Rectifiers: Half & Full-Wave Circuits

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Introduction

- Rectifiers are a key application of diodes that we found any other day.
- A basic circuit rectifier converts an ac signal into a pulsating dc voltage signal. At the end of the process, a filter is required to eliminate any traces from the ac signal and to keep it as smooth as possible.
- Almost whole devices that are plugged requires a rectifier to convert 120 V @ 60 Hz into a broad spectrum of dc voltages

Introduction

- Only one diode is used within a half-wave rectifier
- An oscillatory source $v_1 = V_P \sin \omega t$ is connected to a diode D_1 and a load resistor R_L in series
- In the first part of the cycle, , for which $v_1 > 0$, the source bias the diode $D_1$and a current passes through it in the forward direction. As for the second half of the cycle, $v_1 < 0$. As a negative current is not allowed in the diode (unless breakdown), it opens or turn off. Both states are shown

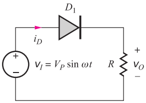


Figure 3.42 Half-wave rectif er circuit.

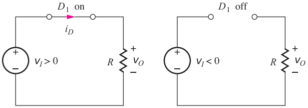
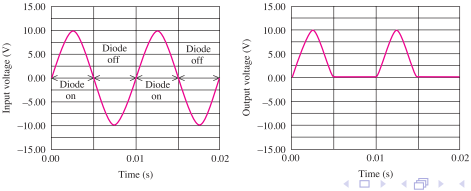


Figure 3.43 Ideal diode models for the two half-wave rectif er states.



Introduction

- Another configuration a bit more complex but a bit more realistic

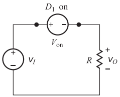


Figure 3.45 CVD model for the rectif er on state.

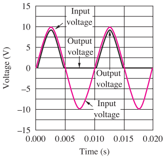


Figure 3.46 Half-wave rectif er output voltage with $V_P = 10$ V and $V_{on} = 0.7$ V.

  In figure in black line, shows that the output signal is smaller than the input, it is due to the diode bias
  $v_0 = (V_P \sin \omega t) - V_{on}$
- The output voltage are zero on the off state interval. The input and output signals for the half rectifier that includes the V_{on} effect as V_P=10 V and V_{on}=0.7 V

Introduction

- In quite a few applications a transformer is used to convert ac signal to a desired dc level
- The unfiltered output signals cannot be used for nowadays applications as such, due to it requires specific characteristics
- A filter capacitor can be added to filter the the output of the circuit

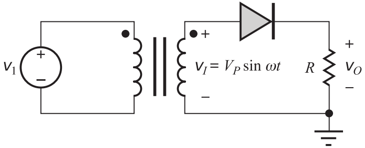


Figure 3.47 Transformer-driven half-wave rectif er.

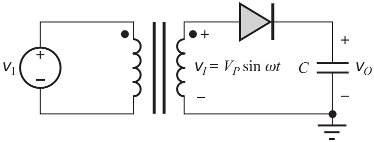
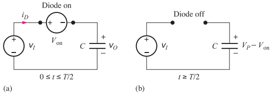


Figure 3.48 Rectif er with capacitor load (peak detector).

Rectified Filter Capacitor

- The peak detector circuit or filter capacitor circuit, considers a capacitor as load than a resistor.
- When the source is on, the diode is biased and the capacitor charges to the source minus v_D
- Once at peak of the input voltage signal, the current through the diode follow a reverse path due to $i_D = C[d(v_1 - v_{on})dt] < 0$
- As a consequence, the diode is disconnected and the capacitor remains charged
- As there is no way for the capacitor to discharge it remains constant

$$V_{dc} = V_P - Von$$



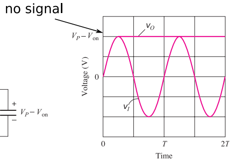
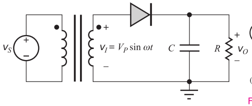


Figure 3.49 Peak-detector circuit models (constant voltage drop model). (a) The diode is on for $0 \le t \le T/2$. (b) The diode is off for $t > T/2$.

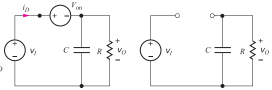
Figure 3.50 Input and output waveforms for the peak-detector circuit.

Rectified RC Filter

- We need to use the energy as a dc signal, this is why, we need to add a resistive load ‘R’ to recover the energy stored
- now there is a way to discharge the capacitor while the diode is not working
- We consider ‘C’ initially discharged. For the initial cycle, the diodes is bias and C is charged. While in inverse current occurs at peak, the diode cuts off and C discharges through the resistor R
- Discharges continues until $v_t - v_{on}$ is larger than the output voltage v_0 that occurs near the peak of the follow cycle.



(a)



(a) Diode on (b) Diode off

Figure 3.52 Half-wave rectif er circuit models.

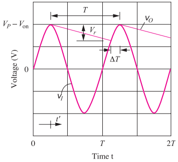


Figure 3.53 Input and output voltage waveforms for the half-wave rectif er circuit.

Rectified RC filter

- As the output voltage is not constant anymore as in the peak detector, it has a ripple voltage V_r and the diode only conducts for a short period of time ΔT during each cycle. ΔT is known as the conduction interval and it equivalent angle θ_c, where $\theta_c = \omega \Delta T$
- By considering a rather small ripple $\Delta T << T$, ripple voltage is defined as:

$$V_r \approx \frac{V_P - V_{on}}{R} \frac{T}{C}$$

- by considering that C is discharged by a constant current, the dc current is defined as:

$$I_{dc} = \frac{V_P - V_{on}}{R}$$

- For a finite time T, if we want to discharge C, we've

$$\Delta V = \frac{I_{dc}}{C} T$$

Rectified Filter Capacitor

- A nonzero current is present in the diode for a small fraction of time T. in contrast, an almost constant dc current if flowing from C towards the lead.
- Whole current deliverately submitted to the load, must be replenished by the current through the diode during the rather small period of time ΔT, that produces high peak diode currents

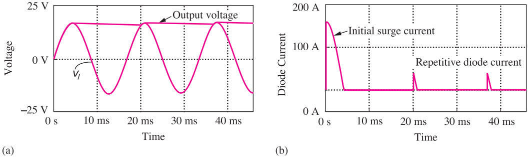


Figure 3.54 SPICE simulation of the half-wave rectif er circuit. (a) Voltage wavefforms (b) Diode current.

- the total charge supplied and consumed by the system is defined as:

$$Q = I_P \frac{\Delta T}{2} = I_{dc} T \Leftrightarrow I_P = Idc \frac{2T}{\Delta T}$$

Key an basic applications

- Indeed it is possible for a diode to conduct in the negative half cycle of the transformer
- the only thing that we need to do is fulfill a few conditions such as

$$v_{dc} = -(V_P - Von)$$

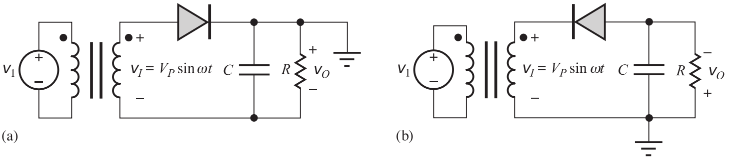


Figure 3.57 Half-wave rectif er circuits that develop negative output voltages.

Introduction

- The discharge of the capacitor goes by half and uses the half of the filter capacitance to achieve the desired ripple
- This configuration uses a tap centered transformer that generates 2 similar voltages equal in amplitud but out of phase by 180°
- By using voltage v_1 applied to the anode of D_1 and -v_1 applied to D_2. Each diode forms a half wave rectifier operating each one in a different cycle of the inner waveform.

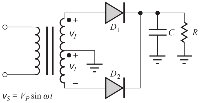


Figure 3.58 Full-wave rectif er circuit using two diodes and a center-tapped transformer. This circuit produces a positive output voltage.

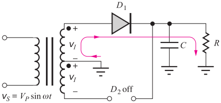


Figure 3.59 Equivalent circuit for $v_I > 0$.

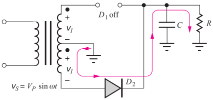


Figure 3.60 Equivalent circuit for $v_I < 0$.

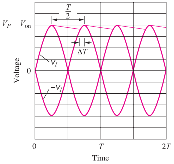


Figure 3.61 Voltage waveforms for the full-wave rectif er.

Introduction

- The load "RC" receives two current pulses per cycle and the discharge capacitor time is reduced by half
- In a similar way as for the half-wave rectifier a few conditions are required such as:

$$V_{dc} = V_P - V_{on}$$
$$V_r = \frac{V_P - V_{on}}{R} \frac{T}{2C}$$
$$\Delta T = \frac{1}{\omega} \sqrt{\frac{T}{RC} \frac{V_P - V_{on}}{V_P}} = \frac{1}{\omega} \sqrt{\frac{2V_P}{V_P}}$$
$$\theta_c = \omega \Delta T = \sqrt{\frac{2V_P}{V_P}}$$
$$I_P = I_{dc} \frac{T}{\Delta T}$$
$$PIV = 2V_P$$

Introduction

- Basically, it is the same, with a simple difference that a central tapered transformer is not needed
- Operation is similar as before, by biasing the diodes D_2 & D_4 a positive cycle passes through while for the negative, diodes D_1 & D_3 are biased in inverse and allows the wave to pass through.

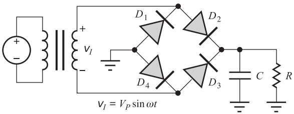


Figure 3.63 Full-wave bridge rectif er circuit with positive output voltage.

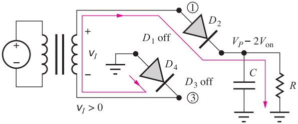


Figure 3.64 Full-wave bridge rectif er circuit for $v_I > 0$.

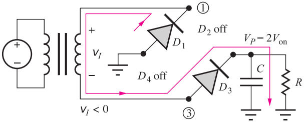


Figure 3.65 Full-wave bridge rectif er circuit for $v_I < 0$.

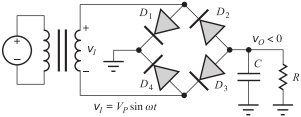


Figure 3.66 Full-wave bridge rectif er circuit with $v_O < 0$.

Photo – Diodes and Detectors

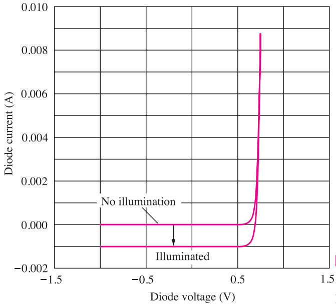
- If PN region is illuminated (give enough eV) at high frequency, photons can provide enough energy to e$^-$ to jump in the semiconductor bandgap creating e^-/h^+ pairs
- For photon absorption, it must has an initial energy E_P that is larger than the semiconductor bandgap

$$E_P = hv = \frac{hc}{c} \geq E_G$$

where h = Planck's constant (6.626×10^{-34} J $\cdot$ s), v = frequency of optical illumination λ = wavelength of optical illumination c = velocity of light (3×10^{8} m/s)

Photo – Diodes and Detectors

- $i - v$ characteristics with/without illumination appear in figure
- photon absorption creates another current crossing the pn junction that is modeled as a current surce in parallel with the pn junction



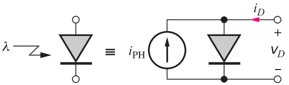


Figure 3.70 Model for optically illuminated diode. i_{PH} represents the current generated by absorption of photons in the vicinity of the *pn* junction.

Photo – Diodes and Detectors

- It is possible to convert the incident optical signal into an electrical one by using an array called photodectector circuit
- Diode in reverse-biased to, due to cascade process, enhance the width of the $\vec{E}$ at SCR
- The curent generated i_{PH} will flow through R and produce a voltage according to: $v_o = i_{PH} R$

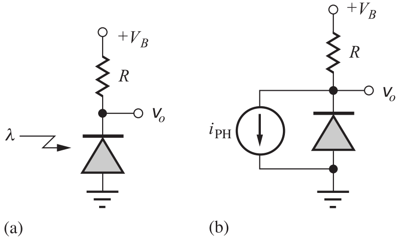


Figure 3.71 Basic photodetector circuit (a) and model (b).

Solar Cell

- According to the photodetector principle, the optical illumination is constant, ergo a dc current is generated
- The milestone is to obtain as much energy as possible from the cell
- In plot the short circuit I_{SC}, open circuit voltage V_{OC} and maximum power P_{max}
- I_{SC} represents whole the current that the cell can deliver and V_{OC} is the voltage across the open circuited cell when the photocurrent is passing in to the internal pn
- In order to give the energy from the solar cell toward a load system, $I_C \times V_C$ should be to operate at first quadrant

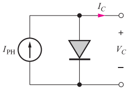


Figure 3.72 *pn* Diode under steady-state illumination as a solar cell.

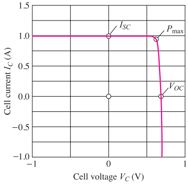


Figure 3.73 Terminal characteristics for a *pn* junction solar cell.

LEDs

- By recombining process of e^- & h^+ rather than by generation of carriers produces a LED
- When an e^- & h^+ recombine and energy equal to the semiconductor bandgap is released as a photon
- This process occurs in forward-biased pn junction diode
- in Si, the recombination process also includes the interaction between photons and phonons
- Optical emission in Si is not efficient as for GaAs, $GaIn_{1-x}As_x$ and $GaIn_{1-x}P_x$
- LDS i those compounds provide a visible illumination and the output color comes from the fraction of As or P in the material