conducting. In Figure 1.37(b), the reverse is true. When the conditioned signal is positive, the diode conducts and an output signal exists, but when the diode is off, no output occurs. Although the operation of the two circuits is different, the two outputs

Figure 1.35
Output waveform for circuit of Figure 1.34(a).

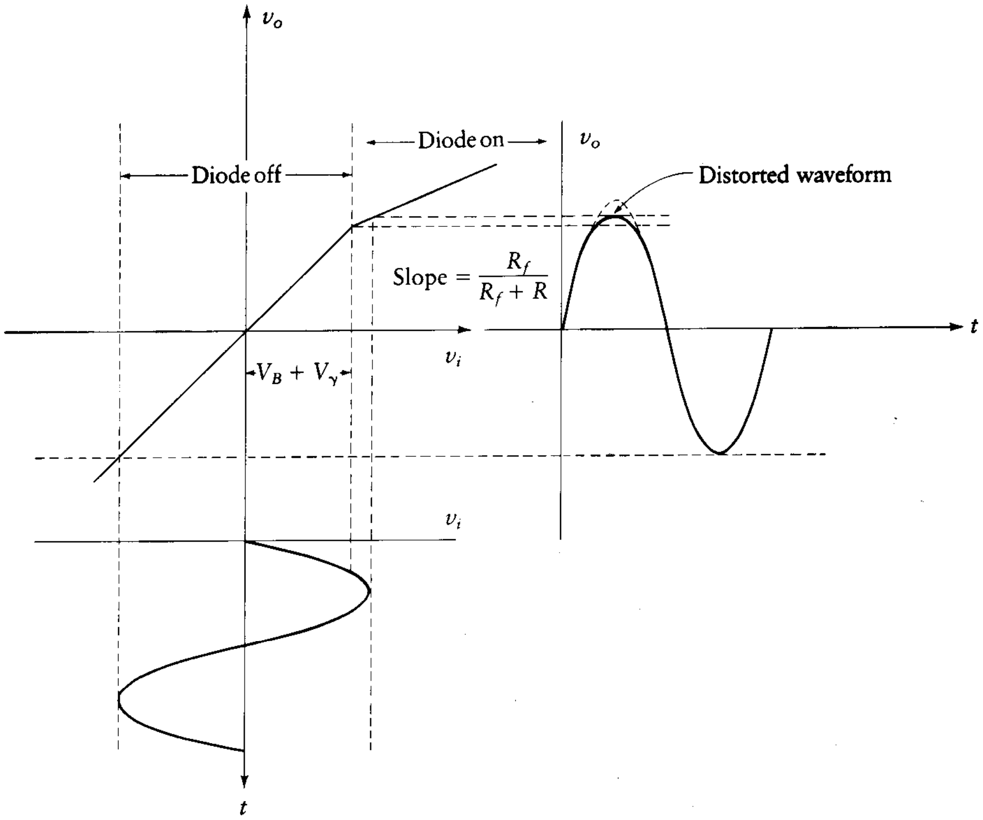
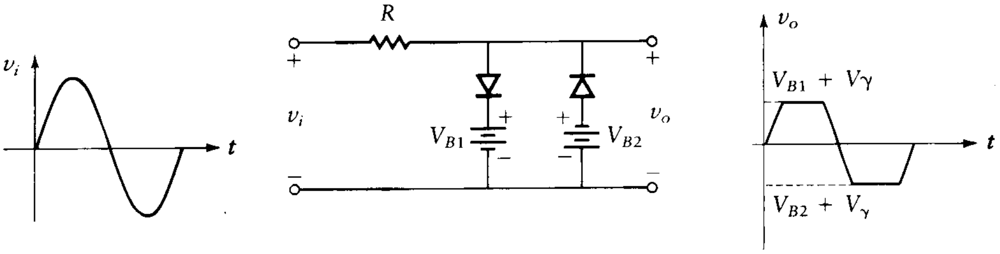


Figure 1.36
Parallel-biased clipper.



are identical. In Figure 1.37(c) and (d) we **reverse the polarity of the battery** and obtain output waveforms as shown.

1.8.2 *Clampers*

A voltage waveform can be shifted by adding an independent voltage source, either a constant or a time function, in series with the waveform. *Clamping* is a shifting operation, but the amount of shift depends upon the actual waveform. Figure 1.38 shows an example of clamping. The input waveform is shifted by an amount that makes the shifted waveform peak at a value of V_B. Thus,

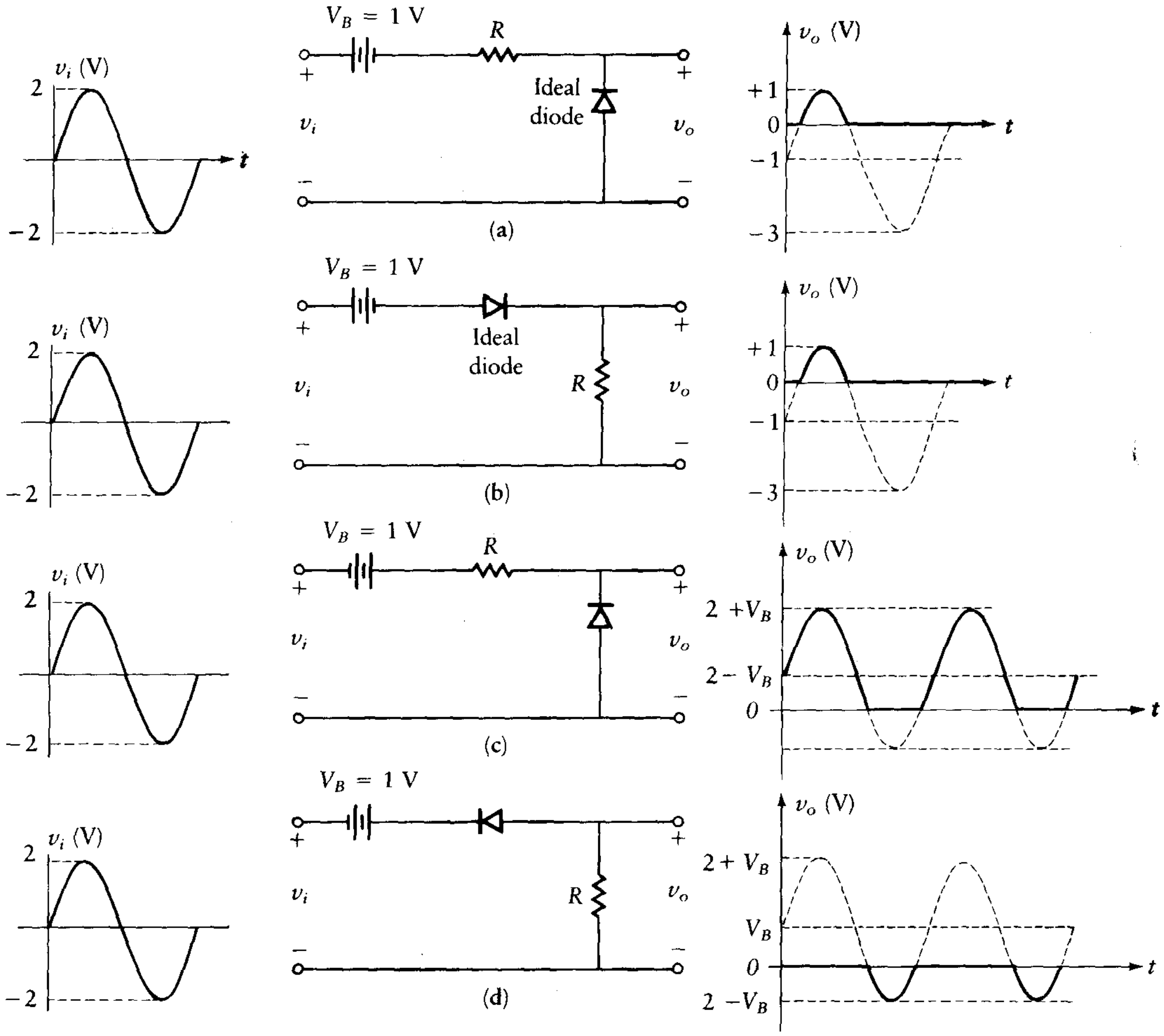
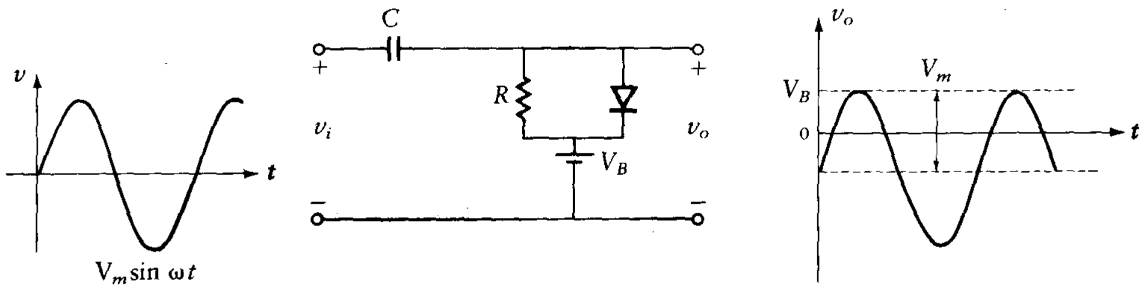
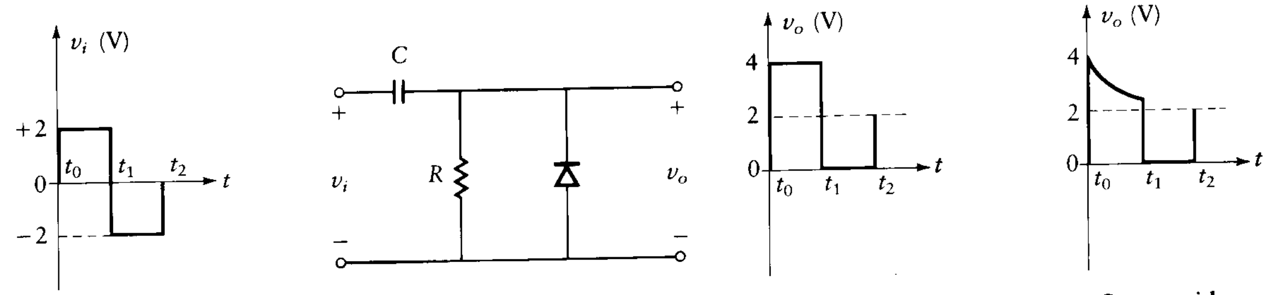


Figure 1.37 Series-biased clipper.



(a) Input (b) **Clamping circuit** (c) **Output when $V_B < V_m$**

Figure 1.38 Clamping circuit.



(a) **Input**

(b) **Clamper with long time constant**

(c) **Output with short time constant**

Figure 1.39 Clamping at zero.

the amount of shift is the exact amount necessary to change the original maximum, V_m, to a new maximum, V_B. The waveform is "clamped" to a value of V_B. If the input waveform changes, the amount of shift will change such that the output is always clamped to V_B. The clamping circuit thus provides a dc component in an amount necessary to achieve the desired clamping level.

A clamping circuit is composed of a battery (or dc supply), diode, capacitor, and resistor. The resistor and capacitor are chosen so that the time constant is large. It is desired that the capacitor charge to a constant value and remain at that value throughout the period of the input waveform. If this condition is met and the forward resistance of the diode is assumed to be zero, the output is a reproduction of the input with the appropriate shift. Whenever the output tries to exceed V_B, the diode forward-biases and the output is limited to V_B. During these times, the capacitor charges. When steady state is reached, the capacitor will be charged to a value of

$$V_C = V_m - V_B$$

Figure 1.39 illustrates a clamping circuit where the output is clamped to zero (i.e., there is no battery, so $V_B = 0$). Because the diode is in the reverse direction from that of the previous circuit, the *minimum* rather than *maximum* of the output is clamped. The circuit is shown with a square wave as input. It is important that the voltage across the capacitor remain approximately constant during the half-period of the input waveform. A design rule of thumb is to make the RC time constant at least five times the duration of the half-period (i.e., five times either $t_1 - t_0$ or $t_2 - t_1$). In this case, the RC circuit has less than 20% of a time constant to charge or discharge during the half-period. This places the final value within 18% of the starting value (i.e., $\exp(-0.2) = 0.82$). If the time constant is too small, the waveform will be distorted, as shown in Figure 1.39(c). ([6], Section 1.22). To reduce the error to less than 18%, the time constant can be increased (e.g., to 10 times the half-period duration).

1.9 Alternate Types of Diodes

This section briefly presents the following types of diodes:

- Schottky
- Varactor
- Tunnel
- Light-emitting
- Photo
- PIN

1.9.1 Schottky Diodes

A *Schottky diode* is formed by bonding a metal, such as aluminum or platinum, to an *n*-type silicon. It is often used in integrated circuits for high-speed switching applications. Its symbol and construction are shown in Figure 1.40. The Schottky diode has a voltage-current characteristic similar to that of the silicon *pn* junction diode, except that the forward voltage, $V\gamma$, is 0.3 V rather than 0.7 V. When the Schottky diode is operated in the forward mode, current is induced by the movement of electrons from the *n*-type silicon across the junction and through the metal. Since electrons move relatively unimpeded through metals, the recombination time is small, on the order of 10 ps. This is faster than an ordinary *pn* junction diode. Therefore, the Schottky diode is of great value in high-speed switching applications. The capacitance associated with this diode is small.

The metallic material in contact 1 and the lightly doped *n*-region form a rectifying junction, whereas the heavily doped *n*-region and contact 2 form an ohmic contact. The forward-direction electrons from the *n*-type silicon cross the junction into the metal, where there are numerous available electrons. This results in a *majority* carrier device. This is in contrast to a standard *pn* junction diode, where the *minority* carriers determine the diode characteristics.

The Schottky diode is sometimes called a *barrier diode,* since a barrier forms across the junction due to the movement of electrons from the semiconductor to the metal interface.

Schottky diodes are useful in IC technology because they are easy to fabricate and can be manufactured at the same time as the other components on the chip. Fabrication of a Schottky diode on a chip requires one less step than fabrication of a *pn* junction diode, since the *pn* junction diode requires the additional *p*-type diffusion. The low-noise characteristics of the Schottky diode make it ideal for application in power monitoring of low-level radio frequencies, detectors for high frequency, and Doppler radar mixers.