

Section B8: Clippers And Clampers

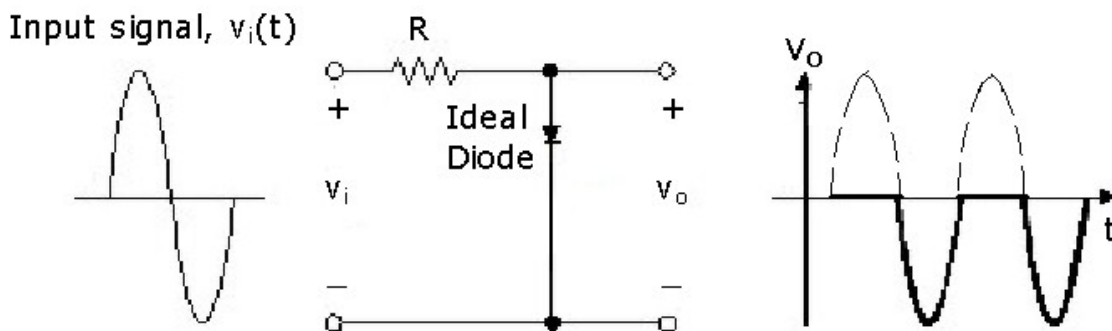
We've been talking about one application of the humble diode – rectification. These simple devices are also powerful tools in other applications. Specifically, this section of our studies looks at signal modification in terms of **clipping** and **clamping**.

Clippers

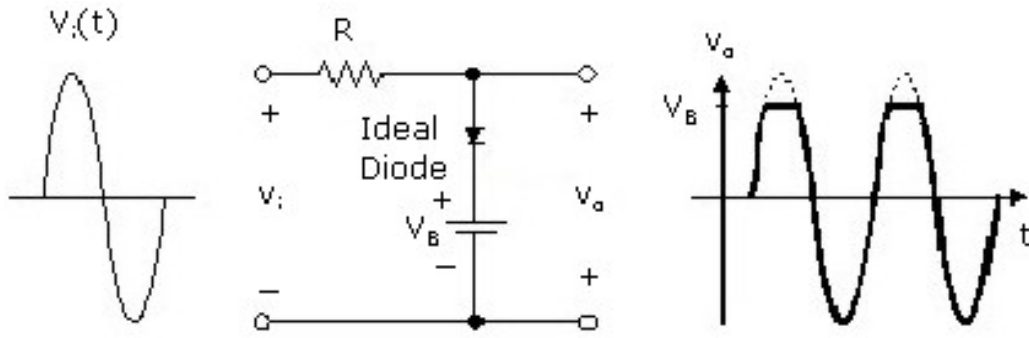
Clipping circuits (also known as **limiters**, **amplitude selectors**, or **slicers**), are used to remove the part of a signal that is above or below some defined reference level. We've already seen an example of a clipper in the half-wave rectifier – that circuit basically cut off everything at the reference level of zero and let only the positive-going (or negative-going) portion of the input waveform through.

To clip to a reference level other than zero, a dc source (shown as a battery in your text) is put in series with the diode. Depending on the direction of the diode and the polarity of the battery, the circuit will either clip the input waveform above or below the reference level (the battery voltage for an ideal diode; i.e., for $V_{on}=0$). This process is illustrated in the four parts of Figure 3.43:

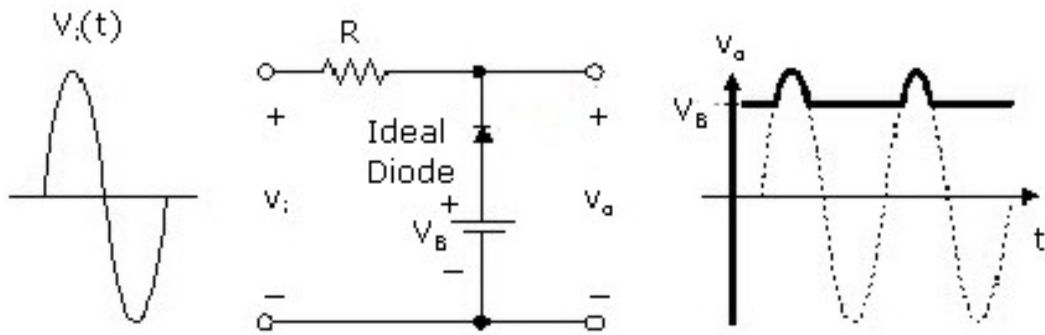
- **Without** the battery, the output of the circuit below would be the negative portion of the input wave (assuming the bottom node is grounded). When $v_i > 0$, the diode is on (short-circuited), v_i is dropped across R and $v_o=0$. When $v_i < 0$, the diode is off (open-circuited), the voltage across R is zero and $v_o=v_i$. (Don't worry; we won't be doing this for **all** the circuits!) Anyway, the reference level would be zero.



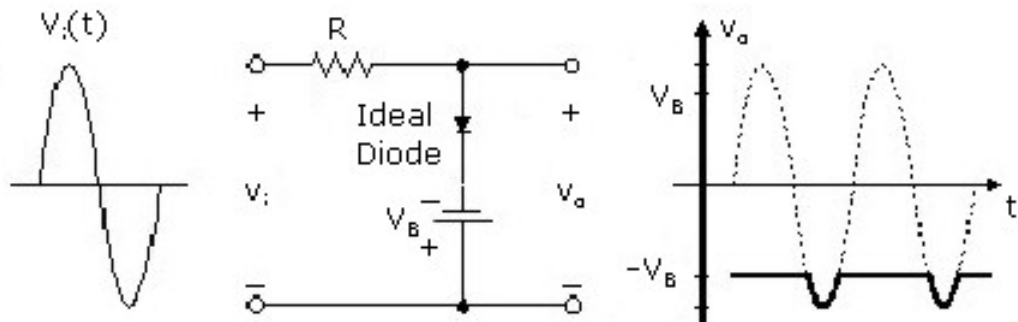
- **With** the battery in the orientation shown in Figure 3.43a (and below), the diode doesn't turn on until $v_i > V_B$ (If this looks strange, revisit the definition of forward bias). This shifts the reference level up and clips the input at $+V_B$ and passes everything for $v_i < V_B$.



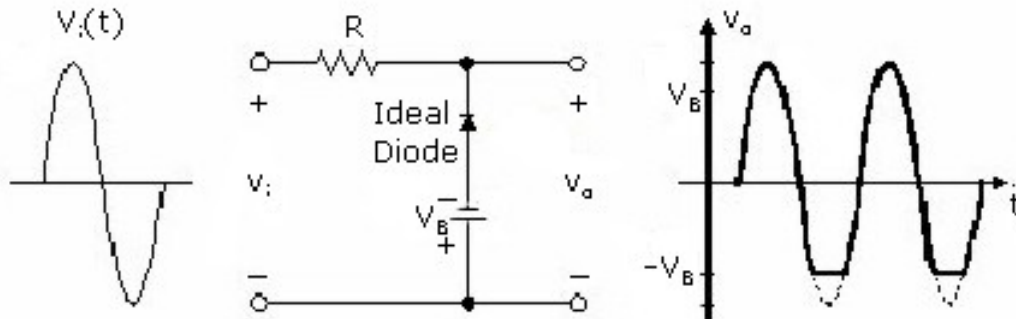
- Figure 3.43b has the battery with the same orientation as in part (a), but the diode has been flipped. **Without** the battery, the positive portion of the input waveform would be passed (i.e., a reference level of zero). **With** the battery, the diode conducts for $v_i < V_B$. This means that the reference level is shifted to $+V_B$ and only $v_i > V_B$ appears at the output.



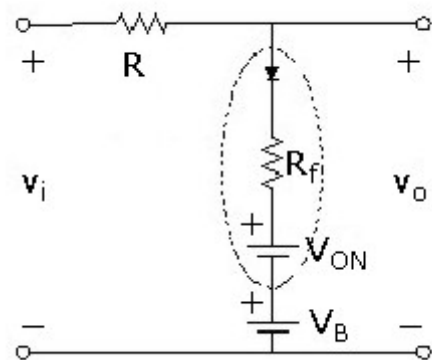
- Again referencing part (a), the diode is in the original position but the polarities on the battery have been switched in Figure 3.43c. The discussion follows the same logic as earlier, but now the reference level has been shifted to $-V_B$. The final result is that $v_o = v_i$ for $v_i < -V_B$.



- Finally, Figure 3.43d behaves the same as part (b), but the polarity on the battery has been switched, shifting the reference level to $-V_B$. The signal that appears as the output is v_i as long as $v_i > -V_B$.

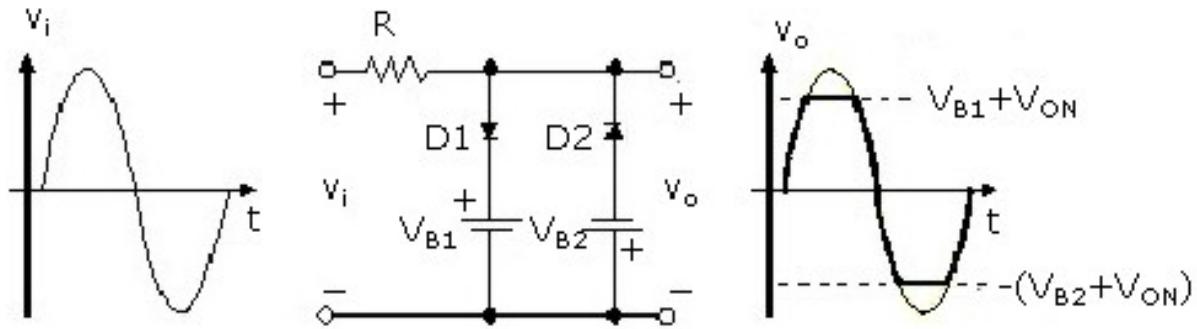


To accommodate a practical diode, the turn-on voltage ($V_{ON}=0.7V$ for silicon) and forward resistance (R_f) are included, along with the ideal diode, in the model (as shown in Figure 3.44a, reproduced to the right). The effective reference level will either have a magnitude of V_B+V_{ON} or V_B-V_{ON} , depending on the relative polarities of the two sources (review combining voltage sources in series if necessary). Including R_f in the diode path creates a voltage divider when the diode is forward biased. The result of this slight drop



across R_f (remember that the forward resistance is generally pretty small), is a slight distortion in the output waveform – it is no longer strictly “limited” or “clipped” to the reference level, as is illustrated in Figure 3.44b in your text. The four possible configurations of Figure 3.43 are still valid, with the effective reference level ranging in magnitude from 0.7V (if $V_B=0$) on up.

A **parallel-biased clipper** is a circuit that clips the positive and negative-going portions of the input signal simultaneously. This is designed by using two parallel diodes oriented in opposite directions – note that it is **very** important that the diodes are oppositely oriented (think voltage sources in parallel – a big no-no!). Just as in our previous discussion, the path containing diode D1 will provide the upper limit with reference level $V_{B1}+V_{ON}$ (with the V_{B1} polarity shown) and the path containing D2 will provide the lower limit with reference level $V_{B2}+V_{ON}$ (with the V_{B2} polarity shown). An example of this type of clipper, with the resulting output waveform is shown below (Figure 3.45 of your text, where it looks like they assumed R_f was negligible):

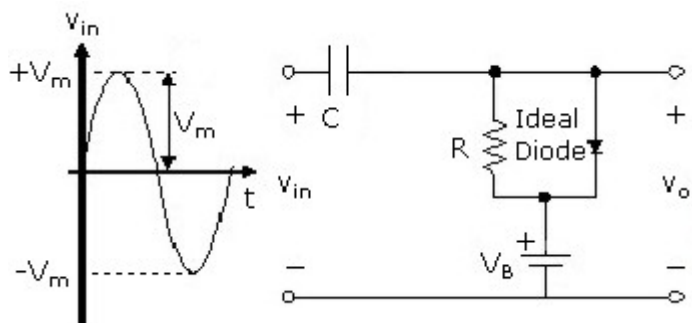


A **series-biased clipper** involves placing a battery in series with the input. The result of this modification is that the input signal is no longer symmetric about the zero axis, but instead shifts by an amount defined by the magnitude and polarity of V_B . In Figure 3.46, the four possible permutations and the resulting output waveforms are shown for an **ideal diode**. When you look at this figure, keep in mind that the input signal is swinging between $+2$ and -2 volts and the battery magnitude V_B is 1 volt. This may avoid some confusion when looking at the output waveforms – the $(2V + V_B)$ is just 3 volts and the $-(2V - V_B)$ may be replaced by -1 volt. The series placement of the battery is not changing the input waveform in any way, it is simply affecting when the diode turns on. To include the effects of a **practical diode**, include V_{ON} and R_F in the diode path and crunch the math...

Clampers

Clamping circuits, also known as **dc restorers** or **clamped capacitors**, shift an input signal by an amount defined by an independent voltage source. While clippers limit the part of the input signal that reaches the output according to some reference level(s), the entire input reaches the output in a clamping circuit – it is just shifted so that the maximum (or minimum) value of the input is “clamped” to the independent source.

Let’s look at Figure 3.48 (input and circuit shown to the right) and see if we can turn this into something that makes sense! Basically, we have a sinusoidal input of magnitude V_m with zero offset (i.e., symmetric signal) fed to the clamper circuit.

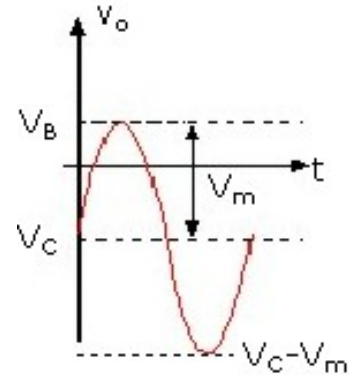


Taking the input by sections to build the output...

- If $v_{in} > V_B$, the diode is on, R is shorted, and the output is V_B .
- When $v_{in} < V_B$, the diode is off, current flows through the resistor, and the capacitor charges to a voltage $v_c = V_B - v_{in}$. The maximum voltage on the capacitor will be related to the maximum swing of the input by: $V_C = V_m - V_B$. After fully charging, the capacitor acts like series source in the circuit (with the RC time constant conditions discussed below). After steady state is reached, the output voltage is found by loop analysis as

$$v_o = v_{in} + V_C.$$

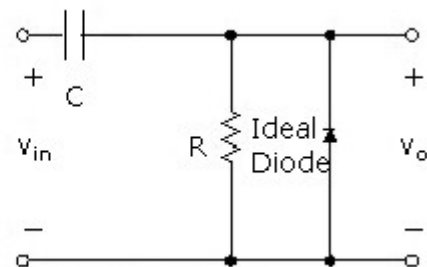
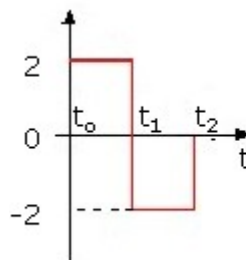
In the circuit shown above, $V_C = -V_m + V_B$ (KVL at maximum negative input, $v_{in} = -V_m$) or $v_o = v_{in} - V_m + V_B$. Specifically, for the extreme values of the input signal: if $v_{in} = +V_m$, $v_o = V_B$ and if $v_{in} = -V_m$, $v_o = -V_m - V_m + V_B = -V_m - (V_m - V_B) = -V_m + V_C = V_C - V_m$ (Whew! I went through all that to get something that looked like it belonged to the figure to the right!).



Keep in mind that the above analysis was for the diode orientation and V_B polarity shown. If the diode had been flipped, the minimum rather than the maximum of the input would have been clamped to V_B .

A clamping circuit has to have an independent source, a diode, a resistor and a capacitor. To keep a constant voltage on the capacitor over the period of the input, the RC time constant must be large. A **design rule of thumb** is to make the RC time constant at least five times the half-period of the input signal, which results in approximately an 18% error over a half-period due to capacitor discharge. If this error is too large, the RC time constant may be increased but, as with everything in design, there comes a point where factors such as size and power dissipation may make any further improvements impractical.

Following our discussion above for Figure 3.48, Figure 3.49 illustrates a circuit that will clamp a square wave to zero ($V_B = 0$).



Can you see how this one is working?

$$V_C = +V_m = 2V$$

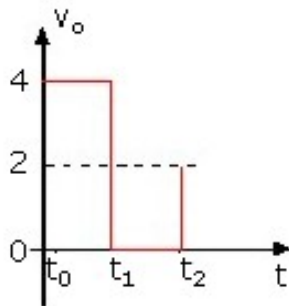
(because of diode orientation and $V_B=0$)

$$V_o = v_{in} + V_C$$

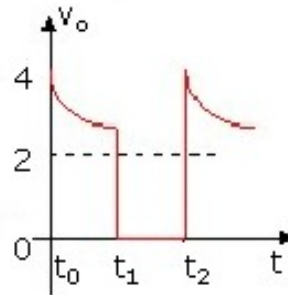
$$V_o = 2 V_m = 4V \text{ for } v_{in} = V_m$$

$$V_o = 0 \text{ for } v_{in} = -V_m$$

Parts (b) and (c) of this figure, shown below, demonstrate the output of the clamper with a long time constant and the distortion introduced by the capacitor discharging for a short time constant. It is noted in your book that this square wave may be considered a worst-case situation since it places the greatest demands on a clamping circuit due to the instantaneous changes in the waveform. (Remember from your discussions of harmonics and signal composition, that instantaneous change requires infinite frequencies.)



(b) Long time constant



(c) Short time constant