Experiment 7
Diode Characteristics and Circuits

1 Motivation

Diodes are a fundamental element of modern electronics. They can be used as rectifiers to convert AC into DC, for signal processing, for circuit protection, and many other circuit applications. They can be constructed to interact with light, as light-emitting diodes (LED) and as photovoltaic diodes used in solar cells. Solid-state diodes are constructed using semiconductor p-n junctions. There are two main classes of semiconductor devices: silicon-based and germanium-based. Each class has relative strengths and weaknesses.

2 Background

An ideal diode satisfies two conditions: $V = 0$ when $I > 0$ and $I = 0$ when $V < 0$. The diode functions as a voltage-dependent switch: it conducts if "forward-biased" and isolates if "reverse-biased". This is obviously a nonlinear relationship between current and voltage. Note that $P = IV = 0$ for an ideal diode, i.e, it does not dissipate energy. Real diodes experience finite dissipation associated with their non-ideal properties.

A real p-n junction comes close to the ideal diode, but it has important non-ideal properties. A forward-biased Si diode has a voltage drop $\sim 0.6\,\mathrm{V}$ when its conduction current is $\sim 1\,\mathrm{mA}$. A forward-biased Ge diodes has a smaller voltage drop $\sim 0.3\,\mathrm{V}$ and is therefore closer to ideal in this respect. When reverse-biased, a Si diode conducts only $\sim 50\,\mathrm{pA}$ while a Ge diode conducts $\sim 10\,\mu\mathrm{A}$, so a Si diode is more ideal in reverse-bias. For standard "rectifier" and "signal" diodes, if the reverse-bias voltage exceeds the peak inverse voltage (PIV), the diode experiences avalanche breakdown and conducts large current that may cause it permanent damage. A Zener diode operates normally in reverse-bias with a well-controlled avalanche breakdown voltage, V_Z. They are available with $V_Z = 3\,\mathrm{V}$-$200\,\mathrm{V}$. Zener diodes are a simple and inexpensive way to achieve DC voltage regulation.

In this experiment you will investigate the basic properties of Si and Ge diodes. You will also investigate basic diode circuits in combination with a resistor or capacitor. One of the most important applications of diodes is their use for rectification, i.e., converting AC waveforms into DC voltage. You will investigate basic rectification circuits and their use in creating DC power supplies powered by 120 V AC.

Table 1: Parameters for the diodes used in this experiment

Diode Part ID	Type	$I_{F,\max}$	Dissipation	I_R	PIV/V_Z
1N4005	Rectifier	1.0 A	1 W	5 µA	600 V
1N270	Signal	0.04 A	80 mW	100 µA	100 V
1N749	Zener	0.2 A	0.5 W	20 µA	4.3 V

3 Equipment

For this experiment, you will use:

- One DC power supply
- Two DMM4020 digital multimeters

- One Tektronix MSO 2014B Digital Storage Oscilloscope
- One AFG2021 Arbitrary Function Generator
- One ELC variable resistance box
- One ELC variable capacitance box
- One circuit board with three diodes
- One circuit board with diode rectifiers and voltage regulator
- One 6.3 V AC center-tapped transformer (two yellow terminals, one black terminal)

4 Procedure

1. Construct the circuit shown in Fig. 1 using a DC power supply, a variable resistor, and the circuit board with three diodes. For each case below, record your data and make graphs summarizing your measurements.
    (a) Measure the forward-biased voltage vs current (V_d vs I_d) for the Si diode (1N4005). Start by adjusting V_0 to obtain $I_d \approx 50\,\mu\text{A}$ and then work up to $I_d \approx 50\,\text{mA}$, increasing I_d by a factor of 2-3 at each step.
    (b) Repeat (a) for the Ge diode (1N270).
    (c) Repeat (a) for the Zener diode (1N749) but measure just enough points to demonstrate that the diode is Si versus Ge. Now reverse-bias the diode and determine the voltages required to produce reverse currents of 10 mA, 20 mA, and 30 mA.

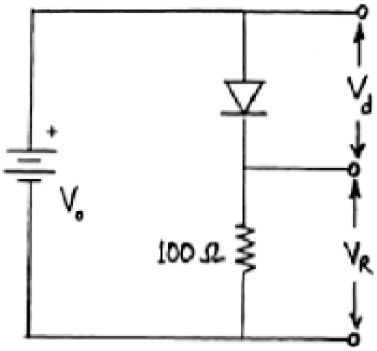
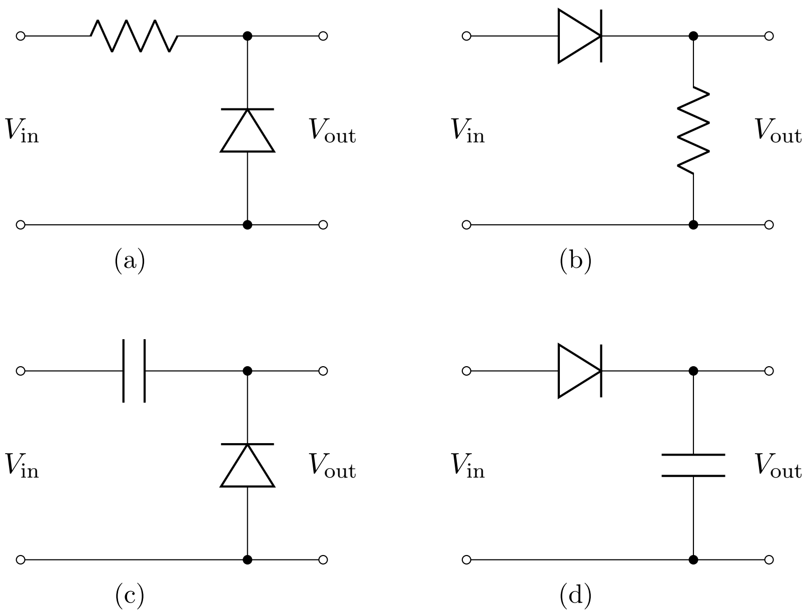


Figure 1: Circuit for characterizing a diode's current-versus-voltage characteristics

2. The four circuits shown in Fig. 2 are diode-resistor and diode-capacitor combinations that perform clipping, rectification, level shifting, and filtering. Construct each of these circuits using the diode board and variable resistor or capacitor boxes. Set $R = 1\,\text{k}\Omega$ and $C = 0.1\,\mu\text{F}$ and input a 1 kHz, 4 V peak-to-peak sine wave to each circuit using the function generator. Use the oscilloscope to measure the output voltage. For each circuit, make a sketch in your lab notebook showing the input and output voltages when using the Si diode. Identify the function of the circuit in your sketches. Observe what happens when you reverse the diode and when you use the Ge diode instead (no sketches required for these cases).

3. The circuit in Fig. 2(d) can be considered a simple DC voltage supply. Observe what happens when you attach a $R_L = 50\,\text{k}\Omega$ load resistance across the output (using a resistor box). Sketch the output waveform and measure the peak-to-peak "ripple", i.e. the AC component in the output voltage. Estimate the ripple based on the expected behavior of an *R-C* circuit and



(a) (b)

(c) (d)

Figure 2: Basic diode-resistor and diode-capacitor circuits

compare with your measurement. How does the ripple change when you draw a larger load current from the supply?

You will now use the pre-wired rectifier circuit board and the 6.3 V AC transformer to investigate diode rectification and the construction of a DC voltage supply. Look at the underside of the circuit board and examine the components. The transformer has a turns ratio that produces 6.3 V rms between the ends of the secondary (yellow terminals "Y"). It also includes a "center-tap" (black terminal "B") connected midway along the secondary winding such that there are two simultaneous outputs, each having 3.2 V rms. The relative phase between one yellow-black terminal pair and the other yellow-black pair is 180°.

4. The sequence of steps below show how an AC waveform is rectified, filtered, and then regulated to create a DC voltage supply. Assemble the half-wave rectifier shown in Fig. 3 using the full 6.3 V rms output of the transformer, leaving terminals ①, ② and ③ open to start. Sketch the circuit in your lab notebook including values/identifiers for the components.

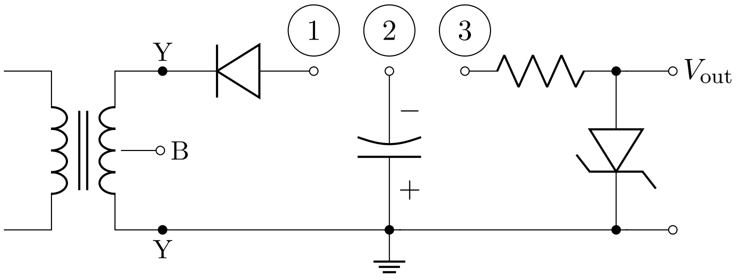


Figure 3: Half-wave rectifier with Zener voltage regulation

   (a) Measure the voltage at terminal ① (relative to ground) and sketch the rectified voltage waveform in your lab notebook. (If the waveform looks odd, temporarily connect 100 kΩ across the terminal to ground, but remove this after you have made the measurement.)

(b) Connect terminals ① and ② using a patch cable and then measure and sketch the filtered waveform at the ①-② node

(c) Add another patch cable between terminal ③ and the ①-② node to complete the circuit, which is a DC voltage supply with regulation provided by the Zener diode. Measure the output voltage waveform (across the Zener) using the scope. Figure out how to measure the current in the Zener diode as a function of time. Make sketches of the output voltage and the current in the Zener diode.

(d) Use two DMMs to measure the DC output voltage and the AC ripple, then repeat these measurements with load resistances of 2 kΩ, 500 Ω, and 100 Ω. (Recall the input impedance of the scope is 1 MΩ.)

5. Now construct the full-wave rectifier in Fig. 4 using the center-tapped transformer outputs. Measure and make sketches of the waveforms at terminal ① alone and with terminals ① and ② connected. How do these compare to your measurements for the half-wave rectifier circuit in steps 4(a)-(b)?

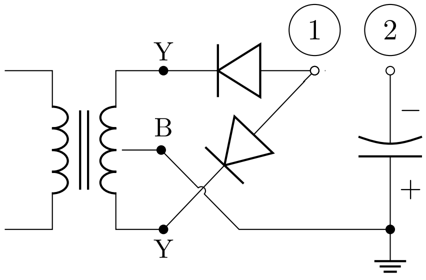


Figure 4: Full-wave rectifier circuit

6. Assemble the DC voltage supply circuit in Fig. 5, which uses a full-wave bridge rectifier and a 3-terminal 7805 voltage regulator integrated circuit (data sheet attached). Repeat the procedure in steps 4(a)-(d) but do not attempt to measure the current into the regulator. Note in your log notebook key differences for how this circuit behaves in comparison to the half-wave rectifier circuit with zener regulation.

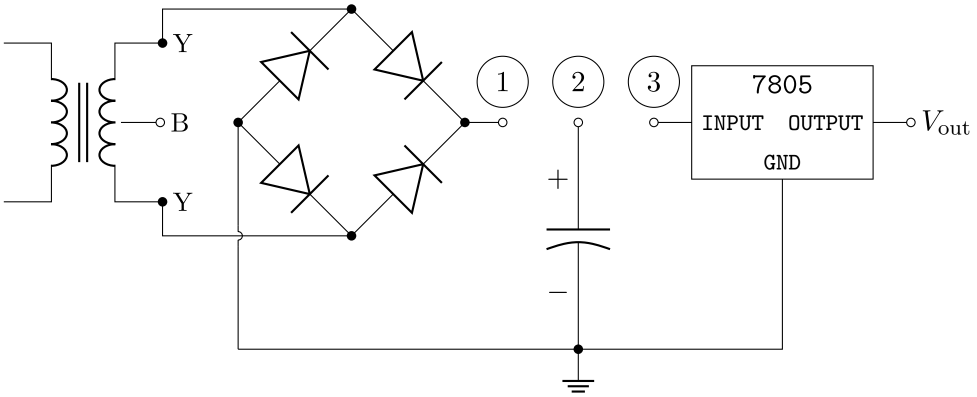


Figure 5: DC voltage supply with full-wave bridge rectifier and 7805 regulation

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KA78XX/KA78XXA

3-Terminal 1A Positive Voltage Regulator

Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

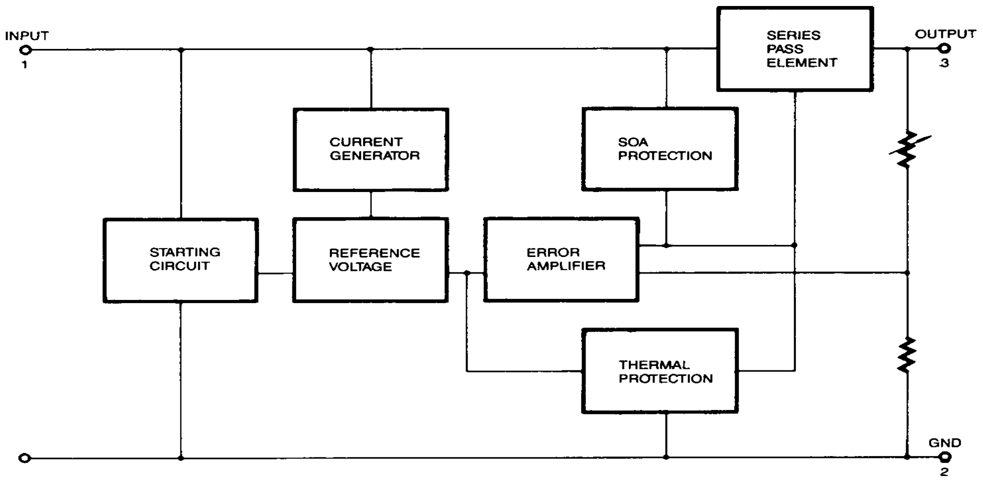
The KA78XX/KA78XXA series of three-terminal positive regulator are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

TO-220

D-PAK

1. Input 2. GND 3. Output

Internal Block Digram



Rev. 1.0.0

Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	°C/W
Operating Temperature Range (KA78XX/A/R)	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Electrical Characteristics (KA7805/KA7805R)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =10V, C_I= 0.33μF, C_O=0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7805			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		4.8	5.0	5.2	V
		5.0mA ≤ Io ≤ 1.0A, P_O ≤ 15W V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note1)	Regline	T_J=+25 °C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation (Note1)	Regload	T_J=+25 °C	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O= 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 °C		-	42	-	μV/V_O
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_o due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Typical Perfomance Characteristics

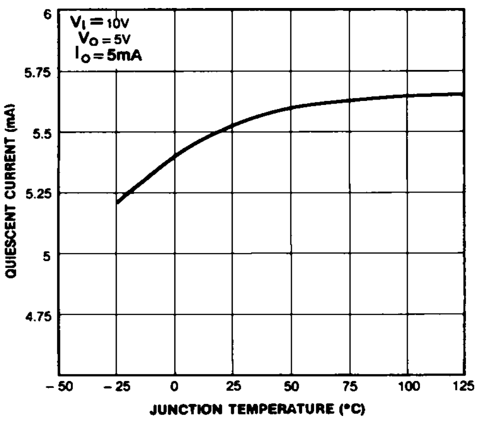


Figure 1. Quiescent Current

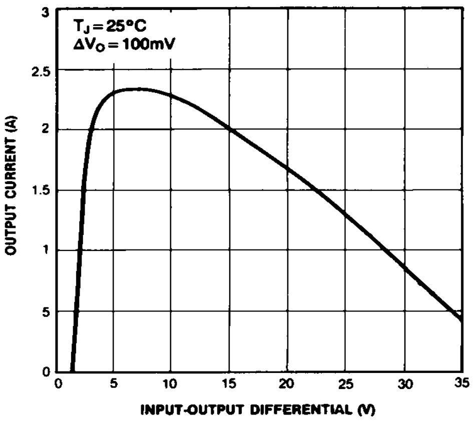


Figure 2. Peak Output Current

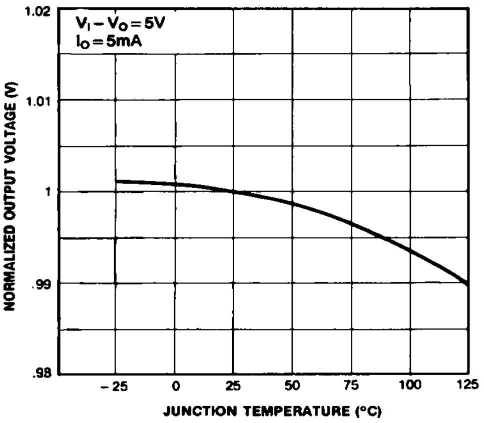


Figure 3. Output Voltage

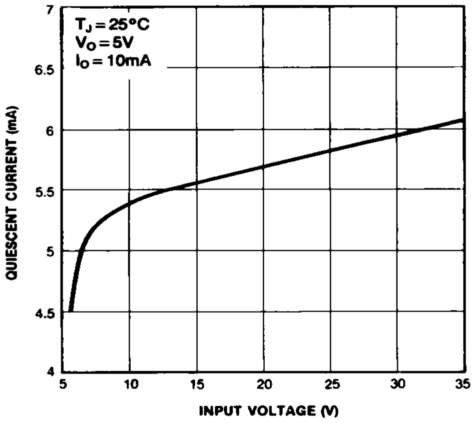


Figure 4. Quiescent Current