ECE231S - Introductory Electronics

2019

Lab Handout

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LAB 4 Diode Circuits ECE231S

Introduction

The diode is a two-terminal, nonlinear device which behaves like a valve, allowing current to flow from the anode to the cathode, but not vice versa. The objective of this lab is to study a collection of basic diode circuits, some of which will be used as building blocks in the following labs.

Preparation

For the preparation, you will simulate the variable diode attenuator circuit using Multisim. Before you begin, read the following Background section, making sure you understand the operation of all the circuits that will be built in the lab. For simulations, use the ‘D1N4148’ diode.

P1) Perform a transient (time domain) simulation of the variable attenuator in 2.6 using values from step E6 in the experiment section.

Tips: For your simulation, place an additional 100 MΩ resistor from the output node, V_{out}, to ground. For v_{in}, use a 100 kHz sine wave of 0.5 $V_{peak\text{-}peak}$.

(i) Include a printed plot of the output waveform, v_{out}, in your lab notebook for the control voltage V_{ctrl} of 1V and 2.5V. Run the simulations from 0 to 100 μs.

(ii) Using Equation 2.1, calculate the expected peak-to-peak voltage of output signal v_{out}, for a control voltage V_{ctrl} of 2.5 V. To calculate the diode current, you can assume that the voltage across each diode is about 0.7 V. How do your calculated results compare with the simulation results above?

(iii) With V_{ctrl} at 2.5 V, change the amplitude of the sine wave of V_{in}, increasing its value until the output waveform is visibly distorted. Include a printed plot of the distorted output waveform in your lab notebook.

(iv) Measure the peak-to-peak amplitude of both V_{in} and V_{out} for this distorted case. Use these values as guidelines for the actual experiment.

Background

Diode Logic Gates (Ref: §4.1.3 Another Application: Diode Logic Gates)

The switch-like behavior of diodes can be used to create simple logic gates. If the diode is forward biased, it behaves as a closed switch. If reverse biased, it acts as an open switch. The following circuit uses light emitting diodes (LEDs) to visually show the on/off state of the diodes.

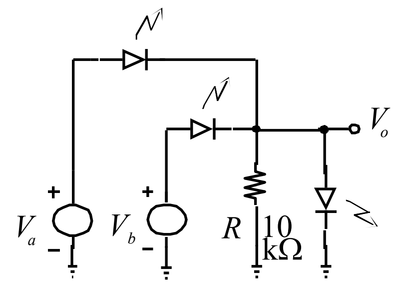

Figure 2.1: Diode logic gate

Half-Wave Rectifier (Ref: §4.5.1 The Half-Wave Rectifier)

Electronic devices require a constant voltage supply. However, electricity is distributed to homes as sinusoidal alternating current (AC). Thus, circuits are required to convert the line voltage from a sinusoidal input to a constant output voltage (DC). The following circuit ensures that the output voltage is never negative, the first step in the conversion process.

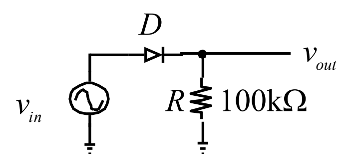

Figure 2.2: Positive half-wave rectifier

Precision (Inverting) Half-Wave Rectifier (Ref: §4.5.5 Precision Half-Wave Rectifier)

Exploiting the feedback properties of the operational amplifier, a diode-like inverting circuit can be constructed that exhibits no drop in the magnitude of the voltage from the input to the output of the circuit, thus implementing a precision half-wave rectifier.

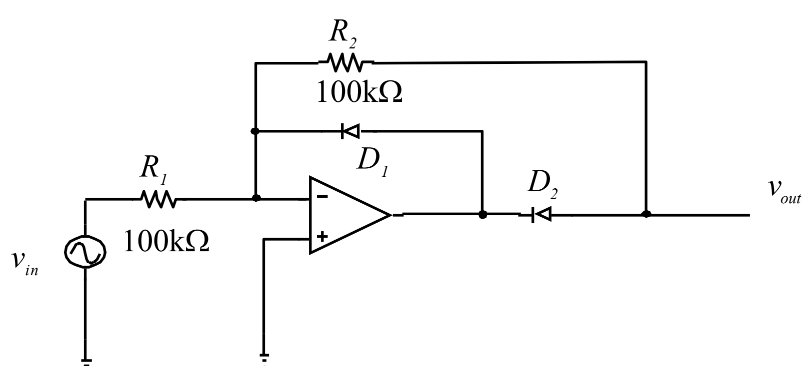

Figure 2.3: Precision (inverting) half-wave rectifier

Peak Detector (Ref: §4.5.4 The Rectifier with a Filter Capacitor)

By adding a capacitor to the output of either half-wave rectifier in Figures 2.2 and 2.3, a circuit called a peak detector is formed which 'remembers' the peak value of the input signal. Figure 2.4 shows the modification for Figure 2.2. The length of time which the circuit 'remembers' peak values is determined by the time constant of the circuit. If the value of the capacitor is very large, a near-constant output voltage is produced, yielding a reasonable approximation of a DC power supply.

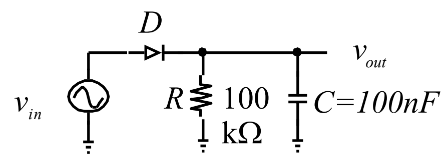

Figure 2.4: Positive peak detector

Charge Pumps for Voltage Multiplication (Ref: §4.6.3 The Voltage Doubler)

Charge pump circuits are commonly used to generate high voltages beyond the supply voltage. The Dickson charge pump is shown in Figure 2.5. It operates by transferring charge from left to right along the diode chain, from capacitor to capacitor. When V_{clk} is high (V_{dd}), diode D_1 conducts until the voltage across capacitor C_1 is charged to V_{dd}. When V_{clk} is low (negative V_{dd}), diode D_2 conducts and transfers charge from C_1 over to C_2. Eventually, the voltage across capacitor C_2 becomes $2V_{dd}$. When V_{clk} goes high (V_{dd}) again, the voltage at node 2 now becomes $3V_{dd}$. This process repeats itself at each stage, with the voltages at each node as shown in Fig. 2.5.

NOTE: The circuit theoretically produces a voltage of $5V_{dd}$. In practice, however, there is a diode voltage drop of V_D at each stage and the final output voltage is $5(V_{dd} - V_D)$. For $V_{dd} = 5$ V and $V_D = 0.7$ V, the output voltage is about 5×(5-0.7)=21.5 V.

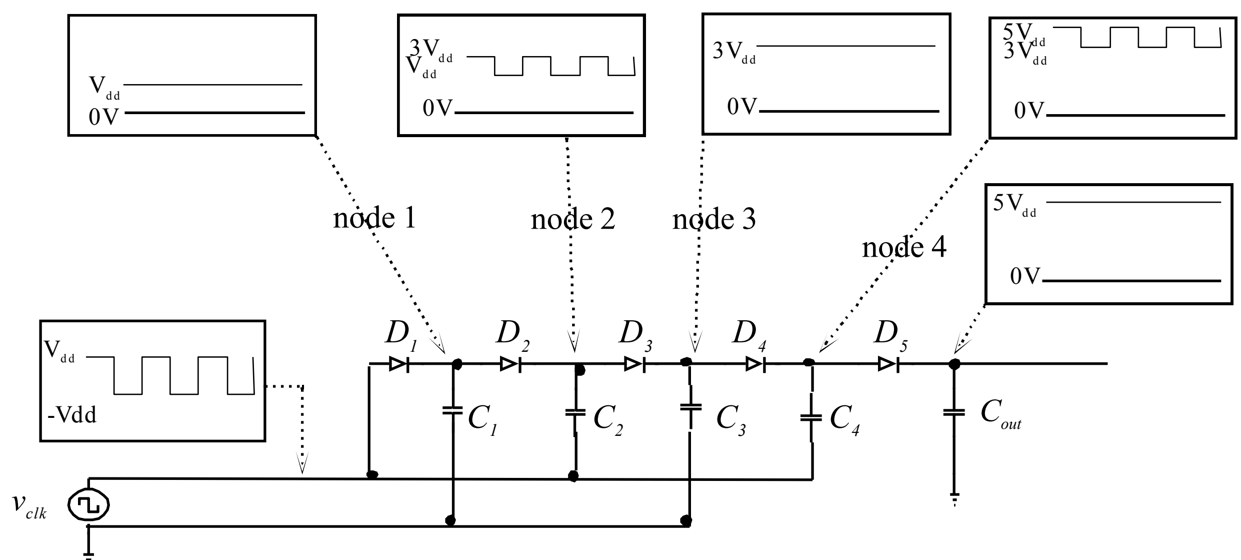

Figure 2.5: Dickson charge pump

Diode as a Small-Signal Resistor (Ref: §4.3.7 The Small-Signal Model)

While the diode is intrinsically nonlinear, when forward-biased with a constant current, the diode can be *approximated* as a linear resistor for small *variations* in current and voltage. This linear approximation of nonlinear devices about a dc operating point is called small-signal modeling.

Application: A Voltage-Controlled Variable Attenuator

The model of a diode as a resistor for small signals can be exploited to implement a voltage controlled variable attenuator as shown in Figure 2.6. At frequencies well above DC, the capacitors in Figure 2.6 can be considered as short circuits. Thus, the amplitude of v_{in} is attenuated by a voltage divider consisting of R_{in} and the small-signal resistance of the two diodes D_1 and D_2, r_{d1} and r_{d2}:

$$v_{out} = \frac{r_{d1}+r_{d2}}{r_{d1}+r_{d2}+R_{in}} v_{in} \qquad \text{Equation (2.1)}$$

The small-signal resistance of diodes D_1 and D_2 is given by $r_d = V_T / I_D$ where V_T is the thermal voltage and is about 25 mV at room temperature, and I_D is the dc current flowing through the diode which is adjusted using the control voltage, V_{ctrl}. Since the resistance R_{ctrl} is far greater than the small-signal resistance of the diodes, R_{ctrl} can be ignored when analyzing the voltage divider.

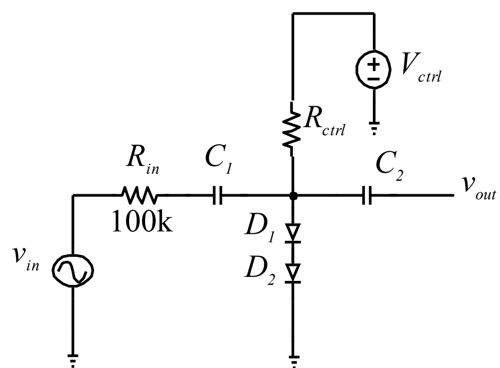

Figure 2.6: Variable attenuator

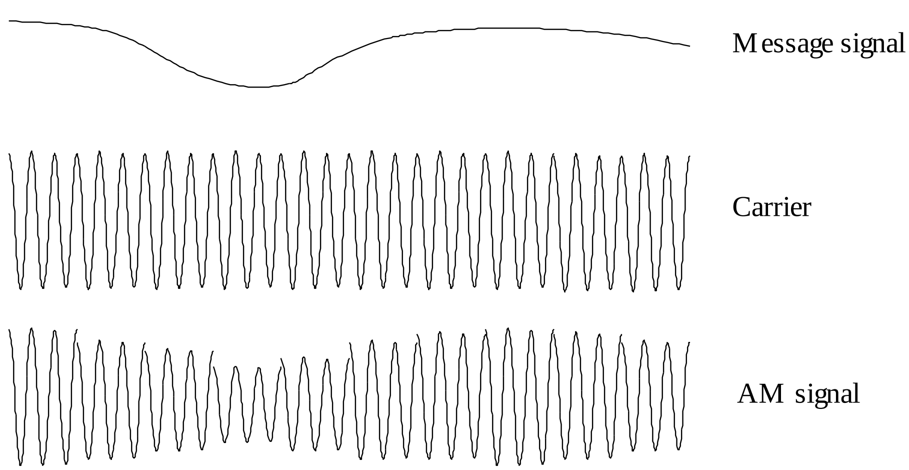

Figure 2.7 Amplitude Modulation in the Time Domain

Experiment:

E1) Build the diode logic gate of Figure 2.1 using red LEDs for the diodes and a resistor value in the range of 10 - 20 kΩ. The longer pin is the anode of the LED. Draw the truth table of the logic gate using +4 V as TRUE and 0 V as FALSE. **Set the current limit of the power supply to be 150 mA.** What boolean function does this logic gate implement? (If the LEDs are not bright enough, slowly increase the voltage up to 5V.)

* NOTE: for the rest of the lab, you will be using the 1N4148 silicon diodes (NOT the LEDs).

E2) Build two half-wave rectifier circuits: build Figure 2.2 using a silicon (Si) diode and R = 100 kΩ, and the precision half-wave rectifier in Figure 2.3. Use standard ±15 V supply voltages for the 741 op-amp. Apply a 5 V(peak-to-peak), 1 kHz sine wave, and sketch the input and output waveforms for both circuits. What are the peak output voltages of each circuit? How do the two waveforms differ?

E3) Build the positive peak detector in Figure 2.4 by placing a 100 nF capacitor at the output of the positive half-wave rectifier built in the previous step. Apply a 1 kHz sine wave to the circuit and sketch the resulting input and output waveforms. Add amplitude modulation (AM) and turn the sine wave into an AM signal. A sample AM signal is shown in Figure 2.7. On the function generator, in the Modulation section, select 'AM' and a particular waveform button and adjust the modulation dial. Sketch both the AM input signal and output of the circuit and notice how the peak detector 'rides' the top of the waves of the AM signal. (You should use 100Hz or lower to avoid signal aliasing.)

E4) Add a 5.1 kΩ resistor in parallel with the 100 nF capacitor, and sketch the new output waveform. How has the output waveform changed with the additional resistor? (use 2×10 kΩ in parallel if you cannot find 5.1 kΩ)

E5) Build the variable attenuator of Figure 2.6 using silicon diodes, R_{in} = R_{ctrl} = 100 kΩ, C_1=100 nF, C_2 = 100 nF. Set V_{ctrl} initially to 1.0 V, and gradually increase it to 2.5 V, while applying a 100 kHz, 0.5 Vp-p sine wave for v_{in}. What effect does increasing V_{ctrl} have on the output signal? With V_{ctrl} set to 2.5 V, slowly increase the amplitude of the input sine wave and watch the shape of the output waveform. Measure the maximum peak-to-peak amplitude of the output waveform before the signal becomes significantly distorted?

BONUS:

E6) Build the charge pump circuit of Figure 2.5, using the 1N4148 diodes, and 100 nF capacitors. Use supply voltages of V_{dd} = 5 V and -V_{dd} = -5 V. Use a 1uF electrolytic capacitor for C_{out}. Apply a 1 kHz, -5 V to +5 V, square clock signal, v_{clk}. Sketch the voltages at each node using the same scale. What is the voltage difference between successive stages, and the final voltage across C_{out}?